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Notice to Members

We have heard from an overseas member that the copy he received of the Spring 1989 issue (44-1) carried four blank pages (page numbers 14, 15, 18 and 19) and also lacked the Subject and Author Index for 1988.

If any other member has received a similar faulty copy please let us know and we will send a free replacement.

Our apologies for the mistake and for any inconvenience this may have caused.

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Estimation of combine harvesting work-days from meteorological data *(refereed paper)*

M B McGechan, T Saadoun, C A Glasbey, K Eradat Oskoui

Information about working periods of combine harvesters on commercial farms in relation to rainfall is analysed. This leads to the development of a new work-day criterion which is an improvement on previous criteria. The new criterion is tested using historical weather data from a range of sites, to show large variations in work-days between different weeks in one year, but little variation in mean work-day values at different times of year. It also indicates a requirement for greater machine capacity in Western than Eastern areas.

1. Introduction

A correct decision about the appropriate harvest mechanisation system capacity, particularly with regard to the size of the combine harvester itself, is an important factor determining the profitability of a cereal enterprise. Too large a combine harvester incurs excessive costs in loan repayments, while too small a machine incurs excessive timeliness costs in terms of grain loss where the harvest is spread over a long period.

Harvesting cereal crops with a combine harvester is an operation which is very dependent on the weather. Hence, when planning the system capacity, an allowance must be made for a typical proportion of days around the appropriate period when weather allows combine harvesting to take place, often referred to as 'combine harvesting work-days'.

This paper describes the development of a new criterion for determining combine harvesting work-days from historical weather data, on the basis of information about when combines were working on commercial farms. Implications of the criterion, in the form of variability of work-days between sites, years and time of year are also explored.

2. Previously available combine harvesting work-days criteria

2.1 General criteria for field operations

Tabular values of the number of days available for field operations, on a monthly basis, have been reported by Nix (1972) and by Agricultural Business Consultants, Table 1 (1984). These average figures take no account of year to year variability, or characteristics of different operations which affect the ability to work under marginal conditions; Agricultural Business Consultants alone take account of variations in weather between different areas of the country, but only by means of a crude East/West division; they give no indication about whether this division is appropriate to the whole of Great Britain. However, in the absence of any more satisfactory information, planning of cereal harvesting mechanisation systems has often been carried out on the basis of just such general figures.

Table 1. Work-days for field operations

	Number of work-days		
	Agricultural Business Consultants (1984)		*Nix (1972)*
	Eastern Areas	*Western Areas*	
January	12	14	16
February	8	14	14
March	14	18	19
April	20	22	20
May	23	24	22
June	25	25	23
July	25	24	23
August	25	24	23
September	24	22	23
October	21	19	19
November	15	16	15
December	16	15	16

2.2 Arbitrary criteria for use in Operational Research models

Two criteria have been specified for ascertaining whether a combine harvester can work on a particular day or farm in relation to recorded historical weather data; both these criteria were devised for use in Operational Research (OR) simulation models of cereal harvesting. While the principles embodied

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in these criteria appear reasonably logical, no actual work-day information has been reported, so the cut-off values in the criteria can only be assumed to be arbitrary.

2.2.1 *Audsley and Boyce combine harvesting work-days criterion*

The Audsley and Boyce (1974) criterion states that combine harvesting can take place on days when the discounted sum of past rainfall is less than 1.27 mm. This discounted sum is the rainfall in the past 24 hours plus 20% of the previous day's discounted sum. This is the same as taking a geometrically decaying sum of past rainfall, with each day given 20% of the weight of the succeeding day. They assumed that the time available for combine harvesting would reduce by 0.02 h each day from an initial value of 9 h on 1 August. Since this is only a very crude way of estimating working hours on working days, this criterion must be regarded as only a work-days criterion.

2.2.2 *Philips and O'Callaghan combine harvesting work-days criterion*

The Philips and O'Callaghan(1974) criterion can be considered to be a proper work-hours criterion since it operates on an hourly basis. It states that combine harvesting can take place during a particular hour for the nine hours between 1000 hours and 1900 hours GMT, provided that:

1) grain moisture content is below 24% wet basis (31% dry basis)
2) no rain has fallen in that hour,
3) less than 1.25 mm of rain fell in the preceding hour, and
4) less than 2.25 mm of rain fell in the hour prior to the preceding hour.

The grain moisture content is derived using an algorithm proposed by Crampin and Dalton (1971). This operates in two phases, one for rainy periods and the other for fine weather, and uses data on rainfall, temperature and relative humidity.

The grain moisture algorithm suggested by Crampin and Dalton (1971) has been criticised by Smith *et al.* (1981) for its lack of scientific basis, using as it did equations obtained empirically from field data. They proposed another algorithm for deriving grain moisture content from hourly rainfall, temperature and relative humidity, based on equations developed from thin-layer drying experiments and using parameter values calculated directly from data. An alternative version of Philips and O'Callaghan's criterion therefore arises, in association with the grain moisture content algorithm of Smith *et al.*.

3. Information for testing combine harvesting work-days criteria

3.1 Information about combine harvesting work-days

A work-study survey of a number of performance parameters of combine harvesters working on commercial farms was carried out at SCAE using automatic telemetry equipment. The equipment has been described by Palmer (1984), and previous applications of the data obtained by McGechan and Glasbey (1982) and McGechan (1984a). For the current study, the only information required was whether and for how long combine harvesters were working on each day at each farm.

The survey of combine harvester performance covered up to six combine harvesters, each on different farms on the southern outskirts of Edinburgh during the period 1977 to 1982. In total, there were 483 combinations of farms and days. Data about observed combine harvesting hours were extracted by inspection of computer output representing descriptive timetables of the combine harvesters' activities (McGechan, 1984a). For the current study, the data were censored in two respects: sometimes, due to faults or failures with the telemetry equipment, combine harvesting may have taken place without being recorded; sometimes combine harvesting did not take place for reasons other than the state of the weather, e.g. because of combine harvester breakdowns or the crop not being ready to cut.

3.2 Weather data

Daily rainfall data recorded at 0900 GMT at sites near the farms and at Turnhouse (Edinburgh Airport) for the required months for 1977-1982 were obtained from the Meteorological Office. The siting of the farms was fortunate in that they were near to reservoirs, pumping stations, filter beds, etc., for the City of Edinburgh water supply, so there were many sites where local daily rainfall was recorded by the Water Board and reported to the Meteorological Office. Each farm could be associated with 3 or 4 daily rainfall sites 1-3 km distant. For some sites, data covered some of the years only.

Hourly weather records were available only for Turnhouse, about 20 km from the farms. Since this site was in a different position relative to a river estuary and a range of hills 500 m high, it was expected to have somewhat different weather conditions from the farms.

4. Testing combine harvesting work-days criteria

4.1 Assembly of tabular data

In the first instance, tables were assembled for each farm and each year, containing the number of hours worked by the combine harvester, and the number of hours work predicted by each of the previous criteria, e.g. Table 2 (McGechan, 1984b). Hours predicted by the Audsley and Boyce criterion were calculated from rainfall recorded at Turnhouse (site 1) and at each of the associated sites. Hours predicted by the Philips and O'Callaghan (1984) criterion using hourly weather data for Turnhouse were calculated using both the Crampin and Dalton (1971) and the Smith *et al.* (1981) grain moisture content algorithm.

Table 2. Observed and predicted work periods for one combine harvester compared with daily rainfall for local sites, 1978

	Daily rainfall A				*Work period, hours* B				C	D	E
	1	*6*	*9*	*7/8*	*1*	*6*	*9*	*7/8*			
Aug											
18	1.6	3.2	2.0	0.5	0.00	0.00	0.00	0.00	7	5	0
19	2.6	3.2	4.1	3.0	0.00	0.00	0.00	0.00	0	1	0
20	0.0	0.0	0.3	0.1	8.60	8.60	8.60	8.60	9	9	0
21	4.6	4.4	6.1	5.2	0.00	0.00	0.00	0.00	2	0	0
22	0.4	1.0	1.9	0.8	0.00	0.00	0.00	0.00	9	7	0
23	3.7	4.2	5.1	4.1	0.00	0.00	0.00	0.00	9	9	5.4
24	0.2	0.1	0.2	0.3	8.52	8.52	0.00	8.52	3	3	0
25	3.2	1.1	2.2	1.7	0.00	0.00	0.00	0.00	6	6	3.0
26	0.5	0.0	0.0	0.0	8.48	8.48	8.48	8.48	8	8	5.0
27	0.0	0.0	0.0	0.0	8.46	8.46	8.46	8.46	9	9	11.0
28	5.0	6.0	5.2	6.3	0.00	0.00	0.00	0.00	9	9	3.9
29	1.9	1.7	1.2	1.0	0.00	0.00	0.00	0.00	8	5	1.5
30	1.0	0.1	0.2	0.2	0.00	8.40	8.40	8.40	3	2	0
31	0.1	0.1	0.0	0.0	8.38	8.38	8.38	8.38	9	9	10.0
Sept											
1	0.0	0.0	0.0	0.0	8.36	8.36	8.36	8.36	9	9	9.5
2	0.0	0.0	0.1	0.0	8.34	8.34	8.34	8.34	9	9	10.5
3	0.6	0.2	0.1	0.3	8.32	8.32	8.32	8.32	8	8	9.6
4	22.9	26.6	23.2	19.2	0.00	0.00	0.00	0.00	5	5	5.2
5	16.6	16.7	19.9	17.2	0.00	0.00	0.00	0.00	0	0	0
6	4.3	3.3	3.2	2.7	0.00	0.00	0.00	0.00	0	0	0
7	0.6	0.4	0.8	0.1	0.00	0.00	0.00	0.00	0	1	0
8	0.0	0.0	0.0	0.0	8.22	8.22	8.22	8.22	9	9	5.2
9	0.0	0.0	0.0	0.0	8.20	8.20	8.20	8.20	9	9	8.1
10	2.7	1.9	2.3	1.1	0.00	0.00	0.00	8.18	4	1	4.4
11	0.4	0.0	0.0	0.1	8.16	8.16	8.16	8.16	9	9	2.8
12	0.0	0.0	0.0	0.0	8.14	8.14	8.14	8.14	9	9	10.9

A Daily rainfall at several numbered weather stations (1, 6, 9, 7/8),mm
B Work-day lengths predicted by Audsley and Boyce (1984) criterion for same numbered rainfall weather stations, hours
C Work-periods predicted by Philips and O'Callaghan (1984) criteria with Crampin and Dalton (1971) moisture content algorithm, hours
D Work-periods predicted by Philips and O'Callaghan (1984) criterion with Smith *et al.* (1981) moisture content algorithm, hours
E Observed work-period, hours

4..2 Testing the Philips and O'Callaghan work-days criteria

Inspection of the tabular data showed that the Philips and O'Callaghan (1974) criterion nearly always predicted more combine harvesting hours than were observed. However, although this suggests a deficiency in the criterion, the discrepancy may have arisen partly because of differences in climate between the weather recording site and the farms. It was concluded that this criterion could not be assessed beyond such general statements, with the evidence available.

4.3 Testing the Audsley and Boyce combine harvesting work-days criterion, and development of a new criterion.

Inspection of the tabular data (Table 2) allowed almost identical predicted work-days based on each of the rainfall sites near the farm, but a somewhat different work-day pattern on the basis of rainfall at Turnhouse. The analysis was therefore carried out using rainfall data from the nearest site only. Some very short combine harvesting periods in the observed data, which may have occurred before or in between rainy periods, were ignored by imposing an arbitrary limiting period of 3 hours; a day was regarded as a work-day only if more than 3 hours combine harvesting took place.

To test the Audsley and Boyce (1974) criterion, a 'truth table' to compare predicted and observed work-days was first drawn up (Table 3). This showed partial agreement between predictions and observations; substantially higher values were found on the main diagonal, but there was some imbalance between the two larger values and the smaller values were not zero.

Table 3. Comparison of observed and predicted combine harvesting work-days using Audsley and Boyce criterion and new criterion

	Number of days combining predicted			
	Audsley & Boyce criterion		*New criterion*	
	Poss	*Not poss*	*Poss*	*Not Poss*
Combining took place	235	66	263	38
Did not take place	57	125	75	107

To reach a better understanding of the effectiveness of Audsley and Boyce's criterion, an indicator variable y_i was calculated, with y_i set to unity if combine harvesting was observed to take place for three or more hours on day i and otherwise set to zero. Then, a standard statistical technique was used of grouping the days into batches with increasing values of dependent variate, in this case the discounted sum of past rainfall without regard for farm or year. Batches of size 21 were chosen as a convenient divisor of 483, the total number of days of survey data. Batch averages were calculated and plotted with rainfall log-transformed to emphasis the features of low rainfall (Fig 1). The revealed trend is sigmoidal; as rainfall increases from zero the proportion of combine harvesting work-days initially does not change, then drops progressively more quickly before slowing down and reaching a new constant level of zero once the rainfall is great enough.

If the discounted sum of past rainfall were the sole determinant of whether combine harvesting could take place, then Fig 1 would have revealed a step function. Below a particular rain threshhold combine harvesting would have been observed with constant rate, dependent upon the censoring probability in the data; above the threshold, no combine harvesting would have taken place. However, the sharp corners of the step function have been smoothed out by variability from other sources such as: (1) the difference in rainfall between the farms and the recording sites; (2) the distribution of rain over each 24 hour period; (3) changes in other climatic variables such as temperature and relative humidity; and (4) differences in field, crop and machinery characteristics between farms or different days on each farm. These variables change over continuous ranges, so the simplest effect on the probability of combine harvesting is to produce a sigmoidal curve.

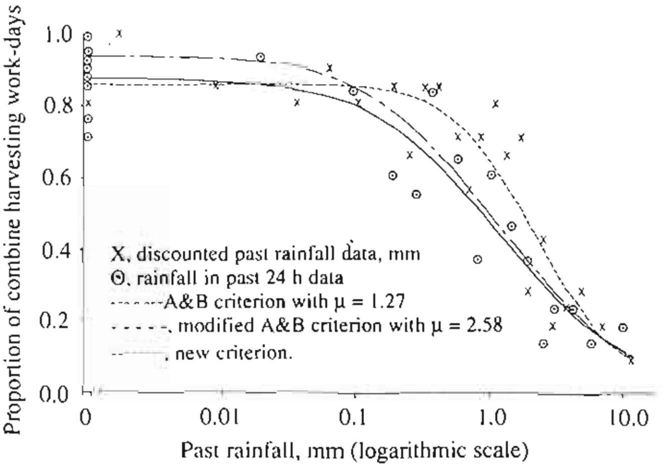

Fig 1. Indicator variable against past rainfall, data grouped into batches of size 21. (A & B =Audsley & Boyce)

The complete statistical procedure used to assess the Audsley and Boyce work-days criterion has been described in detail by Glasbey and McGechan (1986 a) and is summarised here. This employed the technique of 'Probit Analysis' (Finney, 1971) i.e. a form of non-linear regression, fitting the integral of the normal frequency distribution to the data points shown in Fig 1. This is the simplest of a number of alternative functions used to generate curves of sigmoid shape.

$$P = K\,\phi\,\frac{(R-\mu)}{\alpha}$$

where P = proportion of combine harvesting work-days

R = discounted sum of past rainfall

α = discounting factor used in R

K = censoring factor, i.e. probability of combine harvesting being recorded by telemetry equipment on a particular day

μ = discounted sum of past rainfall to give a 50% chance of harvesting

$\frac{1}{\sqrt{2\pi}\,\delta}$ = slope of sigmoid curve where R = μ and where δ = parameter determining slope

$\phi(z)$ = the integral of the standardised normal frequency distribution, i.e.

$$\phi(z) = \int_{-\alpha}^{z} \frac{e^{-x^2/2}}{\sqrt{2\pi}}\,dx$$

The curve was first fitted allowing δ and K to vary, with υ and α constrained to Audsley and Boyce's values of 1.27 mm (0.05 in) and 0.2 respectively. However, by allowing μ to vary also, the fit could be improved in terms of maximising the 'log-likelihood' of the data, the best fit being obtained with a value of μ = 2.58 (Fig 1). Analysis allowing the discounting factor in R to vary as well gave a further marked improvement in fit; the best fit had a discounting factor of zero, and gave the value of μ = 1.4 mm with a standard error of 0.27mm, i.e. the 95% confidence limits being 0.88 mm and 1.96 mm. Clearly, constraining the value of R to 0.2 had distorted the curve and given an unrealistically high value of μ in the previous case. A discounting factor of zero means that the criterion is based on rainfall during the previous 24 h only. Thus a new, improved combine harvesting work-days criterion was specified: combine harvesting can take place when the rainfall in the previous 24 h is less than 1.4 mm.

The number of observed work-days which would be expected from the new criterion, calculated from the predicted work-days and adjusted for censoring, are considerably closer to those actually observed are those that derived from the Audsley and Boyce criterion (Table 4). Also the number of days on which combine harvesting took place, but the criterion predicts that it should not, was lower with the new criterion (Table 3).

Table 4. Expected observed combine harvesting work-days derived by Audsley and Boyce and the new criterion.

	Audsley & Boyce criterion	*New criterion*
Predicted work-days	292	338
Censoring factor,K	0.94	0.88
Expected observed work-days, allowing for censoring	274	298
Actual observed work-days	301	301
Error in expected observed work-days	9.0%	1.0%

5. Deriving combine harvesting work-days information from recorded weather data using the new criterion

A computer program was written to calculate combine harvesting work-days information in various forms, according to the new criterion, from recorded historical daily rainfall data over 10 years at a range of sites (e.g. Tables 5-7). This information was then used to compare work-days at different sites, in different years, and at different times of year.

5.1 Monthly work days

In the first instance, combine harvesting work-days were calculated on a monthly basis, both as the number of work-days per month (Table 5) and also as percentages, for the months of July, August, September and October when combine harvesting might occur in the UK. Values were calculated for each year, together with means and standard deviations. This format is similar to that used by Nix (1972) and Agriculture Business Consultants (1984) to express general field operation work-days.

Table 5. Combine harvesting work-days per month

Year	*July*	*Aug*	*Sept*	*Oct*	*mean*	*s d*
1973	25	21	19	20	21.2	2.6
1974	17	19	20	13	17.2	3.1
1975	19	22	20	26	21.7	3.1
1976	28	27	17	15	21.7	6.7
1977	23	21	21	22	21.7	1.0
1978	21	22	20	27	22.5	3.1
1979	19	18	21	18	19.0	1.4
1980	23	21	15	17	19.0	3.7
1981	23	26	19	19	21.7	3.4
1982	26	20	21	17	21.0	3.7
10 year mean	22.4	21.7	19.3	19.4	20.7	
s d	3.4	2.8	1.9	4.5	1.7	

Site - Dyce (Aberdeen airport)

5.2 Weekly work-days

Eradat Oskoui (1981) expressed workability for soil engaging operations in terms of numbers of days per week for 52 weeks of the year starting with week 1 as 1-7 January, and omitting February 29 in leap years. Combine harvesting work-days have been expressed in a similar format for weeks 27-43 of the year, covering the period 2 July - 28 October. Again individual weekly values, means and standard deviations have been calculated (Table 6).

Table 6. Combine harvesting work-days per week

				July				*August*				*September*					*October*			
	Week ending	*8*	*15*	*22*	*29*	*5*	*12*	*19*	*26*	*2*	*9*	*16*	*23*	*30*	*7*	*14*	*21*	*28*	*mean*	*s d*
1973		5	5	6	7	2	2	7	7	5	5	7	4	2	7	3	2	5	4.8	2.0
1974		3	4	5	4	4	5	2	5	6	2	5	5	6	3	2	3	5	4.1	1.3
1975		7	3	3	4	6	7	3	4	5	6	5	3	4	6	6	6	5	4.9	1.4
1976		7	7	4	7	6	6	6	7	6	4	4	4	3	3	5	3	2	4.9	1.7
1977		7	7	2	4	4	7	7	3	3	4	4	7	5	2	5	7	6	4.9	1.9
1978		2	7	5	5	5	6	4	5	4	4	5	5	5	5	7	5	7	5.1	1.2
1979		5	3	5	6	3	3	2	6	4	6	7	2	6	3	3	5	6	4.4	1.6
1980		5	4	6	7	5	4	5	5	3	3	3	5	4	6	6	1	3	4.4	1.5
1981		6	5	3	6	6	6	5	6	7	7	3	2	5	3	4	5	6	5.0	1.5
1982		6	6	5	6	7	6	4	1	6	4	7	5	3	5	1	3	6	4.8	1.9
10 year mean		5.3	5.1	4.4	5.6	4.8	5.2	4.5	4.9	4.9	4.5	5.0	4.2	4.3	4.3	4.2	4.0	5.1	4.7	
s d		1.7	1.6	1.3	1.3	1.5	1.7	1.8	1.9	1.4	1.5	1.6	1.5	1.3	1.7	1.9	1.9	1.5	1.6	
Probabilities	1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
of workday	2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
number	3	90	100	90	100	90	90	80	90	100	90	100	80	90	90	80	80	90	90	
	4	80	80	70	100	80	80	70	80	80	80	80	70	70	50	60	50	80	74	
	5	80	60	60	70	60	70	50	70	60	40	60	50	50	50	50	50	80	59	
	6	50	40	20	60	40	60	30	40	40	30	30	10	20	30	30	20	50	35	
	7	30	30	0	30	10	20	20	20	10	10	30	10	0	10	10	10	10	15	
Lowest	70% of years	5	4	4	5	4	5	4	5	4	4	4	4	4	3	3	3	5	4.8	
workday	80% of years	5	4	3	4	4	4	3	4	4	4	4	3	3	3	3	3	5	4.4	
value	90% of years	3	3	3	4	3	3	2	3	3	3	3	2	3	3	2	2	3	4.4	
in	100% of years	2	3	2	4	2	2	2	1	3	2	3	2	2	2	1	1	2	4.1	

Site - Dyce (Aberdeen airport)

Values of the probability of each work-day value 1-7 or greater have also been calculated. This is a format similar to that used to express soil workability by Eradat Oskoui (1981).

The lowest weekly work-day value in the best of 70%, 80%, 90% and 100% of years respectively has also been calculated (Table 6). The value for 80% of years is another common format for expressing field operation work-days; this may be favoured by a farmer who replaces his machine every five years, and plans his machine capacity to be adequate in four out of those five years.

5.3 Fortnightly work-days

It has been suggested that one week periods are too short and one month periods are too long for usefully expressing combine harvesting work-days. As a compromise, therefore, work-days have also been calculated on a fortnightly basis for the period 2 July - 21 October. Mean values are shown in Table 7; and values for individual fortnights can be calculated from adjacent weekly values in Table 6.

Table 7. Combine harvesting work-days per fortnight

Work days per fortnight - mean values

July		*August*		*September*		*October*			
15	*29*	*12*	*26*	*9*	*23*	*7*	*21*	*mean*	*s d*
10.4	10.0	10.0	9.4	9.4	9.2	8.6	8.2	9.4	2.4

Site - Dyce (Aberdeen airport)

6. Comparing work-day values at different sites, in different years, and at different times of year

A comparison of weekly combine harvesting work-days for each week in different years, and different weeks of the year at one site is illustrated in Fig 2. This shows a very substantial variation between years in work-days for each week. By comparison, the mean (for 80% of years) numbers of work-days per week vary little between different weeks of the year. This is confirmed by monthly mean work-day figures, where there is only a small decline in numbers of work-days from July to October.

A comparison of mean and 80% of year work-day values for the same ten year period at a number of different sites is illustrated in Table 8. This shows a progressive decline in number of work-days through the sites in the order they have been listed. Comparing sites in the West and East of the country at similar latitudes (Paisley and Auchincruive against Turnhouse and Bush House), slightly higher work-day values are found in the East than the West. Very roughly, there are about 15% more work-days in the East than the West; this suggests that farmers should plan 15% greater machine capacity for a given crop area in the West than the East, a greater difference than suggested by Agricultural Business Consultants (1984). For the sites on the East side of the country, there is an increase in number of work-days moving from North to South, but in this case other factors should also be considered; a particular crop will be harvested earlier in the south, emphasising the benefits of working in the South, but against this working hours per work-day are greater in the North due to longer daylight hours, particularly in the early part of the season.

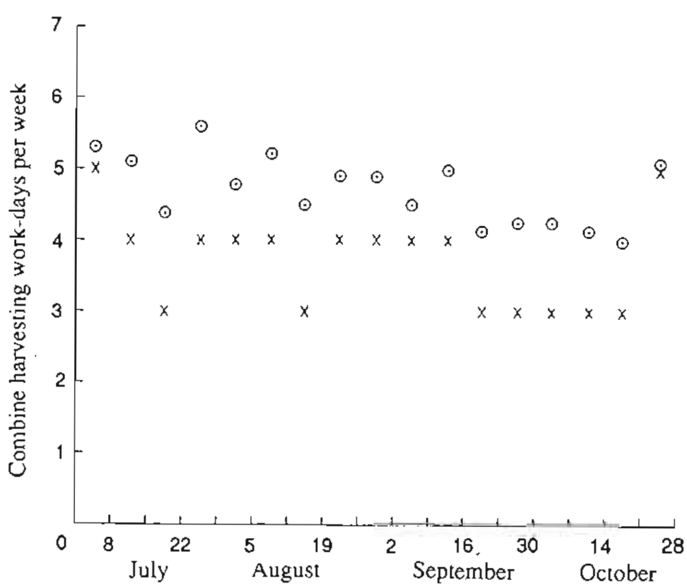

Fig 2. Weekly combine harvesting work-days for one site (Dyce); ⊙, 10 year mean; X, lowest value in 8 out of 10 years.

There is progressive decline in variability between years, as shown by the coefficient of variation (Table 8) as the aggregation period is increased from weekly to fortnightly and monthly. The choice of aggregation period should be made according to the purpose for which information is required.

7. Comparing combine harvesting work-days and soil workability work-days

The new criterion for combine harvesting work-days based on rainfall alone takes account only of whether the crop is in a fit state to be cut. Another factor which should be considered is whether the soil is in a fit state to carry a heavy machine such as a combine or a large trailer full of grain. A criterion for soil workability, based on the lower plastic limit, has been developed by Eradat Oskoui (1981); this was later used in a computer program described by Witney *et al* (1982). This criterion requires historical weather data on daily rainfall, sunshine hours and mean monthly air temperature. The criterion takes account of characteristics of a particular soil, as well as weather data. Work-days for soil engaging operations can therefore be calculated according to this criterion for a particular site in relation to both its weather and its soil type.

Work-days according to the soil workability criterion were calculated using weather records for Bush House and soil characteristics for three soil types - Winton series (heavy), Macmerry

Table 8. Combine harvesting work-day values at different sites over 10 years (1973-82)

	Combine harvesting work-days											
Site	*Weekly, No.*				*Fortnightly, No.*			*Monthly, No.*			*Monthly, %*	
	80% of years	*mean*	*s d*	*cv,%*	*mean*	*sd*	*cv,%*	*mean*	*sd*	*cv,%*	*mean*	*sd*
Hurley	4.9	5.2	1.6	31	10.3	2.8	27	22.8	4.1	18	74.3	13.2
Turnhouse (Edinburgh airport)	4.8	4.9	1.5	31	9.7	2.2	23	21.2	3.6	17	69.2	11.5
Bush House	4.5	4.7	1.6	34	9.3	2.5	27	20.5	4.1	20	66.6	13.0
Dyce (Aberdeen airport)	4.4	4.8	1.6	33	9.4	2.4	26	20.7	3.5	17	67.3	11.1
Paisley	4.2	4.5	1.7	38	9.1	2.7	30	19.8	4.3	22	64.3	13.7
Carlisle	4.3	4.5	1.8	40	8.8	2.8	32	19.6	4.4	22	63.8	13.9
Auchincruive	3.9	4.2	1.6	38	8.4	2.5	30	18.4	4.1	22	59.9	13.0
Eskdalemuir	3.6	3.9	1.8	46	7.9	2.8	35	17.2	4.4	26	56.0	14.0

sd = standard deviation *cv = coefficient of variation*

Table 9. Work-days which satisfy both the combine harvesting work-days criterion and the soil workability work-days criterion for different soil types with weather data for Bush House

Site	*Combine harvesting work-days*											
	Weekly, No.				*Fortnightly, No.*			*Monthly, No.*			*Monthly,%*	
	80% of years	*mean*	*s d*	*cv,%*	*mean*	*sd*	*cv,%*	*mean*	*sd*	*cv,%*	*mean*	*sd*
Soil workability not considered	4.5	4.7	1.6	34	9.3	2.5	27	20.5	4.1	20	66.6	13.0
Darvel series (light)	4.4	4.7	1.6	34	9.3	2.5	27	20.4	4.1	20	66.3	13.0
Macmerry series (medium)	4.2	4.5	1.8	40	9.0	2.9	32	19.7	4.8	24	64.0	15.5
Winton series (heavy)	3.9	4.2	2.1	50	8.3	3.4	41	18.2	6.2	34	59.3	20.1

series (medium) and Darvel series (light). For all these soil types, the numbers of work-days were substantially higher than those given by the combine harvesting work-days criterion based on rainfall. The soil workability criterion alone is therefore clearly unsuitable for use as a combine harvesting work-days criterion.

An alternative criterion was then considered in which a day was considered to be a work-day only if both the combine harvesting work-days criterion and the soil workability work-days criterion were satisfied. Compared with the simple combine harvesting work-days criterion, this criterion gave an almost identical number of work-days with the light soil, and a progressively greater, although still quite small, reduction in the number of work days with the medium and heavy soils (Table 9). With the heavy soil and Bush House weather, the number of work-days was similar to that for the simple work-days criterion and Auchincruive weather.

Since the addition of a soil workability criterion made quite a small adjustment to the number of combine harvesting work-days, even for a heavy soil, for a considerable increase in requirement for weather data, for most purposes it can be ignored, and the simple criterion based on rainfall alone used to determine combine harvesting work-days. Furthermore, even if a farmer were able to identify days when the soil is unfit to carry machines, he would be unlikely to forego an opportunity to cut the crop if the crop itself is in a fit state.

8. Work-hours and work-days criteria in relation to evaporation after rainfall

There are no known reported experiments in which evaporation of surface water from standing cereal crops after rain has been measured. Smith *et al* (1981) reported only grain kernel moisture content variations in relation to weather parameters.

However, typical average rates of daily evaporation from a free water surface in Scotland in summer months are around 2.5 mm (McGechan, 1989). It has been found to take the equivalent of about 1.5 mm of evaporation from a free water surface to evaporate 1.0 mm of surface rainwater from grass swaths lying in the field (Glasbey and McGechan, 1986b). Also, it has been observed that grass swaths can hold about 1.2 kg of rainwater per kg of grass dry matter before runoff starts to take place (Pitt and McGechan, 1987). If a standing cereal crop can hold a similar quantity of surface water to cut grass, and straw yields are typically about 3 t/ha (Staniforth, 1982), the cereal crop would be able to hold about 0.36 mm of rainfall before runoff occurs. The limit of 1.5 mm of rainfall in the previous hour in the Philips and O'Callaghan criterion implies that, allowing for runoff, about 0.36 mm can evaporate in the hour prior to combine harvesting, a rate somewhat faster than that from a free water surface; hence it is not surprising that this criterion predicts more combine harvesting hours than found in practice. The new criterion implies a rate of evaporation in the range 0.36-1.40 mm, depending on the distribution of rainfall and the runoff characteristics, over a period of about 24 h. This daily rate of evaporation is never more than that observed for grass swaths. Hence the new criterion is consistent with the limited available measured figures for evaporation of surface water from crops.

9. Conclusions

A new criterion for determining numbers of combine harvesting work-days from historical recorded weather data has been developed on the basis of data about when combine harvesters on commercial farms were working. This states that combine harvesting can take place on a particular day if rainfall on the previous day is less than 1.4 mm.

The new criterion has been illustrated by producing weekly, fortnightly and monthly work-day information in various formats at various sites for a 10 year period. There is a large variation in weekly work-days between individual weeks in one year, some variation in mean work-day values at different sites, but hardly any variation in mean work-day values at different times throughout the harvest season. Results suggest that harvesting systems with about 15% higher capacity should be planned for West of Scotland areas in comparison with East of Scotland areas.

This study provides more reliable information for mechanisation planning than either work-day values for general field operations or previous arbitrary combine harvesting work-day criteria.

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'Focus on quality' at Annual Convention

The 1989 Annual Convention of the Institution was held at the Norton House Hotel, Ingliston, Edinburgh over 9 & 10 May

Day One of the Convention commenced with the Annual General Meeting at which Professor Brian D Witney, Director of the Scottish Centre of Agricultural Engineering, was elected President for a second year of office.

The AGM was followed by the Conference 'Focus on Quality' where the morning session was devoted to an overview of the major issues influencing the cost/price squeeze. Speakers were Mr J Love, Professor BD Witney, President of the Institution, and Mr D M Walker, President e designate. A summary of the morning's presentations is given in the following pages.

Conflict of consumer interests

At the Annual Luncheon the Principal Guest was Loudon Hamilton CB, Secretary, Department of Agriculture and Fisheries for Scotland. He spoke on the need for quality in agricultural produce.

"The problem", said Mr Hamilton, "is that the consumer wishes to retain the benfits of defect free competitively priced commodities but, at the same time, expects freedom from agrochemical residues. How much or how little crop protection is appropriate?

"Routine 'insurance type' spraying is now widely discouraged and enormous care is exercised in screening crop agrochemicals before they are approved for use. Organic farming can provide the answer for only a small percentage of production and we must look at procedures which can reconcile and balance the demands of protecting crop quality and conserving wildlife and the natural flora".

Presentation of Awards

After luncheon the following Awards were presented:

Branch Meritorious Award for outstanding service in connection with branches of the Institution to Ian Duff, a founder member and former Chairman, Honorary Treasurer and Honorary Secretary, Northern Ireland Branch, and John Weir, former Honorary Secretary, South Western Branch and former Chairman, South Eastern Branch.

The Johnson Medal Award to Andrew Haslock, formerly of Writtle Agricultural College, for his project entitled "Report on the design of an automated sheep dip."

The Johnson Medal, in memory of the late Lt. Col. Phillip Johnson, is sponsored by the Wolseley Agricultural Group and awarded annually for the best project submitted by a final year student studying for a Higher National Certificate or Higher National Diploma or First Degree in Agricultural Engineering.

The Douglas Bomford Trust Meeting Award to Brian Legg, Deputy Director of AFRC Engineering for his paper "Engineering for crops - protected crops" presented at the 1988 Jubilee Conference of the Institution and published in the proceedings of the Conference - "Engineering Advances for Agriculture and Food."

The Award, in memory of the late Douglas Bomford, is made annually for the best technical paper presented at an open meeting of the Institution and subsequently published in its Proceedings.

Product Quality: Design Quality

The afternoon was devoted to 'Product Quality' and 'Design Quality' in which technological opportunities for enhancing quality in the fresh food chain and in farm machine design were presented by a series of speakers in two parallel sessions. In this issue we present the papers from the session on Product Quality, chaired by J. M. Stevenson, Shieldness Products Ltd. Papers from the session on Design Quality will be included in our next issue.

Technical Visits and meetings of Specialist Groups

During the evening of the first day there were meetings of Specialists Groups of the Institution including Crop Drying and Storage, Electronics, Forestry Engineering, Machinery Management and Soil and Water Management.

On Day Two delegates had the choice of a meeting of the Vehicles Specialist Group combined with an afternoon visit to the Scottish Centre of Agricultural Engineering or a series of Technical Visits related to the theme of the Conference.

All those who attended the Convention, were agreed upon its success from both the technical and the administrative standpoints. The organisers, convened by Gwilym Owen of SCAE, are to be congratulated for their work.

Machinery Management

BD Witney

The study of the selection, operation and replacement of farm machines is encapsulated in the term: 'Machinery Management'. As the number, size, complexity, and cost of machines increase, the adequacy of the machinery management policy has a major impact on farm profitability.

The process of agricultural mechanisation is complete and should be given its place in history, an important chapter of rural heritage. Just as the Luddites remind us of change in the textile industry, so mechanisation is inexorably linked with the introduction of individual machines to reduce drudgery, to save labour, to increase output and to improve product quality.

Of course, we still need innovation and new technology, whether it is directed towards the combine harvester flagships for intensive agriculture or towards the three-wheeled All Terrain Vehicles for recreational mobility. Any innovation, however, must be commercially successful within a replacement machinery market.

Accurate costing procedures essential

At the very least, it is necessary to have accurate procedures to calculate the cost of operating individual machines and systems of machines for discrete enterprises. Different enterprises demand different tractor and machinery combinations, and different levels of utilisation for common items of equipment. Even a simple, least-cost solution for machinery selection involves whole farm planning to identify correctly the annual use of machinery.

However, the least-cost machinery system does not necessarily maximise profits. Inadequate machine capacity may incur crop yield penalties through un-

Professor Brian Witney is Director of the Scottish Centre of Agricultural Engineering, Penicuik and President of the Institution.

timely operations, whereas over-capacity may introduce the possibility of greater soil damage. These crop yield penalties are always difficult to predict, and sometimes have an economic value only after conversion into a livestock product - adding further complexities. The time available for field operations is also weather dependent, so that the probability of occurrence of workdays involves risk analysis to provide a comprehensive answer.

There is always the danger that modelling becomes an end in itself. Applied correctly, however, operational research provides a framework and identifies the need for specific management data. Adopting the latter approach has resulted in the ensuing machinery management data and procedures.

A simple estimate of machinery ownership costs on an annual basis can be obtained by averaging straight line depreciation, interest on half the capital investment and repair charges over the full period of ownership. Tax, insurance and shelter are overlooked; whilst annual fuel and labour costs are readily identified separately. This average cost, however, does not reflect any variation in annual operating cost with age of the machine; nor does it account for the changing value of money over the period of ownership.

The accuracy of even this simple estimating procedure can be substantially improved by using decremental depreciation to provide a more precise assessment of the resale value of the equipment at the end of each year (Witney and Saadoun, 1989). For an 'n' year old tractor or combine harvester, the resale value, S_n, is

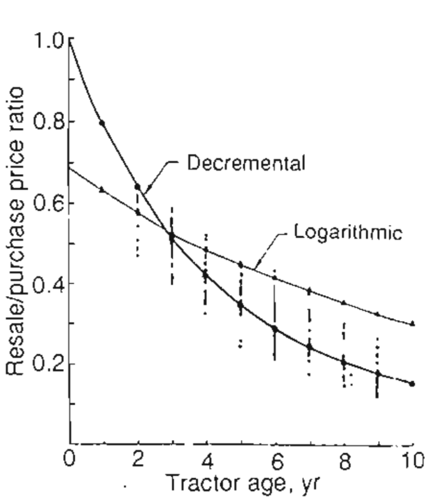

Fig 1. Resale values of two-wheel drive tractors, showing the improved accuracy of decremental depreciation compared with logarithmic depreciation (from Witney and Saadoun, 1989)

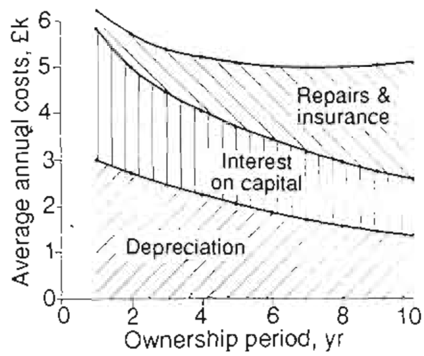

Fig 2. The relative importance of depreciation, interest and repairs using a simple estimate of average ownership costs for a £20,000 tractor.

linked to the purchase price, PP, by the expression:

$$S_n/PP = \exp(-k_1 n + k_2 n^2)$$

where k_1 and k_2 are resale coefficients.

Although decremental depreciation is superior to other methods, the greatest errors occur with one-year old and two-year old trade-ins for which data is sparse and where dealer discounting on the manufacturer's list price has the greatest effect (Fig 1).

The availability of more accurate written-down values also improves the estimates of the interest charges on the capital invested in the machine and the insurance premiums.

Repair and maintenance costs – compensation for operating speeds

The typical trends in repair and maintenance costs based on accumulated use were first prepared in the USA some thirty years ago and , more recently, were adjusted to account for operating speed variations (Rotz, 1987). Speed compensation ensures that the fewer hours of accumulated use for a high speed operation do not result in lower repair costs than for a slower speed operation with the same machine. British repair cost data, although very limited, is in close agreement with the American information (Morris, 1988).

The relative importance of depreciation, interest and repairs on a simple estimate of average ownership costs for a £20,000 tractor is shown in Fig 2. As the ownership period lengthens, the proportion of the average annual ownership cost on depreciation and interest decreases whilst repairs increase.

For a more accurate appraisal of complex agricultural mangement problems, the present annual machinery ownership costs can be calculated using actual cash flows which occur each year. Three types of cash flows are involved in the calculations of the annual cost of a machine.

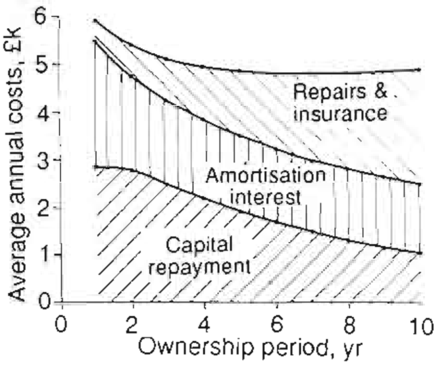

Fig 3. The proportions of the ownership costs represented by capital repayment, amortisation interest and repairs and insurance using actual cash flows for a £20,000 tractor.

1. the capital cost with interest charges;
2. the recurring annual repair and insurance charges;
3. the income from selling the machine

In this machinery cost model which has been fully described elsewhere (Witney and Saadoun, 1989) the capital cost is amortised over the period of ownership, other programs being available to compare the cost of different financing arrangements. Assuming 14 per cent loan interest, 10 per cent investment interest, 7 per cent inflation and no tax, the proportions of capital repayments, interest and repairs are not dissimilar from those for the simple estimating procedure (Fig 3). The totals are somewhat less however, because the essence of the discounting procedure is that present money is worth more than future money.

Effect of tax relief

Various machinery costs are eligible for tax relief, namely annual capital allowances, interest payments, repair and insurance charges, and fuel and oil costs. These allowances only benefit those farmers who make sufficient profit to pay tax – the more profitable the business, the higher the marginal rate of tax and the greater the financial advantage from the allowances. For taxation purposes, the annual rate of capital allowance in 1988 is 25 per cent on a diminishing balance basis, that is on the written down value of the machine.

The effect of tax relief is both to reduce the annual machinery ownership costs and to reduce the cost saving of extending the period of ownership (Fig 4).

Also shown in Fig 4 is the marginal holding cost which represents the extra costs incurred by keeping a machine for an additional year. For an ownership period of only one year, the marginal cost is equal to the present annual ownership

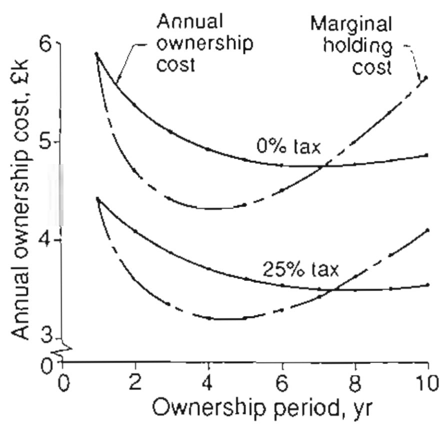

Fig4. The effect of tax relief on the annual ownership cost and the marginal cost of estending the ownership period for a £20,000 tractor.

costs. Once the marginal cost ceases falling, there is a declining advantage in extending ownership. Once the marginal cost is equal to or exceeds the annual ownership cost, there is an increasing financial penalty for prolonged ownership.

The costing principles applied: alternative forage harvester systems

The machinery cost model was used in an operational research study of alternative forage conservation systems which included:

- direct cutting or wilting to various degrees
- a range of chop lengths using a precision chop harvester, a double chop harvester or a flail harvester
- the use of addititives

The quality of grass silage is generally improved by better wilting, shorter chopping, and the use of additives. All theseoptions, however, incur costs. In order to assess whether the additionsl costs were justified, the benefits were evaluated for a mild production system (McGechan. 1989). Crop growth and field wilting were simulated in relation to the weather, swath drying rates for field wilting also being influenced by the type of mower employed and on any subsequent treatments. Both field and storage losses affected the monetary value of forage.

The field operations in the grass conservation systems included cutting, spreading, tedding and windrowing, and picking up by either a forage harvester or a big roll baler. Forage harvesting on the livestock farm, like primary tillage on the arable farm, differs from most other operations in that the work rate is limited by the available tractor power. The travel speed of the forage harvester is influenced by the chop length, the grass dry matter content, the haulage load and the uphill slope angle, with an overriding maximum speed of 7 km/h. In addition to the three-in-line combination of tractor, harvester and trailer, transport and loading the silo requires a further two tractors and associated equipment. A three tractor system is also used for big bale silage – one with the baler and two for transport.

The hourly costs of the machines which are shared between silage making and other farm operations are based on an arbitrary annual use of 1000 h for tractors and 300h for other items. This is acceptable for this type of system comparison but introduces errors on a whole farm study by underestimating the allocation of fixed costs when the actual use undershoots this arbitrary level.

Forage chopping policy generally depends on the type of harvester selected, typical median chop lengths being 80 mm, 60 mm and 30 mm for flail, double chop and precision chop harvesters, respectively. A median chop length of 10 mm can be achieved with a precision chop

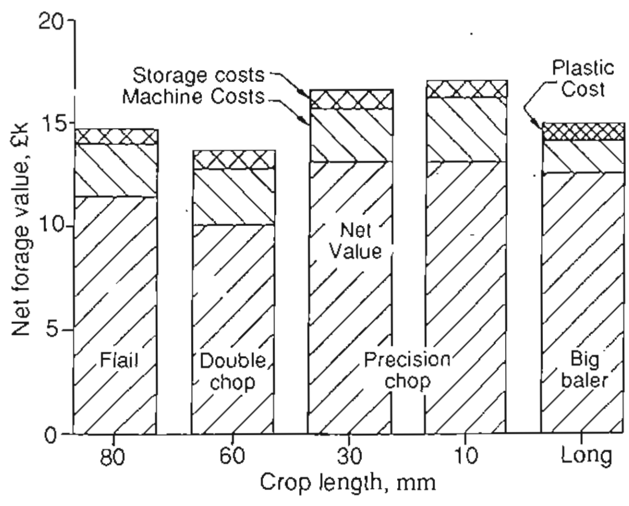

Fig 5. Gross forage value, production costs and net value of silage produced with alternative harvester and chop length policies for a first cut conservation area of 40 ha (from McGechan, 1989).

The gross forage value, production costs and net values of the silage are shown in Fig 5 for the alternative systems.

The precision chop harvester system produces the highest quality silage and the higher machine costs are more than justified by the increases in net forage value, but the result of short chopping is not materially different from that for standard chopping. A double chop harvester costs more than a flail harvester but produces silage of similar quality, and this fact is reflected in its poor economic performance.

Big bale silage, made correctly, has a net value markedly higher than that made with the flail forage harvester and approaches that for precision chop harvester.

Over 30 ha, best economic choice is precision chop harvester

The effect of varying the first cut conservation area, with a pro-rata change in the second cut area and the herd size in the

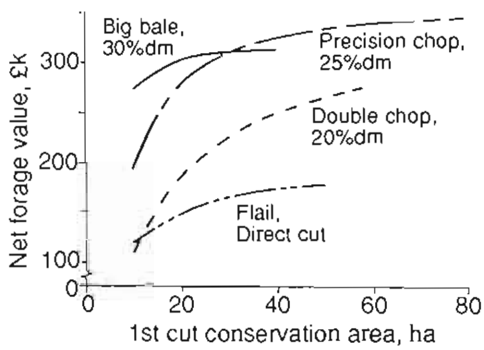

Fig 6. Net forage value with alternative harvesters and a range of farm sizes (from McGechan, 1989)

forage evaluation procedure is shown in Fig 6.

For small areas, big bale silage has a higher net forage value than precision chopped silage, due mainly to its low mechanisation cost, but above 30 ha the precision chop harvester is the best economic choice.

Benefits of timeliness

Realistic area capacities for different sizes of machines are determined by timeliness constraints – the shorter the operational window, the higher the rate of work required by using either a larger size of machine or a larger number of units. Both solutions involve extra costs which must be covered by the economic benefit from timeliness.

Small machines have a higher labour charge and large machines incur a soil compaction penalty.

The penalties of untimely crop establishment can be expressed as the percentage yeild loss due to the crop being established either too early or too late, against a timescale of the number of days deviation from the optimum date of establishment (Witney and Elbanna, 1985):

$$Y_L = K_t (t_0 - t)^2$$

where:

Y_L = yield loss, %;
K_t = timeliness coefficient;
t_0 and t = optimum and actual dates of establishment, days.

Different timeliness coefficients for early and late establishment allow for assymetry of the response curves, whilst retaining a smooth transition from one curve to another because the gradients of both curves are zero at the optimum date of establishment (Fig 7). Integrating the yield loss equations over the period of establishment gives the mean yield loss which is kept to a minimum by spanning the optimum establishment date.

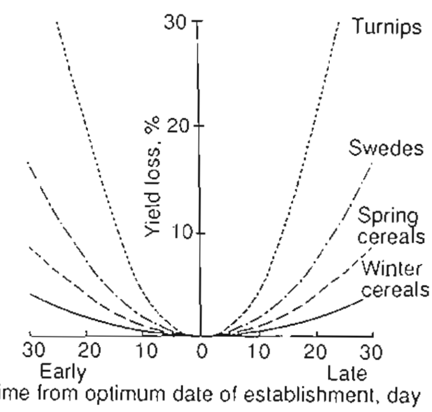

Fig 7. Percentage yield losses from untimely establishment (from Witney, 1988)

Soil compaction penalty

As yet, there is no soil compaction penalty index to account for crop losses from vehicles. In an economic analysis of zero traffic and conventional traffic systems for winter barley, Campbell and McGregor (1989) indicate that the advantage of eliminating traffic from the crop areas is £50/ha (Table 1).

The results from the zero traffic system, as well as always outyielding the conventional traffic system, gave more uniform crops, smaller seasonal variations in yield, better root penetration and hence water availability, and reduced cultivation energy requirement. As the machinery costs were based on over-powered experimental equipment and as the draught power was some 15 kW less for the zero traffic system, it is possible that the gross margin differential could rise by £7.50/ha.

A further differential of £7.50/ha could accrue by saving 10% of the time required for ploughing, which in turn could eliminate penalties for untimely establishment which would otherwise be incurred.

Table 1. The effect of traffic systems on crop yield and gross margins for winter barley

Traffic system	*Average yield, t/ha*	*Gross margin, £/ha*
Zero	7.0	211
Conventional	6.3	161
Differential	0.7	50

The time available for field work is mainly determined by the moisture status of the soil and the weather conditions on the day on which the field operation is to be carried out.

Table 2. Field workdays for three soil types in eastern Scotland for 18 years out of 24

Month	*Number of workdays*		
	Light soil	*Medium soil*	*Heavy soil*
January	24	18	12
February	23	17	12
March	24	18	15
April	25	19	17
May	26	22	20
June	26	24	24
July	27	26	26
August	26	25	24
September	25	23	20
October	23	19.	17
November	22	18	17
December	23	18	14

A field workday occurs when the soil is dry enough to sustain the weight of the machinery (trafficable) and wet enough to produce maximum tractive efficiency (tractionable), as well as minimising the soil damage (workable).

Prediction of field workdays

Using a soil moisture model and meteorological data for the Edinburgh area, the number of field workdays was determined when the soil moisture content was not greater than the lower plastic limit and when the rainfall was less than 1.4 mm in that day. The results are presented in Table 2 for three soil types (light, medium and heavy) and for 18 years out of 24 (Eradat Oskoui, 1986).

The prediction of field workdays was not sensitive to rainfall in excess of 1.4 mm, but a 30 per cent reduction in workdays was noted for a rainfall criterion of 1.3 mm.

It is interesting to note that this same rainfall criterion was obtained from a statistical comparison between weather records and observations of workdays for combine harvester operations, such that combine harvesting could take place when the rainfall in the previous 24 hours was less than 1.4 mm. As the combination of the harvesting and the soil workability criteria made such a small adjustment to the number of combine harvesting workdays for a considerable increase in the requirement of weather data, antecedent rainfall alone is considered an adequate criterion (McGechan *et al*, 1989). It is also more realistic because a farmer would be unlikely to forego a harvesting opportunity when the crop was in a fit state even if soil damage might occur.

Table 3. Frequency of workdays and non-workdays

Current day	*Previous day*	
	No work	*Work*
No work	20	22
Work	20	706
Total	40	728

Table 4. Frequency of tillage only and harvesting workdays

Current Day	*Previous Day*		
	No work	*Tillage only*	*Harvest*
Tillage only	10	230	120
Harvest	10	124	232
Total	20	354	352

As well as the probability of occurrence of workdays, the sequence of wet and dry days is critical for sequential field operations. In order to produce quality hay, for example, there are only about two starting days for five-day dry periods, whereas there are five starting days for two-day dry periods suitable for making silage (Witney, 1988).

For the harvest period, it is equally important to identify not only the non-workdays but also the days when harvested land may be cultivated if further harvesting is not possible (Tables 3 and 4). When the previous day is a non-workday, there is a 20/40 chance that the current day will also be a non-workday, whereas there is only a 22/728 chance of a non-work day following a workday (Fawcett *et al*, 1988). Given that the current day is a workday, it can be classified as suitable for tillage only or for harvesting which are mutually exclusive.

When the previous day is a workday, there is a 10/20 chance of either tillage or harvesting. When the previous day was suitable for tillage, the persistency factor is high at 230/354. Such a process will produce patterns of workdays to give cumulative probability distributions for stochastic dominance analysis.

Farming risk

Management risk in selecting machinery sets is high because of the uncertainty of the weather conditions. The difficulty of ranking the various options is best illustrated by means of a simple example.

Let E, F, G, and H be risky prospect functions uniformly distributed on the axis as the net financial outcome (Fig 8). The two risky prospects E and F have identical means, but F has a smaller variance for a given level of expectation than E which is less risk efficient and may be discarded. The mean of the risky prospect G is greater than that of F, but the variance of F is less than G, so that both must be retained in the risk efficient set. On the other hand, the mean and variance of risky prospect H are less than those for F and G and lie everywhere to the right of risky prospect H. In this case, H is stochastically dominated in the first degree by both functions F and G. The accumulative probability function of H will never be selected in preference to functions F and G.

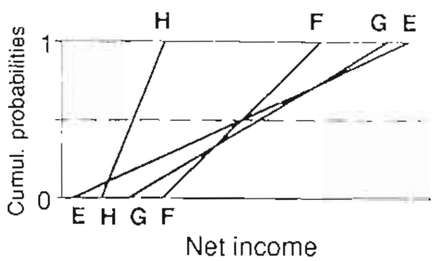

Fig 8. Display of alternative risky prospects (from Saadoun, 1989))

In cases where the functions intersect, second degree stochastic dominance requires that the area under the function F should be less than or equal to the area under function G. Function F would be preferred to function G by those persons who are risk averse and consequently value the income in the lower cumulative probability range more highly than income in the upper range.

In a simulation experiment on a 250 ha arable farm with cereals and potatoes, the ranking of the solutions is not unexpectedly in accordance with the capacity of the alternative sets of machinery (Fig 9). The highest gross revenue is attained with the largest machines which minimise penalties of untimely operations (Saadoun, 1989). After deducting the annual costs of machinery operation, the cumulative net revenue curves are ranked in a different order. The high technology solution has the lowest net revenue because of the high machinery costs. The other two net revenue curves cross and second order stochastic dominance is used to identify that the mid-technology solution is the preferred choice.

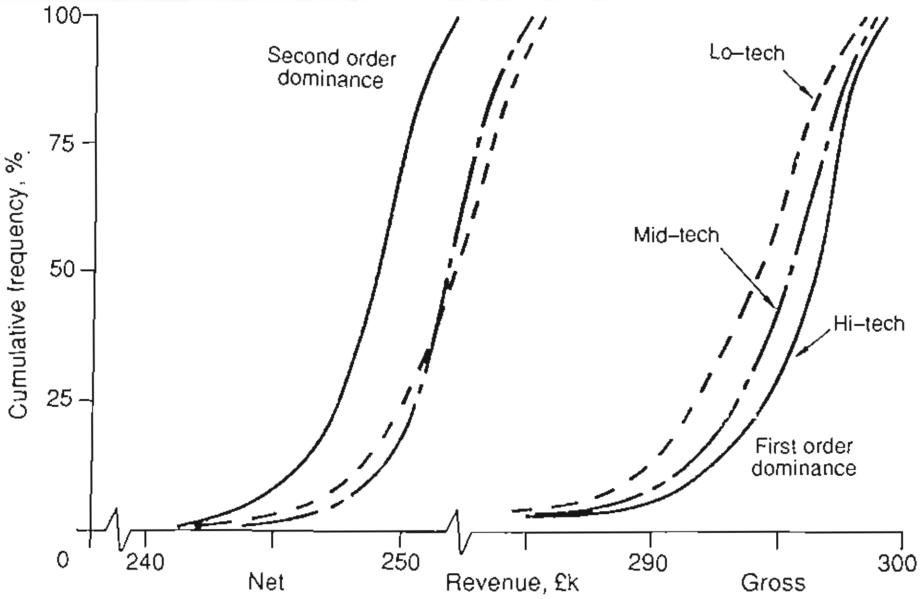

Fig 9. The gross and net revenues for three levels of machinery complements, illustrating first order and second order stochastic dominance (from Saadoun, 1989).

Conclusions

The inclusion of tax allowances and accurate resale values improves the assessment of machinery ownership costs.

In a comparison of forage conservation systems, the highest net forage value is obtained with a precision chop harvester, except for a first cut conservation area of less than 30 hectares where the big baler system is marginally more economic.

Crop yield penalties from untimely establishment are proportional to the time deviation from the optimum date.

Although the development of a compaction penalty index is still incomplete, there is ample evidence to show that a zero traffic system outyields a conventional system in winter barley, giving a conservative differential of £50/ha in favour of the zero traffic system.

The occurrence and sequence of workdays for soil workability and for combine harvesting are presented and used in the calculation of cumulative probability functions for gross revenue.

First and second order stochastic dominance is used to rank the cumulative probabilities of net revenues for different machinery complements.

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1992 – What does it hold for us?

D M Walker warns that the Single European Act will bring many changes - benefits, opportunities and some threats. He urges British industry to take note in good time and get the best out of it. We present here extracts from his important message.

Today, we are all concerned about what 1992 holds in store for us insofar as the EEC is concerned. However, let me say that the Single European Act becomes effective not in 1992 but on 1st January, 1993 – but that is still just four years away.

Of course, we will not go to bed on 31st December, 1992 and wake up on 1st January, 1993 and see a complete change in our way of life – it will not be like that. Many of the changes will be gradual and phased over many years.

Vast increase in the 'Home' Market

How is it going to affect us in the agricultural world?

Well, instead of a home market of some 250,000 farmers in the UK, it will move to 11 million farmers with an average farm size throughout the Community of approximately 13 hectares with the highest average of 65 in the UK and the lowest in Greece of just over 4 hectares. Clearly, we are going to have to think about our farming practices as there is a vast difference between the cool and relatively wet northern part of the Community compared to the warm and more arid southern part of the EEC – quite apart from the farm size.

Initially, at least, the most obvious change from what exists at the present time will be in the freer movement of people and goods. Crossing borders will be very much simplified.

It is estimated that the potential benefits from the Single European Market will be an increase of domestic product, a decrease in prices of 6% (I suspect in reality that will not happen, but rather there will not be the price increases), and new jobs to the extent of 2-5 million. Now whilst this sounds a lot of people, in relation to the population of the Community it is still relatively insignificant but at least it is a move in the right direction.

The day of the protected farmer within the Community is rapidly coming to a close and he is going to have to compete in ways to which he has not been accustomed in the past.

Clearly, partly as the result of structural changes in farming, there are going to be changes in the supplying industry to agriculture and this is one area where I hope that legislation may be of assistance in producing common standards rather than the complexities which exist today.

Technical harmonisation

I am pleased to note that a desire to have technical harmonisation on many issues is a key feature of the Act.

Let me give some examples of what I mean. In the UK a safety cab is required on all tractors sold here and must have a noise level currently below 90 dB(A). There are other countries in the Community where there is currently no legislation either for a cab or sound level. A second seat is very often fitted in the cab of tractors sold in Germany but a similar seat here, in general would not be accepted by the Health & Safety Executive. Different glass requirements for cabs is another example.

Similar situations apply with agrichemicals. You may be sure that these barriers will disappear because it is stated that from the beginning of the Single Market any product sold in any one Member of the Community can be sold in the others. This I velieve is an over-simplification of the situation and will probably have to be given some serious thought. For example, I cannot see tractors without a cab being sold in the UK. Quite apart from noise considerations, our farmers have come to expect high standards of operator comfort and bear in mind, here we are talking about Health & Safety as distinct from technical specification.

Dare I say also that the quicker that we in the UK get onto the metric system fully and completely, the better off we will be.

Role for European Parliament

Who decides on all these changes? Less and less is it the various national governments (in our case in Westminster) but more and more the bureaucracy in Brussels.

One of the top priorities in my view is that the European Parliament must become an effective legislative body given teeth, which is not the case today. The bureaucracy is very much judge and jury – a situation which clearly cannot be allowed to continue. It must be answerable to a freely elected legislative body.

Learn a second language

I would like to intersperse here a comment concerning language. I suspect the Community will move towards English with French as the second language, but we are not there yet and it will be some time away before this happens. I would urge all of you to learn at least one other major language, preferably French or German – to allow you to deal on equal terms because, as I am sure most of you know, any businessman worth his salt in Europe speaks English perfectly and can conduct business not only with you but, more importantly, with your customer.

The cross country acceptance of qualifications is exceedingly difficult especially when you take language into account. More students and post-graduates will be attending universities in other countries of the EC to broaden their educational outlook and experience.

Manufacturers should join forces – strengthen product lines

Now look at the position as it affects the manufacturer. One positive benefit for the UK manufacturer is the European Standard for quality management known as EN29000 (harmonised with BS 5750 which has been around for about 10 years) and International Standard ISO 9000. Here a BS has been taken as suitable and this means others may have to adapt to a greater extent than the UK manufacturer.

I have already referred to the variable climatic conditions within the Community and if, as I suspect, livestock farming and dairy products are best suited to the cooler and wetter conditions, then our manufacturers are going to have to give serious thought as to how they will supply that market, perhaps at the expense of the arable sector. On the other side of the coin is the need for the UK manufacturer to ensure that his product is acceptable and

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Douglas Walker is Managing Director of John Deere (UK) Ltd and President Designate of the Institution saleable in the rest of the Community.

The patent position is also changing into an EC patent law as distinct from individual national requirements. The European Patent Office is in Munich and not so readily convenient as London. Searches will be much greater and presumably so will costs as language barriers yet again come up. In general, I believe that most companies will welcome a law that covers the Community as it will be easier than negotiating in individual countries where companies want cover.

What do we have to do to get into the other markets within the Community? Perhaps it might be necessary to join forces with one or two or even three manufacturers in other parts of the Community who have complementary lines which when put together can create a strong product line which can be saleable inthe Community at large. This will probably assist in gaining access to dealers through an already existing selling organisation. I believe that this may well be the best solution for many companies but so far there has been little movement in that direction within our own industry.

An alternative of course, is to go it alone but this has to be considered a difficult option for smaller companies as they will be highly dependent on finding suitable distributors in the rest of the Community and of course, they will be in competition with companies from other parts of the Community with a similar type of product.

Potential problems for dealers

What impact does all this have on an agricultural dealer today and in the future? I believe that the main impact on the dealer's business will be with the franchises which are currently held and which he may wish to hold in the future. As things stand today, many dealers have franchises solely with a UK manufacturer or a UK distribution company. Seldom do they have an agreement with a company outside the UK because of the potential problems.

The first and most obvious potential problem is to be able to converse in a common language. Dealers will probably have to order economic loads. They will need to ensure that the operator manuals, parts lists, service manuals etc., are in English. The machines must be properly guarded and safety decals in English will be essential.

It will be necessary to stock parts in sufficient quantity to ensure a proper back up to the customer. Remember that the local (i.e. UK) safety laws will continue to apply.

Product liability should not be forgotten. An importer should ensure a proper contract with a supplier to cover this vitally important subject as this is potentially one of the areas of high risk. The EC proposals on product liability are much more severe than the existing UK requirements. You are warned to take careful note.

However as far as UK supplies to the UK dealer is concerned, I don't see dramatic changes except inevitable changes by the manufacturing supplier as he may broaden his product range or he may amalgamate with others.

I strongly urge you all to take note of what is happening as a result of the plans for 1992 and ensure that you get the best out of it.

The fresh food chain

Current and future requirements reviewed by J Love

Environmental issues will in future increasingly influence the standards set for growers supplying the supermarket fresh food and vegetable chain.

There will be pressure for a reduction in pesticide usage, for the more accurate targetting of sprays and for physical weed control to meet the increasing demand for 'organically' grown crops.

Mechanical damage to crops is still a problem – for example, in the harvesting and handling of potatoes – and there is a need for better storage facilities at source.

With the laser and computerised selling equipment now availabel the modern supermarket is able to collate daily, precise information on sales. Buyers from the depots supplying each supermarket are then expected to procure the right mix of products, perhaps with only 24 hours notice.

Growers are now responsible for maintaining the quality standard of their produce whilst a 'flying squad' of inspectors do random sampling on behalf of the supermarket chain. In the past, only 40 per cent of a crop reached marketable quality. Now this figure has been improved to 80 per cent through better husbandry techniques and by selling the same crop to both the fresh and the prepack markets, thus utilising most unit sizes.

Many suppliers now use the 'cool chain' to keep produce fresh. Refrigerated transport has become commonplace.

On a specific 'Scottish' issue, Mr Love gave a view that depots in central Scotland would not rule out Aberdeen and surrounding areas as too far to receive produce from growers wishing to supply supermarkets.

J Love is Senior Development Manager for J. Sainsbury plc.

CORRECTION

In the review of the new Caterpillar Challenger 65 tractor (44 (2). 63) we incorrectly listed Levertons Ltd as holding the Caterpillar dealership for the whole UK. We are now advised that three companies in the UK are registered Caterpillar dealers.

H Leverton Ltd are responsible for Northwest and Eastern England; Finning Ltd for Scotland, Wales, the Midlands and South West and McCormick McNaughton Ltd for Northern Ireland and the Republic of Ireland.

TECHNOLOGY

US Government Science and Technology Database now available in Europe

The National Technical Information Service (NTIS) of the US has signed an agreement with a UK specialist publisher, ILI, to disseminate throughout Europe the huge amount of technical information available from the US Government. NTIS was founded by Congress to act as a clearing house for US and foreign scientific and technical information.

ILI points out that the database is strong in the field of Agriculture and Farming and the majority of the reports in the system have not been published outside the US before.

The entire content of the system is some 2 million reports with about 70,000 new ones being added every year. The reports contain the results of US and foreign government, industry and private R & D.

To use the system the starting point is a request to ILI for a free database search, quoting appropriate key words of interest. ILI then mail by return a print-out with all the citations relevant to the key words chosen.

Any particular report required can then be provided by ILI from the vast library of microfiches held at Ascot. Prices for the reports range from £13.20 to £60.00 for reports in the 500-600 page range.

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Machine vision using spectral imaging techniques

A Y Muir, I D G Shirlaw, D C McRae

With an increasing demand for higher quality produce in the food industry the need for machine vision inspection systems has become apparent.

Machine or industrial vision is the technology of providing automated production processes with vision capabilities. By this means, automatic inspection, selection by shape or feature and orientation of components or materials are possible. Machine vision can simplify production processes, can make them more efficient and can reduce the need for human intervention.

The majority of inspection tasks are highly repetitive, extremely boring and depend for their effectiveness on the efficiency of the human operator. Recent research has indicated that the efficiency of manual inspection of potatoes for defects using roller tables can range from as little as 8% to over 60%.

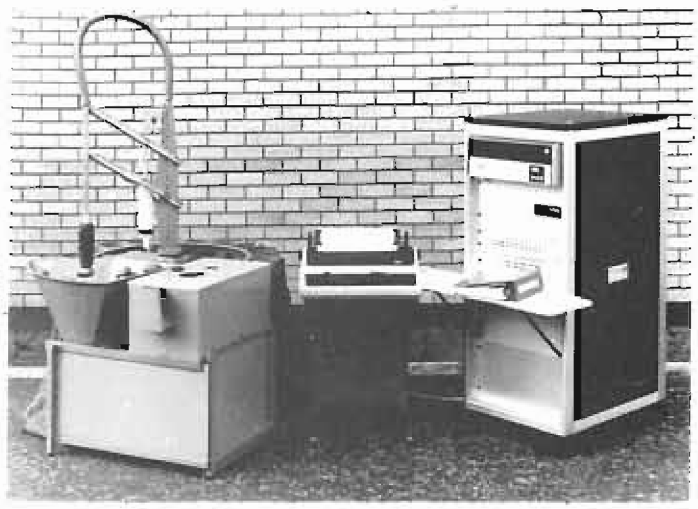


Fig 1. the SCAE optical detector

Over the last five years, machine vision systems have been applied in most sectors of industry including, for example, those of steel, timber and domestic appliances. The main impetus, however, has come from the electronic and automotive industries which account for the majority of applications to date. The variety of applications is expanding rapidly and the market for machine vision is expected to continue to expand at the rate of 50% per year for the next five years.

That there is a large difference in the level of sophistication in systems is indicated by the wide price range which extends from less than £10,000 to greater than £750,000. Increased awareness of the need for quality control and the pronounced competitive drive towards industrial automation have made manufacturing companies accept the need for such investment in machine vision systems.

Spatial and spectral pattern recognition

The main applications of machine vision are inspection and manipulation. Ninety per cent of the machine vision market is in inspection and quality control (Bailey, 1988). In industrial situations, where the components are usually man made, inspection consists of measurement or comparison of spatial geometries with those of known patterns. This is spatial pattern recognition.

Machine vision combines computer and television technologies. The software is usually developed for use with a particular hardware configuration. This fact has resulted in a wide range of vision systems each of which is applicable to a specific situation. Common to all such systems are three basic processes: image capture, digitisation and computer processing.

In image capture, a sensor converts an optical intensity pattern into an electrical signal. In the case of a two dimensional solid state sensor, a lens transmits an image onto the sensor which converts the image to a two dimensional charge pattern. The image is effectively quantised in both spatial dimension and intensity. After accumulation, the two dimensional charge pattern is read out in a serial train of discrete pulses.

The pulses from the sensor are passed to an analogue-to-digital convertor where they are digitised and transferred to computer memory or frame grabber. The frame grabber ensures that there is a known correspondence between the sensor pixels and the location in memory. The resultant array of numbers representing the scene or object is known as a digital image.

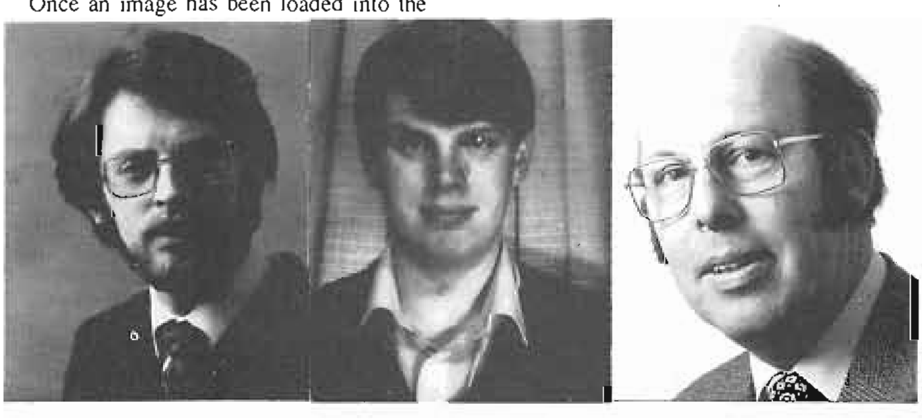
Once an image has been loaded into the computer, it can then be processed. This series of actions or operations is dependent on the particular task of inspection. Thus, an object may be classified into one of several categories by virtue of some geometric criteria.

Spectral imaging based on highly complex phenomenon

Whereas spatial imaging resolves objects into 2 or 3 dimensions, spectral imaging has generally no spatial resolution whatsoever. As a technique, it owes its origins to the analytical chemistry laboratory and the science of remote sensing.

The interaction of light and natural matter is a highly complex phenomenon. The absorbing molecules of matter are excited to specific vibrational states or energy levels dependent on the energy of the incoming radiation. For example, long (low energy) wavelength radiation such as radio or microwaves can excite gases while liquids and solids can be affected by radiation with shorter (high energy) wavelengths such as x-rays.

According to quantum theory, molecules



Andrew Muir, left: Ian Shirlaw, centre: Douglas McRae, right, are Research Engineers at the Scottish Centre of Agricultural Engineering, Penicuik.

absorb light in the visible and ultraviolet because their electrons can move to higher energy states. Infrared light does not have enough energy to excite electrons in molecules. Instead, excitations resulting in molecular absorption come from vibrations and rotations of molecules.

Rotational absorption bands are predominantly in the far infrared. Vibrational absorption bands are those which involve the near infrared, which has been applied extensively to component analysis of food and agricultural materials.

The complexity of molecular absorption can be simplified by assuming that molecules only vibrate at fixed frequencies when excited and so only absorb light of that particular frequency or associated wavelength.

Each material has its characteristic 'spectral fingerprint'

Light which has interacted with a surface, that is, has penetrated just beneath the surface and been exposed to possible absorbers and then re-emitted from the surface is said to have been diffusely reflected. As such it contains information on the absorbers present in the material.

By using an instrument which can measure the intensity of diffusely reflected light at wavelengths across a waveband it is possible to obtain the characteristic spectral fingerprints of materials.

These spectral patterns or images are multi-dimensional and the process of distinguishing between them is spectral pattern recognition.

Special problems in adopting machine vision in food/farming

Although vision analysis systems have become more widespread, the food industry has been somewhat slow in adopting the technique for several good reasons.

The first problem concerns the major differences in requirements between the engineering and the food industries. As inspection system requirements are dictated by the particular characteristics of say a food processing line, each vision system has to be tailored to a particular application. Therefore, it is not possible for machine vision manufacturers to supply off-the-shelf systems (Gagliardi *et al*, 1985).

Another problem is in inspection standards or criteria of inspection. Manual inspection consists of qualitative descriptions of objects; there is little or no quantitive aspect. It is, therefore, not a simple task for a vision system to emulate the inspection criteria of a human. Factors which have to be considered in the application of machine vision products to food processing are listed in the panel.

Factors to be considered in application of machine vision

1. In produce inspection or processing operations, due to the low value of individual produce items, high production line throughputs are necessary – 5 to 10 objects a second would not be uncommon. The vision system, therefore, has to acquire the image, extract the appropriate features and make a decision in 100 - 200 ms (depending upon object spacing and the necessary throughput rate).

2. Food processing lines present randomly orientated products to human inspectors. A vision system has to be able to scan such unconstrained objects and to detect the random presence of defective material and remove it from the line.

3. Defects found on whole fruit and vegetables tend to be discrete lesions or small areas ranging in size from less than 1% to greater than 50% of the surface area. Such lesions may appear to the human eye as subtle changes in colour or simply darkening of the skin. Indeed some defects may be invisible to the human eye (Muir *et al*, 1982). It is unlikely that the subtle colour changes due to these defects could be detected and classified by a typical vision system without recourse to multiple optical filters.

4. Although the introduction of an efficient vision system may reduce labout costs, this criterion is minor in comparison with the gains to be realised in the improvements in quality control of the end product.

Techniques developed for quality measurement

Many instrumental techniques have been developed for measuring the quality of agricultural products. Quality as related to these products is difficult to define in terms of physical parameters which can be readily quantified. In general, it is the chemical composition of the product which really determines the quality and indeed it is easier to develop techniques to measure composition than it is to measure quality.

Colour measurement is an extremely important indicator of quality in food. Not only can colour be used as an indicator of maturity and freshness but, in some instances, maybe more importantly, as an indicator of the presence of disease or defect. The two usual ways of measuring colour are spectrophotometry and tristimulus colorimetry. In either method, there is no spatial resolution whatsoever. Both methods present average colour measurements over the field of view of the instrument.

The technique developed by Norris (1983), and others, for visible and near infrared analysis has been applied to the detection of such things as anthocyanins, chlorophyll, carotenoids and other pigments. Both reflectance and transmittance measurements can be used to evaluate colour and to detect defects. Broadly, this is spectral rather than spatial pattern recognition.

An optical disease detector for potatoes

Many products can be sorted automatically based on reflectance measurements in the visible to near infrared region of the electromagnetic spectrum. Instruments designed for these purposes, however, although derived from analytical instruments do not represent the optimum design for compositional analysis. Generally they are much simpler in construction and utilise only a few well chosen wavelengths in the spectral region of interest.

At the Scottish Centre of Agricultural Engineering (SCAE), a study has been made of the use of visible to near infrared spectrophotometry as a detector of diseases and defects in potato tubers (Porteous *et al*, 1981). The original work using an analytical instrument suggested that it was posible to detect 12 to 15 different types of defect with about 85-90% success.

It was found that it was necessary for best discrimination to use 8 wavelengths. These included some as high as 1650 nm.

In order to identify which wavelengths best convey the relevant information, spectra were analysed using the statistical technique of discriminant analysis. Briefly, this procedure selects that subspace of the data in which the vectors representing the mean curves of the various diseases are most widely separated. The number of wavelengths defining the axes of this space is reduced to a minimum consistent with the successful recognition of defects. The variables used might be either straightforward reflectance measurements, or more often, functions of these.

With the wavelengths and algorithms presented by analysis it was possible to define the necessary parameters for a simple optical disease detector as shown in Fig 1. This instrument was effectively a flying spot scanner with only 1 pixel of the surface of the target tuber examined at any one time. The instrument was slow but it gave the opportunity to assess sorting strategies and to quantify the efficiencies of various algorithms, variables and sets of coefficients. Also it allowed the gathering of fresh data with which to form further more efficient predictors.

The defect categories detected in the original work included:

- Bacterial soft rot *(Erwinia carotovora var. atroseptica)*
- Blight *(Phytophthora infestans)*
- Common scab *(Streptomyces scabies)*
- Powdery scab *(Spongospora subterranea)*
- Dry rot *(Fusarium solani var. caeruleum)*
- Gangrene *(Phoma exigua var. foveata)*
- Greening
- Skin spot *(Polyscytalum pustulans)*
- Damage *(old wound and new wound)*
- Black scurf *(Rhizoctonia solani)*
- Soil adhering to surface

Calibration against decisions of experienced inspectors and pathologists

Some experiments were conducted with the disease detector in order to form an opinion as to its true performance (Porteous and Muir, 1987). This was an attempt to calibrate the instrument against the decisions of seed potato inspectors and plant pathologists who were experienced at detecting different diseases and estimating quantitatively the percentage area

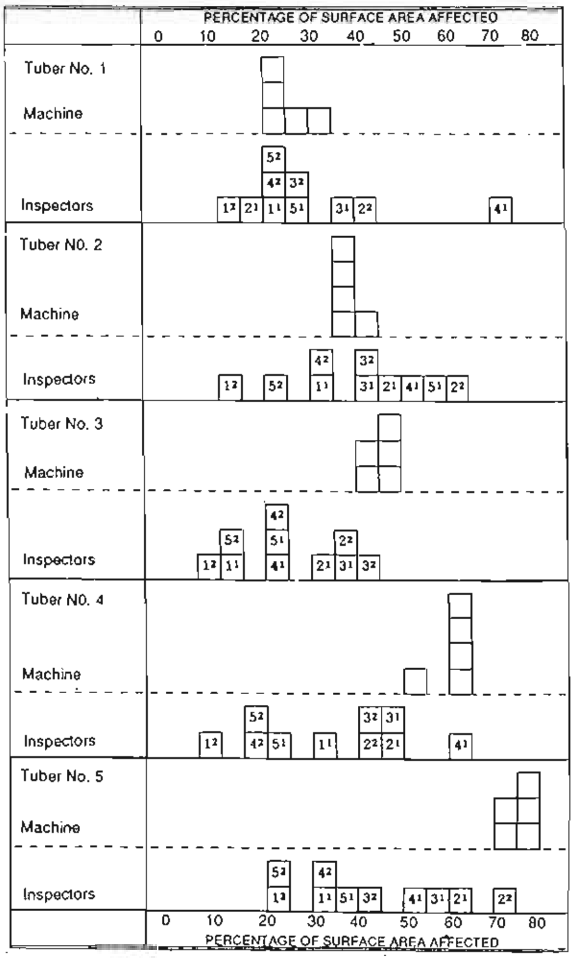


Fig 2. Estimates of common scab on potato tubers made by grading machine and by 5 inspectors

1^1 = 1st estimate by inspector No 1, etc.
1^2 = 2nd estimate by inspector No 1, etc.

of disease present.

The comparison revealed a marked lack of unanimity among the assessors. Estimates of the extent of disease on tubers varied widely, both between assessors and between repeated assessments of tubers by individual assessors. These results are shown in Fig 2. The detector proved very much more consistent than humans. An interesting point was that any batch, selected by any one assessor, was not passed by any other assessor (Fig 3).

The results of these experiments were evidence of the difficulties which inspectors face and typify the best that can be expected from any group of human operators, however well qualified.

A tuber may display many unimportant blemishes as well as signs of more serious disorders. Obviously, inspectors must first distinguish the diseased regions from these trivial defects and then estimate whether the aggregate of their area exceeds some predetermined tolerance. It is not surprising that a machine is capable of better repeatability than humans in such a task.

It is probable that these results are applicable wherever human observers are used for inspection purposes.

However, it must not be forgotton that the system described cannot judge shape and variety or whether there is evidence of mechanical damage in the form of surface cracks. These defects involve recognition of two-dimensional spatial patterns as well as multi-dimensional spectral patterns. Enhancement of the above system to handle both these tasks is at present under consideration.

Spectral pattern recognition potentially useful but severe problems still to solve

Despite the widespread use of machine vision in the engineering industry, the food processing industry has not, as yet, been able to fully utilise this technique for quality control. Spectral pattern recognition could be a useful method for defect detection.

Having accepted the necessity for such systems of sorting and that the spectral technique works the next step is to apply the technique at commercial speeds. For this, it will be necessary to image all surface pixels or a substantial proportion of them virtually simultaneously. There are severe problems to be overcome.

In the case of potatoes:

a) The whole surface of the tuber has to be viewed in up to 8 wavelengths simultaneously.
b) Surface pixel resolution has to be of the order of the smallest lesion required to be detected.
c) A decision to be made on each surface pixel.
d) A decision has to be made on the whole tuber.
e) Maximum time allowable to scan one tuber is of the order of 300 ms.

The computational element may be soluble in the near future as computer speeds are increasing and parallel processing is becoming commonplace. It is the presentation of the whole surface of the tuber to an optical system in the limited time available which provides a fundamentally difficult problem.

Although the work described relates to potatoes the same principles may be applied to other vegetables and fruit. Solving the problem for one application will open the door to many others.

Acknowledgements

We are greatly indebted to Dr James McLean, Heriot-Watt University, for his helpful suggestions regarding the content of the paper and to Norma Shillinglaw for typing the paper and correcting grammatical mistakes. Finally, we are indebted to DAFS who have funded the research presented.

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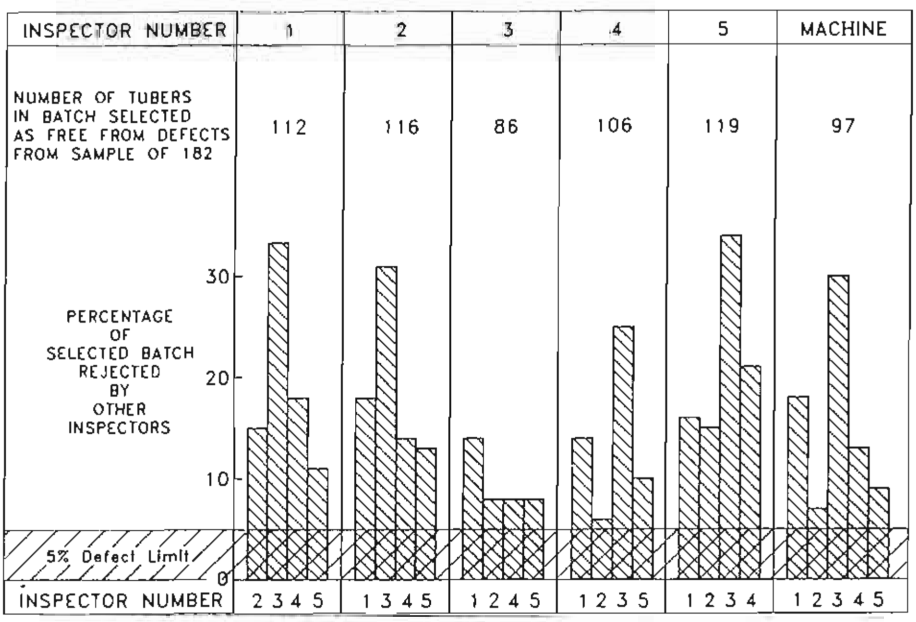
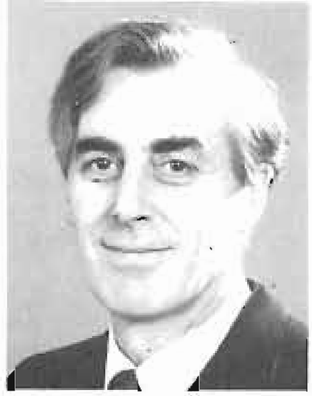


Fig 3. How the batches of tubers selected by the machine and by each assessor, to comply with the inspection standard, were graded by ech of the remaining assessors.

Sparing the spray



I Rutherford notes that the general public opinion of agriculture, farmers and food production is changing very rapidly. In 1989 everything the farmer does is scrutinised and often criticised by 'les nouveaux verts'. Pesticides are a particularly emotive subject area with several recent examples of gross bias and misrepresentation by the media. Today it seems hardly possible that less than only three years ago we enjoyed a voluntary scheme for the registration and approval of pesticides.

The media is fanning flames of shock and resentment that farmers are permitted to produce and sell anything other than 'good wholesome food'. Farmers are clearing forests which some believe leads to the greenhouse effect; farmers use fertilisers and pesticides which are said to be polluting our rivers and seas; and more recently farmers have been blamed for producing meat and eggs which are not safe to eat.

Increasing pressures from the public and legislation are making farmers look more carefully at their spraying operations.

The Food and Environmental Protection Act (FEPA) 1986 (Standard Instrument, 1986) laid the foundations for the regulations which now control the registration, approval, storage sale, use and disposal of all pesticides in the United Kingdom.

How has this legislation affected agricultural engineers and their customers?

Collaboration between engineer and biologist

The label on the pesticide container has become even more important and has statutory force under FEPA. A method of application is recommended in more or less detail depending on the product, the crop and the chemical company concerned. There is real concern that failure to mention a particular method of application would prevent its use. In practice, this has led to closer links between engineer and biologist. We are seeing earlier collaboration on new machine designs where before there was little or none. There are recent examples of good joint experiments with the pesticide manufacturers trying out prototype or pre-production machines with a view to producing label recommendations as soon as the machine appears on the market.

Benefits of training felt throughout the industry

FEPA requires all those who apply pesticides to be competent operators. New entrants to the industry and contractors must have a certificate to prove that they have received adequate instruction. It is estimated that there are about 100,000 spray operators in UK. By December 1988, approximately 37,000 had been trained by the Agricultural Training Board and others on recognised courses (Harris, 1988). Of these, 7,000 received their full certificate of competence by October 1988.

The provision for training has been of considerable benefit to the industry as a whole. It has improved general levels of awareness of operators, and has led to improvements in communication between manufacturers and users. The British Crop Protection Council (BCPC) system for nozzle description, for example, has reduced the chances of error caused by selecting an unsuitable nozzle for a particular task (BCPC, 1986).

Like the Highway Code, the FEPA revised draft code of practice (MAFF, 1988) does not have statutory force. It is, however, considered to be the source of information to guide farmers and their operators on such matters as storage, use in the field, and disposal of unwanted pesticides.

This last item, disposal, is becoming an increasingly contentious issue with the new privately owned water companies likely to take an increasingly severe view of any disposal of pesticides which may find its way into water bearing strata or to the rivers themselves.

Innovative agricultural engineers have identified this potential market and the Allman/ICI Sentinel pesticide treatment plant is a good example of the UK leading Europe into a very sensitive and potentially lucrative new market.

The COSHH regulations

In a most unfortunate coincidence of timing, farmers still digesting the FEPA regulations and code of practice are now having to con-

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Pesticide disposal – a potentially lucrative market. The Allman Sentinel plant with ICI carbo-flo system sider the implication of yet more legislation. The COSHH regulations (Control of Substances Hazardous to Health). Statutory Instrument, 1988) seek to rationalise almost 100 years of statutes aimed at protecting employees at work. Thus, miners, paint sprayers, flour millers, cotton spinners and farm workers, to name but a few, are all having their own specific health and safety regulations distilled into one comprehensive set of regulations which deal with all hazards likely to be encountered at the place of work.

Engineering design – separate operator from risk: protect the environment

The main thrust of the act is that operators should not be exposed to hazard if at all possible. Either the dangerous material should be substituted by another less toxic one, or engineering design will separate the operator from the risk. Only as a matter of last resort should one consider providing protecting clothing for the worker. A more elegant solution must be found.

Here again, our agricultural engineers are in the vanguard in the design of 'closed' systems. The system proposed by the Institute of Engineering Research (IER) (Frost, 1988) not only gives the operator added protection but also makes a significant contribution to avoiding pollution by reducing the problem of disposing of surplus diluted pesticides.

Only a minute proportion of the pesticides emitted from the nozzle actually achieves the desired effect on the target. In the Royal Commission on Environmental Pollution 7th report on Agriculture and Pollution (HMSO, 1979), hopes were expressed that new, more efficient methods of application would emerge which would be kinder to our environment.

Integrated pest control, another laudable aim, has not achieved the impact in UK that has been seen in some countries abroad. But the pressure to reduce the burden of pesticides on the environment is building up. Sweden and more recently Denmark (Thonke, 1988) have both published targets to reduce pesticides by 25% by 1990 and a further 25% by the year 1997. What are we doing in UK to move towards this laudable aim?

Apart from a few notable exceptions (Miller, 1987), the basic design of farm sprayers has remained static for many years. Improvements have been in materials and in detailed changes. Boom suspension systems have improved markedly in recent years due in large measure to research (Frost, 1987) at IER. Active boom suspension now enables very wide booms to operate with predictable stability on fields of varied surfaces and topography (Frost, 1988).

As the stable platform increases the uniformity of coverage, levels of confidence in a predicted deposit are increased. A significant operational change in the last five years has been the lowering of overall volumes of diluent. Whereas 200-250 l/ha was the norm for many years, there are now many label recommendations for application rates down to 100 l/ha.

Evaluation of spraying systems

The Home Grown Cereals Authority (HGCA) is currently funding a study of spraying systems in England and Scotland. This is a series of collaborative experiments involving the Agricultural Development & Advisory Service (ADAS), the Scottish Centre of Agricultural Engineering (SCAE) and the Agricultural & Food Research Council (AFRC) Institutes at Silsoe and Long Ashton.

The aim of this project is to evaluate and compare some of the newer pesticide application equipment available to farmers with the 'industry standard' of 200 l/ha using a medium quality spray produced by hydraulic nozzles. To maximise the benefit of this collaborative AFRC/ADAS study, each part will contribute specific data which builds up into a comprehensive understanding of the interactive nature of spray production, deposition, efficacy and safety.

Six application systems are being compared with an untreated control. They are: Hydraulic 200 l/ha, medium; Hydraulic 100 l/ha fine: Airtec 100 l/ha, coarse; Airtec 100 l/ha, very coarse; Superjet 100 l/ha, fine; and Crop Tilter 200 l/ha, medium. The design of the field experiments used four replicates of 14 treatments in randomised blocks. Results so far show some significant differences in efficacy in trials with herbicides and fungicides.

Table 1 shows the physical characteristics of the six spraying systems featuring in the experiments

Drop size not the sole criterion

Predictions and measurements on the basis of drop size alone are shown to be inadequate in explaining spray behaviour. The marked differences in the velocity of the spray particles emitted from the various systems may have a greater effect on spray drift than has been hitherto realised. Another significant finding has been the fact that the twin fluid nozzle liquid break-up results in air being entrained within the drop of liquid.

Table 1. Summary of measured drop sizes

Spraying system	*Volume l/ha*	*VMD µm*	*% vol <100µm*	*Diameter at 90% volume*	*Diameter at 10% volume*	*Mean vertical velocity m/s*	*BCPC spray category*
Hydraulic nozzle	200	254	2.23	338	164	3.83	medium
Hydraulic nozzle	100	240	2.15	323	163	3.12	fine
Superjet	100	269	0.56	364	184	1.16	medium
Airtec as a 'coarse' spray	100	332	0.59	461	213	2.16	coarse
Airtec as a 'very coarse' spray	100	360	0.34	479	224	1.80	very coarse
Crop Tilter	200	254	2.23	338	164	3.83	medium

VMD – Volume Median Diameter

Market forces - obsession with cosmetic perfection

A feature of trends in food retailing in the last decade has been the concentration of buying power in the hands of a very few. Their perception of what the customer wants and is prepared to pay for is critical to all producers. There is obsession with cosmetic perfection of produce – tinted lean meat, precisely graded vegetables, daisy fresh fruit. There is no question of failing to meet the specification. If our farmers are unable to do so, then those in Israel, Spain, California or New Zealand will fly in their produce to fill the gap.

Organic trend significant but market still demands efficient low cost systems

But is there a crack developing in this facade of bland uniformity and regimentation? The demand for 'wholesome organic' food would suggest that this may be the case. If it is 'organically grown' the odd blemish or even maggot on an apple is perceived by the fickle housewife as a sign that this is the genuine article. This trend may not be a large one in terms of volume, but it is too great in value terms to be ignored by progressive farmers.

However, although a few will pursue these specialist markets, the great majority will be looking for efficient low cost production systems. The modern sprayer will continue to be one of the most important tools on the farm. With the latest technology, the sprayer can now be seen to be more precise and accurate in hitting the target and less hazardous to the operator and to the environment.

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Crop gantries

J B Holt discusses the application of gantries, particularly in vegetable growing and examines the scope for further development.

Various forms of wide span machines, known as gantries, have been developed for the mechanised production and harvesting of crops ranging from cereals to cauliflowers. In comparison with conventional tractors or other self propelled machines wide span vehicles already offer real benefits in the mechanisation of some crops in appropriate circumstances and considerable engineering developments are possible to expand and improve their application.

Depending on the application, the reasons for using a gantry instead of more conventional vehicles are some or all of the following:

(i) Red uced crop damage. This is particularly relevant to the selective harvesting of crops such as cauliflowers or calabrese,

(ii) Reduced soil damage. This has been the principal reason behind the development of gantries for cereal growing,

(iii) Improved access for harvesting when the soil is very wet. The soil in some of the principal cauliflower growing areas has a low strength when saturated and this, at times, prevents tractor-based harvesting equipment from working,

(iv) Increased work rate due to a greater carrying capacity for materials or produce or workers. A greater working width is possible with operations such as transplanting or crop spraying,

(v) Improved working conditions provided by an enclosed stable work platform.

In recent years a small number of gantries have been constructed in a number of countries for experimental or commercial purposes (Tillet and Holt, 1987). Although most of these machines have had spans of between six and twelve metres, a Swiss machine built for commercial use about twelve years ago has a span of 21 m.

Most gantries have been equipped with four wheels which can be turned through 90⁰ for travel end-ways on along a headland and from field to field. some machines such as the one at the National Tillage Laboratory, U.S.A., have all four wheels driven, whereas others are fitted with two steerable driven wheels and two non-driven castor wheels.

The exceptions are the experimental tracked gantry (as shown in Fig 1) designed and constructed by the Agricultural and Food Research Council (AFRC) Institute of Engineering Research, and the two commercially constructed machines related to that gantry. These run on crawler tracks and span a bed which is about nine metres wide, and are raised on wheels when they are to be towed end-ways on.

Another way of categorising gantries is according to the number of workers who are carried. Machines intended for cereal production (i.e. for drilling or broadcasting seed, applying fertiliser and spraying the crop) are designed to carry just the driver, whereas those for vegetable harvesting have a work platform on which up to nine people in addition to the driver can trim, weigh and pack the produce and stack the containers on pallets.

Fig 1. The experimental vegetable gantry developed at AFRC Engineering

The tracked vegetable harvesting gantries are designed to carry three or more tonnes of produce stacked on pallets. In the case of the AFRC experimental gantry the pallets are carried on six separate fork lift devices but on the commercial gantries they are placed on a trailer which is carried on one side of the gantry beam.

Less crop damage: less soil compaction

The AFRC Institute of Engineering Research's experimental tracked gantry was conceived as a means of avoiding the damage to cauliflowers which commonly occur during multi-pass harvesting. The quality of the curd can suffer due to the leaves being damaged by wheels on a pass through the crop prior to harvesting, and also by soil falling from tyres. There is often no market for damaged or soiled cauliflowers.

A conventional tractor-based harvesting 'rig' equipped with cup conveyors will typically cover 12 rows which means that one third of the rows of produce are liable to suffer some vehicle-related damage.

Provided that the pathways for the gantry's crawler tracks are wide enough there will be no crop damage due to the gantry passing over the crop.

If a gantry is used for all the cultural operations from planting to harvesting, the avoidance of soil compaction in the growing area may provide additional benefits in respect of crop growth and reduce the subsequent cost of cultivation (Chamen *et al*, 1985). The experimental gantry has been used for transplanting brassicas, drilling lettuces, applying lime and fertiliser, crop spraying, harvesting in three different ways and incorporating crop residues with a rotary cultivator (Tillet *et al*, 1988).

Growers seem to accept that they will not be able to harvest all their cauliflower crop at the optimum times because of soft wet soil conditions. These are prevalent because much of the crop is grown on silt soils. The vegetable gantry was equipped with 0.5 m wide and 3 m overall length crawler tracks to enable it to operate under all likely conditions. Experience with both the experimental gantry and the commercial derivatives has confirmed the

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effectiveness of this feature, and suggested that narrower track plates might be considered for a nine metre span gantry with consequent increase of the cropped land area.

Packing for market on the gantry further reduces crop damage

A vegetable harvesting gantry is essentially a load carrying vehicle with its own materials handling facilities and the ability to carry and power harvesting aids such as crop conveyors, with ample space for workers packing the produce. Until relatively recently cauliflowers were rarely packed in the field into non-returnable containers and an appreciable amount of damage was subsequently caused during transfer from bulk bins or field boxes to 'face-packs' or other containers in a packhouse.

To avoid this handling damage there has been a switch to packing on mobile packhouses which have tended to suffer from space restrictions. A gantry can easily be designed to have both the required weight-carrying capacity and the space for the volume of material as well as the platform area for packers. This contrasts with the design problems associated with a conventional vehicle which has to pass through gateways and along public roads.

Ideally, a gantry would be able to carry all the produce harvested from a full span width bed along the full row length (and possibly also on a return run to the headland along another bed). This in many circumstances will not be practicable; the row lengths and proportion of the crop to be cut vary considerably.

So far, with gantries the practice has been to travel to a headland to unload as necessary but the practices adopted with some other mobile vegetable and lettuce harvesting machines could perhaps be adapted to gantry operations (The Grower, 1988).

A gantry transport vehicle could follow the harvesting gantry along the bed and the load could be transferred at any time, or as with a specialist lettuce harvesting system, the load could be transferred sideways (over the end of the gantry) on to a vehicle (transport gantry) running alongside. Although it might seem that the track-pathway between those adjacent beds would have to be twice the normal width, this may not be essential as the gantries could be in a staggered relationship during load transfer.

Alternatively, rapid materials handling on headland

In the absence of such equipment, rapid materials handling on the headland is important and four methods have been considered. These are shown in Fig 2.

(i) Six separately operated fork-lift mechanisms as found on the experimental gantry. These permit pallets to be offloaded selectively and, for example, a pallet holding packing materials could be retained on the gantry. However, in the absence of cage pallets, experience has shown that the stability and security of containers is a problem.

(ii) A two-wheeled trailer carried on one side of the beam on a widely spaced pair of forks. This arrangement permits rapid interchange of trailers although the logistics of the movement of tractors and trailers on the headland requires some thought. Sides on the trailer and built-in load securing straps can ensure the stability of the load. Considerations are the weight of the trailer, the trailer platform height when the wheels are carried clear of the crop and, partly because of the wheels, the distance of the centre of gravity of the load away from the edge of the beam. These points have been met in the commercial designs.

(iii) A demountable load carrying platform, or stillage, carried on a pair of forks. This could either be offloaded directly on to a trailer or perhaps a lorry, or could be placed on the ground for picking up by the type of 'U' shaped trailer used for handling bulk bins of fruit (Holt, 1973). These platforms could have load protecting superstructures similar to those used for handling the demountable trailers.

(iv) The platform height of the existing vegetable gantries is somewhat greater than that of a farm trailer but a different form of gantry being considered (see also Fig 6), would make it posible to carry pallet loads of produce on the deck of the gantry and transfer them over the end of the gantry on to a trailer fitted with roller conveyors. Provision has to be made for reloading the gantry with empty pallets and containers. One possible method is shown in Fig 3.

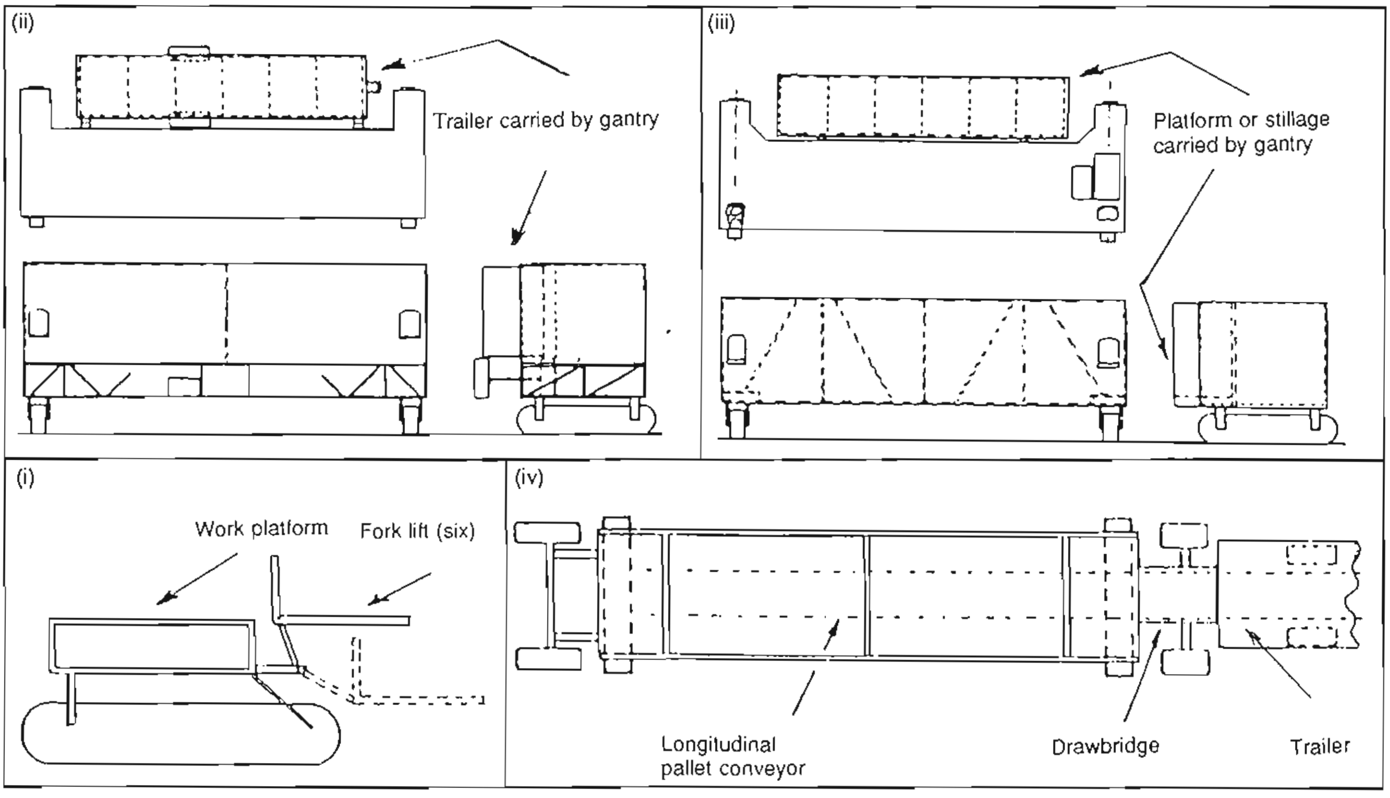
Unfortunately, palletised containers and bulk bins used to supply cauliflowers to various supermarkets, the wholesale market and processors are of various dimensions and this method of handling would only be suitable for a restricted range of unit load sizes.

The gantry structure

The vegetable gantries have a lattice beam of rectangular cross section which supports a work platform on its upper face as shown in Fig 4.

On the experimental gantry the track units are pivotally attached to the beam to allow for travel over uneven surfaces and to enable the beam to be tilted so that the inclination of the fork lift units can match that of an adjacent trailer deck. On the derivative gantries the track units are rigidly attached to the beam with no apparent signs of trouble.

The experimental gantry has jack-down



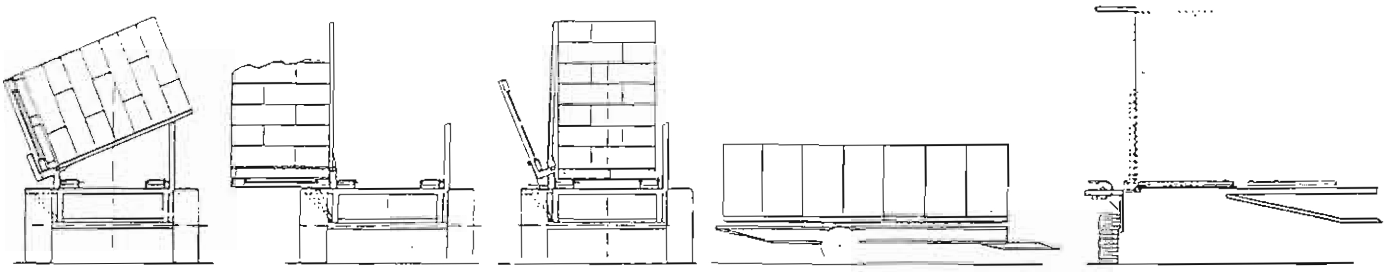


Fig 3. Trailerfor receiving loads from the end of a gantry

wheels at both ends, those at the drawbar end being steered by the drawbar. When the gantry is towed by a tractor, manoeuvering, for example, out of a gateway, on to a road can be difficult. In some circumstances the rear track can be lowered to the ground and driven to swing the rear of the gantry, but another option would be to provide a small amount of steering to the rear wheels.

The gantry as a workplace

Apart from the options on structural form, wheels and load carrying arrangements, vegetable gantries could:

- be of different spans
- be equipped to carry and operate a range of implements and equipment such as plant ers and crop sprayers

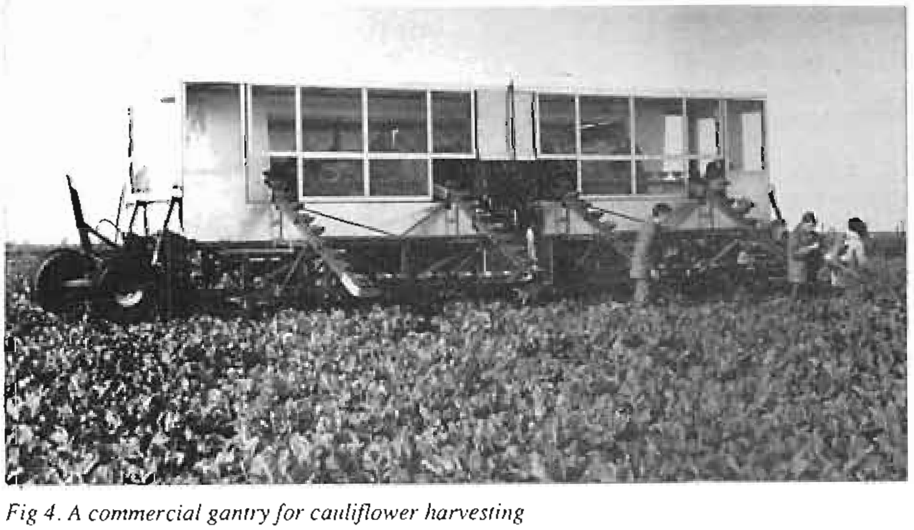


Fig 4. A commercial gantry for cauliflower harvesting

However a tracked gantry need not be fitted with wheels. Fig 5 shows a detachable four wheeled bogie which could be used to support the gantry near the centre of the beam for transport. The lifting mechanism could be powered by the gantry or by the towing tractor. An alternative could be to fit the gantry with jack-down wheels as shown in Fig 6. The intrusion of the raised wheels into the platform area of the gantry could be acceptable.

Wheels are not used to move a tracked gantry from one bed to another. It can pirouette on the headland so that it can run broadside on to the next bed.

- have an enlarged work space with extension platforms
- be fitted with produce weighing and pack ing equipment and
- readily be equipped with a toilet and washing facilities.

Experience has shown that wherever possible the gantry and the detachable implements or equipment it uses should be designed so that attachment can be performed without the aid of separate lifting equipment.

During harvesting a significant part of the packers' time is involved in the handling of the empty and full produce containers. In some situations a worker might be employed solely in such handling but it is difficult to arrive at the correct ratio of cutters to packers (and box handler). A mechanical palletiser or a mechanical aid to palletising might be a justifiable addition to a gantry if it smoothed the work pattern of the packers and reduced the requirement for a buffer store in the produce conveying system.

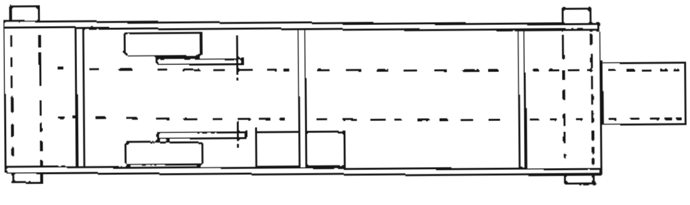
Automatic steering to reduce tedium

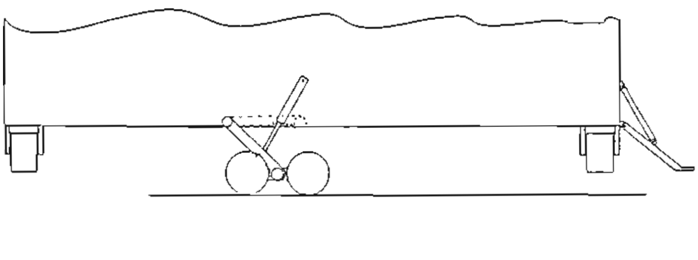
Some form of automatic guidance is particularly appropriate to a vegetable gantry because for its most time consuming operation, harvesting, it travels at very low speed. Not only is manual steering tedious but it is made difficult because the edges of the track pathways can be partly obscured by leaves from the adjacent rows of plants.

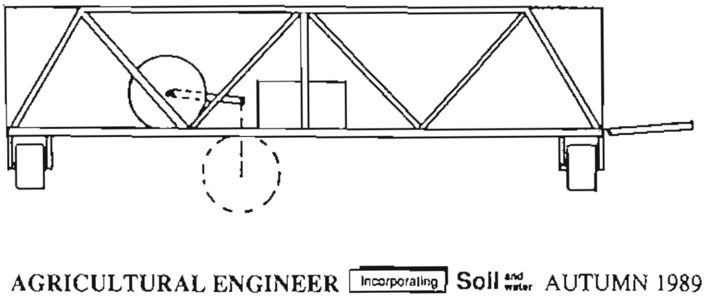
Although there are a number of possible ways of guiding a gantry, experience with a leader cable system for the experimental tracked gantry has shown that this is a practicable method. The vehicle will follow a cable, bur-

Fig 5. (below) Gantry with separate bogie for travel on roads

Fig 6. (right) A deep-beamed gantry with one pair of retractable wheels







ied 350 mm below the surface of a track pathway and carrying a 2 kHz, 50 mA maximum current signal, with an accuracy of ±50 mm. and further refinements are possible.

Optimum span determined by crop and manoevrability requirement

It is not easy to arrive at the optimum span for a gantry which is principally required for brassica harvesting. In recent years row spacings have been chosen to suit the bed width which could readily be spanned by a tractor, and with cauliflowers, for example, row widths of 24" to 28" are common. This has led to growers conceiving a gantry span which is a multiple of these tractor bed widths. However, if a gantry is to be used for the range of operations from planting to harvesting, row widths can be chosen which suit the plant rather than the width of the tractor tyres.

For the selective mechanical harvesting of cauliflowers the work pattern would typically be one worker cutting two rows and one packer dealing with the produce cut from four rows. A 12 or 16 row bed would therefore seem attractive.

When deciding on a span, other factors to be considered are the manoeuvrability of the gantry when it is being moved from field to field, its span in relation to the field size, obstructions such as pylons, the gang size required to operate it at full capacity, the payload (the amount of crop harvested in a pass along a bed being proportional to the bed width) and the cost of the gantry in relation to the amount of crop.

Early standardisation desirable

A useful compromise seems to be a span of about nine metres for the larger or more specialist grower although a span of about six metres might be attractive on the many smaller areas of crop.

Standardisation of the span or space in the early stages of the development of this new form of mechanisation is desirable for a number of reasons. There would be some economy in design and manufacturing costs but more importantly equipment could be shared or hired in the event of breakdowns or peak requirements. It would also be more practicable for a contractor to provide a spraying or harvesting service if the planting had been in a standard bed width. The market for second-hand gantries would be improved by standardisation.

Although row spacing does influence plant growth, an effective way to adjust the plants per unit area is to vary the spacing in the row. The adoption of a standard gantry span with some adjustment of the number of rows in the bed to satisfy particular requirements is strongly advocated.

Some limitations – but traffic - free farming a possibility

As with virtually all systems of mechanisation, the ideal field for a gantry is large, flat, rectangular and free from obstructions such as poles, trees or ponds. The wider the gantry, the greater will be the problems in working an irregular shaped field and it may be necessary to crop some parts separately. Even quite severe undulations are unlikely to cause problems with a vegetable gantry but the underbeam clearance would be affected and one track may need to be able to articulate relative to the other, as it can on the experimental gantry.

Small scattered fields are not likely to suit this sort of mechanisation and there will be inadequate benefits in respect of some crops. It remains to be seen whether methods can be developed for using gantries for harvesting cereals and root crops. Such developments would enable the same pathways to be used over many seasons during the production of vegetables and cereal break crops and would pave the way for traffic free farming.

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Sponsorship in Agricultural Engineering

M J Watchorn finds students are missing out on potential sponsorship and he offers a guide to the range of funding sources available.

I am 23 and a post-recipient of sponsorship which enabled me to undertake a M Phil. I was fortunate in obtaining financial support and through it achieved a higher level of education.

I cannot believe in this day and age of education spending cuts, unemployment and falling student numbers that universities, schools and students can afford to miss out on any available funds. I was, therefore, dismayed in 1987 when the grant awarding body, who backed my studies, could not spend the quota for that year's sponsorship due to inadequate applications.

Michael Watchorn is a Design Engineer with Soil Machine Dynamics of Stokesfield, Northumberland

The aim of this short summary is to outline from where you can get support, some awards are for whole courses and years, some act only as back-ups or are for special needs and projects.

Company sponsorship

Some sponsorship is informal and not awarded each year — engineering companies are included in this group.

By sponsoring a student through some form of higher education, a company by a small investment directs a potential future employee's

continued on page 88

TECHNOLOGY

Environmental protection technology offered grant aid

The fourth invitation for research proposals has been announced by the Department of the Environment under the terms of their Environmental Protection Technology (EPT) Scheme.

The EPT Scheme identifies priority areas for research and development where the Department foresees a need to raise environmental standards. About £2m per year is available for the funding of approved projects.

The latest addition to the priority list is for the in-situ cleaning of contaminated soils. The full list of priority areas reads:

A Thermal treatment municipal solid waste
B Odour control
C Reduction of organic compounds in industrial effluents
D Emissions to atmosphere of chlorofluoro carbons and halons
E Emissions to atmosphere of volatile or ganic compounds
F In-situ cleaning of contaminated soils

The scheme is open to all firms operating in the UK including sole traders and partnerships. Full details from the EPT office, 01 276 8318.

continued from page 87

education into some specific areas needed to fulfil a job within the firm. Moreover, the student can often undertake holiday work with the company and during this time, employers can observe students working, see how they settle in and where their strengths lie. At the end of the sponsorship term the students should fit into the working team quicker after this holiday work because they will know the job.

As for the student, sponsorship by a company gives him/her the chance to look at the company without obligation and to get a feel for how they work. An employer may move students around within the organisation to give them the chance to try several jobs, thereby making career choice easier later. It also gives students the chance to find out how much they do not yet know while still involved in the course so they can fill in some of the gaps in their knowledge before they leave.

Education just beginning when course finishes

Please believe me that when you finish your course your education has only just begun. Industry is completely different from ideas gleaned at college, on the whole, courses do not grasp all that employers require of their young post higher education employees. By being sponsored and, if possible, taking a summer job, a student can have some of the advantages of a sandwich course while maintaining a full time academic course.

Sponsoring bodies

A list of sponsorship bodies is given in the panel; it is by no means complete. If you know of grant awarding bodies which are not included then please write to me, c/o I.Agr.E., and I will try to include them in an addendum which may be published in a future issue.

- The list is split into three major sections:
  Bodies who make awards to all students, i.e. non-specific.
- Bodies who make awards to non-specific educational establishments but restrict applications in some other way.
- Bodies who restrict applications to a specific teaching establishment.

In the case of possible funding from individual companies – some companies contact educational establishments with specific sponsorship details. You should contact your Head of Department or Tutor.

Other companies may be induced into sponsorship. Try writing to the Personnel Manager or Managing Director of companies local to your home or college or ones with which you have had contact. If possible, think of a package to put to the company, offer to undertake some project work on their behalf or ask if they have a small, well defined project you could work on as part of your course. Present the scheme to the company as professionally as possible because first impressions are really important. Try and sell yourself.

Sponsoring bodies

Non-Specific

Douglas Bomford Trust: At least one scholarship each year for one full year's study in research bearing on British agricultural engineering industry (limited to post grad). Other awards - top up grants, travel sponsorship for anyone studying or working in agricultural engineering. *The Secretary, The Douglas Bomford Trust, 1 Manton Spinney, Knuston, Wellingborough, Northants. NN9 7ER*

AFRC Engineering: For summer and 3 other weeks work at the Institute. Undergrad and postgrad bursaries. *AFRC Engg, Wrest Park, Silsoe, Beds. MK 45 4HS.*

Ministry of Agriculture, Fisheries and Food. Postgrad courses and study for PhD, MSc made to college for specific projects. *Head of Department or Tutor.*

Department of Trade and Industry: Several – some 'top-up', some for full MSc. courses. At Silsoe College only, in collaboration with a company. *Silsoe College.*

Department of Agriculture and Fisheries for Scotland: Postgrad studies, 3 yr PhD, 1 year MSc courses. *Room 602, Chesser House, 500 Gorgie Road, Edinburgh. EH11 3AW.*

Department of Agriculture, Northern Ireland: Postgrad studies, 3 yr PhD, 1 yr MSc courses. *Dundonald House, Upper Newtonards Rd, Belfast, BT4 3SB.*

Manpower Services Commission: Postgrad retraining scheme MSc and PG Diploma. *Local Manpower Services Commission office.*

Local Education Authority: Discretionary for MSc prelim year, PG Diploma (Possible to link for second year with other award body). *Local Education Authority.*

Non-specific – restricted

British Council administered scheme. Fellows and Scholars. *British Council, 10 Spring Gardens, London SW1.*

- British Council Scholarship. For MSc and PG Diploma, also PhD and MPhil programmes. Ages 25-35. Applications 12 months before commencement of academic session.
- Commonwealth Scholarship and Fellowship: For all levels postgrad study. Commonwealth citizens and British protected persons. Applications one year before start date. *Commonwealth Scholarship Agency, in candidates own country of permanent residence, usually the Ministry of Education*
- British Overseas Development Association: MSc and PG Diploma courses. The courses supported by ODA vary from year to year. *The candidates own government.*
- Colombo Plan: For MSc and PG diploma. Open to SE Asian Commonwealth, Canada, India, UK.
- European Development Fund: For undergrad/postgrad courses. Countries of origin eligible are where EC has technical cooperation agreement with training element.

Sino-British Friendship Scheme: For 6 months to 3 yrs – MSc, PhD, also for research attachments. *State Education Commission, Beijing, China.*

Rotary International: Restricted to permanent residents of countries with active Rotary Clubs. *Rotary International, 1600 Ridge Avenue, Evanston, Illinois, USA, 60201, or RIBI, Kinwarton Rd, Alcester, Warwicks. B49 6DP.*

- Rotary International Graduate Scholarships: For MSc and PG Diploma programmes. Ages 20-28. Applications by 1 March of year preceding tenure.
- Rotary International Freedom from Hunger Scholarships: Postgrad courses for up to 3 years. 50 scholarships 1986/87. Applications by 31 October each year.

United Nations Fellowships: For 1 year MSc and PG Diploma. *Country's own Government.*
UNESCO: For MPhil and PhD programmes of research. *National Commission for UNESCO in Candidate's own country.*

Rockefeller Foundation: People from developing countries holding or will hold appointment in university, research institute or government body. *Rockefeller Foundation in candidate's own country.*

Food and Agriculture Organisation of UN: Nationals of countries where FAO has technical assistance projects provided candidate working on such project. Senior Fellowship Officer, Fellowships Group, FAO, via delle Term di Carcalla, 00100, Rome, Italy.

World University Service (UK): For MSc and PG Diploma. Candidates must be refugees already in UK of certain African, Central American nationality. *World University Service, 20 Compton Terr, London N1 2UN.*

Specified teaching establishment –

Silsoe College, Silsoe, Bedford MK45 4DT.

- Overseas Development Administration shared scholarship. For 1 and 2 yr courses. Candidates nominated by College to be not resident in country of origin at time of application nor eligible other British government scheme. Applications by 1 April each year.
- Overseas Research Students Fees Support: For MPhil and PhD programmes. Candidates nominated by college. Applications May each year.
- Silsoe College Awards: Various, for tuition and maintenance. *Tutor, Head of Department or College Principal.*

Department of Engineering, University of Newcastle upon Tyne, Newcastle upon Tyne NE1 7RU

- Women in Engineering. BEng student supported through whole course in one of University's engineering faculties. *Tutor or Head of Department.*
- South African Scholarship: South African or Namibian students administered by the University.

Nitrates and water supplies in the UK

R J Unwin sets the scene

Agricultural production has increased at about 3% per annum for the last 30 years. This has been achieved partly by increases in the use of fertiliser nitrogen. Although our soils contain large reserves of nitrogen only a small proportion is made available to crops in a given year. Much nitrogen can be lost through drainage water and, to a lesser extent, through surface run off.

Nitrogen contamination of our water supplies is now a matter of concern. The 7th report of the Royal Commission on Environmental Pollution and the report of the Royal Society Study Group both concluded that agricultural land was the source of much of the nitrate in both ground and surface waters used for public supply. Besides being a source of pollution, such loss of nitrogen also represents a loss to the farmer.

The Nitrate Co-ordination Group report has reviewed the situation in England and Wales and in 1986 published its recommendations to reduce the impact of agriculture on nitrate concentrations in water supplies. Nitrate loss has been studied by lysimetry, field studies and computer modelling. Results from studies in the United Kingdom have been reviewed recently by the author.

The subject is one of current and continuing importance and at the instigation of the Soil and Water Management Specialist Group we are presenting in this issue up-to-date reports relating respectively to nitrates on arable land and nitrates on grassland. With these we also have a report from the point of view of the water supply company.

What is to be done? The Department of the Environment has indicated (The Nitrate Issue, 1988) that in some areas it may be less costly to reduce nitrate leaching than to require water undertakings to find alternative supplies or to treat water to remove nitrate. In mid 1989 the UK Government is consulting on the implementation of a Nitrate Sensitive Areas Scheme which would seek to agree land management practices to limit nitrate leaching in a given area to acceptable levels. At the same time negotiations are in progress on a draft ECT Directive to limit the nitrate leaching from land (6).

Whatever the precise outcome of these initiatives it is certain that some changes will have to be introduced into agriculture in the UK in order to reduce the loss of nitrate into water supplies.

Roger Unwin is an ADAS Soil Scientist based at Bristol.

Soil water and nitrates interaction on grassland

A C Armstrong

A supply of both water and nitrogen is essential for the continued growth of grass.

Water supply is generally adequate in the wetter soils of the west of the country, although too much water can bring the attendant problems for grass utilisation. Nitrogen is most commonly supplied as either fertiliser or as animal slurry.

In order to increase the supply of nitrogen to grass, the rate of fertiliser application has increased over the years, although the mean rate applied in England and Wales of 200 kg N/ha is well below the optimum which is close to 400 kg N/ha (Morrison *et al* 1980).

Nitrogen, particularly in the form of nitrate, is highly soluble in water, and consequently highly mobile. A combination of the application of high quantities of nitrate to soils with an abundant water supply may give a high grass yield, but may potentially create a problem of the leaching of nitrates from the land to receiving water bodies. In order to examine some of the consequences, it is necessary to consider the nitrogen cycle in grassland.

The nitrogen cycle: cut swards

On cut swards, the nitrogen cycle is quite simple: the two dominant processes are the addition of fertiliser nitrogen, which is taken up by the plant, and the removal of nitrogen in herbage by repeated cutting. Only when there is excess of nitrogen supply over demand is there any great potential for losses from cut swards, either gasesously by denitrification or by direct leaching. If grass growth is not restricted by water deficit, then nearly all the applied nitrogen is recovered at moderate rates of application. However, where high soil moisture deficits occur, grass growth is restricted, and applied nitrogen is not taken up but is available in excess for leaching.

Irrigation - because it controls the soil moisture deficit and thus stimulates the growing crop to take up nitrogen - may in fact reduce the rate of nitrate leaching. For example, Garwood (1988) quotes results from lysimeter experiments at Hurley:

Table 1. Nitrogen applied, mean recovered nitrogen and leaching loss (kg/ha): cut swards.

	Applied	*Recovered*	*Leached*
Irrigated	420	417	20
Un-irrigated	420	346	43

Further data also demonstrate that rates of nitrate loss are strongly dependent on the development of a 'pool' of un-utilised nitrogen. Consequently, application of nitrogen at high rates over and above the ability of the crop to use it results in losses of that nitrogen, normally by leaching.

The nitrogen cycle: grazed swards

The introduction of the grazing animal complicates both the agronomic management of the sward, and dramatically alters the nitrogen cycle. Any nitrogen applied is still taken up by the growing grass, but it is used *in situ* by the grazing animal, and then returned in a highly mobile state as dung or urine.

Garwood (1988) has shown that at the end of the grazing season, the animal exports from a sward around 30 kg/ha of nitrogen in the form of liveweight gain, whereas the cut herbage would have removed around 300 kg/ha. The remaining nitrogen must either accumulate or be lost.

In general, the rate of nitrogen accumulation is low and, consequently, grazed grass swards lose considerable quantities of nitrogen to their environment. This loss can either be as gaseous loss (as nitrogen or as ammonia), or leaching carried by excess water.

A wider view of the nitrogen economy of cut swards should also include such losses for when conserved grass is fed to animals nitrogen is again lost in urine and dung, although in a different location and at a later date.

The role of drainage

Because of the high potential losses of nitrogen from grazed swards, and the vital role of soil water in both controlling the rate of grass growth, and in providing one of the routes for nitrogen loss, soil water management, both drainage and irrigation, can be expected to

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have large effects on the nitrogen economy of swards. Drainage has often been advocated as a means of extending the grazing season by increasing the soil strength and reducing poaching risk. It therefore has great potential for increasing the utilisation of existing grass production.

To determine the effects of drainage a joint experiment was established in 1982 at North Wyke, Devon between ADAS and AFRC Institute for Grassland and Animal Production (IGAP). In this experiment the aim has been to measure all aspects of the hydrology, the grass production, the animal utilisation and the animal production, from paired drained and undrained swards (Armstrong & Garwood 1989).

Although some of the techniques used are still under development, and there are large errors associated with some of the figures, it has been possible from this experiment to establish a rough balance sheet for this site, at two levels of nitrogen input and including all the components of the nitrogen economy of a grazed grass sward. The results are summarised in Table 2 (from Garwood 1988) and several interesting features can be seen:

- The nitrogen inputs are roughly balanced by outputs.
- As nitrogen inputs increase, so does the relative importance of leaching to gaseous loss.
- Leaching losses on drained plots are higher than on the undrained, and where the pool of available nitrogen is high, so too is a high total amount lost by leaching.
- Gaseous losses are higher on the undrained plots, in response to waterlogged anaerobic conditions.

The foregoing data demonstrate that although high amounts of nitrogen are added to the site in the form of fertiliser, only quite small amounts are removed from the same site as animal products. The rest of the added nitrogen is either lost by leaching or gaseously via the soil surface. "Lost" nitrogen is not wasted, because it has first been used to increase the yield of the grass crop and then consumed by the grazing animal before being returned to the soil.

What the figures do show, however, is the potential for high leaching losses from grazed swards receiving high nitrogen inputs.

Where water is encouraged to move through nitrogen-rich conditions, then it naturally leaches the soluble nitrates. Drainage, furthermore, leads to better aeration of the soil, in which nitrogen mineralisation processes are encouraged.

By comparison, undrained sites tend to greater gaseous losses, greater denitrification, and more accumulation of nitrogen in the soil organic matter, all of which are a reflection of the more anaerobic conditions that these soils experience.

Control measures to reduce leaching

Contrary to simplistic view which sees grassland as safe from nitrogen losses, grass swards can in fact release significant quantities of nitrogen. Water draining from intensely used swards can have nitrate concentrations at least as high as those recorded from arable land. However, careful consideration of the supply of both water and nitrogen to the sward can do much to reduce these losses.

Nitrogen increases grass yield, but leaching loss can be high with grazing.

Table 2. Provisional annual nitrogen balance (kg/ha) for grazed grass swards.

	Undrained	*Drained*	*Undrained*	*Drained*
N-input	*200*	*200*	*400*	*400*
Animal output (cattle LWG)	24	27	28	30
Leached	20	56	48	187
Denitrified	90	56	111	84
Ammonia loss	30	30	60	69
Storage in soil organic matter	72	64	48	45
Total N recorded	236	233	295	415

These results indicate that it is possible to take simple measures for the reduction of nitrate leaching without neccessarily prejudicing levels of production.

An initial technique is simply the careful control of the nitrogen supply, so that mobile nitrogen is not present in the soil whenever leaching occurs. This usually means targetting nitrogen applications closely to the time of maximum requirement. Current work at IGAP North Wyke is examining ways in which nitrogen applications can be matched to measured nitrogen content of the soil in mid- to late-season.

High clover swards also offer an alternative way of maintaining the nitrogen supply to swards without the use of nitrogeneous fertiliser. These are being investigated on the North Wyke drainage experiments, and first indications are that they release only small quantities of nitrate.

Leaching of nitrate under arable crops

M I Goss summarises 10 years experiment at Brimstone Farm

In 1978 ARFC and MAFF established a joint experiment at Brimstone Farm in Oxfordshire bringing together the hydrological expertise of the ADAS Field Drainage Experimental Unit with the soil and plant interests of the AFRC Letcombe Laboratory. In 1985, when Letcombe closed, the experimental input for soil and plant disciplines was made from Rothamsted Experimental Station. The aims of the experiment were threefold:

- **to establish the secondary drainage requirements of crops established after simplified cultivation**
- **to investigate the effects of tillage systems on the drain discharge and the impact on arterial drainage**
- **to study the nitrogen economy of autumn-sown arable crops**

The measurement of nitrate leaching, a major component in the nitrogen economy, is very difficult in most soils. However, clay soils (accounting for about 50% of the land on which cereals are grown in England and Wales), being mostly only slowly permeable, do require subsoil drainage and during winter most of the surplus rainfall (200 mm average in cereal growing areas) is removed by the drainage system. This offers the possibility of measuring the nitrate content of the drainage water directly.

The experiment at Brimstone Farm provided such an opportunity for a detailed study of nitrate leaching.

The nitrate leaching experiment

The site at Brimstone Farm was chosen on soil of the Denchworth series. It was divided into

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20 plots each of which was hydrologically separated to a depth of 1.1m using a system of trenches and polythene barriers. Half the plots were drained by a mole and pipe system and the rest were not. All plots had collector systems that intercepted water flowing over the soil surface (surface runoff) and water moving laterally at the bottom of the plough layer (interflow).

Water from the collectors and from the mole and pipe system on the drained plots passed through sealed pipes to monitoring points where flow rates were recorded using v-notch weirs, and where samples were collected automatically for determination of the nitrate content using standard chemical methods or nitrate ion-specific electrodes.

In addition to these measurements, the soil water regime was studied using a calibrated neutron moisture meter, tensiometers and piezometers. The offtake of nitrogen in the crop was monitored and changes in soil mineral nitrogen were measured in some seasons.

For the first two seasons 1978/9 and 1979/80 all plots were cultivated to a depth of 250 mm using tines and final seedbed tilths formed by secondary cultivations. For the remaining 8 seasons half the plots of each drainage level were direct-drilled and half were ploughed and drilled. Crop residues were burnt throughout the experiment. From 1986 onwards local bylaws required the ash to be incorporated after the burn which resulted in some disturbance on the direct-drilled plots but this normally took place 3-4 weeks before drilling and was confined to the top 50 mm. Winter wheat, winter oats and oilseed rape were grown during the course of the experiment; the sequence is given in Table 1. Nitrogen fertiliser was applied to the seedbed of some crops to determine how this affected leaching loss.

Table 1. Cropping sequence and nitrogen fertiliser applications.

*Year**	*Crop*	*Nitrogen fertiliser (kg N/ha)*	
		Autumn	*Spring*
1979	Wheat	17	116
1980	Wheat	24	140
1981	Wheat	0	149
1982	Wheat	24	148
1983	Oats	30	111
1984	Wheat	17	223
1985	Rape	46	239
1986	Wheat	0	130
1987	Oats	0	100
1988	Wheat	0	194

** In which the crop was harvested.*

Yields were good throughout the experiment: the 7 wheat crops averaged 7.9 tonnes per hectare on drained plots and the presence of mole and pipe drains increased yields by an average of 9%. Tillage had no significant effect on yield but there was an interaction between drainage and cultivation such that yields showed a greater increase due to drainage on direct drilled plots than on ploughed plots.

On the drained plots the average takeoff of nitrogen in grain and straw was 190 kg N/ha and differences between tillage treatments were usually small and not statistically significant. On plots without subsoil drains the takeoff was reduced by about 5%.

Nitrate leaching greater on drained plots

The average annual loss of nitrogen from drained ploughed plots was 40 kg N/ha, equivalent to 23% of the applied fertiliser. This includes results from 1983-4 when there was only 73 mm drainflow and leaching was unusually small. Most of the nitrate leached from drained plots was lost through the subsoil drains (Table 2).

Table 2. Average loss of nitrate in water from the three collector systems of drained plots.

Collector system	*Nitrate leached kg N/ha*
Surface runoff	1
Interflow	3
Subsoil drains	36

On plots without subsoil drains the loss in surface runoff and interflow varied from season to season (Table 3). However, the total loss was small compared with that from drained plots but only 50% of the excess rainfall was collected.

Nitrate loss greater in harvest to spring

Loss of nitrate through mole and pipe collectors in the subsoil was greater in the period between the harvest of one crop and the spring application of nitrogen fertiliser to the next crop (Table 4).

Table 4. Average loss of nitrate (kg N/ha) through the subsoil drains before and after spring topdressing.

harvest to spring	*after topdress to harvest*
36	4

Loss of nitrate after spring top dressing amounted to 3.1% of the spring fertiliser application.

Table 3. Seasonal variation in losses of nitrate in surface runoff and interflow from plots without subsoil drains.

Year	*Tillage*	*Nitrate leached (kg N/ha)*		
		Surface runoff	*Interflow*	*Total*
1980	Tine	0.31	11.50	11.81
1981	Plough	0.07	2.55	2.62
	Direct-drill	5.83	2.85	8.68
1988	Plough	0.87	1.34	2.21
	Direct-drill	2.68	0.31	2.99

Compared with seasons when no autumn fertiliser was applied, losses of nitrate over this period were increased by amounts similar to the autumn application except for the 1984-5 season when oilseed rape was grown (Table 5). This is consistent with oilseed rape taking up more nitrogen in autumn than does winter wheat. However, the loss in the year following the rape crop was 30 kg N ha more than the average loss under crops following wheat and not given autumn nitrogen.

In the period before spring top dressing the leaching loss through the subsoil drains was 25 per cent less on direct-drilled lots than on ploughed plots. However, in the period after spring top dressing this effect of tillage was reversed, and direct-drilled plots lost 28% more on average than did ploughed plots.

Table 5. Effect of autumn fertiliser application on the loss of nitrate (kg N/ha) through the subsoil drains.

Applied fertiliser in autumn	*Average leaching loss*
0	22
17	40
24	48
30	51
46*	41

**Application to oilseed rape*

None the less the average annual leaching loss was 20% more after ploughing than after direct-drilling.

Leaching loss related to rainfall

A simple relationship has been obtained to relate the loss of uitrogen by leaching to the rainfall that follows a fertiliser application in spring assuming that the soil was at field capaeity when fertiliser was applied. It is presented as a simple predictive graph in Fig 1.

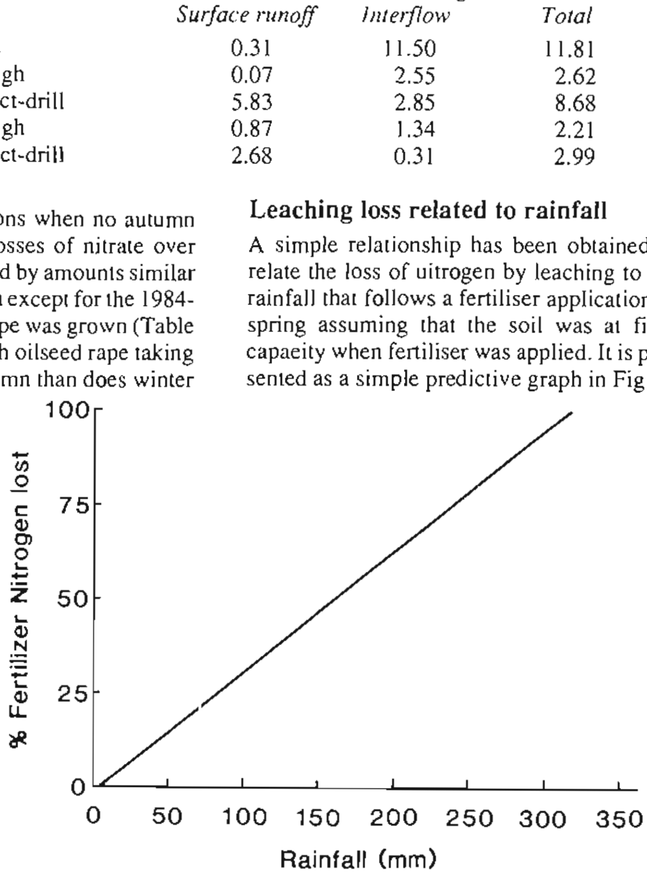


Fig 1. Relationship between rainfall after top-dressing and the proportion of nitrogenous fertiliser loss by leaching

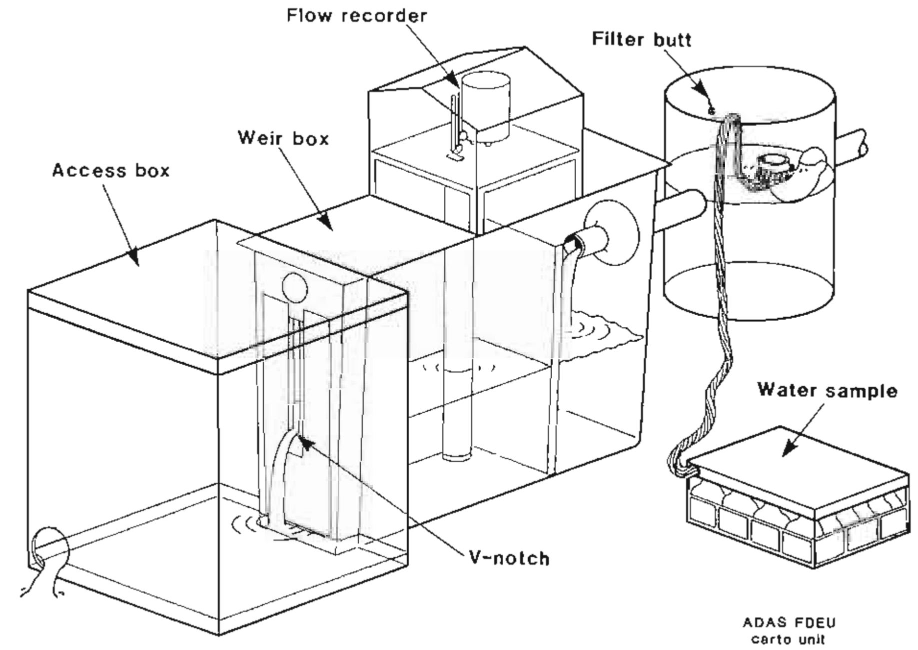
Good fertiliser practices, including splitting the nitrogen top-d and delaying applications when soils are wet and heavy rain is forecast, can prevent excessive leaching of fertiliser. The loss to the farmer and the consequences for the environment in wet springs can be predicted from Figure 1.

Soil management the key to reduced leaching of nitrates and pesticides

The large nitrate loss during autumn and winter, even when no autumn nitrogen was applied, demonstrates the importance of the contribution from mineralisation of organic matter and crop residues. This appears to be particularly large from oilseed rape residues. The timing of the release of nitrogen from idfferent crop residues over winter needs to be assessed in relation to the demands of the following crop. Equally the results are consistent with the view that bare fallows should be avoided during winter.

As only 50% of excess rainfall was intercepted by the collector systems in plots without subsoil drains it is possible that large quantities of nitrate were lost through deep seepage. As less nitrogen was removed by the crops from undrained soil more nitrate was probably available for leaching. Alternatively denitrification could have been greater, though attempts to estimate gaseous loss by measuring of N_2O after using the acetylene blocking technique gave equivocal results. My colleague Philip Colbourn has found that drainage reduces denitrification to a greater extent in ploughed plots that in direct-drilled plots.

The facility at Brimstone Farm is currently being used to investigate how soil management can be modified to reduce the leaching of nitrogen over winter and to study the leaching of pesticides.



The Brimstone Farm experiment – the sequence of instruments for sampling water and monitoring drainflow.

Tackling the nitrate problem - a water company's approach

by A J Woodward and I J Fletcher

Nitrate levels in water supplies have been of concern since the identification of the relationship between nitrate and infantile methaemoglobinaemia in the 1950's (1) and the subsequent publication of the World Health Organisation European Standards (2) recommending a maximum of 100 mg/l in water supplies. The EC Drinking Water Directive (3) implemented in 1985 set a maximum admissable concentration (MAC) of 50 mg/l nitrate in water supplies and resulted in further attention being focussed on the problem of rising nitrate levels.

Initially, the U.K. Government issued derogations to the EC limit for supplies containing nitrate levels exceeding 50 mg/l provided they did not exceed 80 mg/l as a quarterly average or at any time exceed 100 mg/l. However, under mounting political pressure from Europe the U.K. Government has now withdrawn these derogations and the water industry is facing potential substantial costs to comply with the 50 mg/l limit.

The national perspective with regard to nitrates in water has been examined in some detail by the Nitrate Coordination Group under the auspices of the Department of the Environment (4). High nitrate levels in water supplies are predominantly found in eastern and central England in areas where rainfall is low and intensive arable cropping is practised. During 1986 some 82 water supplies serving 2.5 million people exceeded 50 mg/l on one or more days.

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Groundwaters particularly vulnerable to nitrate pollution are those where the aquifer outcrop is unconfined. Confined aquifers protected by a layer of low permeability strata exhibit low and stable nitrate levels whereas vulnerable aquifers have shown steady rises in nitrate levels since the 1940s in line with increases in fertiliser application rates. Nitrate levels in such groundwaters are expected to continue rising until an equilibrium is achieved dependent upon the type of agriculture practised and the local rainfall. Equilibrium levels of between 50 and 150 mg/l are expected for the majority of affected public supply boreholes.

In river waters the pattern is less clear. Nitrate levels in river waters fluctuate season-

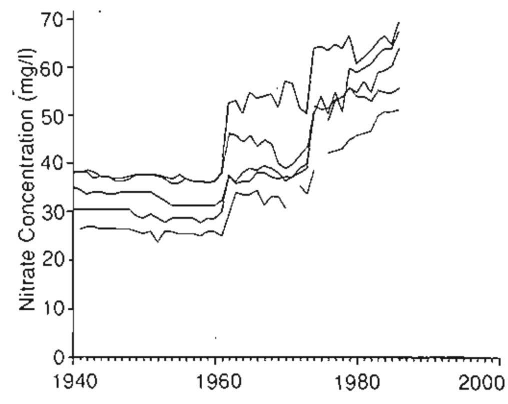


Fig 1. Historical nitrate levels – five boreholes in Sutton Zone aquifer

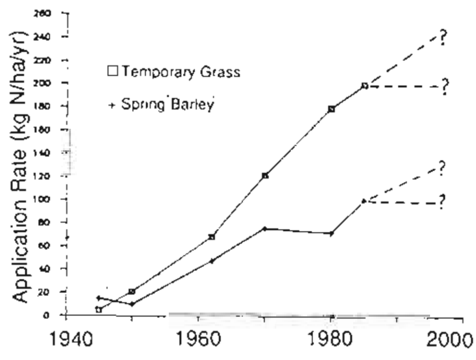


Fig 2. Fertiliser appication rates – South Staffordshire

ally and up to the drought year of 1976 rivers had exhibited steady rises in the annual average concentration by varying rates. Since then some rivers have maintained fairly steady levels and future trends cannot be stated with confidence. During 1986 some 34 surfaee water sources exceeded 50 mg/l.

The South Staffordshire Water Company obtains 50% of its supply from 28 borehole sources drawing water from Triassic sandstone aquifers. Seven of these sources exhibit nitrate levels exceeding 50 mg/l and a further seven have levels that are approaching 50 mg/l. In one aquifer five boreholes currently exceed the EC MAC and levels are rising at a rate of approximately 1.0 mg/l per annum (Fig 1). These rises are coincident with increases in fertiliser application rate in the area (Fig 2). The Company supplies about 1.25 million people and an estimated 10% (130,000) receive nitrate levels in excess of the EC standard.

Future nitrate levels

Future nitrate concentration in a particular source water cannot be predicted with any accuracy on the basis of national or even regional trends.

Fluctuation in nitrate levels are strongly catchment specific and are dependent upon local land use, agricultural practices, meteorological conditions and hydrogeology. Linear extrapolation of historical data is useful for short term planning.

In the long term, however, we can expect that fertiliser application rates will stabilise, if not reduce and consequently nitrate concentration in boreholes should also reach an equilibrium level. If a plan to control nitrate concentrations is to be resilient in the long term an estimate of these equilibrium concentrations is required.

Mathematical model suggests equilibrium level of 65-85 mg/l.

To enable such prediction the Water Research Centre developed mathematical simulation models (5). These models make use of historical cropping and fertiliser application rates records combined with knowledge of the nitrate leaching rates for various agricultural land uses to compute the nitrate leached from the soil zone to the aquifer. The model then simulates transport of nitrate down through the unsaturated zone to the water table and through the saturated zone to pumping stations.

The results of modelling one aquifer by this technique are illustrated in Fig 3 and indicate that for this aquifer current rates of rise of nitrate concentrations in boreholes can be expected to continue to about the year 2000. Increases will then start to reduce with values stabilising at equilibrium levels of between 65 and 85 mg/l by the year 2040.

In utilising such information for planning purposes it is important to be aware that the simulation is dependent upon the underlying assumptions in the model on nitrate leaching rates, the mode of transport through the unsaturated zone and the depth of mixing in the saturated zone. In particular, introduction of newer crops or a change in farming practice can significantly modify the prediction.

In using the model it was found that changes in cropping practice for winter cereals and new information on nitrate leaching rates from grassland resulted in a reduction of predicted equilibrium levels in pumping source from 120 mg/l to 85 mg/l.

Control Options

There are a number of options for controlling nitrate in water supplies. These are summarised in the adjacent panel.

Costs of compliance with EC directive

In order to identify the most appropriate solution to ensure compliance, accurate cost information is required. Discussion of the costing of agricultural options is not possible but to achieve a level of 45 mg/l in one aquifer significant changes in agricultural practice are required (Table 1).

Table 1. Impact upon agriculture of achieving 45 mg/l nitrate in the water supply by fertiliser restriction policies in one aquifer

Catchment wide, reduction in fertiliser application rate		23% - 48%
Protection zone	- radius	930m - 2500m
	- area	2.7 km^2 - 25 km^2
Proportion of catchment area requiring protection,		49%

For the Company, costs will primarily be related to blending and treatment. Blending may entail main laying and possibly reservoir construction costs. Additionally if compliance is to be guaranteed then further expenditure will be required on flow meters, nitrate monitors and telemetry in order to ensure that blending is satisfactory.

Nitrate treatment is a new departure for the Company and currently ion exchange is a technique that is being pursued. For boreholes of between 5 and 15 Ml/day output, capital costs of £750K to £2000K are expected with annual operating costs of between £70K to £250K. In terms of unit costs, nitrate removal raises the cost of groundwater treatment to that of surface water i.e. between 3.5 to 5.0 p/kl.

From these investigations the total cost to the Company of a mixed treatment and blending solution to the nitrate problem has been calculated at approximately £10 million pounds capital costs with annual operating costs of approximately £800K.

Nitrate Control Options

Control at source:
- reduce fertiliser application rate
- amend agricultural practices to reduce nitrate leaching - e.g. more autumn sown crops
- change land use - e.g. forestry, golf courses, etc.
- establish protection zones around boreholes

Water company controls
- Operational options
  - blend high nitrate waters with low nitrate waters
  - replace high nitrate sources
- Treatment options
  - ion exchange
  - biological denitrification
  - other techniques - under investigation are reverse osmosis, electrodialysis, chemical reduction and others.

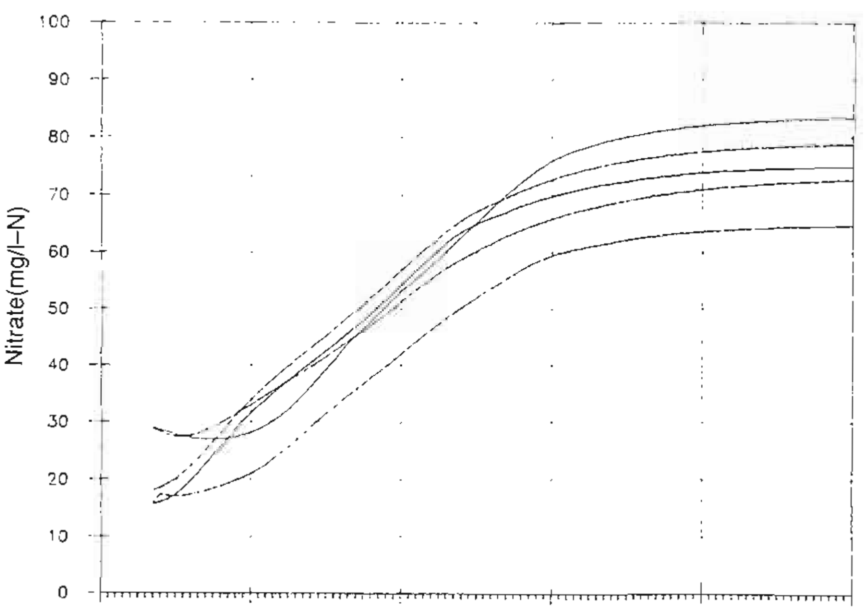


Fig 3. Nitrate prediction model (fertiliser application rates unchanged)

These large increases and the effect upon water supply charges raise the important question of "who pays?" Increases in nitrate levels are a direct result of current farming practice and it may be argued, under "the polluter pays" principle, that such costs should be borne by the agricultural community. However, current nitrate levels are the result of activities some years previous when the use of fertiliser to increase agricultural production was being actively encouraged as government policy.

Big reduction essential in nitrate leaching if high treatment costs to be avoided

Total costs for controlling nitrate levels to 45 mg/l until 2040 have been estimated for one aquifer for three situations, a) no change in current agricultural practices, b) a catchment wide 20% reduction in fertiliser application rate and c) a 48% reduction in fertiliser application rate.

The results show (Table 2) that for this aquifer a 20% reduction in fertiliser application rate produces only small savings attributable to reductions in operatingcosts.

For significant savings to be made a reduction in nitrate leaching is required that will eventually eliminate the need for treatment i.e. a 48% in fertiliser application rate. Even then significant interim treatment costs are incurred whilst the restriction takes effect.

Table 2. Total costs for controlling nitrate levels to 45 mg/l until 2040 in one aquifer for various agricultural scenarios.

	Reduction (catchment wide) in fertiliser application rate %		
	0	*20*	*48*
Actual costs, £m (1988 prices not inflated)	15.5	13.8	5.6
Net present cost, £m (5% discount rate)	5.9	5.9	3.5

Conclusions

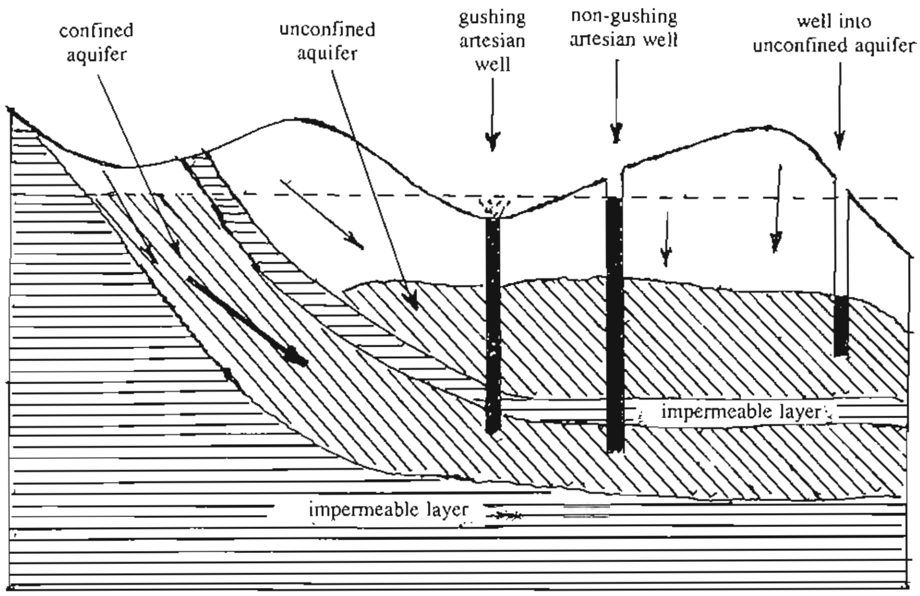
1. Nitrate levels in the Company's groundwater sources are rising in line with fetiliser application rates and will continue to rise for a further 5 to 15 years even if action is taken now to reduce nitrate leaching.

2. In existing high nitrate areas it is unlikely that compliance with the nitrate requirements of the EC Directive can be achieved without introducing treatment.

3. In existing high nitrate areas control of nitrate leaching at source will entail substantial changes to agricultural practices or land use that have important social and environmental considerations.

Acknowledgement

The authors wish to thank the Managing Director of South Staffordshire Water Company for permission to publish this review. The views expressed are those of the authors and not necessarily those of the Company.



Cross sectional representation of confined and unconfined (vulnerable) aquifers

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Irrigation surveys by ADAS

– developing a long term projection of water demand

C B Stansfield

Since the early 1980s the Ministry of Agriculture has been collecting detailed information on the extent of irrigation in England and Wales. Such information is needed so that improved methods can be developed to project long term water demands and help water authorities plan for the future.

In its 1980 report "Water for Agriculture: Future Needs" the Advisory Council for Agriculture and Horticulture drew attention to the lack of information on the quantity of water used by farmers.

Although water authorities are aware of the demands of agriculture for water they need sound information if they are to plan effectively and to have adequate water available when and where it is required.

Accordingly, the Ministry of Agriculture, through its Agricultural Census Branch, set in motion a series of statistically-based surveys with the aim of collecting data on water used for irrigation in England and Wales.

Survey based on June Census

The basis of the Ministry survey is that irrigators are selected from the main June Census by a trigger question "Do you irrigate outdoor crops?". Anybody answering "Yes" then receives a more detailed questionnaire seeking information on the type and area of crops irrigated, how much water is used, where the water comes from and how it is stored. Further questions ask for information on the type of equipment used and also on trickle and frost protection irrigation.

The data collected, although showing a wide variation from season to season, is nevertheless already providing Water Authorities with a firmer basis for assessing likely water demand both short term and long term. Survey information is also used by the Water Authorities Association, Department of the Environment, European Commission and the Water Research Centre, as well as manufacturers, suppliers, other trade organisations and for a variety of research activities.

The Ministry is very conscious that farmers do not like form-filling so an easy-to-use form was designed for this Survey. Farmers are also reassured that no data on individual holdings is released and that only data grouped together is published. There are still some problems with form-filling especially between imperial and metric units but the MAFF statisticians make sure information is validated before it is released.

Chris Stansfield is ADAS Senior Soil and Water Engineering Adviser, London.

The results are published by MAFF, Agricultural Census Branch, Government Buildings, Epsom Road, Guildford, Surrey GU1 2LD. Tel: Guildford (0483) 68131 Ext. 3577. A variety of analyses are available for different uses and include national material and county-based figures.

Table 1. Actual areas of crops irrigated and volume of water applied.

	Crop area, ha			*Water volume ($1000m^3$)*		
	1982	*1984*	*1987*	*1982*	*1984*	*1987*
Potatoes harvested by 31 July	8,050	7,720	5,360	4,680	4,920	2,350
harvested after 31 July	22,810	34,610	29,520	15,280	32,730	14,700
Sugar beet	15,770	25,500	10,110	8,260	17,370	3,430
Orchard fruit	3,100	3,250	1,330	2,180	2,430	550
Small fruit	3,610	3,560	2,230	1,890	2,660	970
Vegetables for human consumption	14,810	17,460	11,040	6,830	11,390	4,640
Grass	16,440	18,940	6,970	10,030	13,550	3,550
Cereals	14,800	24,700	7,510	5,040	8,300	2,160
Other crops grown in the open	4,100	4,890	2,440	1,020	4,030	1,270
Totals	103,490	140,600	76,520	55,210	97,370	33,620

Totals may not exactly agree with the sum of their components due to rounding.
Reference to other published statistics suggests that the acreage of the crops grown each year remains broadly constant over the period concerned. The variations from survey to survey in the area irrigated and in the volume of water used thus reflect the nature of the season and do not indicate any sudden change in acreage of a particular crop.

Fluctuation in area irrigated annually

Since the 1980 report, Irrigation Surveys have now been carried out in three years - 1982, 1984 and 1987. The next Survey is planned for 1990. Table 1 summarises the data for 1982, 1984 and 1987 on the actual areas of crops irrigated and the volume of water applied.

The area of crops irrigated between 1982 and 1984 rose by 36% and fell from 1984 to 1987 by 46%. The most important crop irrigated continues to be potatoes and in 1987 some 35,000 hectares used 17m cubic metres of water out of a total of 34m cubic metres. Other important crops are sugar beet, vegetables and grass.

Rivers, streams supply 50% of water

Table 2 shows the sources of water supply. Rivers, streams and watercourses consistently supplied around half of all the water used in the three Surveys. The next most used sources

Table 2. Sources of water and volume used

	Water volume ($1000m^3$)		
Water source	*1982*	*1984*	*1987*
River, stream or other watercourse	27,520	47,840	16,000
Spring rising on holding	2,580	4,370	1,580
Well	2,560	3,210	1,130
Deep boreholes	11,540	24,840	9,090
Pond or lake	5,800	8,470	2,870
Gravel or clay working	1,070	1,260	380
Public supply (main)	2,040	3,840	1,100
Other source	1,830	3,540	1,470
Totals	54,940	97,370	33,620

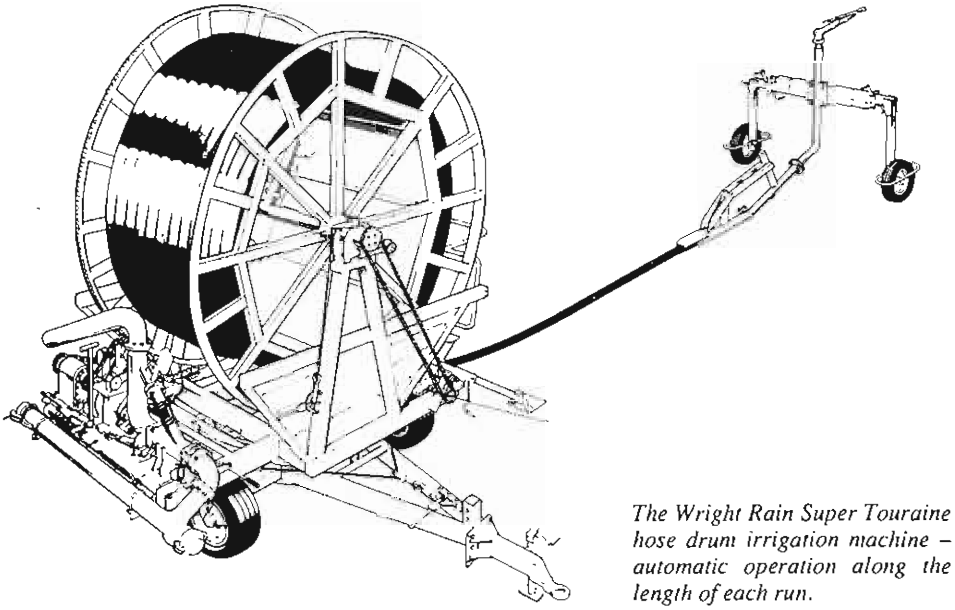
**Not all water is accounted for because of independent raising of figures for non-response.*

were deep boreholes, followed by ponds and lakes.

The capacity of storage facilities has increased from 21.7m cubic metres in 1982 to 33.6m in 1984 and 37.2m cubic metres in 1987, although the number of reservoirs fell between 1984 and 1987 by 10% to 2,420. It is pleasing to see the increase in storage capacity as this makes farmers' supplies more independent of outside pressures and storage can now provide well over one-third of the irrigation requirements.

Table 3. Equipment – Self-propelled irrigators

Irrigators	*No. of Machines*		
	1982	*1984*	*1987*
Rain guns	2,720	4,210	4,530
Boom type	440	560	350



The Wright Rain Super Touraine hose drum irrigation machine – automatic operation along the length of each run.

Trends in methods and practices

Besides the data collected on water requirements the Surveys are also being used to measure trends in methods and practices. Summarising such information in Tables 3 and 4 it is shown that there has been a significant decline in the use of labour-intensive distribution equipment and a steady growth of self-propelled irrigators. The area on which trickle irrigation is used has declined steadily through the three Surveys, (from 2040ha in 1982 to 1550ha in 1984 and 1330ha in 1987), whereas the area of frost-protected irrigation continues to increase (1160ha in 1982 to 2080ha in 1984 and 2710ha in 1987).

Table 4. Equipment - Number of holdings using other types of equipment

Equipment	*Number of holdings*		
	1982	*1984*	*1987*
Sprinklers and spray lines	6,550	4,070	2,890
Rain guns (not self propelled and not for slurry)	700	580	370
Trickle equipment	890	640	490
Mini-sprinklers (orchards)	350	200	130
Other equipment (eg. centre pivot, linear)			140

Due to response difficulties from holdings who did not irrigate during 1987 the figures relating to the type of equipment may be understated for that year. Nevertheless, Table 3 does show the steady growth in the number of rain gun types and the overall decrease in the number of boom types although no information is given on the capacity of the two types.

Weather conditions to be considered

Naturally in any survey of irrigation practice proper account must also be taken of the relevant weather conditions. Table 5 presents Potential Soil Moisture Deficit (PSMD) information for four locations within the main irrigation areas and compares them with the long term averages. PSMD is the soil water deficit that the soil would achieve if the crop were to transpire at the full potential rate i.e. assuming the crop is not under water stress. As such it differs from Soil Moisture Deficit (SMD) which relates to deficits actually achieved.

Although 1984 was considered to be a drought year this was not true in all areas of England and Wales with East Anglia, in particular, below the long-term average – and the East Midlands being well above. It is this variation in rainfall over a period of years – and geographically within years – that throws up interesting problems for the water planners. In 1982 the East Midlands potential soil moisture deficit was below the long-term average and yet Central and South-East England were somewhat higher but then not as high as in 1984. 1987 was overall an unusually wet season with little sunshine across the whole country.

Although the present series of irrigation surveys is now specifically devoted to developing data on future trends and requirements there have been earlier surveys with information gathered on areas of irrigated land.

Figure 1 presents data from twelve surveys covering the period 1955 to 1987 inclusive. The overall trend is towards an increased area

Table 5. Weather conditions compared

		Potential Soil Moisture Deficit (PSMD), mm					
		April	*May*	*June*	*July*	*Aug*	*Sept*
Cambridge	1977	35	85	110	205	140	185
	1982	135	180	170	200	275	275
	1984	55	45	55	150	175	110
	1987	40	80	50	60	55	75
	Average	20	60	105	140	155	160
Oxford	1977	20	60	35	140	75	115
	1982	45	95	115	175	215	215
	1984	70	70	140	240	295	265
	1987	35	70	60	120	165	190
	Average	15	40	80	115	120	110
Maidstone	1977	25	55	45	120	140	170
	1982	60	110	125	180	220	220
	1984	60	70	95	175	240	235
	1987	40	80	85	85	105	125
	Average	10	45	100	140	155	145
Nottingham	1977	30	70	50	135	120	140
	1982	50	120	50	130	90	95
	1984	65	80	115	210	215	185
	1987	35	90	65	90	95	110
	Average	15	45	90	130	130	125

of irrigated land but with marked seasonal fluctuations due to climate effects.

Factors affecting forecasts

Forecasts of irrigation water requirements will continue to be subject to the influence of climatic variations. It must be remembered that, increasingly, irrigation is being used, not only to ensure reliability of cropping, but also to satisfy customer demand for quality produce and continuity of supply.

Above all, the forecasts must then be related to the economic considerations - of farming in general and of the individual irrigated crops in particular.

In preparing to meet farmers' irrigation requirements the water authorities need to have an idea of likely volume and to be preparing to provision it, or indeed already to have adequate water in the right place before the season of demand begins. The information now being gathered is still something of a 'mixed bag' but it is nevertheless progressively allowing more accurate computer models of water demand to be prepared. Projects such as the augmenting of water storage facilities, the initiation of water transfer schemes and the further development of river regulating operations can be pursued with more confidence.

Water is an expensive commodity that has to be used precisely to provide a return on the investment. Long term forecasts than can be relied on are essential for future planning so that the greatest benefit can be achieved and at the least cost.

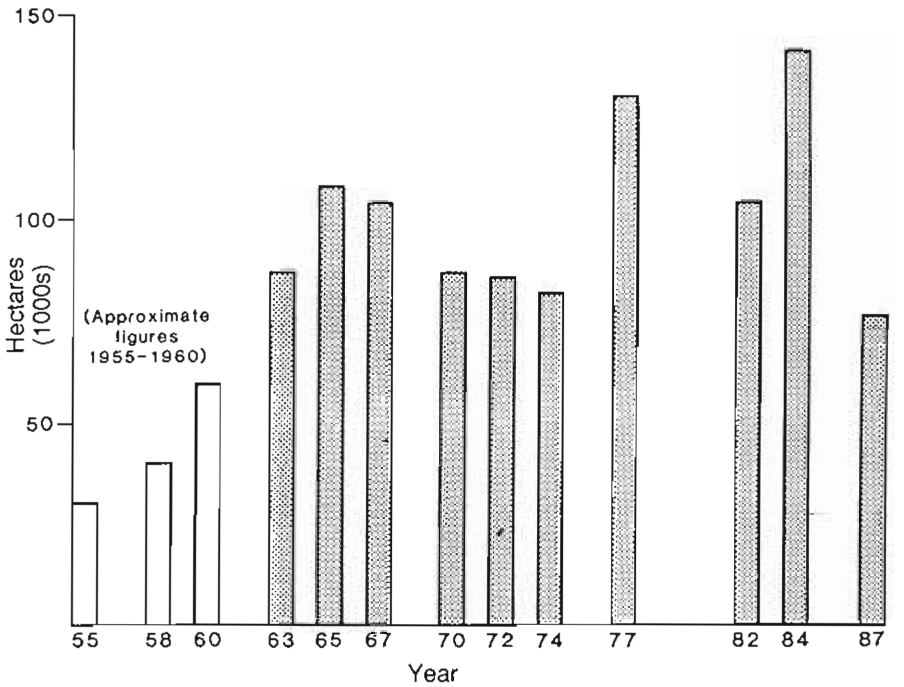


Fig 2. Area of irrigated land (twelve surveys 1955 to 1987)

Acknowledgements

To Mrs R. G. Woodley, Agricultural Census Branch and Mr E. Spackman, Agrometeorology Department, ADAS.

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Reversible ploughs recognised by World Ploughing Organisation

Until now, only 'conventional' ploughing in lands has been allowed in the prestigious annual competition organised by the World Ploughing Organisation to find the World Champion Ploughman.

That restriction may soon be lifted. A report in the latest bulletin of the WPO notes that "the WPO Governing Board is mindful of the fact that an increasing number of younger generation ploughmen in European countries are only acquainted with 'reversible' ploughs".

Accordingly, the Board is undertaking a feasibility study to determine whether or not both methods of ploughing, each requiring a different scale of aspect assessments when judged, can be practically and fairly included in future World Ploughing Contests. The big question is to determine whether or not there can still be a supreme overall World Champion Ploughman or, alternatively, must there be two World Champions, perhaps individually of lesser degree than an overall winner but each supreme in his respective discipline.

This year an Invitation Reversible Ploughing Match will be held in conjunction with the 36th World Ploughing Contest in Norway. The following year, at the Contest in Holland, there will be a Friendship Reversible Ploughing Match. Based upon the experience of these two practical studies subsequent deliberation will determine the place of "reversible" in regard to the World Ploughing Contest.

The World Ploughing Contests were established in 1952. At the 35th annual event in USA last year the winner of the World Ploughing Championship was Graeme Witty of Malton, North Yorkshire (plough - Kverneland; tractor - Case IH).

Soil density gauge from SCAE

The SCAE soil density gauge, together with equipment for providing access to the soil and for sampling soil water content.

Following two decades of development, testing and refinement, the Scottish Centre of Agricultural Engineering is now marketing the production version of their gamma ray transmission soil density gauge.

According to SCAE by far the most accurate and convenient method of assessing compaction levels in field soils is by measurement of dry bulk density. Measurements should be taken in thin layers of soil and in layers close to the soil surface. Such readings can then give an accurate indication of the variation in bulk density with depth and show up any dense, compacted, but thin layers in an otherwise adequately loose soil.

The SCAE soil density gauge consists of a twin probe gamma ray transmission system. In one probe there is a 5mCiCs137 gamma ray source and in the other the detector assembly comprising a NAI (TI) crystal narrow bore photomultiplier.

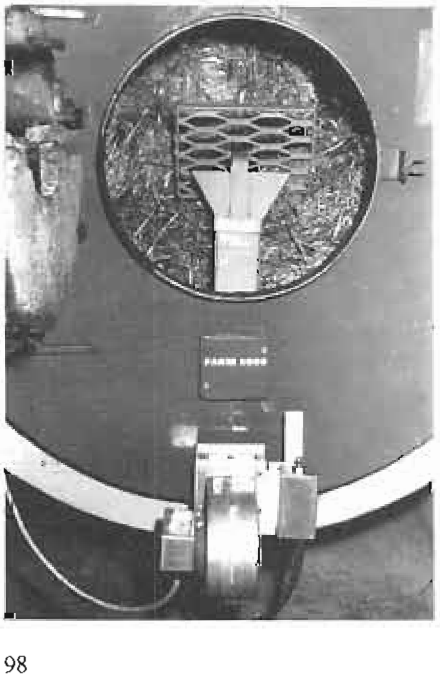
In operation, access holes are made in the soil through a steel alignment jig, either by driving steel spikes or hy augering. The jig is then removed and the probes lowered into the holes to the various depths at which measurements are required.

Linked to the gauges's detector assembly is a scaler which for normal high resolution operation counts only the gamma rays which pass unscattered directly from the source. However, if high spatial resolution is not required, the time to collect a given number of pulses may be reduced without loss of precision by counting both unscattered and some scattered rays.

A detailed description of the gauge and its performance has been given in the Journal of Soil Science, 1983, 34, (3), 453-463. Modification to the standard design can be offered to meet specific requirements.

Further information: the Soil Engineering Department, SCAE, Bush Estate, Penicuik, Midlothian EH26 0PH. Tel: 031 445 2147.

Straw fired boilers environmentally friendly



Farm 2000 announce a second generation of their straw fired boilers with substantially reduced smoke emission and higher combustion efficiency.

When straw is burned there is an initial period when combustible volatiles are given off as smoke. The new Farm 2000 straw fired boilers now incorporate a forced draught fan which initially blows air into a baffled area where the smoke is burned and afterwards diverts the air to the bottom of the combustion chamber to burn the fuel.

A fully automatic electronic control unit monitors temperature levels and precisely regulates primary and secondary air flow according to preset requirements.

Farm 2000 Ltd., Bradley Green, Redditch B96 6RP. Tel: 052 784 621

Ludlow "Modern Measurement' range

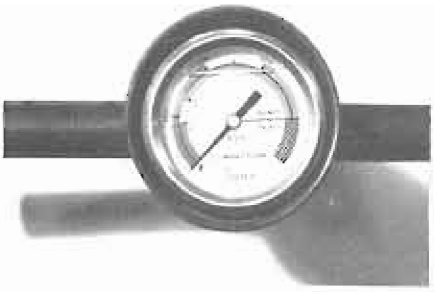
Ludlow (Farm Laboratory) Services Ltd., of Shottlegate, Derby - Tel: (0773 89) 454, have now added a spray nozzle tester to their 'Modern Measurement' range of measuring equipment.

Called the Fair-Grade Flow Meter, in a matter of seconds it accurately measures the flow rate of the sprayer jets. An accompanying handy chart is calibrated in litres/acre, litres/hectare, or gallons/acre. Priced at only £29.00 plus VAT, the Fair-Grade Flow Meter gives the spray operator a simple, quick and inexpensive way to check spray rates.

Other products in the 'Modern Measurement' range include special thermometers; electronic flashing barometers; rain gauges; bushel weight testers and moisture meters.

Soil Compaction Tester

Now available in the UK is the new Soil Compaction Tester made by the US agricultural electronics specialists DICKEY-john. Importers AgriTEK of Acle, Norwich aim to supply a range of DICKEY-john monitoring and control equipment both to original equipment manufacturers and also to farmers.



The Soil Compaction Tester is a lightweight, hand held unit which allows the simple measurement of the depth of the soil pan and its thickness. It consists of a 24" long probe which has its stem graduated in 3" segments and a pressure gauge on the top.

The probe is pushed into the ground and the soil resistance is recorded on the three band pressure gauge to indicate good, bad or intermediate growing conditions. If a soil pan is reached, its depth below the surface can be read off the probe and its thickness measured by pushing the probe through until the pressure gauge shows resistance has lessened.

The DICKEY-john Compaction Tester can make subsoiling more accurate and effective, say AgriTEK. It costs £149.

Other DICKEY-john products now available from AgriTEK include equipment for sprayer control and monitoring; control equipment for granular fertiliser spreader, a grain loss monitor and a shaft speed sensor.

Direct chemical injection reduces costs improves safety

Dramatically reduced chemical eosts and improved human/environmental safety are the benefits claimed for the AgriFutura Dose 2000 system of direct chemical injection for field crop sprayers.

In an exclusive agreement with AgriFutura AB of Sweden, the UK eompany, Farm Dealership Limited, has acquired UK rights for this and other advanced spraying technology from the Swedish innovators. "With the Dose 2000 system", says Mike Dawson, General Manager, "the sprayer carries straight, unmixed water in its main tank. Straight chemical is loaded separately onto the sprayer and metered, *as it is used*, into the spray lines. There is no operator contact with neat chemical and no mixed chemical left at the end of the field."

Further details from Farm Dealership Limited, 25. The Parade, Marlborough, Wilts SN8 1NE. Tel: (0672) 55655.

Global warming – greenhouse effect

–could improve agricultural potential

Increases in temperature in the UK resulting from the 'greenhouse effect' could open up opportunities for UK farmers to produce more for EC and world markets in order to make up for reduced agricultural potential elsewhere, according to geographer Professor Martin Parry, of Birmingham University.

Addressing an NFU audience in London earlier this year, Professor Parry pointed to indications that higher temperature and reduced moisture in the 'breadbasket' areas of the US Great Plains and the Canadian prairies as a result of greenhouse warming would significantly reduce farming potential in that region. At the same time, an increase in average temperatures would lengthen the growing period in northern Europe while shortening it significantly in the Mediterranean countries.

Professor Parry warned, however that there is still much uncertainty about how temperatures or rainfall will alter. Only the broadest of estimates can be made. Perhaps by the year 2050 to 2100 the temperature rise in the UK could be around 3°C with a more pronounced warming in winter than in summer.

Even half a degree warming can shift limits of cultivation about 90 miles northward. The increases envisaged therefore, could lead to a substantial northward shift in the potential for growing crops such as grain maize and sunflowers in Britain and perhaps even soya and navy beans in Southern England.

Much will depend though on possible future changes in rainfall and about this aspect there is very little yet known.

"Geographers need to know more", said Professor Parry, "about how quickly agriculture can adapt to the kinds of climate changes that may be experienced and how they can assist in that adaptation."

– will dramatically alter UK soils

"The threat of climatic change is a more serious environmental problem than any yet faced", declares Professor Bullock, Director of the Soil Survey and Land Research Centre. "If the greenhouse effect remains unchecked current UK soils could be very different by the year 2020".

"There appears to be little research commitment into the problem yet nobody can be entirely certain what climatic changes we could be facing. If temperatures rise, many key biological and chemical soil reactions will accelerate.

"Organic matter will be broken down more rapidly, increasing the risk of erosion, particularly if the drier soils remain uncropped for longer periods. If combined with lower rainfall, nitrate concentrations in groundwater could be higher.

"Alternatively, the effects of climatic change could open up possibilities to double crop land with new species.

"The UK must wake up to the possibilities and recognise the key role of soil scientists and their national resource databases in sustaining a healthy pattern of land use whatever the future environmental conditions", stressed Prof Bullock.

Dowdeswell Engineering Co Ltd, Stockton, Warwickshire have introduced a 1.80m (6ft) working width heavy-duty scrub-cutter designed for use with tractors of up to 100hp. Cutting height can be set from 60 to 135mm (2.5 to 5.5 in). Rotary blades are recommended for scrub growth and brush wood, with flail chains for other duties including bracken control.

National Nitrates Conference

Lincolnshire Agricultural Society is staging a National Nitrates Conference - "Living with Nitrates" on Thursday, 9th Nov. 1989.

Lord Plumb of Coleshill will make the opening address speaking on the theme of The Politics of Nitrates. Subsequent speakers will be Dr. David Forman – Imperial Cancer Research Fund; Mr A E Johnston – former Head of Soils and Crop Division, Rothamsted Experimental Station; Dr D B Davies – Regional Soil Scientist, ADAS and Dr Nigel Williams – Wye College.

Mr Eric Carter, FWAG will sum up.

Current developments on tyres for agricultural use

G M Pocket explains how increases in agricultural vehicle speed requirements are setting tyre manufacturers major new design goals.

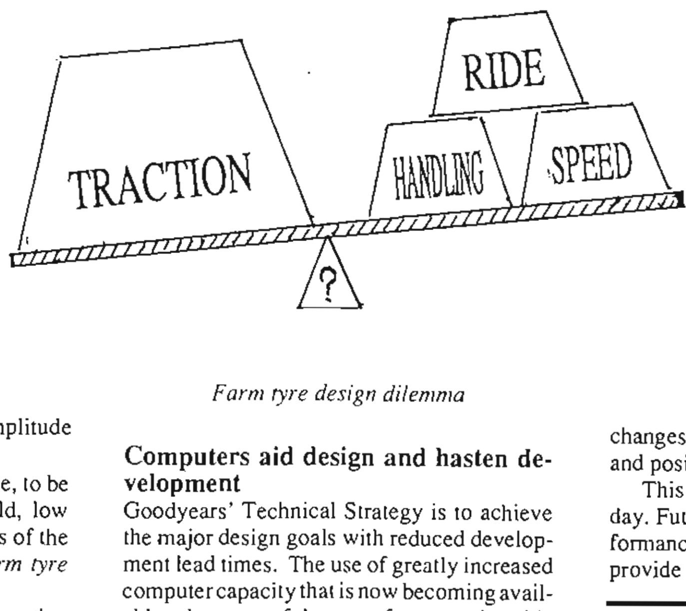
Tyre development runs hand in hand with vehicle development, user requirements and future expected trends. Tractor speeds up to 50 km/h are now with us. This development is expected to become more widespread. Tyre manufacturers must also take account of industrial type equipment such as the backhoe which also runs on agricultural tyre sizes with industrial type tread faces.

The increase in agricultural vehicle speed – with some tyre ranges requiring 90 km/h capability – has lead to a number of major design goals. These are:-

1. The tyre is to give safe and effective vehicle handling properties and to provide the necessary directional stability to suit load and speed.
2. Tyre induced vibrations and noise become even more critical with increased speed. A quirk of modern quiet tractor cab design is that we now have an extremely sensitive medium for amplifying tyre induced ride disturbance at any speed.
Changes in the traditional agricultural tread patterns can therefore be expected.
3. Unsprung vehicle ride properties are provided to a great extent by tyre damping, spring rate and also by directional stability. Tyre properties that provide these features are to be re-tuned to meet the increased road speeds.
4. There must also be improved resistance to tyre heat build up (caused mainly by frequency and amplitude of tyre deflection).
5. The foregoing features are of course, to be achieved without detriment to in-field, low speed, high torque traction capabilities of the agricultural drive tyre. *This is the farm tyre design dilemma.*
It is perhaps also worth pointing out here that a tyre does not have to look clean to provide the best traction in sticky soil conditions.
6. The trend towards reduction of soil compaction requires the tyre manufacturer to provide maximum tyre footprint for a given size. He must also provide a full range to enable the user to select the largest practicable tyre size to suit the vehicle, soil tillage and crop spacing.

This comment is tied in with the subject of rim width. Most tyre sizes have a recommended rim width (for optimum tyre performance) and a permitted rim width, usually one inch narrower than the recommended. If the tractor manufacturer uses recommended rim widths it is then possible for the user to fit one tyre size wider on the same rim provided, of course, that 4 wheel drive ratio tolerances are maintained, (normally a 1 to 5 per cent lead on the front axle).
7. The tyre range must be designed for global use, be evaluated globally and capable of production in factories throughout the world. We must not forget that a tractor produced in the UK is likely to be exported to work anywhere in the world.
8. Finally, and always to be borne in mind, the tyres must be produced at a price level that the tractor manufacturers' purchasing departments and the end users are prepared to pay.

Geoff Pocket is a Staff Engineer in the Automotive Engineering Division of Goodyear Great Britain Ltd, Wolverhampton.



Farm tyre design dilemma

Computers aid design and hasten development

Goodyears' Technical Strategy is to achieve the major design goals with reduced development lead times. The use of greatly increased computer capacity that is now becoming available, plus state of the art software makes this possible.

Some of the main areas to which this facility will be applied are:-

- Tyre to soil interaction
- Internal tyre stresses under high torque conditions
- Tyre ride and comfort performance

Time saving benefits will be achieved in tyre concept stages of assessment, development and evaluation.

Radial tyre sidewall markings have changed. Load indices figures replace ply ratings and speed symbol letters define the speed at which the load index applies. Details can be seen in the "Farm Tyre Data Book". New agricultural tyre size markings are becoming metric in the first part of the size definition. This indicates nominal section width, (as is standard on car tyres size marking).

Tubeless tyres - still a fitting problem

The tubeless situation with large agricultural tyres remains unresolved.

From purely a technical point of view, for the tyre and equipment manufacturer, the tubeless tyre is a more "airtight" maintenance free product at a lower cost. However, from an in-field service point of view, re-mounting the large tractor or combine tyre without a tube and withour special inflation equipment can be a nightmare, i.e. obtaining the air seal between tyre bead and rim requires a high volume blast of compressed air.

Changes – internally and externally

In summary it is forecast that the external appearance of the newly developed agricultural type tyre will show changes to tread element design and sidewall markings. Internally there will be changes to rubber compounds and reinforcing materials, with changes to component gauges, dimensions and positioning within the tyre carcass.

This is the tyre development situation today. Future demands, such as even higher performance and new legislation (1992?), will provide further design goals for tomorrow.