# NITROGEN TRANSFER FROM COMPANION CROPS: A LITERATURE REVIEW AND COMPUTER MODELLING EXERCISE

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## SUMMARY

*Literature review*

- There is little direct N transfer (via rhizodeposition and mycorrhizal interactions) that is of agronomic significance in companion cropping systems.
- The indirect route of nutrient transfer via the mineralisation of dead root and shoot material (following defoliation/suppression) is more important.
- Forage legumes have the greatest potential as a companion crop as they obtain over 90% of their N from atmospheric fixation compared to just 50% by grain legumes. This provides a greater net N contribution to the system by 'freeing' more soil N for the associated crop.
- There is little quantitative information on nutrient transfer in companion cropping systems. Many factors will affect the amount available for transfer including legume species, age and management, soil nutrient supply, soil microbial mineralisation and immobilisation and residue quality.
- Much of the N released may be either immobilised within the soil microbial biomass or recycled back to the leguminous crop (which itself may inhibit N fixation). This makes the accurate quantification of the amount transferred difficult to assess.

*Modelling of N mineralisation*

- Recent measurements of clover (above-ground) dry matter returns provide the preliminary conclusion that weekly cutting and mulching returns more N than monthly cutting and mulching.
- Regardless of the cutting frequency, all models suggest that c.70-75% of the residue N will be mineralised within the first year after cutting.
- The models show reasonable general agreement in these estimates.
- The pattern of release will depend on the temperature and moisture regime of the soil, however, and also differs between models.
- The models assume the residue is ploughed into the soil: they have not been validated for surface applications and the pattern and rate of mineralisation could be different for mulched residues.
- As a first step, however, the desk study has given some useful information on amounts and timescale of N release.
- Using this approach, it is not possible to account for below ground release and transfer.

# PART A - NUTRIENT TRANSFER IN COMPANION CROPPING SYSTEMS: A REVIEW

Companion cropping is a form of intercropping whereby two crops are grown in association with each other, with one of the crops (typically a legume) grown specifically for the benefit of the other (cash) crop. It can take a number of forms including:

- 'Live mulch' - a system whereby a cash crop is sown directly into a legume understorey, which has been temporarily suppressed (Clements *et al.*, 2000). Alternatively, the cash crop may be grown in alternate rows between a green manure crop which is partially tilled or periodically cut with the cuttings thrown onto the cropped area (Grubinger & Minotti, 1986).
- 'Intercropping' - several rows of cereal crops are interspersed with legumes (Giller *et al.*, 1991). In this case, both crops are often harvested for yield.
- 'Alley cropping' - a form of agroforestry whereby crops are grown in 'alleys' formed by a row of trees, with the tree prunings returned to the cropped area (Mulongoy & Akobundo, 1990).

The potential benefits of such systems include: improved utilisation of resources (water, light, and nutrients), transfer of nutrients (particularly N) from the companion to the cash crop, soil protection, weed and pest control.

Companion cropping, particularly alley cropping and intercropping, is commonly practised in tropical agriculture as a solution to infertile soils and limited inorganic fertilisers: consequently, there is much literature on such systems. However, very little companion cropping occurs within temperate climates, where it tends to be restricted to low input and organic systems, or in locations where soil erosion is prevalent.

## Mechanisms of nutrient transfer in companion cropping systems

Possible mechanisms for the transfer of nutrients from the companion ('donor') to cash ('receptor') crop include:

- Mineralisation of foliage cuttings and crop residues (above ground),
- Mineralisation of root material (below ground),
- Rhizodeposition: the loss of organic materials from roots as they grow through the soil (Jensen, 1996).
- Direct transfer via mycorrhizal connections between the plants (below ground),

Where the companion crop is a legume (virtually all cases, except in some alley cropping situations), there is the added advantage of an additional N supply via atmospheric N fixation. This not only means the receptor crop can exploit a larger soil N pool than if it was grown as a monoculture (Giller *et al.*, 1991; Ong, 1995), but N may also be transferred from the legume to non-legume.

### *Transfer of nutrients below ground*

The evidence for the direct transfer of N from the root system of a legume to that of an associated non-legume via rhizodeposition or mycorrhizal connections, is contradictory. Much of the evidence in its support has come from research on mixed grass/legume swards, which persist in the field for much longer periods of time and whose root systems are often more closely associated than in most intercropping systems (Giller *et al.*, 1991). However, even studies on grass/legume associations report conflicting results. For example, McNeill & Wood (1990) saw no evidence of rapid direct transfer of N from clover to ryegrass after 129 days growth (using $^{15}N$), whereas Haystead & Marriott (1979) observed that c. 12% of ryegrass N was derived from the white clover grown in association with it for 105 days. In other associations, Jensen (1996) observed that 19% of barley N uptake was derived from the associated pea crop after 10 weeks growth, but this was less than 1% of the total pea N content. Likewise, Giller *et al.* (1991) observed that the amount of N transferred from bean to maize was never more than 4% of the bean N, although it amounted to 20% of the maize N. Here, although the maize derived some of its N from the bean, this did not contribute to better growth and yield of maize, with the N uptake of intercropped maize no greater than a monocrop of maize. It was suggested there may have also been transfer of N in the opposite direction from the maize to the bean.

The degree of N transfer depends upon the quantity and concentration of legume N, microbial mineralisation and immobilisation in the rhizosphere, the availability of other N sources and the degree of utilisation by the associated crop (Ofori & Stern, 1987). Release of N from legumes is thought to increase, when the legume is stressed e.g. by shading, defoliation or following physical damage. However, rhizodeposits can be quickly immobilised by the microbial biomass, which depending on the rate of re-mineralisation, can reduce or delay N transfer (Jensen, 1996). The amount of N available and pathway of transfer have also been seen to depend on the legume species. For example, Dubach & Russelle (1994) estimated c. 13 kg/ha of symbiotically fixed N could potentially be released from decomposing fine alfalfa roots but only c. 2 kg/ha of fixed N from decomposing trefoil roots. By comparison, trefoil was seen to have more root nodules, estimated to provide c. 6 kg/ha N to the top 30 cm soil, compared to only c. 2 kg/ha from alfalfa nodules.

It has been suggested that mycorrhizal interactions between the companion plants may enhance N (and P) transfer. This symbiotic association between plants and fungi has the effect of increasing the nutrient absorbing zone of the root, which is particularly important for the uptake of immobile nutrients such as P. The hyphal network associated with one plant is capable of infecting an associated plant thereby potentially facilitating the transfer of nutrients. Frey & Schuepp (1993) observed that up to 4.5% legume N (‘Berseem’) was transferred to an associated apple tree in the presence of mycorrhizal infections, with no transfer evident in the absence of mycorrhizae. However, Ikram *et al.* (1994) observed that just 0.07% and 0.8% of the legume N and P, respectively, was transferred to an associated non-legume irrespective of whether mycorrhizae were present. This increased to 0.27% N and 1.6% P when the legume shoot was removed. Johansen & Jensen (1996) also observed no significant transfer of N and P in the presence of mycorrhizae. Here, N and P transfer from pea to barley only occurred when the pea shoots were removed and again this amounted to less than 3% of the pea N and P. In this case, transfer was enhanced when the *receptor* (barley) plant was infected with mycorrhizae, suggesting an improvement in the ability of the barley to acquire nutrients from the decomposing pea roots.

There appears to be very little direct transfer of N (and P) from a healthy legume to associated non-legume and that which does occur is agronomically insignificant. However, that left as dead legume roots (and shoots) is more substantial and it is this slower, indirect transfer which is thought to be more important in companion cropping.

***Transfer of nutrients above ground***

There have been a number of estimates of the potential contribution of N to soils from legumes. These have been largely associated with studies on cover or green manure crops, whereby the legumes are grown as a monoculture, either over winter (cover crops) or as the fertility building phase of an organic rotation (green manures), followed by soil incorporation at maturity. There is very little information on the nutrient contribution from companion crops (particularly cut and mulch systems), with most work conducted on agroforestry systems in the tropics and subtropics.

The quantities of N in the above and below-ground parts of a number of temperate green manure crops are given in Table 1. Not all this N will have been derived from N fixation. Forage legumes can obtain over 90% of their N from fixation compared to just 50% for grain legumes (Paul & Clark, 1996). Forage legumes also remain in the field for longer periods of time and can therefore fix more N, with a greater proportion accumulating in the roots compared to grain legumes. As the majority of the N fixed by grain legumes is often removed in harvested product, they do little to restore soil fertility (Fisher, 1996).

Table 1. Offtake of N in tops and roots of various legumes (Heinzmann, 1981, cited by Shepherd *et al.*, 2000)

| Crop | N in tops (kg/ha) | N in roots (kg/ha) | Total N (kg/ha) |
|---|---|---|---|
| *Grain legumes* | | | |
| Lupin, white | 448 | 93 | 541 |
| Faba bean | 320 | 57 | 377 |
| Field pea | 291 | 40 | 331 |
| Spring vetch | 238 | 36 | 274 |
| *Fodder legumes* | | | |
| Red clover | 381 | 118 | 499 |
| White clover | 322 | 131 | 453 |
| Lucerne | 469 | 157 | 626 |
| Sainfoin | 184 | 140 | 324 |

Cormack (1996) measured the accumulation of N by several different legumes grown as fertility building crops (green manures) in a stockless organic rotation. The legumes were cut and mulched several times during the season, with total N offtake determined at each cut. Estimates were of a similar order of magnitude to those in Table 1, with 525-690 kg N/ha from red clover, 562-720 kg N/ha from lucerne, 316-589 kg N/ha from white clover and 222-296 kg N/ha from sainfoin. Similarly, Stopes *et al.* (1996) measured an N accumulation of 371, 328 and 94 kg N/ha from red clover, white clover and trefoil, respectively, during a 13 month fertility building phase of a stockless organic rotation (the legumes were cut and mulched 5-6 times during this period). In both cases, these are likely to be an over-estimate of the total N contribution by the legume, as much of the N would be recycled back to the ley following each mulch. After just one cut, Stopes *et al.* (1996) measured an N contribution of 21, 17 and 12 kg/ha for the red and white clover and trefoil, respectively. Other reports suggest an N accumulation of between 77 and 130 kg/ha N for red clover and 43-143 kg/ha for white clover (Shepherd *et al.* 2000).

The amount of N fixed by a legume will depend on the species, its age, morphology, density of planting and management. The existing soil N supply will also affect how much N is fixed (less fixation if the supply is high). The actual amount of N available to an associated (or following) crop will in turn depend on the rate of mineralisation of the mulchings (and below-ground parts). The C:N ratio of the mulched material can provide a crude estimate of the potential rate of N mineralisation, although this is not always a good indicator of residue quality, with the lignin, hemicellulose and polyphenol content all demonstrated to have an effect. Mulched residues will tend to decompose slower than if incorporated into the soil, with a greater potential for gaseous N losses (Larsson *et al.*, 1998).

**Case studies**

There are very few examples of cut and mulch companion cropping systems in the literature, except in the case of tropical alley cropping or agroforestry systems. Here, the prunings of various hedgerow trees have been shown to increase the yield of associated crops, although the recovery of N from hedgerow prunings can be low (Mulongoy & Akobundo, 1990) and it has been suggested the system cannot be adequately maintained without the addition of fertiliser (Garrity, 1994; Finck, 1998).

In more temperate climates, there has been some research into the benefits of growing cereals in a permanent legume understorey (‘live mulch’). To reduce competition and stimulate the release of N (by decomposition of roots and shoots), the legume is usually suppressed (with herbicide or by cutting or partially cultivating) prior to direct drilling the cereal. The legume (usually clover) can then re-establish once the cereal has been harvested. Yields may be depressed in the first year of legume establishment (e.g. Mulongoy & Akobundo, 1990, Henriksen *et al.* 2000 and Tersbol & Thorup-Kristensen, 2000) but, thereafter there is a positive net N contribution and increase in the yield of the cereal crop (Grubinger & Minotti, 1986, Mulongoy & Akobundo, 1990, Jones, 1992, Clements *et al.* 2000; Zemenchik *et al.* 2000), compared to growing the cereal alone. The actual N contributed by the legume was not quantified in any of these studies, but most suggested it was adequate for the cereal’s requirements.

**Conclusions**

- There is little direct N transfer (via rhizodeposition and mycorrhizal interactions) that is of agronomic significance in companion cropping systems.
- The indirect route of nutrient transfer via the mineralisation of dead root and shoot material (following defoliation/suppression) is more important.
- Forage legumes have the greatest potential as a companion crop as they obtain over 90% of their N from atmospheric fixation compared to just 50% by grain legumes. This provides a greater net N contribution to the system by ‘freeing’ more soil N for the associated crop.
- There is little quantitative information on nutrient transfer in companion cropping systems. Many factors will affect the amount available for transfer including legume species, age and management, soil nutrient supply, soil microbial mineralisation and immobilisation and residue quality.
- Much of the N released may be either immobilised within the soil microbial biomass or recycled back to the leguminous crop (which itself may inhibit N fixation). This makes the accurate quantification of the amount transferred difficult to assess.

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## PART B - MODELLING THE RELEASE OF N FROM MULCHED CLOVER RESIDUES

To make some estimates of the likely return of N in clover and its dynamics of release following cutting and mulching, a small modelling exercise was undertaken. This used the first data on clover dry matter and %N content collected from the Wakelyns site in spring 2001 (Table 2). These, albeit few, data show some interesting trends:

- For the weekly cut, apparently more above-ground dry matter and N from the plots where the clover is cut and mulched *in situ*, rather than returned to the vegetable crop: this may be because the mower is also collecting residue from previous cuts.
- Larger dry matter and N returns for the weekly cut compared with the monthly cut.

Table 2. Summary of measurements of total above-ground DM (t/ha) and N (kg/ha) returned after cutting and mulching the clover. 'Clover' or 'veg' denotes where the foliage was placed after cutting: back on the clover or on to the leek crops, respectively.

| Date | Total DM (t/ha) | | | | N returned (kg/ha) | | | |
|---|---|---|---|---|---|---|---|---|
| | Weekly cutting | | Monthly cutting | | Weekly cutting | | Monthly cutting | |
| | Clover | Veg | Clover | Veg | Clover | Veg | Clover | Veg |
| 15/05/01 | 0.61 | 0.57 | 0.56 | 0.57 | 32.2 | 30.7 | 30.2 | 30.7 |
| 22/05/01 | 0.57 | 0.51 | | | 31.3* | 27.7* | | |
| 29/05/01 | 0.75 | 0.70 | | | 42.6 | 39.4 | | |
| 05/06/01 | 0.46 | 0.38 | | | 26.8* | 22.0* | | |
| 12/06/01 | 0.42 | 0.39 | 1.29 | 1.35 | 24.5 | 23.0 | 63.7 | 65.9 |
| **Total** | **2.81** | **2.56** | **1.85** | **1.92** | **157** | **143** | **94** | **97** |

* N content wasn't measured these weeks: mean data used

Using these data on cutting dates and dry matter and N returns for each cutting date, three models were used to estimate the amounts and patterns of N release from the applied plant material: SUNDIAL, WELLN and the Jenkinson equation. Only data from the plots where the mulch was returned to the leek plots were used (i.e. avoiding any possibility of double accounting for N from previous cuts that was picked up on the clover plots, as described above).

### Method

Total DM and N content of the mulched clover residues (applied to the vegetable crop) were inputs to the models. To initialise the SUNDIAL and WELLN models, basic soil (clay content & AWC) and weather (temperature + soil moisture deficit) data were used: weather data from 1996 and the soil at Gleadthorpe (6% clay; AWC in top 10 cm of 15.6 mm).

Each cut was modelled separately and the output summed to give the total net N mineralisation from the first 5 cuts (14/5/01-12/6/01). Output was continued until August (*c*. 3 months).

## Models and results of the simulations

Three 'models' were used. Two (SUNDIAL and WELL-N) simulate dynamics, whereas the Jenkinson equation gives an estimate of N release in the first year, but says nothing about the pattern of release.

*SUNDIAL*

A simplified version of the mineralisation routine within the Sundial model (Bradbury *et al.*, 1996) has been constructed as an Excel spreadsheet. This estimates the mineralisation of a crop residue into soil microbial biomass, humus and mineral N (or $CO_2$). Mineralisation of the newly formed biomass and humus is also estimated and added to that of the residue (only one cycle of mineralisation is followed). The simulation is based on the top 10 cm of soil.

Using Gleadthorpe temperatures and SMD data, the model predicts N mineralisation in the first months but suggests net N immobilisation from July onwards (due to high SMDs), as shown in Figure 1. Table 3 shows the calculated total N release. The data were therefore re-run with the soil moisture and temperature factors adjusted to 1.0 (i.e. no effect on N mineralisation), Table 4. This was equivalent to an SMD of 9.8 mm and temperature of 9°C (for Gleadthorpe). Obviously, increases in temperature would result in an increase in the rate of mineralisation.

Figure 1. Predicted N mineralisation/immobilisation dynamics from the SUNDIAL and WELLN models.

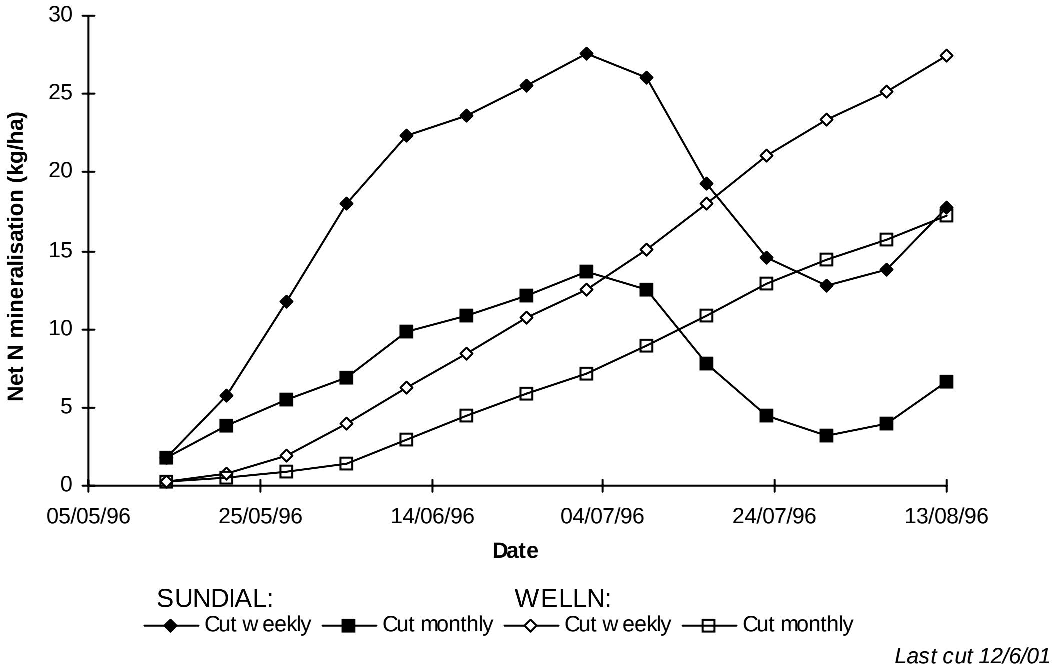


Table 3. Calculated N mineralisation after 3 months, using SUNDIAL and WELLN models.

| Model | SUNDIAL | | WELLN | |
|---|---|---|---|---|
| Cutting frequency | Weekly | Monthly | Weekly | Monthly |
| Total N mineralisation (kg/ha) | 28 | 14 | 27 | 17 |
| % of N applied in mulch | 20 | 14 | 20 | 18 |

Table 4. Calculated N mineralisation using SUNDIAL and WELLN models, assuming moisture and temperature are non-limiting.

| Model | SUNDIAL | | | | WELLN | | | |
|---|---|---|---|---|---|---|---|---|
| Cutting frequency | Weekly | | Monthly | | Weekly | | Monthly | |
| Time elapsed (months) | 3 | 8 | 3 | 8 | 3 | 60 | 3 | 60 |
| Total N mineralisation (kg/ha) | 90 | 110 | 57 | 72 | 43 | 122 | 27 | 81 |
| % of N applied in mulch | 63 | 77 | 59 | 74 | 30 | 85 | 28 | 84 |

*WELLN*

A simplified version of the mineralisation routine within the WELLN model (Greenwood *et al*., 1996) has been constructed as an Excel spreadsheet. This estimates the mineralisation of a crop residue into soil mineral N (e.g. Figure 1) and the results are shown in Tables 3 and 4 (temperature non-limiting - fixed at 20°C).

*Jenkinson equations*

Jenkinson (1982) suggested that decomposition (mineralisation) can be represented by a 2-stage process, a relatively rapid initial first phase, during which about 2 thirds of the plant carbon is lost, followed by a sharp transition to a much slower phase. Using this, together with the observation that most well drained neutral topsoils have a C:N ratio of 10, he was able to predict the amount of N mineralised (or immobilised) by a given quantity of plant material. Using these same principles, it was possible to estimate N mineralisation from the mulched clover residues during the first year of decomposition. This was 109 kg/ha (76% of the N applied) for the weekly cuttings and 71 kg/ha (74% of the N applied) for the monthly cuttings (NB only the first 5 cuttings were considered).

**Comparison of models**

Output from the 2 simulation models is very similar for the 3 months following the first cut, except that SUNDIAL predicts N immobilisation after 2 months (due to high SMD), but WELLN continues to mineralise the residue (no adjustment for soil moisture). The weekly cutting mineralises c. 28 kg/ha N (20% of the N applied) compared to 14-17 kg/ha from the monthly cutting (14-18%).

If it is assumed that temperature and moisture have no effect on the rate of mineralisation, SUNDIAL mineralises all the residue within 8 months, with approximately 75% of the N applied released as mineral N (the rest would be tied up in organic matter). Although all the residue is mineralised, SUNDIAL does continue to mineralise the products (biomass and humus) at a very slow rate. By comparison, WELLN takes a lot longer to mineralise all the residue (disappears after 5 years), with c. 85% released as mineral N. However, c. 70% of the residue N is mineralised within the first year. The results are very similar to those estimated using the simple equations of Jenkinson (1982). In fact, the mineralisation routine within SUNDIAL is based on these principles.

**Conclusions**

- Cutting and mulching frequency appears to affect total dry matter and N returns to the soil, with differences between monthly and weekly: weekly was better.
- Regardless of the cutting frequency, all models suggest that c.70-75% of the residue N will be mineralised within the first year after cutting.
- The models show reasonable general agreement in these estimates.
- The pattern of release will depend on the temperature and moisture regime of the soil, however, and also differs between models.
- The models assume the residue is ploughed into the soil: they have not been validated for surface applications and the pattern and rate of mineralisation could be different for mulched residues.
- As a first step, however, the desk study has given some useful information on amounts and timescale of N release.
- Using this approach, it is not possible to account for below ground release and transfer.

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# OF0181 Companion cropping for organic field vegetables

# PRODUCTION DATA AND ECONOMIC ANALYSIS -2001

**Professor Martin Wolfe**

## 1. INTRODUCTION

Different observations and data gained through 2001 are collated here to give an overview of the performance of the vegetable-clover inter-crop system in the second season of production in North Field.

Records used include yield and sales data collected by those involved in harvesting and marketing (M Gaze, A Wolfe), cultivation costs from P J and M J Wards, contracting data, and other observations and sampling completed during the season (M S Wolfe with assistance).

### Cropping conditions

In the early part of the year, the weather was poor for vegetable production. Continuous wet conditions, particularly in March, but stretching into April, delayed sowing of most crops. Unfortunately, shortly after planting many crops in late May into wet soils, there was a period of rapid drying which stressed young seedlings with limited root systems. These conditions were particularly unfavourable for broad beans, the Allium crops and carrots. Fortunately, the late part of the year was highly favourable, with adequate moisture and, after a relatively cool September, the fine, warm conditions lasted into December.

### Assessment methods

A range of different forms of assessment of crop and system performance was used throughout the season. The main approach was observation by those involved in working with the system (5 persons concentrating on different aspects) and discussion with numerous visitors. More formally, all harvest weights (trimmed for sale) and sales were recorded on a crop/day basis. Areas for individual harvests were not recorded because all harvesting was done by hand on the basis of selecting the best available plants on the day. The total area of each crop was known accurately and this was used as a reference for scaling weights to tonnes per hectare of total crop area (40% crop plus 60% clover). These data are in section 2 below.

Crop densities were estimated from counts of plants in standard row lengths, averaged, and scaled to hectares from the measured bed lengths. These values were then compared with the calculated seed/planting rates for each crop to determine establishment rates. These data are in section 6 below.

Additional yield estimates were obtained mainly to determine the absolute yields of a range of crops, excluding the ‘cut-and-come-again’ leaf vegetables and the crops regarded as failures. Some of these assessments also allowed estimates to be made of the effects of applied manure. The assessments were made as randomised samples of standard row lengths of crop, weighed, again, as trimmed plants. Since the manure treatments had been randomised, it was possible to analyse some of the data as randomised blocks. These data are in section 7 below.

Comparisons with the previous year were made on the basis of weight and value of total marketed crop per unit area, for which complete values were available for 2000 and values to December for 2001.

## 2. CROP PERFORMANCE: INDIVIDUAL CROPS

### a.) Beans

Apart from a few plants, broad beans failed, largely because they were planted three months later than normal under the poor spring conditions. Dwarf beans were more successful, though still low yielding. The crop was not harvested.

### b.) Beetroot

From observation, Detroit Globe appeared to be the better variety throughout the 2001 season. Statistical comparison was not made because the two varieties were grown in different beds. The yields, measured in September 2001, were lower than expected, probably because the larger beets had been harvested early, with more being available in the Detroit Globe bed.

**Table 1.** Beetroot yield, September 2001.

| Cultivar | plants/ $m^2$ | g/plant | t/ha |
|---|---|---|---|
| Detroit Globe | 28 | 52.1 | 14.6 |
| Detroit Bolivar 2 | 23 | 48.1 | 11.1 |

The higher yielding Detroit Globe was re-assessed for yield in December 2001. At this stage, the root size had increased considerably; the estimated yield was then 25.5 t/ha. This yield was about the average for organic production (Lampkin & Measures, 2001). Nevertheless, the yield was probably lower than in 2000, which may have been due to the later sowing date (May 24, 2001 compared with May 12, 2000).

### c.) Cabbage

Cabbage production was characterised by a wide variation in varietal performance. This may explain why this crop, using other varieties, almost failed in 2000. It is not clear what aspect of Cuor di Beu made it so productive in 2001. However, it appears well able to produce a crop from seed under the local conditions where other varieties may be more productive from transplants. Indeed, the yield of this variety was well up on the organic average for white cabbage grown from transplants (Lampkin and Measures, 2001).

Of the varieties used, only Savoy Vertus was common to both 2001 and 2000; it performed similarly in each season.

**Table 2**. Cabbage yield, early December 2001.

| Cultivar | plants/ $m^2$ | g/plant | t/ha |
|---|---|---|---|
| Cuor di Beu | 12 | 400 | 48 |
| Savoy Violaceo | 6 | 300 | 18 |
| Marner Allfrueh | 6 | 100 | 6 |
| Savoy Vertus | 3 | 150 | 4.5 |
| Ormskirk | 3 | 100 | 3 |

Sales figures do not appear in the later tables because harvesting did not begin until November 2001.

### d.) Calabrese

Green sprouting calabrese was used for repeated cutting; yield was low but further production will be possible through winter 2001/02. The variety Romaneso was more satisfactory with an estimated field yield of 8 t/ha from 80 $m^2$ of crop. Up to half should be marketable by February/March 2002.

### e.) Carrots

Carrot production was disappointing in 2001 even though some carrots remain to be harvested. Although there were again considerable differences among the varieties grown, the generally poor performance may have been due to a combination of poor spring conditions and the competitive effects of the clover. This may have been exacerbated by the decision not to hand weed so as to avoid crop disturbance and possible attraction of carrot fly (*Psila rosae*).

**Table 3.** Carrot yield.

| Cultivar | plants/ $m^2$ | g/plant | t/ha |
|---|---|---|---|
| Autumn King | 18 | 22 | 4 |
| Nantes 2 | 17 | 18 | 3 |
| Berlicum | 12 | 21 | 2.6 |
| Stella | 20 | 12 | 2.4 |
| Nantes 3 | 17 | 12 | 2.2 |
| Rothild | 5 | 32 | 1.6 |

The variety Rothild was particularly poor in establishment although it compensated to some extent by producing relatively large roots.

### f.) Celeriac

Celeriac transplants were produced on-site and transplanted with a reasonable level of success. Productivity was low, however, from otherwise healthy plants, probably because the celeriac bed had been used for high yielding potatoes in 2000 so that the soil nutrient reservoir had been heavily depleted. By December 2001, marketed yield was 1.8 t/ha, but this will increase during the winter.

### g.) Chard

The Swiss chard variety was highly productive, as in 2000, though difficult to estimate because of continuous cropping. The total amount harvested and marketed will be less than in 2000, largely because one major customer stopped buying produce from Suffolk during the autumn. The red chard variety, Feurio, was less productive than the same variety used in 2000.

### h.) Chicory/endive

The yield of the variety Stratego was high with marketed heads averaging 250 g each. More than one-quarter of the 850 plants produced on 90 $m^2$ were sold. Quality was excellent and notable for the complete lack of slug (*Deroceras reticulatum*) damage. The red varieties used were much less successful, producing a smaller number of smaller heads. More should be sold from December onwards.

### i.) Fennel

Fennel production was much reduced relative to 2000, probably because the sowing date was six weeks later and the plants were grown in one of the potato beds from 2000. The variety Romanesco (2 t/ha) was higher yielding than Zefo Fino (<1 t/ha).

### j.) Kale

The mixture of Westland Winter and Dwarf Green Curled established well (17 plants/$m^2$) in 2001 and produced a reasonable yield, which will continue through the winter. The small area of Cottager’s Kale and Nero di Toscana mix was less productive than in 2000.

### k.) Leek

The major part of the leek production was from transplants. Yield was poor at 3.4 t/ha. The same variety grown from seed produced only few plants, due partly to extremely late sowing (4 May 2001).

### l.) Lettuce

Because of the late development and modest performance of the lettuce in 2000, a large area (5 beds) was planted in 2001. Surprisingly, therefore, the current lettuce crop, grown as a mixture of 22 varieties, was one of the most successful in terms of crop quality and yield. Many of the varieties produced highly marketable heads, giving an attractive display of variation in colour and form. Detailed yield data for lettuce from the two sowing dates were not taken.

One potential problem was slug infestation. In practice, only one variety, Pinokio (Little Gem type) was severely damaged. Other varieties, often those with strong pigment, were highly resistant and undamaged. The late season meant there was a late start to marketing and then an early cut-off to the consumer's interest in salad crops so that a significant part of the crop was not harvested.

### m.) Onions

Onions were planted as sets or sown as seed. The sets started well but then failed due to neck rot (*Botrytis allii*), probably imported with the sets. Seedlings appeared to establish well initially but then failed to produce a saleable crop. This was due mainly to the poor spring conditions. The direct negative effect on onion development was probably compounded by competition from the clover and the lack of hand-weeding.

### n.) Parsley

Parsley was very high yielding in 2000: the equivalent of 2 t/ha was sold, which represented only a small proportion of the total production. For this reason, only a small area was planted in 2001, which was grazed and not covered as in 2000. The resulting yield was much reduced, but with more to come through the winter.

### o.) Parsnip

Field production was assessed in December. Again, there was a large variety effect with the highest yielding variety, White Gem, producing almost twice as much as the organic average (Lampkin and Measures, 2001). However, the plant stand was variable with a relatively high proportion of small roots.

**Table 4.** Parsnip yield, December 2001.

| Cultivar | plants/ $m^2$ | g/plant | t/ha |
|---|---|---|---|
| White Gem | 42 | 900 | 37.8 |
| Halblange White | 27 | 600 | 16.2 |
| Tender and True | 15 | 500 | 7.5 |

### p.) Spinach

Spinach (var. Perpetual Leaf Beet) yield is difficult to estimate because of the continuous cropping. Overall, the crop was highly productive but it was noticeable that the earlier sown bed (24 May 2001) was much more productive than the bed sown on 19 June 2001. This may have been because of the overall late sowing dates for the crop but it may also have been influenced by stronger competition from the clover on the later sown spinach plants. The total amount harvested and marketed will be less than last year, largely because one major customer stopped buying produce from Suffolk during the autumn.

### q.) Swede

In late September 2001, the variety Marion, and a mixture of Marion and Melfort, outyielded Melfort significantly ($P<5\%$) due both to a greater number of plants and to higher yield per plant. The mixture yielded more than the mean of Melfort and Marion ($P<0.1\%$), which reflected an increase in yield of both varieties. At the stage when the main observations were made, the plants were still actively growing. A further yield assessment in December (bottom row in table 5) indicated a large increase in yield of both varieties and the mixture. At this stage, the mixture yield was the same as the mean of the components; the ratio of the two varieties in the mixture was also the same as in the pure stands.

**Table 5.** Swede yield in September and December 2001.

| Variate | Melfort | Marion | Mixture | SE | Prob. |
|---|---|---|---|---|---|
| No. plants/m$^2$ Sept. | 13.75 | 20 | 20 | 2.1 | * |
| g/m$^2$ Sept. | 1300 | 2075 | 2235 | 300 | * |
| g/plant Sept. | 99 | 111 | 119 | 16 | NS |
| g/m$^2$ Dec. | 4810 | 7200 | 5990 | | |

**r.) Turnip**

The turnip crop, assessed in September 2001, showed a marked difference in yield among varieties, with White Globe, in particular, achieving a reasonable yield for organic production.

**Table 6.** Turnip yield, September 2001.

| Cultivar | plants/ m$^2$ | g/plant | t/ha |
|---|---|---|---|
| White Globe | 37.5 | 96 | 36 |
| Golden Ball | 51 | 62 | 31.5 |
| Purple Top | 42 | 64 | 27 |

## 3. ROTATION EFFECTS

Because many crops were relatively low yielding in both years, marked effects from major nutrient removals were not expected. Nevertheless, it is important to note that in two beds, high yielding crops in 2001 (turnips, kale mix) followed high yielding crops in 2000 (respectively, spinach and chard). However, at least part of the poor performance of some of the umbelliferous crops could be because they followed high yielding crops in 2000 (carrots after potatoes and after brassicas; celeriac and fennel after potatoes).

The leek transplants were grown in two adjacent beds for convenience, one following high yielding beetroot in 2000 and the other following relatively low-yielding lettuce. There was no significant difference in leek yield between the two beds, which may be because the leeks were relatively low yielding in both cases.

## 4. STACKED MANURE

An extra treatment in the intercrop system was the addition of stacked manure to some areas of the three cropping alleys. This material was a mixture of well-rotted horse manure with garden compost, all more than one year old. The material was not analysed.

The vegetable alleys were divided into either four blocks or six, depending on alley length, with each block approximately 30m long. Half of the blocks were treated with stacked manure and half not on 14 May 2001. The manure was applied with the specially designed spreader, set to deliver at 25 t/ha, but only on the crop strips. Treatments were assigned randomly to allow within-crop observations and assessments of the effects of the stacked manure. The material was not applied to the Allium beds.

For 10 of the crops assessed visually late in the year, there was a tendency for the appearance of the crop to be better (larger plants, more uniform stands) where treatment had been applied. Simple estimates of yield were made for beetroot and carrot by comparing random samples from treated and untreated blocks. A more comprehensive check was made with swedes, which allowed a simple anova analysis of the treatment effects.

### a) Beetroot

From a sub-sample, the better performing variety Detroit Globe appeared to be unaffected by manure application whereas the lower yielding Detroit Bolivar 2 gave an apparent yield increase of 50%.

**Table 7.** Effect of manure on yield (t/ha) of beetroot, September 2001.

| Cultivar | With manure | No manure |
|---|---|---|
| Detroit Globe | 14.3 | 15.2 |
| Detroit Bolivar 2 | 12.5 | 8.2 |

### b) Carrots

Averaged over six varieties, there appeared to be small positive effects of the manure treatment on plant numbers per square metre and on scaled yield in tonnes per hectare. It is unlikely that the differences would have been statistically significant.

**Table 8.** Effect of manure on yield of carrots, December 2001.

| Variate | With manure | No manure |
|---|---|---|
| plants/m$^2$ | 15.9 | 14.1 |
| t/ha | 2.69 | 2.59 |

### c) Swede

In the swede sample, the manure increased the overall yield (P<5%), apparently by increasing the number of plants per square metre (P<5%) more than the weight per plant. As with the beetroot, the manure had the greatest effect on the lower yielding variety. This was also true within the mixture: Melfort increased more than did Marion as a result of the manure application (data available separately).

**Table 9.** Effect of manure on yield of swede, September 2001.

| Treatment | plants/$m^2$ | g/$m^2$ | g/plant |
|---|---|---|---|
| No manure | 15.2 | 1553 | 108 |
| With manure | 20.7 | 2187 | 111 |
| SE | 1.8 | 200 | 13 |
| Probability | * | * | NS |

## 5. PESTS, DISEASES AND WEEDS

### a) Pests

The major source of pest problems was a range of larger animals including hares, pheasants and, late in the season, rabbits. Potentially the worst, however, were slugs, because of the large population throughout the field. Over the season, however, the damage was considerably less than feared initially. One reason may be that the slug population is founded in, and survives, on the clover crop, where food is plentiful. In the earlier, drier parts of the season, it may be that the slug population prefers to remain in the clover where the atmosphere is humid and food abundant. Later in the season, particularly in wet periods, they did attack other crops. It would be interesting to know whether maintaining the system encourages a build-up of slug predators and diseases and, if so, to what extent this reduces the population (carabids are currently numerous in the plots).

In the meantime, it was clear that there are marked varietal differences in slug susceptibility. For example, in swedes, there was less leaf damage on the variety Marion than on Melfort. By the end of the season, this had translated into worse damage on Melfort roots, reducing their marketability relative to those of Marion. The mixture was little different from expectation, but there was a slight tendency to more slug damage in the presence of the stacked manure treatment.

**Table 10.** Effect of swede cultivar and manure on slug grazing on swedes (percentage of leaf area damaged)

| Treatment | Melfort | Marion | Mix Mel | Mix Mar |
|---|---|---|---|---|
| No Manure | 28 | 8 | 25 | 14 |
| With Manure | 33 | 15 | 28 | 15 |

Slug resistance was also noted in other crops. Remarkably, plants of the endive Stratego often contained a number of slugs, but they caused no damage. Among the lettuces, few varieties were grazed severely by slugs and coloured varieties, particularly, for example, Cerise, were often not damaged at all. Interestingly, in this respect, there may be a tendency for red pigmented potatoes to be less prone to slug damage, although there are, in addition, large differences among white-skinned varieties. Among the turnips, the highest yielding variety, White Globe, was more affected than were Golden Ball or Purple Top.

In contrast, traditional insect pests appeared to have little effect. Notably, in the carrot and cabbage plots, there was no evidence of fly (*P. rosae, Delia brassicae)* damage, which must have been due, at least to some extent, to the confusion effect of the clover background. Similarly, there was little thrips (*Thrips tabaci*) damage on the leeks.

**b) diseases**

A number of diseases were evident late in the season, but the only notable damage was caused by neck rot on the onions grown from sets. This was probably imported with the sets since it was not seen on seed onions. Additional assessments were done, and will be reported, as part of the DOVE project (DEFRA OF0168).

**d) weeds**

As anticipated, the clover occupied and competed for the space between the crop strips that would otherwise have been occupied by weeds. The weeds that did develop in the crop strips were restricted by mechanical weeding; hand weeding was limited to the early-planted onion sets and to dealing with a few foci of creeping thistle (*Cirsium arvense*). Hand weeding was also used for restricting broomrape *(Orobanche minor),* a weed that is parasitic on clover and not uncommon in the region. Dependence largely on mechanical rather than hand weeding helped to reduce costs.

The two beds where weeds were more problematic, particularly grass weeds (*Poa annua*), were those following potatoes in 2000. Partly because of the wet early part of the season, it proved difficult to re-establish the clover cover ahead of grass weed development (potatoes were eliminated from the rotation in 2001). Chickweed (*Stellaria media*) was more evident than in 2000, which may be regarded, partly, as a positive sign since it is usually indicative of fertile, disturbed soil conditions.

From observations during the year, although clover is generally competitive against weeds, it is less effective against grass invasion. Keeping the pure clover sward intact relies on a regime of repeated mowing which helps to control grass and other weeds without discouraging the clover.

## 6. PLANT ESTABLISHMENT DATA

Because of the late and wet spring, sowing dates for most crops were considerably later than recommended, which helped to account for the generally low levels of establishment (table 11).

The correlation between rate of establishment and final crop yield was generally poor, again due to the early growing conditions. Among the endives, Stratego developed particularly well from a low rate of establishment.

**Table 11.** Plant establishment, 2001.

| Crop | sowing date | seed/m$^2$ | plants/m$^2$ | % establishment |
|---|---|---|---|---|
| Beans | May 25 | 30 | 20 | 67 |
| Beetroot | May 24 | 40 | 26 | 65 |
| Cabbage | May 29 | 90 | 6 | 7 |
| Calabrese | May 29 | 90 | 15 | 17 |
| Carrot | May 23 | 90 | 15 | 17 |
| Celeriac | June 4 | transplants | 9 | 75 |
| Chard | May 24 | 22 | 12 | 55 |
| Chicory | June 19 | 70 | 9 | 13 |
| Fennel | June 4 | 20 | 8 | 40 |
| Kale | May 29 | 90 | 15 | 17 |
| Kohlrabi | May 29 | 90 | low | low |
| Leek | May 4 | 15 | 15 | 90 |
| Lettuce | May22,June19 | 24 | 16 | 67 |
| Onion seed | May 25 | 80 | 40 | 50 |
| Onion sets | April23 | 20 | 18 | 90 |
| Parsley | June 4 | 64 | 12 | 19 |
| Parsnip | May 23 | 36 | 18 | 50 |
| Spinach | May24,June19 | 36 | 27 | 75 |
| Swede | May 29 | 90 | 22 | 24 |
| Turnip | May 29 | 90 | 43.5 | 48 |

## 7. ABSOLUTE YIELD COMPARISONS

As described above, absolute gross yields were measured for a number of crops from harvests of measured lengths of row on single dates; results were scaled-up to a per hectare basis. Several species, including most of the root vegetables together with chard and spinach, produced yields that would be generally acceptable. Others, notably carrots (4 t/ha), onions and broad beans (both less than 1 t/ha), were poor.

**Table 12.** Absolute yields (Gross t/ha).

| Crop | Best variety | Worst variety | Lampkin & Measures (2001) |
|---|---|---|---|
| Swede | 72 | 48 | 32 |
| Turnip | 36 | 27 | - |
| Beetroot | 26 | 20 (est.) | 22 |
| Lettuce | 24 | - | - |
| Chicory | 23 | <1 (est.) | - |
| Parsnip | 38 | 8 | 25 |
| Cabbage | 48 | 3 | 32 |
| Celeriac | 11 | - | - |
| Calabrese | 8 | - | - |
| Carrot | 4 | 2 | 40 |
| Fennel | 2 | <1 (est.) | - |
| Lettuce (dozen/ha) | 13,333 | - | 6500 |

The low yield of celeriac, expressed as poor bulb filling rather than plant establishment, was almost certainly caused by low nutrient availability. This may have been because the transplants were grown in a bed which had been cropped with potatoes in 2000.

One of the most striking features of the gross yield comparisons was the variability in varietal performance. It is not clear whether soil, site or system are the most important factors in relation to varietal adaptation. However, such variation suggests that, with appropriate testing, it should be possible to select a range of species and varieties that would be highly productive in the system.

## 8. COSTS OF PRODUCTION IN 2001

Costs of production were divided into three categories, as follows:

- **Seed** costs were adjusted to the costs for the areas planted. Of the three transplanted crops, onions were bought as sets, leeks were prepared by Delflands Nurseries and the celeriac plants were home produced.
- **Cultivation** costs were based on an average total of 33 passes per crop which included all bed preparations, sowing and subsequent regular mechanical weeding and mowing. The costs included labour, diesel, machinery preparation and depreciation.
- **Labour**: the separated labour cost included all time involved in harvesting, trimming, grading and preparation for sale, adjusted for crop type, and direct marketing.

In table 13, the gross value of sales to December 2001 are expressed as a percentage relative to the actual production costs for each crop. This allows a direct comparison of the profitability. The positive returns for the first four crops reflect the relatively large sales volume for these crops. Sales of spinach, chard and beetroot were nevertheless low relative to 2000 largely because of the loss, during the autumn, of a large and previously regular customer who reduced the size of his enterprise.

**Table 13. Actual total costs of production (£) for the area grown of each crop**

| Crop | Actual total production cost (£) | | | | Sales as a % |
|---|---|---|---|---|---|
| | Seed | Cult | Labour* | Total | of total costs |
| Endive | 5 | 2 | 54 | 61 | 202 |
| Spinach | 15 | 10 | 52 | 77 | 143 |
| Chard | 18 | 19 | 60 | 97 | 119 |
| Lettuce | 15 | 29 | 270 | 314 | 107 |
| Kale | 35 | 6 | 37 | 78 | 93 |
| Turnip | 3 | 1 | 57 | 61 | 73 |
| Parsnip | 5 | 7 | 51 | 63 | 72 |
| Beetroot | 18 | 9 | 121 | 148 | 70 |
| Swede | 30 | 4 | 57 | 91 | 58 |
| Carrot | 14 | 22 | 148 | 184 | 40 |
| Calabrese | 16 | 6 | 2 | 24 | 32 |
| Leeks | 175 | 19 | 100 | 294 | 31 |
| Onion (seed) | 20 | 7 | 4 | 31 | 20 |
| Celeriac | 112 | 3 | 62 | 177 | 18 |
| Beans | 64 | 21 | 0 | 85 | 0 |
| Onion (sets) | 54 | 50 | 0 | 104 | 0 |
| Total | 599 | 215 | 1075 | 1889 | 64 |

Carrot and calabrese returned a poor yield so that sales could not offset production costs. Celeriac sales were reasonable in volume but were insufficient to make up for the high cost of establishing the crop from transplants.

The main root crops, turnip, parsnip, beetroot and swede showed a low relative return largely because much of the crop was still in the ground at the time of assessments; winter sales from December onwards are expected to improve the returns from these crops.

In table 14, the three cost headings are re-calculated as proportions of the total overall cost for each crop. Not surprisingly, for the majority of crops, the final labour cost from harvesting to marketing was by far the largest item. There are only three exceptions. For kale, the relatively low labour and high seed costs reflect a relatively poor harvest by December; this will improve over the winter. The high ‘seed’ cost for celeriac reflected the, generally, high cost of using transplants rather than seed, as with leeks and onion sets.

**Table 14.** Apportioned relative costs by crop

| Crop | Costs as a percentage of total costs | | |
|---|---|---|---|
| | Seed | Cultivations | Labour |
| Chicory | 8 | 4 | 88 |
| Spinach | 19 | 13 | 68 |
| Chard | 19 | 19 | 62 |
| Lettuce | 5 | 9 | 86 |
| Kale | 45 | 8 | 47 |
| Turnip | 5 | 2 | 93 |
| Parsnip | 8 | 11 | 81 |
| Beetroot | 12 | 6 | 82 |
| Swede | 33 | 5 | 62 |
| Carrot | 8 | 12 | 80 |
| Calabrese | 67 | 25 | 8 |
| Leeks | 60 | 6 | 34 |
| Onion (seed) | 65 | 22 | 13 |
| Celeriac | 63 | 2 | 35 |
| Beans | 75 | 25 | 0 |
| Onion (sets) | 52 | 48 | 0 |
| Total | 32 | 11 | 57 |

In terms of sequence, the lettuce crop was the first to be harvested with strong sales from the beginning of August through to early October. The first beetroot and turnips were sold during September. From early October, a wide range of vegetables was sold each week, directed largely by customer needs.

## 9. GROSS MARGIN ESTIMATION

Because of the developmental nature of the project, it is difficult to determine a practically useful basis for estimating gross margins for vegetables produced in the intercrop system. A direct estimate based on the current layout is entirely arbitrary. More useful, perhaps, is to consider a current best case scenario. This can be based on a range of crops and varieties selected to form a reasonable rotation with predictably acceptable yields. The crops that have been tried so far can be categorised roughly into three groups (based on 2 years observations):

a) High yield in both years: Beetroot, spinach, chard, kale

b) High yield in one year: Brassica (some cabbage, swede, turnip), endive, lettuce, parsley, parsnip

c) Low yield in both years: Allium crops (leeks, onions), Brassica (sprouts, some cabbage, calabrese), carrots, celeriac, broad and dwarf beans

From these categories, nine crops were selected as shown in the table (parsley could be a tenth candidate).

For each crop, values for production, sales and costs were calculated on the basis of 1111 $m^2$ of each, which gives a total of one hectare. Where information is available, the highest yielding variety was chosen for each crop. From the data given above, estimates were then made of the marketable yield from these standardised areas. Marketable yields were converted to sales based on our local direct marketing prices.

**Table 15.** Estimated best-case gross margins (for 1111 $m^2$ of individual crops, 1ha overall for the totals)

| Crop | Saleable yield (kg) | Sales (£) | Costs (£) | Gross margin (£) |
|---|---|---|---|---|
| Endive | 644 | 1541 | 607 | 934 |
| Swede | 211 | 444 | 169 | 274 |
| Kale | 124 | 242 | 124 | 117 |
| Spinach | 224 | 321 | 301 | 19 |
| Chard | 279 | 557 | 202 | 354 |
| Parsnip | 1399 | 1129 | 1177 | -48 |
| Beetroot | 354 | 324 | 217 | 107 |
| Lettuce | 539 | 471 | 386 | 85 |
| Turnip | 1130 | 1068 | 386 | 682 |
| Total | 4904 | 6095 | 3571 | 2524 |

The overall gross margin is of the same order of magnitude as those for a range of field vegetables quoted by Lampkin and Measures (2001). However, there are two major points:

a) On average, these marketable yield values, based on marketed produce in 2001, represent only about one-fifth of the estimated gross yields. This value is dependent almost entirely on the harvesting and marketing system rather than on the cropping system. In other words, a more commercial system should be better able to exploit the levels of production achieved.

b) For a stockless production system, the intercrop approach appears, so far at least, for a restricted range of crops, to be achieving the crucial objective of simultaneous fertility building and crop production. This means that continuous cropping with a limited range of species may be possible without a non-productive break of, say, one year in five. In comparison with the Lampkin and Measures data, therefore, a significant positive fraction could be added to the gross margin.

## 10. DISCUSSION AND CONCLUSIONS

Interpretation of the performance of the system is difficult because it is not obvious whether different effects are due to species, soil, site or system, or some interaction among these factors. Nevertheless, some characteristics of the overall production were clear.

## Crop performance: individual crops

Some varieties of most species performed well in one or both years including both leaf (spinach, chard, lettuce, escarole) and root vegetables (beetroot, parsnip, swede, turnip). Within each, there was a large variety effect: limiting the range of varieties or species could have led to a misleading interpretation of the productivity of the system.

In particular, chard and spinach performed well in 2000 and less so in 2001, in contrast to lettuce, which was much more productive in 2001 than in 2000. This reversal is probably indicative of an interaction of crop with season. It might be expected that any large negative effect of the system would affect all or most crops.

Overall, the range of crops used in 2001 did at least as well as in the previous season. This suggests that soil fertility was at least maintained at a level similar to the previous season. Several further seasons of production are needed to determine whether there is any upward or downward trend related to changes in soil structure or fertility.

## Rotation effects

Removal of cereals and potatoes from the rotation was highly beneficial in terms of grass weed control and maintenance of the clover sward. Otherwise there were no obvious rotational effects at this early stage.

## Stacked manure

Despite the variations among species and varieties, it seems likely that the stacked manure had a positive effect on vegetable crop yields. The reason is unclear. Nutrition may have been important, but equally, given the relatively small amounts of material that were applied, it is also likely that the addition of plant growth promoting rhizobacteria was important, either through improving the availability of soil-borne nutrients or through the promotion of disease resistance.

The application system was highly economical; although 25 t/ha was applied to the crop, this was equivalent to a hectare rate of only 10 t/ha since the clover was not treated. On the other hand, this raises a question in terms of standards: applying a rate of 60 t/ha on the crop strips only, is equivalent to 24 t/ha overall. Would this be acceptable?

## Pests, Diseases and Weeds

Pest damage was limited to that from larger animals. Better fencing and off-season control would reduce the damage from hares, rabbits and pheasants. This leaves the problem of slugs. However, despite the high populations, anecdotal evidence and comparison suggest that damage levels were no worse than in conventional organic systems. An important aspect for future consideration is the variation in crop species and varietal resistance.

The proposed advantages of the clover system in providing protected habitat for beneficial invertebrates and in causing confusion to potential pests, appeared to be working since there was little evidence of insect pest problems.

Similarly for diseases, it seems likely that the highly diversified cropping over the whole area helped to restrict establishment and spread of specialised crop pathogens. Moreover, the limited appearance and spread of *Septoria* spp. on the Umbelliferous crops may be an indication of the protection afforded by the clover understorey against the spread of splash-borne diseases.

Weed control was restricted principally to mechanical weeding. Hand weeding might have improved carrot development, but the additional labour cost would have made the crop even less profitable than it was. The clover clearly, and continuously, occupied the inter-crop space that might otherwise have been weed infested. This has an obvious advantage in the current season, but it needs to be underlined that, relative to conventional organic systems, this system should also limit future increases in the weed seed bank. It may also be that the continuous cultivation of the small volume of soil that is cropped could deplete the weed seed bank over a period of years. This potential effect would be better realised by using compost rather than stacked manure, which would import fewer weed seeds each year.

Mowing is regarded primarily as the means by which nitrogen accumulation by the clover is transferred to the crop. However, it is important also to stress the value of mowing in supporting the weed suppression due to the clover.

**Plant establishment**

In relation to plant establishment, practical experience indicates the importance of the rigid chisel tine tool developed in spring 2001, which was used for all crops except onion sets. Further improvement should be possible simply by making more use of the tool before planting. This should help simultaneously to control any clover growth in the crop strip, to provide a weed strike and to help to mineralise soil nutrients. This is a particularly important aspect for cereal-clover bi-cropping.

**Absolute yield**

Encouragingly, a number of species and varieties were equally successful in both 2000 and 2001 growing alongside, respectively, first year and second year clover. Importantly in relation to this second year, the warm and bright autumn with good growing conditions until late in the year helped to make up for the slow, late start in the spring. The fact that most crops continued to grow under these conditions indicates that, within the clover inter-crop system, some species of crop plants were not seriously limited for moisture or nutrients.

So far, the observations indicate that the main reason for developing the system, to provide simultaneous cropping and fertility building, is working for some crop species. By maintaining crop production throughout a rotation, the operation should be more economically feasible than a system in which at least one year in five has to be given over to fertility building alone.

**Costs and production**

There is no doubt that for some crops in both 2000 and 2001, higher yields would have been obtained by using transplants than by using seed. However, as noted from the cost analysis, this would have increased significantly the costs of production against limited potential returns from the small areas of individual crops. In the example of cabbage, choice of variety turned out to be crucial. Following poor production in 2000, the introduction of the white cabbage variety Cuor di Beu and the Savoy, Violaceo, led to reasonable production from seed in 2001 despite the late sowing.

Despite the apparently large number of tractor passes over the crops, largely due to the need for clover mowing and mechanical weed control, cultivation costs represented only a small proportion of the overall costs for all crops. These costs could be reduced significantly in a scaled-up system by:

- Using machinery adapted for 5-row beds rather than the 3-row beds currently used. This would also halve any tendency to field compaction since tractor wheelings would not overlap between beds and there would be no need for any change in tractor weight or power.
- With some design modifications, the weeder unit could be fitted to the rear of the tractor with the front-mounted strip mower unit to allow simultaneous mowing and weeding.

An important point to stress in relation to the number of tractor passes is that compaction did not become a problem. Partly, this was due to the use of light tractors, but, much more important, to the system itself in that the presence of the permanent clover made this activity much more feasible and less damaging than if the inter-crop spaces had been left as bare ground. This aspect was also commented on frequently by those involved in harvesting and other pedestrian operations, which were never delayed after rain: the vegetable crops were always accessible from the clover ‘paths’.

**Gross margin estimation**

Any estimation of gross margins from such a developmental system is fraught with analytical difficulties and approximations. However, an attempt at a best case scenario using a potential rotation of the best varieties, does indicate that such a selective approach could be at least as effective as average organic production systems. The critical issue is to determine how well, or badly, the system develops over a whole rotation. Only then will it be possible to observe, for example, changes in fertility, the direction of development of the weed flora, or the maintenance of the restriction of pests and diseases.

**Summary of crop and system performance**

From the summary given in section 9, some crops perform consistently well in the inter-crop system while others do not. This suggests that some crops are relatively well adapted to competition with clover while others are less so. This has also become clear in the cereal-clover bi-cropping project where oats have performed consistently better than either wheat or barley.

On this basis, it should be relatively straightforward to develop a successful clover-intercrop rotation based on the use of beet crops (spinach, chard, beetroot), some brassicas (kale, some cabbage, swedes, turnip), parsnips, lettuce and endive. The success of the beets also raises the possibility of a sugar beet/clover intercrop, which would have potential interest for organic growers.

On the other hand, a wide range of crops did not do well, notably all of the alliums, legumes, carrots and some of the brassicas. Despite the fact that other factors may have been important (late sowing, soil type), it appears that these crops are poor competitors against vigorous clover and that the competition factor offsets the various positive benefits of the clover intercrop.

An important challenge, therefore, to extend the usefulness of the positive benefits of the system, is to determine how to increase the range of crops that can be intercropped with clover. Given that a reasonably wide range of crops does appear able to compete with clover, and that there are considerable differences among varieties in their competitive ability, then three approaches suggest themselves:

- **Agronomic modification**. This would involve, essentially, physical limitation of the interaction between clover and crop either in space or time or both. The critical question would be to find the point at which such limitation allows, on the one hand, acceptable crop yields, and on the other, the advantages of the clover intercrop in terms of nutrient availability, weed restriction, stable habitat for earthworms and micro-organisms, and so on.
- **Crop variety**. Other than some grasses, no crops have been bred for intercropping with white clover. It may be regarded as fortunate then, that a number of crops appear to compete well and to be productive. This raises the possibility of testing further for ecological combining ability among available crops and varieties to extend the useful range. In the long term, it also raises the question of breeding vegetable varieties directly for their ability to compete with clover.
- **Clover variety.** Logically, the third possibility would be to select for clover varieties, or legume species, that would be less competitive. The problem here is that a loss of competitiveness would almost certainly lead to an increase in weed problems (as experienced, for example, with vetch in the Home Field experiments). For this reason, further development would best be concentrated on a combination of the first two approaches above.

**Summary**

1. A range of vegetable species and varieties performed at least as well in 2001 as in 2000 in the second season of the newly established vegetable-clover intercrop system in North Field.

2. For most species, there were considerable differences in the performance of different varieties, but it was not clear whether this variation was related to soil, site or system or to interactions among these factors.

3. Addition of stacked manure at 25 t/ha to the crop strips at the beginning of the season appeared to have a positive effect on crop production.

4. Pest problems were limited to larger animals. One possible way to limit slug problems is by choice of resistant varieties.

5. A range of vegetable crop diseases was present, but none was of significance for vegetable quality or yield.

6. Clover occupied much of the space that would otherwise have been occupied by weeds. Hand weeding was confined largely to onion sets and to restriction of thistles and broomrape. Mechanical cultivation was used regularly both for weeding and soil nutrient mineralisation.

7. Plant establishment was often low, at least partly due to the late, wet spring. Some improvement should be possible through more frequent use of the specially designed rigid chisel tines before planting.

8. Yields varied considerably among species and varieties. Encouragingly, some varieties of a number of species produced acceptable yields for organic production.

9. Some crops produced a positive return against production costs, others did not, mostly related to low crop yields. The major cost line in the production system, as with all vegetable enterprises, was the labour involved in harvesting and marketing. The use of seed rather than transplants was much more economical. Cultivation costs were a relatively small proportion of overall costs, but they could be further reduced.

10. A simple gross margin analysis based on a best case scenario, indicated a return at least equivalent to average production of organic field vegetables.

11. Observations from the two seasons suggest that some crops are competitive with clover and therefore intercrop well, while others are less competitive. The range of useful crops and varieties could be extended by agronomic modification of the interaction and by selection (and ultimately by breeding) for crop varieties adapted to clover intercropping.

12. Although there is scope for improvement in different directions, it was generally felt that a successful start to vegetable-clover inter-cropping has now been achieved.

## 11. REFERENCES

Lampkin N. & Measures M. 2001 Organic Farm Management Handbook. Organic Farming Research Unit, Institute of Rural Studies, University of Wales, Aberystwyth.

# COMPANION CROPPING PROJECT
# EXPERT GROUP MEETING

Tuesday 31st July 2001

Wakelyns Agroforestry, Suffolk

## Meeting Report

Dr James Welsh

# 1. OBJECTIVE OF EXPERT GROUP MEETING

The objective of the expert group meeting was two-fold:

i. To consider the applicability of companion cropping in its present form to commercial production at a range of enterprise scales (from small box schemes to large field scale units).

ii. To consider future development that needs to be made in order for this approach to be commercially viable.

# 2. MEMBERSHIP OF EXPERT GROUP

The group members were selected to include a wide range of expertise, including commercial growers, advisers, researchers, policy makers and research funders. In total, the group comprised thirteen members:

Dr. Bob Clements (IGER). *Researcher.*
Dr. Bill Cormack (ADAS). *Researcher and Project Leader*.
Mr. Andrew Dennis. *Commercial Grower (large scale).*
Mr. Guy Donaldson (IGER). *Researcher.*
Mr. Roger Hitchings (EFRC). *Adviser.*
Ms. Lorna Jackson (HDRA). *Researcher.*
Mr. Mark Measures (EFRC). *Adviser.*
Mr. Mel Myers (Marshalls of Butterwick). *Commercial Grower (Large scale).*
Mrs. Marina O'Connell. *Lecturer and grower (small scale).*
Dr. Mark Shepherd (ADAS). *Soil Scientist.*
Dr. Roger Unwin (DEFRA). *Policy and research.*
Dr. James Welsh (EFRC). *Researcher.*
Prof. Martin Wolfe (EFRC). *Researcher and grower (small scale).*

# 3. MEETING REPORT

The meeting was divided into three parts:

i. Introduction to companion cropping project and outline of the system;

ii. Visit to the field to look at the companion cropping system and machinery;

iii. Discussion.

### 3.1 Introduction to Companion Cropping

The companion cropping system comprises growing a range of salad and vegetable crops in a semi-permanent stand of perennial white clover. The advantages of this are:

a) Simultaneous cropping and fertility building rather than separate phases for each which has positive implications for economic viability;

b) Effective nutrient cycling;

c) Protection against wind and water erosion;

d) Maintaining an open soil structure with increasing organic matter;

e) Increased water permeation;

f) Weeds replaced by clover; limitation of crop area requiring intensive weed control;

g) Stable habitat for deep burrowing earth worms and for mycorrhizae;

h) Confusion of insect pests and habitat for beneficial insects, spiders etc.;

i) Reduction of splash dispersed diseases and reduction of disease spread;

j) Bee habitat with potential for improved crop pollination (and honey);

k) Improved field access relative to bare soil.

However, there may also be disadvantages:

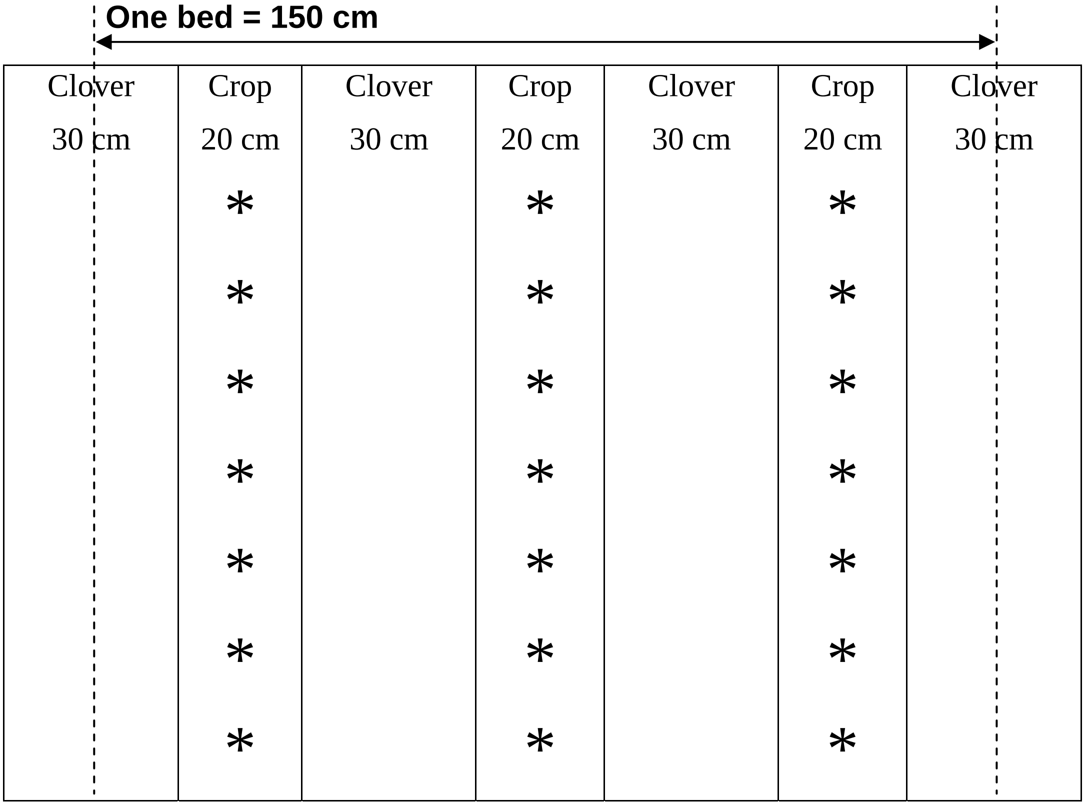
a) More management input;

b) Competition by clover for space, light, water and nutrients;

c) Is clover allelopathic against other species?

The system at Wakelyns uses a bed system that allows for good access to implement crop management operations. The layout of the beds and the crop rotation are given in Figure 1 and Table 1.

Figure 1. *Individual bed structure*




- The arrangement of the beds (i.e. 20 cm crop rows and 30 cm clover rows) was based on findings from some earlier work reported by Stan Finch (HRI). The emphasis of this work was to look at the 'confusion' of pests by introducing strips of green cover into the cropped area. The conclusion from this work was that the most effective 'confusion' resulted from 60% green cover and 40% crop.

- After two years experience of running this system, some modifications have had to be made. The main change has been to remove cereals and potatoes from the rotation, as these crops tended to result in problems with grass weeds.

- To avoid potential soil-borne pest and disease problems, crops are moved three beds along at the end of each season (Table 1).

**Table 1.** ***Crop rotation in North Field***

| **Year** | *Bed 1* | *Bed 2* | *Bed 3* | *Bed 4* | *Bed 5* | *Bed 6* | *Bed 7* | *Bed 8* | *Bed 9* | *Bed 10* | *Bed 11* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2000** | **Brassica** | **Alliums** | **Legume** | **Betae** | **Lettuce** | **Brassica** | **Alliums** | **Umbellif.** | **Misc.** | **Lettuce** | **Potato** |
| **2001** | **Legume** | **Betae** | **Lettuce** | **Brassica** | **Alliums** | **Umbellif.** | **Betae** | **Lettuce** | **Brassica** | **Allium** | **Umbelif.** |

This layout was applied as far as possible in each of the three 18m crop alleys used, giving a total of 33 beds, which averaged about 150 metres in length.

Because of the need for the two experimental leek beds to be planted side-by-side, there was a minor modification to this layout in 2001. In the western alley, the leeks were grown in alleys 4 and 5. In the central alley, brassica crops were grown in bed 10, rather than alliums, to make up for the brassica bed lost in the western alley.

### 3.2 Field visit and machinery

Having considered the underlying principles of companion cropping, the expert group moved to the field to see the system in operation.

Plate 1. *The Expert Group examines the system in detail.*

Plate 2. *Examples of various crop species being grown in the companion cropping system including, (**A**) Beet, (**B**) lettuce and (**C**) Onions*

To manage the crops in the system it has been necessary to develop appropriate equipment to facilitate cultivations, drilling, weeding, irrigation and compost inputs. The staff at Wakelyns have developed and built a suite of equipment for this purpose.

Plate 3. *Paul Ward explaining the range of equipment developed as part of the project.*

### 3.2.1 Primary cultivation

A standard rotavator (square shaft) has been adapted to cultivate the 20 cm cropped strips within the 30 cm strips of perennial white clover (Plate 4A). The rotavator blades are of the speed blade type (Plate 4B) to minimise pan formation and are shielded by rubberised sheet skirts to retain the cultivated soil within the 20 cm crop strip. The angle of these speed-blades overcomes the smearing effect that often results when using standard rotavator blades.

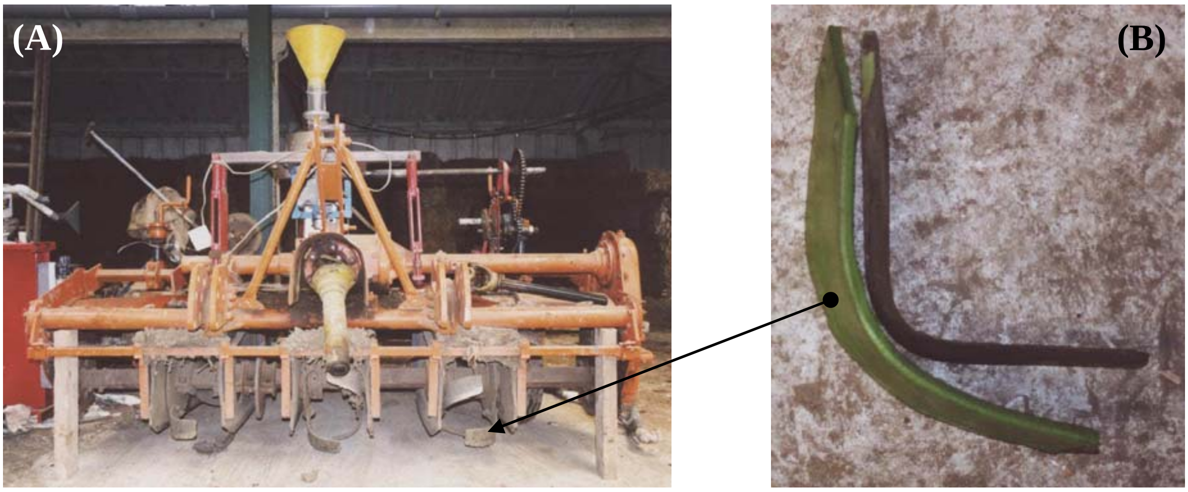


Plate 4. (**A**) *The rotavator used to cultivate the cropped strips in the perennial white clover.* (***B***) *A comparison of speed-blades (left) and standard rotavator blades (right).*

The development of a rigid chisel tine cultivator (Plate 5) has assisted in the production of root crops such as carrots. The cultivator has three narrow legs set at 50 cm spacing so that each leg follows down the centre of each crop strip in a single bed. The unit is designed for relatively deep cultivation, up to 20-30 cm so as to break up any soil pan present.

**Plate 5.** *Rigid chisel tine cultivator***.**

3.2.2 Secondary cultivation

Secondary cultivations are achieved using a tool bar equipped with flat discs that run along the clover/crop interfaces (3 pairs per bed). Sprung A-shears or other tines can then run between the discs with the moving soil kept within the crop strip.

3.2.3 Seeding

At present, the majority of the crops are grown from seed. This is achieved using two different systems, depending on the crop species:

a) A 3-row precision drill based on precision hand seeder units with changeable discs depending on seed size (Plate 6). The drill also has two gears to extend the range of seeding rates. Each drill unit can be set with different discs and different gears to allow for different species or varieties in adjacent rows if required.

b) An underground strip broadcaster fitted to strip rotavator (see Plate 4A). Seed is delivered to the ground within the protective skirts while rotavated soil is airborne. Each of the three crop strips is fed from a different hopper to allow planting of different species or varieties through individual metering units into each of the three crop strips in one bed. The hopper unit can be replaced by an Ojyord header for planting plot trials. The seed delivery tubes on the underground strip broadcaster can be turned inwards into the spaces between the rotavated crop strips for broadcasting clover seed.

**Plate 6.** ***Front and profile view of the seed drill***

3.2.4 Maintaining clover/crop interface

Whilst machinery has been developed to manage the crops, it is also necessary to manage the white clover. Two pieces of equipment have been developed to control the clover, a cultivator (with a number of attachments) and a strip mower

a) Cultivator (Plate 7):

i. Above ground: straight spring tines (10 mm). These are run along the clover/crop interface and have the action of weeding and of loosening clover rhizomes. This causes clover to grow out over the edge of the crop strip without being rooted in it. This is advantageous in terms of pest camouflage and weed smothering.

ii. Surface: flat discs set to run along the crop/clover interface will cut through clover rhizomes provided soil moisture conditions allow some penetration.

iii. Below ground: interface knives (6 legs), again running along the line of the crop/clover interface, but at greater depth than the discs, will help to cut through roots. This is important for less competitive crops where the majority of roots in this region will tend to be clover growing into the vegetables rather than the reverse.

iv. Discs with L-blades for undercutting clover: discs are again run along the crop/clover interface but with short-reach L blades fitted close to the discs and running into the clover strips. These undercut the clover, again to reduce competition while maintaining clover growth from the more central part of the clover strips.

Plate 7. *The cultivator (with disc cutter attached) used to manage the clover/crop interface.*

b) Strip Mower (Plate 8):

The four-head rotary strip mower, hydraulically powered and mounted on the front of the tractor, has been developed specifically for mowing the clover strips while avoiding the crop strips (Plate 8A). Two rotary blade sizes are available, 33 cm for a full cut and 30 cm for when crop plants are larger. The mower is also fitted with a hand control for allowing the clover mulch to be deposited either on the clover strips only or, mostly, on to the vegetable strips (Plate 8B).


Plate 8. *(A) The strip mower used to manage the white clover. (B) Side guards control the lateral movement of clover mulch.*

3.2.5 Weeding

Two types of weeding operation are used:

a) Discs with light spring tines (7 mm): the discs are set to run close to the crop strips with the spring tines running alongside in the soil between crop and clover. The discs ensure that the tines do not disturb the crop plants.

b) Discs with L-blades to undercut weeds: again, the discs are set close to the crop plants to avoid disturbance.

Most of the processes of interface maintenance and weeding should also help with nutrient mineralisation.

3.2.6 Irrigation and Compost applications

Compost / manure is delivered by a modified rear discharge manure spreader (Plate 9A). The modification consists of a metal sheet cover, which restricts the spread to the width of a bed. Two inverted V-shaped metal baffles held in the cover ensure that compost delivery can be further restricted to the crop strips only. This helps to direct competition in favour of the crop rather than the clover, to ensure that nitrogen fixation is maintained, and to provide economical use of the compost/manure.

The simple irrigator (Plate 9B) comprises a water tank drawn on a trailer behind the tractor. Water from the tank is fed into a manifold from which three downpipes are set at 50 cm centres. The pipe exits are about 10 cm above the soil surface. This system ensures that water is delivered directly to the crop rows only. The pressure of delivery ensures soil penetration. Rate of application is determined by tractor forward speed.


Plate 9. *(A) Modified muck spreader for compost applications, and (B) Simple trailed irrigator*.

Table 2. *Field diary 2001 (Feb – July)*

| | Legume | Betae | Compositae | Cruciferae | Alliums | Umbellifers |
|---|---|---|---|---|---|---|
| **Feb** | **Flail mow, rotavate, roll** | | | | | |
| **Mar** | **RAIN !** | | | | | |
| **Apr** | **Flail mow, rotavate, roll** | | | | Cultivate, punch holes, plant sets | Flail mow, rotavate, roll |
| **May** | Mow, compost, soil loosener, roll, drill | Mow, compost, soil loosener, roll, drill, irrigate | Mow, compost, soil loosener, roll, drill, irrigate x 2 | Mow, compost, soil loosener, roll, drill | Weed sets, roll, harrow, roll, plant leeks, irrigate, mow sets x 3, Reekie tines | Mow, compost, soil loosener, roll, drill, irrigate |
| | **Rotary mow and disc edge** | | | | | |
| **Jun** | | | | | | Plant and drill celeriac, parsley and fennel |
| | | **Irrigate x 3** | | Irrigate x 4 | Irrigate x 3 | Irrigate x 4 |
| | **Disc edge and tine weed x 2** | | | | | |
| | | **Late sowings, roll, irrigate** | | | | |
| | **Full mow x 2** | | | | Full mow x 1 | Full mow x 2 |
| **Jul** | Disc edge and tine weed x 2<br>Tine weed only<br>Strip mow x 2<br>Interface knives if possible | | | | | |
| **Aug** | **Mow x 2, Weed x 1** | | | | | |
| **Sep** | | | | | | |
| **Oct** | **Mow x 1, disc edge x 1** | | | | | |

Most operations were carried out at approximately 1 ha per hour with a Grey Ferguson or MF250 (strip mower) or Smallholder (MF35: rotary or flail mower). Thirty to thirty-five operations were conducted over six months, i.e. 1.5 operations per week on average.

Roughly half a day to a day per week has been enough for this one hectare system except at drilling time, when more time was needed both for sorting out drilling rates and calibration, and for drilling (N.B. this is for a three-row system: a five-row system would take no more time but would cover a 67% greater area)

### 3.3 Discussion

A wide-ranging discussion took place throughout the day. The main issues raised were:

*1. Is there potentially too much nitrogen in the system?*

This is a function of the quantity of clover compared with the cropped area. The reason for the current proportions of clover and crop are to maximise the confusion of pests. This could be adjusted to take account of the crops' nitrogen requirements, but there is no information available to determine what the optimum should be. Clearly, a range of factors including soil type, soil fertility and climatic conditions will affect this. The additional work being conducted by ADAS on the timing and frequency of clover cutting may provide some indications on nitrogen supply from the clover.

The other issue relating to the proportion of clover is that of competition for water and other nutrients. It was suggested that certain clover varieties (e.g. small-leaved) might be better suited to this type of system than others. Also, other species such as trefoil could be considered as companion crops. Further work is needed to address these issues.

*2. Would transplants be better than growing from seed?*

A considerable amount of time was spent considering the benefits of using transplants. The large-scale commercial growers considered that transplants would perform much better than crops grown from seed. This would be particularly important on the silt soils that tend to cap, as emergence can be seriously inhibited. Also, the transplants would be much more competitive. The difficulty with transplants relates to cost as they are much more expensive than seed, although this may be more than compensated for by better crops.

*3. Choice of Species*

It was clear that some species and varieties were better suited to this type of system than others. For example, the beets appeared to be performing well, whilst onions seemed to be suffering from competition with the clover. Therefore, if this approach is to succeed, it is important to establish which species and varieties should be included, and more importantly, which should not.

*4. Soil type and seedbed conditions*

There was some concern over seedbed quality. Many of the group thought that the seedbed tended to be too coarse. This could be partly due to the problems associated with cultivating narrow strips. However, another reason could have been the very wet weather that was encountered during cultivations. Again, using transplants could overcome this problem, as they would be more tolerant of a range of seedbed conditions. The experiments at Wakelyns were conducted on clay soils, but a number of the group felt that the system may work better on lighter soil types where it would be easier to establish small-seeded crops and also better suited to growing root crops

*5. Slugs*

A number of the group were very concerned about the potential for serious slug damage, since the clover provides an excellent habitat for the slug population to multiply. This, however, had not been a problem, as the slugs appeared to be happy to stay in the clover strips rather than venturing out into the crop rows. Further monitoring of this will take place throughout the rest of the season.

*6. Commercial viability*

In general, the group considered that, at present, companion cropping was better suited to small-scale production serving local markets. The large-scale producers were concerned about the level of input required to manage the clover and crops. Individual species are sown on a single row basis, but this would present major difficulties for large-scale enterprises in terms of harvesting. To overcome this, single species would need to be established either on a bed system or in larger scale blocks. However, this moves away from the concept of increasing diversity to minimise pest, disease and weed problems. Also the crops are being harvested by hand so mechanisation of this process would be important for field-scale production.

## 4. CONCLUSIONS & FUTURE WORK

There are a number of areas where further development is required, principally:

- Optimisation of the proportion of crop and clover to take account of N supply from the clover, competition for water and other nutrients and pest and disease restriction.
- Identification of suitable varieties of clover as well as other companion crops.
- Identification of the most appropriate crop varieties for companion cropping system.
- Testing the system on a number of different soils to include lighter soil types.
- Identify and develop ways of simplifying the system to make companion cropping acceptable to large-scale organic producers.

## 5. ACKNOWLEDGEMENTS

This project was funded by DEFRA (Project No: OF0181). We would like to thank the members of the expert group for their time to consider and discuss the companion cropping approach. We would also like to thank Martin & Ann Wolfe for hosting the expert group meeting.