Project title	Extension of FV 299 – Investigation into the adoption of green manures in both organic and conventional rotations to aid nitrogen management and soil structure.
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Project leader:	Peter Knight, VCS
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Location of project:	Norfolk
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Date project completed (or expected completion date):	29th January 2010
Key words:	Green manure, cover crop, ley crop, soil fertility, nutrient, nitrogen, organic matter, soil structure

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results obtained have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was carried out under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Peter Knight
Project Leader
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Signature .... Date 27/01/10 ....

Tim Lacey
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Report authorised by:

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Grower Summary

Headline

There is no consistent measurable benefit that can be attributed to green manures in the second cropping year after their incorporation within a conventional root crop rotation.

Background and expected deliverables

Vegetable production in the UK, particularly root vegetables, is based on light land - largely to better manage quality and uniformity of produce. However, production on these soils is not without its problems: lack of organic matter and frequent working of the soil can lead to poor structure that impedes root growth resulting in non-uniform crop development and the increased potential for soil erosion. In addition, soil nutrient and water management can be difficult as light soils have little holding capacity for either resource. Traditional practices of applying Farm Yard Manure (FYM) to light soils are likely to be limited by new regulations as nitrogen leaching is of major concern, particularly in the period after harvest of certain crops like onions where land is often left bare through the winter until spring crops are sown. Not only do these issues have direct economic implications for growers, but they can also represent major obstacles within regulatory frameworks (e.*g.* NVZ, Cross-Compliance, Single Farm Payments, grower protocols etc).

Green manures serve a multi-functional purpose. The recent spiraling input costs of fertilisers have reduced profits for growers. Green manures offer the potential to increase on-farm nutrient security and stability. Understanding their role in improving soil structure is of considerable importance to growers with light soils, specifically as an aid to reduce capping, slumping , erosion, improving crop rooting and enhancing water holding capacity. A sizeable amount of attention has been paid to green manures in recent years, mainly with respect to organic production. However, much of this work has been somewhat piecemeal and therefore has largely failed to provide growers with sufficient understanding of green manures. Consequently, the under-utilization of green manure crops, particularly within conventional horticulture, represents a valuable untapped resource.

HDC project FV 299 aimed to help fill the knowledge gap by undertaking a comprehensive review of previous studies followed by large-scale field trials. Findings were communicated to growers through open days and grower visits. Critically, data from FV 299 suggested that increased crop growth and yields resulting from green manures were not consistently linked to soil nitrogen levels. Rather, it appeared that better soil structure and water retention may have been of greater than expected importance to the yield of the following crop. In addition, there were suggestions from proponents of green manures that many of the green manure advantages tend to be more prominent in the second year after incorporation, than in the first season.

The overall aim of this extension was to increase on the knowledge base of green manures developed in FV 299 by following the progress of soil-related changes due to the ley crop and the consequences for a second season of cash cropping on one of the replicated field trials set up in FV 299. Improved knowledge would guide growers on the adoption of green manures within vegetable rotations, potentially assisting them to maximize returns through reduced fertiliser requirements; more uniform crops due to better soil structure and; improved soil water management possibilities. In addition, the use of green manures could help growers meet regulatory requirements.

Summary of the project and main conclusions

FV 299 Extension utilised only one of the original four sites used for FV 299. The selected site was conventionally farmed and all normal inputs were applied to achieve a commercially acceptable crop. Green manures were established either in autumn 2006 or spring 2007 and were grown during 2007. After incorporation the crop grown in 2008 was potatoes followed in 2009, the year of this project, with bulb onions.

The project aimed to:

1. Examine if there was an impact on nitrogen availability from green manures in the second year after incorporation, which could not be seen in the first year.
2. Investigate whether the impact of green manures on soil structure and soil moisture was sustained for a second cash crop.
3. Investigate the yield response of a vegetable crop in the second year after green manure incorporation.
4. Determine if there are any stimulatory or detrimental effects on the performance of the second commercial crop in the rotation.
5. Re-assess the economic impacts of green manure crops based on observations and measurements over two seasons after incorporation.
6. Report project results to growers and the HDC as set out in the work plan.

The results from these investigations suggested that in a conventional root crop rotation on light soils, the benefits of green manures that were measured in the first year of cropping after their incorporation (as reported in FV 299 final report) are not consistently sustained in the second year of cropping. Although there were some minor variations that could be attributed to the different green manure treatments (e.g. slightly improved crop establishment), few were statistically significant. It is considered that a sustained benefit from green manures may have been more marked within an organic rotation, whereas the nutrient applications within a conventional rotation may have largely masked the positive effects of the green manures.

Financial benefits

With no consistent yield differences or sustained soil nutrient/physical differences found within this project, there could be no significant financial effect of green manures on the following second cash crop in a conventional rotation. However in organic rotations a short or medium term green manure will be the most likely entry ahead of two years of cash crops and, in this situation, is an acceptable cost for building fertility.

The cost of establishing a green manure crop was considered and priced as of 2007 in the proceeding project. For Mixture 2, the most frequently utilised green manure, establishing and managing the sward in 2007 cost £206/ha. This has risen to £243.67/ha in 2010, an increase of 18%. Assuming an average contribution by this sward of 120 kg N per ha (based on FV 299 data for this site), this equates to £2.03 per kg of nitrogen.

An average forecast price of £240/tonne of ammonium nitrate fertiliser (34% N) in 2010, would give a cost of £0.71 per kg of nitrogen. Prices have recently peaked (mid 2009) at around £420/tonne, resulting in a cost of £1.24 per kg of nitrogen. With the potential for an increase in and more volatile energy prices, nitrogen costs could again rise to high levels, considerably reducing the price deficit between nitrogen obtained from green manures and that from artificial sources. For instance, to match the cost of nitrogen secured by green manures (assuming this to be the only benefit), ammonium nitrate would have to reach £690/tonne.

However, it should be noted that there are other benefits to green manures that are not easily either measured or quantified financially, such as: the potential impact on soil organic matter and structure (particularly when used on a regular basis); assistance in meeting regulatory requirements (Cross-Compliance/NVZ/Single Farm Payment etc.); reducing carbon footprint within the agribusiness. These less well-defined benefits should not be discounted when considering a green manure within the rotation.

Further economic analysis of the green manures used in this project and their costs/benefits to the first year cash crop can be found in the final report of FV 299.

Action points for growers

- In conventional root vegetable rotations on light land, green manures are likely to only show measurable benefits in the first year of cropping after incorporation.
- Consider green manures in the rotation as part of your soil management plan for meeting regulatory obligations.
- Consider the contribution that green manures can make to sustainable farming systems and to the reduction of an agribusiness' carbon footprint (artificial nitrogen fertilisers contribute a large proportion to agricultural greenhouse gas emissions).
- Establishing green manures as soon as is practical after harvesting a cash crop will help capture a high percentage of any residual nitrogen.
- Consult the review on green manures that was created as part FV 299 for more information.

Science Section

Introduction

Leguminous green manures are the principle source of nitrogen in all organic farming systems but there is a place for green manures within both organic and conventional field vegetable production. There is an increasing need to improve nitrogen management to reduce leaching, particularly during the winter months when much land is left bare. Cross-compliance necessitates that all farmers draw up a soil management plan. This plan must address strategies for minimizing soil erosion and nutrient leaching; special considerations apply in Nitrate Vulnerable Zones.

In large-scale vegetable production, straw crops have provided commercially viable breaks, particularly within light soil rotations. In recent years, cereal production became more marginal (largely due to increasing nutrient costs and decreasing commodity product prices), giving a real opportunity to introduce green manures into the rotation. Light land soils traditionally rely on FYM to boost soil organic matter; this approach has led to increasing soil phosphate levels, lush crop growth and, often, the introduction of alien weed species. The introduction of green manures in these rotations would provide a more sustainable approach to maintaining soil organic matter and fertility. Potential new EU legislation may severely restrict the on-farm storage of FYM, effectively preventing its use in certain circumstances. Green manures may present a viable alternative.

A number of projects have examined the use of 'fertility-building crops' in the UK. Most of this work has been conducted in organic systems, although some of the results are of relevance to conventional systems as well. HDRA has researched a range of green manures/fertility building crops in organic rotations and assessed their ability to conserve nitrogen as well as maintain and enhance soil fertility and structure. This work has considered both short-term winter cover crops and also the role of longer-term leys in crop rotations.

The main research focus of this research has been on the use of winter green manures, or cover crops, since these offer the greatest potential for reducing the leaching of nitrogen. HDRA investigated the nitrogen dynamics of a range of winter green manures (conservation, mineralization and utilization of N by subsequent crops) in two DEFRA funded projects (OC 9016 and OF 0118T). Another DEFRA project (NT 2302) summarized these findings, together with other cover crop research that had been conducted by ADAS and HRI.

Subsequent work has also considered longer-term crops. HDRA has led three DEFRA funded projects which have considered the impact of contrasting fertility-building strategies during the period of conversion to organic field vegetables and in the early years of full organic production (OF 0126T, OF 0191 and OF 0332). The fertility-building strategies have differed in terms of duration (six months to two years), species (e.g. pre clover or grass and clover) and method of establishment (e.g. some were undersown). The effects on crop yields, soil fertility, weeds, pests, diseases and economics of production have all been monitored. This work commenced in 1995 and was completed in 2009 (OF 0363).

Fertility-building crops were also the subject of a recently completed ADAS project (OF 0316). A major review of the effects of these crops was conducted and there were also trials to test the performance of a range of novel legumes (although these concentrated on the growth of the crops rather than their effects). Research has also been carried out in other northern European countries (e.g. Denmark).

Computer modeling offers one way to draw together research findings and make them of relevance in a particular situation. An EU project, EU-Rotate-N (QLK5-CT-2002-01100) had the aim of producing a model that will enable farmers, advisors and policy makers to evaluate the agronomic and economic effects of various nitrogen management strategies. This was developed specifically for field vegetables and considers issues specific to fertility building crops (eg litter loss, nitrogen fixation and the effects of mowing and mulching).

Whilst most of this work concentrated on the effects of green manures on soil fertility, a recent HDC project (FV 273) also investigated the role of Caliente mustards for nematode and pythia control.

FV 299 (of which this project was an extension) commenced in the autumn of 2006 and was completed at the end of 2008. It investigated the adoption of green manures in both organic and conventional rotations as an aid to nitrogen management and the maintenance and/or improvement of soil structure. Benefits were identified in some of the areas investigated and further observations indicated that better soil structure and water retention might be of greater than expected importance to the yield of the following crop. In addition, there have been suggestions from proponents of green manures that many of the advantages tend to be more prominent in the second year after incorporation than in the first season.

This project, FV 299a, aims to extend the previous work by further investigating the impacts of the green manures on a second cash crop (bulb onions) at one of the original sites. The project focused specifically on nitrogen, soil structure, soil moisture retention and crop yield.

Materials and methods

Field Site

Of the four sites used in the original FV 299 project, only one site was monitored during this follow-up work due to financial limitations and crop rotation considerations. This was the conventionally farmed site at Elveden Farms Ltd, Thetford, Norfolk (site W). The cash crop in the second season after incorporation of the green manures (i.e. being monitored in this project) was bulb onions. Plots were re-located after crop drilling using GPS data from FV 299.

Experimental design

Experimental layout was the same as in FV 299 for the site, given for information below.

There were six treatments in each trial, laid out in a randomised complete block design with three replicates as given in Appendix 1A. Each plot was approximately 2208 m^2. Green manure treatments for these plots are listed below:

1. Crop sown autumn 2006 (cocksfoot, 12.5 kg/ha; red clover, 7.5kg/ha; white clover, 1.25 kg/ha)
2. Crop sown autumn 2006 (perennial rye grass, 12.5 kg/ha; red clover, 7.5 kg/ha; white clover, 1.25 kg/ha)
3. Crop sown spring 2007 (perennial rye grass, 12.5 kg/ha; red clover, 7.5 kg/ha; white clover, 1.25 kg/ha)
4. Crop sown spring 2007 (cocksfoot, 5 kg/ha; red clover, 3.7 kg/ha; white clover, 1.25 kg/ha; crimson clover, 2.5 kg/ha; sweet clover, 3.7 kg/ha; trefoil, 2.5 kg/ha)
5. Crop sown spring 2007 (cocksfoot, 12.5 kg/ha; red clover, 7.5 kg/ha; white clover, 1.25 kg/ha)
6. Control (bare ground maintained by herbicides or cultivations)

Cocksfoot (*Dactylis glomerata*) cv Prairial
Perennial ryegrass (*Lolium perenne*) cv Calibra
Red clover (*Trifolium pratense*) cv Milvus
White clover (*Trifolium repens*) cv Aberconcorde in Treatment 1, 2, 3 and 5 and Aberherald in Treatment 4
Crimson clover (*Trifolium incarnatum*) cv Contea
Trefoil (*Medicago lupulina*) cv Bergo Pajbjerg
Sweet clover (*Melilotus alba* and *M. officinalis*) *no specified variety*

Crop husbandry

The grower conducted all husbandry operations according to their standard procedures. Husbandry of the green manures and cash crops during FV 299 are given in the final report for the project. In brief, green manures were established either in September 2006 (for autumn swards) or March 2007 (for spring swards) and were topped as required during their growing season (four passes at approximately monthly intervals). Swards were desiccated in December 2007 and were incorporated in January/February 2008, prior to cultivation for the first cash crop. Potatoes (variety Lady Rosetta) were planted late March 2008 and harvested early August 2008. Following the 2008 cash crop, a short-term nutrient “catch crop” of ryegrass was sown. This was desiccated in September before manure application and cultivations for the 2009 cash crop. Onions (variety Dinaro) were precision drilled on the 5th March 2009. Husbandry of the onion cash crop from this point onwards followed standard practices; details are given in Appendix 1B.

Monitoring methods

Soil composition was sampled at the beginning, middle and end of the season (8th March, 5th June and 17th August). A pooled sample composed of several auger cores was taken from each plot (0-30 cm and 30-60 cm samples were kept separately). Sampling below this depth was very difficult at the site due to the abundance of stones. The samples were kept cool and rapidly transferred to a laboratory for analysis (by Anglian Soil Analysis Ltd). Mineral nitrogen (as nitrate and ammonium) and soil moisture was determined at every date. Other nutrients (pH, P, K and Mg) were only tested for at the beginning and end of season. Soil organic matter content was not tested due to an administrative error. However, since organic matter content varied by only a small amount (from about 2.8% to 3.5% throughout FV 299), it is exceptionally unlikely that any significant results could have been gained from testing.

Soil physical parameters were measured at the start and end of the season (2nd April and 17th August). Soil dry bulk density at c150 mm depth (corresponding to main rooting zone) was measured using a standard bulk density ring (internal diameter 54 mm, length 20 mm) driven horizontally into the soil. Six replicated samples per plot were taken, amalgamated to a single sample, weighed, oven dried, then re-weighed. Soil penetrability was evaluated in a number of plots using a DICKEY-John Soil Compaction Tester (penetrometer). However, no evidence of variability between plots was discernable, therefore further penetrability measurements were not carried out. Observations of soil structure were also noted when sampling. Soil infiltration rate was measured using a double-ring infiltrometer (internal diameters of 151 mm and 259 mm) using five repeat measurements of a short falling head technique (50 mm drop) at two points in each plot. Measurements were taken on the 25th May and 5th August. The soil surface was relatively dry at each measurement.

Soil moisture was monitored in each plot using a Diviner 2000 capacitance probe system. Weekly readings were taken from tubes installed using standard procedures in each plot from early April to early August. Data was converted into soil moisture deficits, using the necessary assumption that the soil was at field capacity at the first reading.

Cash crop establishment was measured as population per m^2 at three dates (10th April, 24th April and 8th May) using four replicate counts of 1 m of bed (1.83 m wheel centres) per plot. Three dates were used to determine if green manures affected the rate of crop emergence.

Crop biomass samples (whole plant, including as much root as possible) were taken at three dates during the season (5th June, 10th July and 14th August). Samples comprised of a known number of entire onion plants (typically 15-20 per sample) taken throughout the plots. Samples were analysed for dry matter content and nitrogen content (by Anglian Soil Analysis Ltd.). Rooting depths were noted at each sampling interval.

Crop yield and quality was measured at crop maturity immediately prior to harvest (19th August). Three samples of 1 m bed (1.83 m wheel centres) were hand-harvested, netted and transferred to an onion store for curing following typical practices. Samples were assessed for yield (by size grade) and for disease/defects following standard protocols.

Weed populations were assessed on 12th May, prior to significant herbicide/cultivation control. Weed species were identified and their prevalence assessed on a scale of 0-5, where 0=no weed and 5=high weed pressure. Due to the nature of this data, it was not suited to statistical analysis.

Pest and disease observations were carried out during other sampling procedures. Significant instances of pest or disease were noted where there were indications of a treatment effect.

Economic assessment

The economic assessments carried out in FV 299 were updated for this project, using current costing information where applicable.

Results and discussion

Weather

- Weather data from Cambridge NIAB is presented in Appendix 1D
- At the time of drilling the cash crop 2009, it was relatively dry with temperatures slightly above average, following a wetter and cooler period through February.
- Conditions generally remained good for crop growth through late spring and early summer, with above average temperatures and sunshine hours.
- Below average rainfall during this period led to significant need for irrigation, but tended to reduce downy mildew risk.
- July and August continued the trend of average or above-average temperatures and sunshine hours, despite rainfall being significantly above average for this period.
- As a consequence of the generally warm and bright conditions, the crop matured very early (2-3 weeks earlier than typical). However, this earliness was generally consistent with other ware onion crops in the locality.
- The wetter conditions later in the summer assisted with the development of high yields, but may have contributed to some of the disease issues seen in the crop during storage.

Soil mineral nitrogen

- Soil mineral nitrogen is ammonium plus nitrate (i.e. the forms available to plants). The results are presented in Appendix 1E showing kg of mineral N/ha for two soil depths (0-30 cm and 30-60 cm) and for 0-60 cm soil together.
- These measurements represent the net effect of mineralization of nitrogen in crop residues, green manures and soil organic matter (plus nitrogen from the fertilisers and manures applied – see Appendix 1B) and uptake by the cash crop (plus other losses such as denitrification or leaching).
- Soil mineral nitrogen levels were a little variable, and there were no significant differences or trends that could be attributed to treatment effects.
- There was a considerable increase in soil nitrogen at the June sampling (of an average of 75 kgN/ha from March measurement). This follows closely the N additions made during this period of 98 kgN/ha, accounting for some crop uptake and other losses. The majority of this additional soil nitrogen (and that from further fertiliser applications) was either used by the crop or otherwise lost by the end of the season, since soil N fell back to levels similar to those at the start of the season.

Other soil nutrients and organic matter

- Other soil nutrient data are presented in Appendix 1F. There was a slight increase in P index through the life of the onion cash crop (68 to 84 mg/l, sufficient to increase index by one unit), corresponding with a slight decrease in K index (266 to 184 mg/l, sufficient to decrease index by one unit in most cases). Mg levels remained similar.
- Soil organic matter content was not tested. However, since organic matter content varied by only a small amount (from about 2.8% to 3.5% throughout FV 299), it is exceptionally unlikely that any significant results would have been gained.
- None of the changes in soil P, K or Mg could be attributed to treatment effects from the green manures.

Soil physical parameters

- Soil dry bulk density gives an indication of the soil structure relating to the degree of compaction, the ease of root penetration and the degree of root-soil interface for nutrient/water absorption. Typically, well-cultivated light soils would be expected to be in the range of 1.4-1.7 g/cm^3. Data is presented in Appendix 1G.
- Soil dry bulk density was significantly lower but more variable at the April sampling than August. This is likely to be a result of bed formation cultivations making the soil light and “fluffy” at the start of the season, which then settled and compacted as the season progressed. There were no obvious treatment effects on soil bulk density.

- Soil penetrability was evaluated in a number of plots. However, since no evidence of variability between plots was discernable, further measurements were not carried out. All soil within the crop root zone appeared to be easily penetrated (reading approximately 100psi on the DICKEY-John Compaction Tester using the ½ inch tip). This was thought to be largely due to the rigorous cultivation operations carried out to form a suitable substrate for onion growth.
- The soil infiltration rate gives an indication of the ability of a soil to absorb and transport water, and is related to soil texture, structure and porosity. The improvement of soil structure (as might be expected after the use of green manures) might be expected to increase the infiltration rate of heavier soils and reduce the infiltration rate of light soils where water passes through too quickly.
- Soil infiltration rates are presented in Appendix 1G, with only the initial and final infiltration rates given for clarity. Typical to the measurement technique, the values obtained were quite variable between replicates, between plots, between treatments and between sampling timings. There were no significant differences in infiltration rate attributable to treatments.
- Final soil infiltration rates were lower than initial rates as the soil became saturated, nearing saturated hydraulic conductivity rate. At the May measurements, recent wet conditions had created a less permeable crust, reducing both initial and final infiltration rates. In contrast, at the August measurements, despite some overall compaction of the soil within the beds, the surface was relatively loose (due to several passes of a mechanical hoe during the season) and had not crusted over due to rainfall or irrigation. Consequently, infiltration rates were higher at this time.

Root zone soil moisture

- Root zone (0-30 cm) soil moisture deficit was quite variable between plots and between treatments (Appendix 1H). Although treatments 1 and 6 (control) tended to have a fractionally higher soil moisture deficit and treatments 3 and 5 tended to have a slightly lower soil moisture deficit during periods of increased water stress, these were not significantly different. Examination of soil moisture data from greater depths (up to 60 cm) also indicated no significant differences between treatments.

Cash crop establishment and growth

- The onion cash crop was drilled on the 5th March (see Appendix 1B for details) and was assessed on 10th April (emerging to post-crook), 24th April (0.5-1TL) and 8th May (1-2TL) (see Appendix 1I).
- Crop emergence at the first assessment was significantly higher in treatments 2 and 3 than treatments 1 and 4, which were in turn higher than treatment 5 and the control. At later counts, populations generally remained higher in treatments that had had green manures (1-5) than in the control, although the differences were no longer significant. It was noted that in the control plots, where establishment appeared to be slower than the other plots, the first post-emergence herbicide application might have slightly reduced the plant stand.
- Observations during measurements indicated noticeably earlier crop germination, more even stand and slightly greater crop size in green manure plots (1-5) than the control (treatment 6).
- Crop biomass data is presented in Appendix 1I. Note that biomass for August was estimated based on final cured bulb yields, assuming that the cured bulb yield was equivalent to 80% of the fresh plant biomass at harvest. Although variable between samples, biomass did not differ significantly at any assessment as a result of green manure treatments.
- Crop rooting depth was assessed at biomass sampling dates. Rooting depths were consistent with typical onion crops, with the majority of roots in the top 30 cm. No differences in rooting depth were noted between treatments.
- Crop nitrogen levels (kg N per tonne fresh weight) varied considerably between sampling dates, with nitrogen levels in early June being nearly twice those in late July

and nearly 2.5 times those in late August (Appendix 1I). This corresponds to the high soil mineral N levels in June, which in turn largely relate to the timings of nitrogen fertiliser application during the crop growth. From approximately this point in the season onwards, crop development is very rapid, utilising the majority of the available N.

- Although variable, crop N was not significantly different at the June or July sampling. At the August sampling, treatment 4 showed significantly higher crop N than the control and treatment 1. However, it is likely that this difference is not meaningful.
- Crop nitrogen uptake (kg N per ha) are also presented in Appendix 1I (note that the same estimated biomass data for August has been used for this data). Nitrogen uptake was generally quite variable between treatments, but was significantly higher in a number of the green manure treatments (particularly 3, 4 and 5) in August compared to the control. The reason for this is not clear.

Cash crop yield and quality

- In general, total (gross) crop yield and gross yield of target size bulbs (55-80 mm) tended to be slightly higher in green manure treatments than in the control, though these differences were not significant (Appendix 1J).
- Defect levels are presented in Appendix 1J. Treatment 1 showed significantly higher levels of neck rot than all other treatments. There was a slight trend towards more double centred bulbs on green manure treatments, though this was not significant. All other defects showed no significant differences between treatments. It was also noted that there was one sample in treatment 4 that had atypically high levels of bacterial rot. As it was unlikely that this result was related to the treatments, the data was reviewed both with and without this data-point. However, since there was little difference in the outcome by discounting the data, the data-point was subsequently included in all analyses.
- Partly as a result of bacterial rot issues, treatment 4 showed significantly lower marketable yield (total yield minus defects) than treatments 2 and 3 (Appendix 1J). However, all other marketable yields were similar to the control (although somewhat variable).

Weed observations

- Weed observations in mid-May (before significant herbicide or mechanical weed control) are presented in Appendix 1K.
- Although observations during crop emergence counts indicated that the control plots (treatment 6) may have been weedier and with more advanced weeds than other plots, recorded data from mid-May does not fully support this. At this assessment, treatments 4, 5, and 6 appeared to have a similarly high weed burden (mainly nettle, potato and redshank) whereas treatments 1 and 3 had a lower weed burden, with treatment 2 in between. Due to the nature of the data, statistical analysis could not be carried out. It is unlikely however that any significant differences in weed burden existed between treatments by this point.

Pest and disease observations

- A small number of bean seed fly (*Delia platura*) and some onion thrips (*Thrips tabaci*) were occasionally noted within the crop, but were not at levels beyond those experienced in the locality and not associated with any particular treatment.
- Occasional downy mildew (*Peronospora destructor*) and bacterial leaf infections (*Pseudomonas* spp.) were noted within the crop, but not at levels beyond those experienced in the locality and not associated with any particular treatment. *Fusarium* was noted at a relatively high level in some areas of the field, but again did not appear to be associated with any particular treatment.

Economic assessment

With no consistent yield differences and no sustained soil nutrient or physical differences found within this project, there could be no significant financial effect of green manures on the second following cash crop. However in organic rotations, this situation is likely to be different, where a short or medium term green manure will be the most likely entry ahead of two years of cash crops and, in this situation, is an acceptable cost for building fertility.

Costs are given below for the typical purchase price of green manure seed mixtures and for establishment and maintenance of the sward at 2010 prices (*2007 prices in brackets*)[1].

- Mix 1 - £107.42/ha (*£80.70*) (cocksfoot, 12.5 kg/ha; red clover, 7.5kg/ha; white clover, 1.25 kg/ha)
- Mix 2 - £87.42/ha (*£68.50*) (perennial rye grass, 12.5 kg/ha; red clover, 7.5 kg/ha; white clover, 1.25 kg/ha)
- Mix 3 as mix 2
- Mix 4 £99.87/ha (*£71.50*) (cocksfoot, 5 kg/ha; red clover, 3.7 kg/ha; white clover, 1.25 kg/ha; crimson clover, 2.5 kg/ha; sweet clover, 3.7 kg/ha; trefoil, 2.5 kg/ha)
- Mix 5 as mix 1

Seed bed preparation, drilling and rolling (if required)	£86.25/ha (*£75.00*)
Topping @ £14.00/ha (*£12.50*) average of 5 x per season	£70.00/ha (*£62.50*)
Total	**£156.25/ha (*£137.50*)**

Since 2006/7 (when the green manures for this project were established), seed prices have risen by 33%, (herbage seed prices tend to reflect cereal returns) and the cost of establishment and management has increased by 14% (due to rising prices of fuel, machinery and wearing parts).

Mixture 2 is the most frequently utilized as a green manure sward, giving a total cost of establishment and management of a typical sward as £206 at 2007 prices, which has risen to £243.67 in 2010, an increase of 18%. Project FV 299 indicated that the typical green manure sward contributed at least 100-150 kg N per ha at the Elveden site. Assuming an average of 120 kg N per ha, this equates to £2.03 per kg of nitrogen.

Current (January 2010) prices for nitrogen (as “Blue Bag” ammonium nitrate 34%N) are approximately £200/tonne, expected to rise to £250-300/tonne during 2010. Assuming an intermediate price of £240/tonne, this gives a cost of £0.71 per kg of nitrogen. However, during the recent high fertiliser prices (mid 2009), ammonium nitrate peaked at around £420/tonne (£1.24 per kg N). With the potential for increasing and more volatile energy prices (closely linking to fertiliser costs), nitrogen could again rise to such levels (or even higher), considerably reducing the price deficit between nitrogen obtained from green manures and that from artificial sources. For information, to match the cost of nitrogen secured by green manures (assuming this to be the only benefit) ammonium nitrate would have to reach £690/tonne.

However, it should be noted that there are other benefits to green manures that are not easily either measured or quantified financially, such as: the potential impact on soil organic matter and structure (particularly when used on a regular basis); assistance in meeting regulatory requirements (Cross-Compliance/NVZ/Single Farm Payment etc.); reducing carbon footprint within the agribusiness. These less well-defined benefits should be taken into account when considering a green manure within the rotation.

Further economic analysis of the green manures used in this project and their costs/benefits to the first year cash crop can be found in the final report of FV 299.

[1] 2007 costs were based on average contract prices in *Agro Business Consultants “Farm Machinery Costs”*. 2010 costs were obtained through discussion with the editors to establish an average increase from 2007 prices, accounting for fuel, labour and machinery increases but also considering market pressure to reduce rates.

Conclusions

This project was an extension of FV 299, and aimed to further evaluate the potential benefits of green manures by investigating the impacts of the treatments in FV 299 on a second cash crop. Only one site from FV 299 was chosen for this extension project on a conventional farm running a typical root crop rotation on light soil. The investigation focused specifically on nitrogen, soil structure, soil moisture retention and crop yield (bulb onions).

Measurements through the season showed that there were no significant differences in soil N, P, K, Mg, bulk density, penetrability, infiltration rate or moisture deficit that could be attributed to green manure treatments. However, the control and one of the longer-term green manure treatments showed a relatively consistent but small trend towards higher soil moisture deficit during periods of crops stress.

Crop emergence was observed to be more rapid and uniform in most of the green manure plots than in the controls at a time of low rainfall and high temperatures. This later development may have contributed to a lower final plant stand in the control plots, as the first post-emergence herbicides may have scorched the younger plants. Conversely, observations indicated that weed emergence was slightly greater within the control than green manure plots.

Crop biomass, rooting depth, and nitrogen content were not affected by green manure treatments. Crop nitrogen off-take was significantly higher in some of the green manure plots than the control in August, although it is not known why. Crop yields tended to be a little higher in green manure plots than the control, but not significantly so.

Although some initial differences in weed levels were visually observed, these were not sustained. No differences in pest or disease levels were noted between treatments.

Overall, few conclusive impacts from the green manures (either positive or negative) were seen in soil nutrients, soil physical condition or in the second cash crop after sward incorporation at this site. It is possible that more marked differences may have been seen at an organic site where lower nutrient inputs may have masked the effects of green manures to a lesser degree.

Based on this study, it can be assumed that any financial benefits from green manures need to be realised within the first year of cash cropping for conventional root crop rotations on light soil. There may be other medium to longer-term benefits or gains of green manures – for example the potential to: capture N; improve soil condition; help meet Cross Compliance/NVZ/Single Farm Payment requirements; help reduce the carbon footprint of agriculture. However, it would be prudent to consider these a bonus to the benefits obtained in the first year after green manure, rather than as an integral part of any calculation of potential benefit.

Technology transfer

Due to the nature of this project as a short-term extension to a completed project, no intermediary technology transfers were possible.

A grower handout and/or HDC article summarizing the project results of both FV 299 and the extension with recommendations is proposed during 2010.

Further dissemination of information relating to green manures (including this work) is to be included within a proposed Ryton Garden Organic (HDRA) new project.

References

Reports submitted to DEFRA:

OC 9016. The use of green manures in organic horticultural systems (1995). Project led by HDRA in collaboration with SCRI.

OF 0118T. Optimization of nitrogen mineralization from winter cover crops and utilization by subsequent crops (1999). Project led by HDRA in collaboration with Warwick HRI.

NT 2302. Utilizing N in cover crops (2000). Project led by ADAS in collaboration with HDRA and HRI Wellesbourne.

OF 0126T. Conversion to organic field vegetable production I (2000). Project led by HDRA in collaboration with HRI Wellesbourne, EFRC and Aberystwyth University.

OF 0191. Conversion to organic field vegetable production II (2002). Project led by HDRA in collaboration with HRI Wellesbourne, EFRC and Aberystwyth University.

OF 0332. Organic field vegetable production - baseline monitoring of systems with different fertility building strategies (2006). Project led by HDRA in collaboration with Warwick HRI and EFRC.

OF 0316. The development of improved guidance on the use of fertility building crops in organic farming (2003). Project led by ADAS in collaboration with IGER and ABACUS.

Reports submitted to the EU:

QLK-CT-2002-01100. EU-rotate_N (2007). Development of a model based decision support system to optimize nitrogen use in horticultural crop rotations across Europe. Project led by Warwick HRI with partners in six countries.

Reports submitted to HDC:

FV 273. A costed study in the use of selected green manures/biofumigants to control selected nematode pests and pythia and their influence on soil nutrition status (2006). Project led by VCS in collaboration with CSL.

FV 299. An investigation into the adoption of green manures in both organic and conventional rotations to aid nitrogen management and maintain soil structure. Project led by VCS in collaboration with Ryton Garden Organics.

Appendix 1A: Experimental plot layout

Plan of the experiment at Site W (Elveden). Plots were 46 by 48m.

1	2	3	Block A
4	5	6	
6	5	1	Block B
4	3	2	
2	3	1	Block C
5	4	6	

Appendix 1B: Details of husbandry operations

	W; Elveden (conventional)
Sowing of autumn swards	22/9/06
Sowing of spring swards	19/3/07
Mowing 1	3/5/07
Mowing 2	4/6/07
Mowing 3	9/7/07
Mowing 4	20/8/07
Incorporation of green manures and land preparation for following crops	December 2007 Desiccated with mixture of Glyphosate + Carfentrazone-ethyl. (latter added to ensure good kill of clovers). January 2008, double disced and deep ridged. February 2008, the ridges were tilled to break up the turf, and then de-stoned
Cash crop 2008	Lady Rosetta (potatoes)
Planting date	19/3/08
Fertilisers	19/2/08: 12 month composted horse manure and pig slurry at 36 tons/ha: N 6.9 kg/t P 3.4 kg/t K 6.7 kg/t Mg 1.6 kg/t 23/4/08: 55 kg/ha Nitrogen 9/6/08: 102 kg/ha Nitrogen
Commercial harvest date	2/8/08
Cultivations post-harvest	2-3/7/08 – double disced + power harrow combi-drill (ryegrass) + rolled
Winter cropping	Ryegrass (*Lolium perenne*) Desiccated 15/09/08 with Glyphosate
Cultivations pre-crop 2009	27-28/11/08 – Disced + subsoiled + ridged + destined 05/03/09 - Bedtilled
Cash crop 2009	Onions (Dinaro)
Drilling date	05/3/09
Fertilisers	25/11/08: Elveden composted manure @ 40t/ha. Approx. available: N 1.1 kg/t P 1.9 kg/t K 4.3 kg/t Mg 1.1 kg/t 23/02/09: K 150kg/ha + Mg 82kg/ha 15/03/09: N 18kg/ha + P 46kg/ha 23/04/09: N 40kg/ha 13/05/09: N 40 kg/ha 20/05/09: P 99kg/ha 13/06/09: N 40kg/ha 09/07/09: N 40kg/ha
Irrigation	27/04/09: 10mm 26/06/09: 15mm 01/08/09: 15mm 10/08/09: 15mm 21/08/09: 15mm
Commercial harvest date	25/08/09

Appendix 1C: Photographs of the trials

Topping green manures 9th July 2007

1st cash crop yield difference (July 2008)
Control plot on left, green manure on right

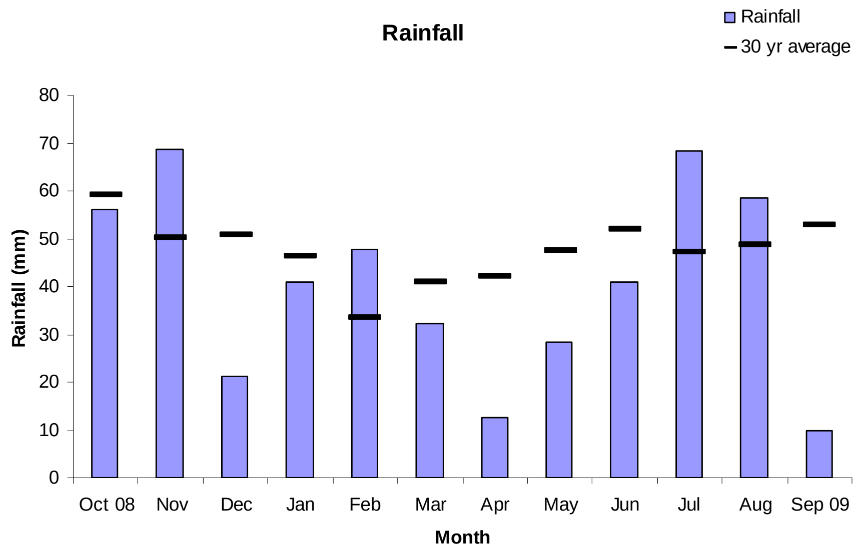
Weed burden in 2nd cash crop on 24th April 2009
Control plot

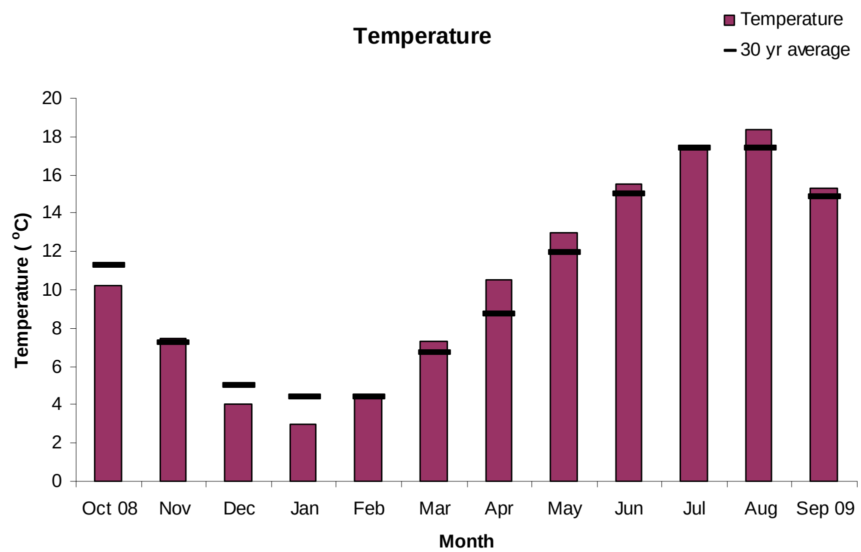
Crop foliage development
5th June 2009

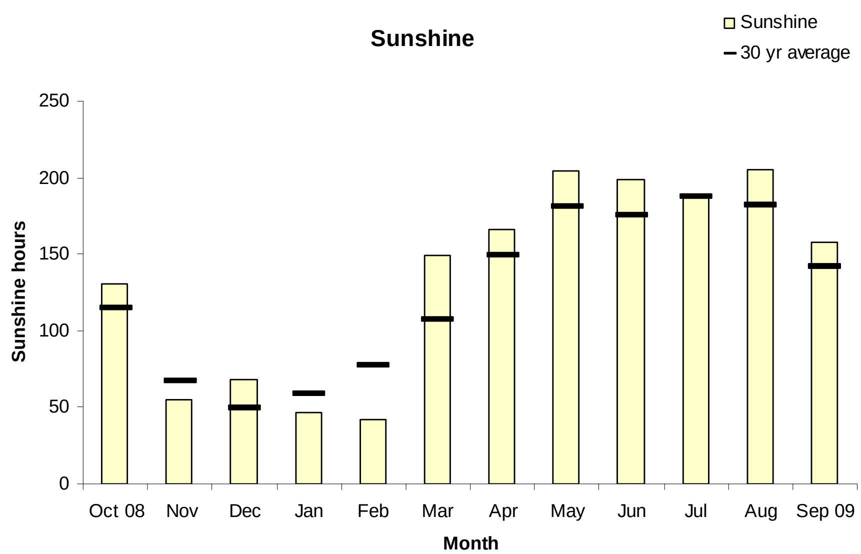
Crop root development
5th June 2009

Final biomass sampling
14th August 2009

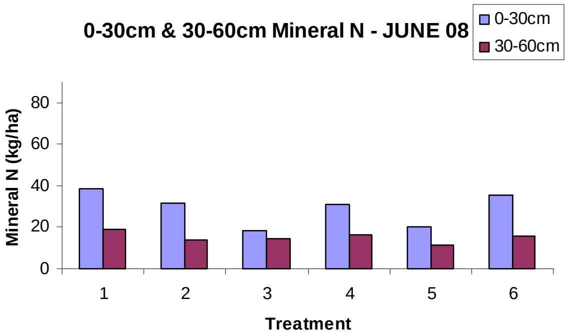
Appendix 1D: Weather data from Cambridge NIAB weather station

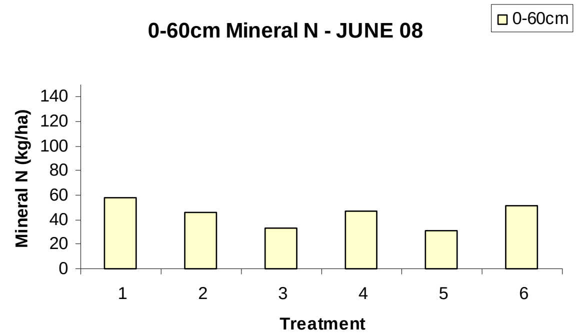


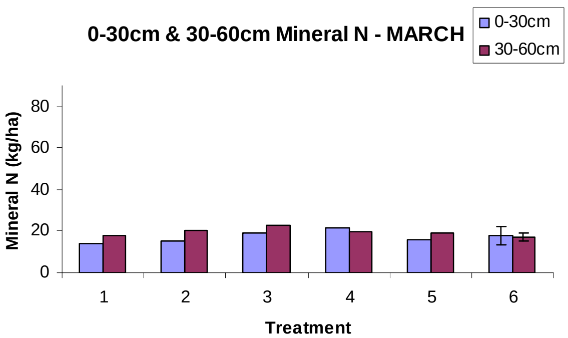


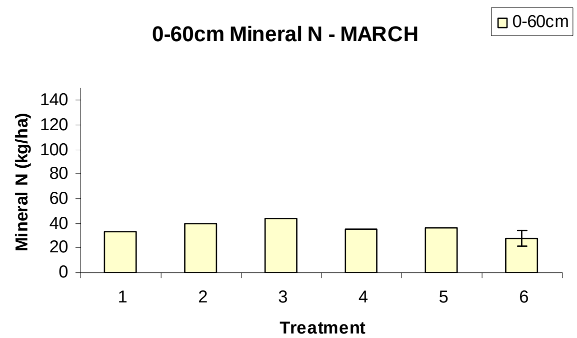


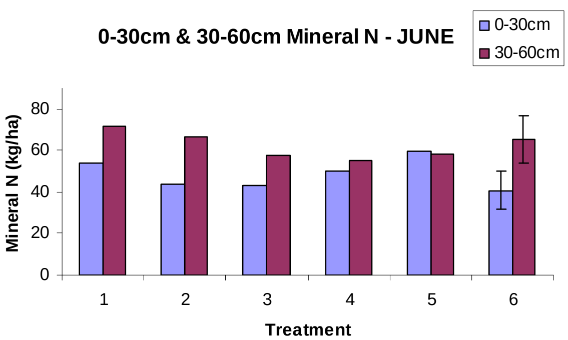
Appendix 1E: Soil mineral nitrogen

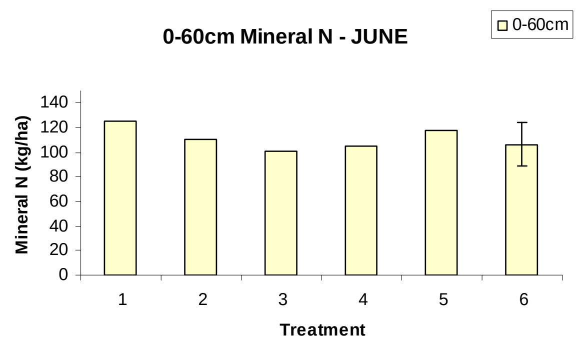


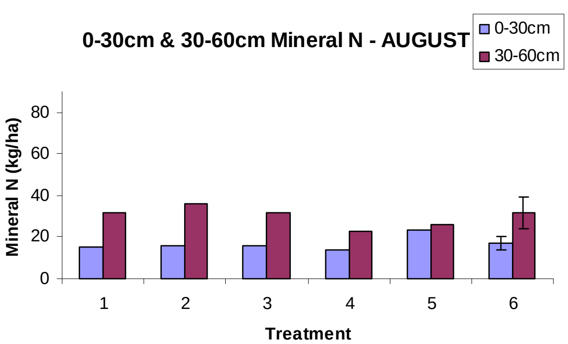


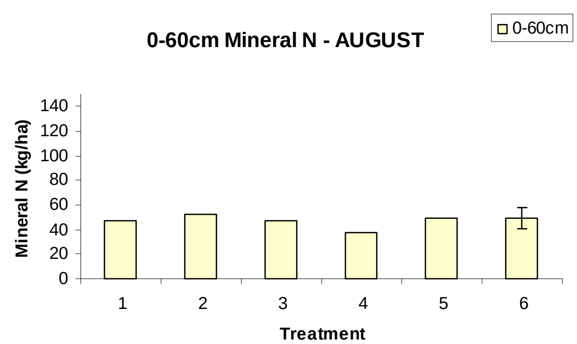












Error bars indicate LSD for each data series (p<5%).

Appendix 1F: Other soil nutrients

Soil P index (average over each treatment)

Treatment	P index	
	March 09	August 09
1	4	5
2	4	5
3	4	5
4	4	5
5	4	5
6	5	5

Soil K index (average over each treatment)

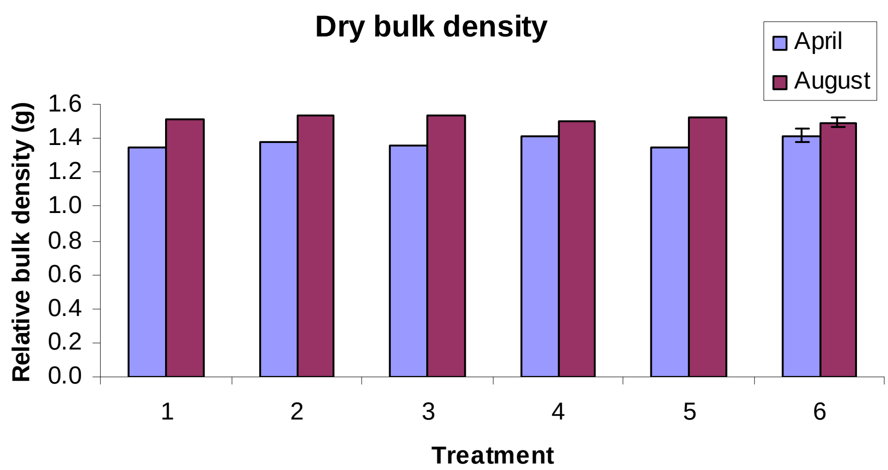
Treatment	K index	
	March 09	August 09
1	3	2+
2	3	2+
3	3	2+
4	3	2+
5	3	2+
6	3	2-

Soil Mg index (average over each treatment)

Treatment	Mg index	
	March 09	August 09
1	2	2
2	2	2
3	3	3
4	2	2
5	3	2
6	2	2

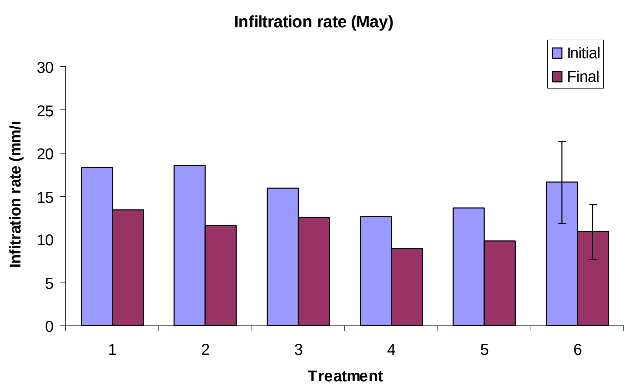
Appendix 1G: Soil physical parameters

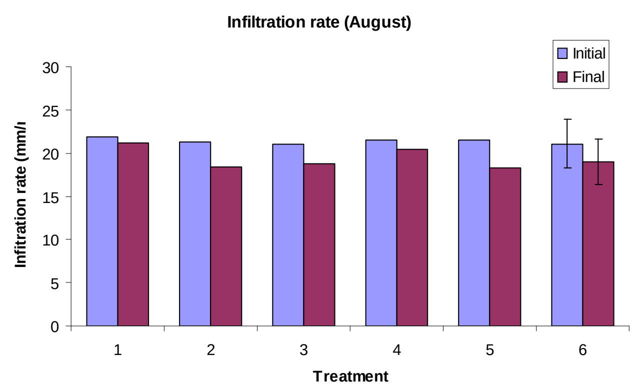
Dry bulk density



Error bars indicate LSD for each data series (p<5%).

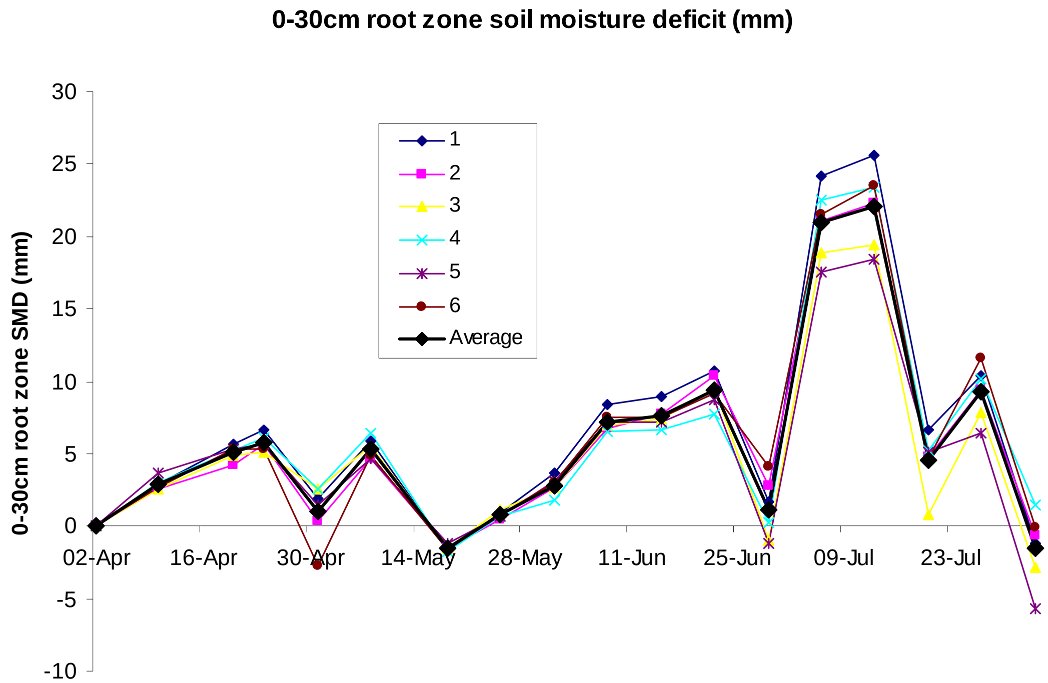
Soil infiltration rate





Error bars indicate LSD for each data series (p<5%).

Appendix 1H: Root zone soil moisture



Appendix 1I: Cash crop establishment and growth

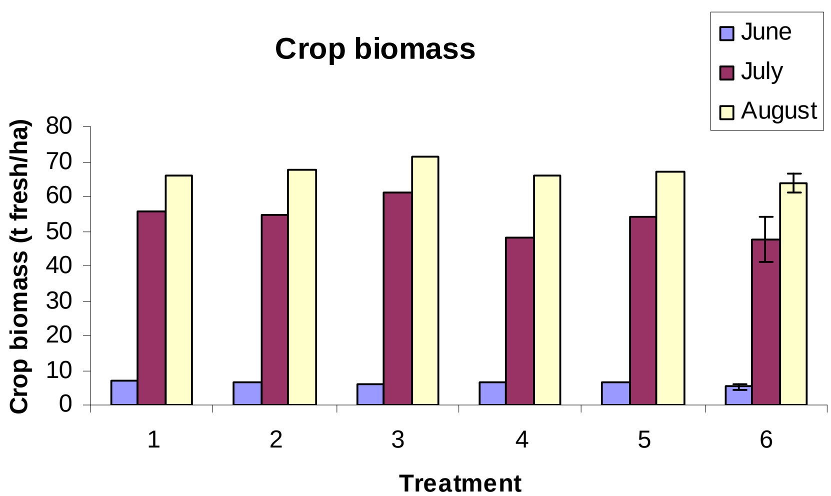
Crop emergence

NB target population = 48 plants/m^2

Error bars indicate LSD for each data series (p<5%).

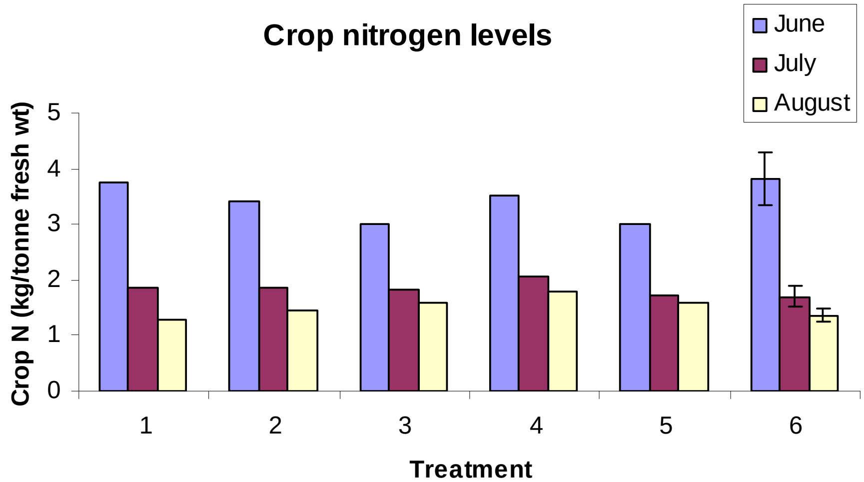
Crop biomass

Note that biomass for August was estimated based on final cured bulb yields, assuming that the cured bulb yield was equivalent to 80% of the fresh plant biomass at harvest.



Error bars indicate LSD for each data series (p<5%).

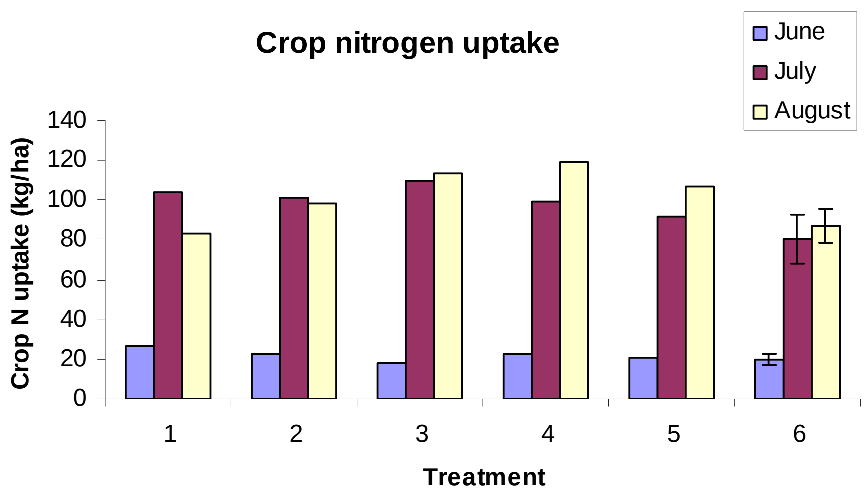
Crop nitrogen levels



Error bars indicate LSD for each data series ($p<5\%$).

Crop nitrogen uptake

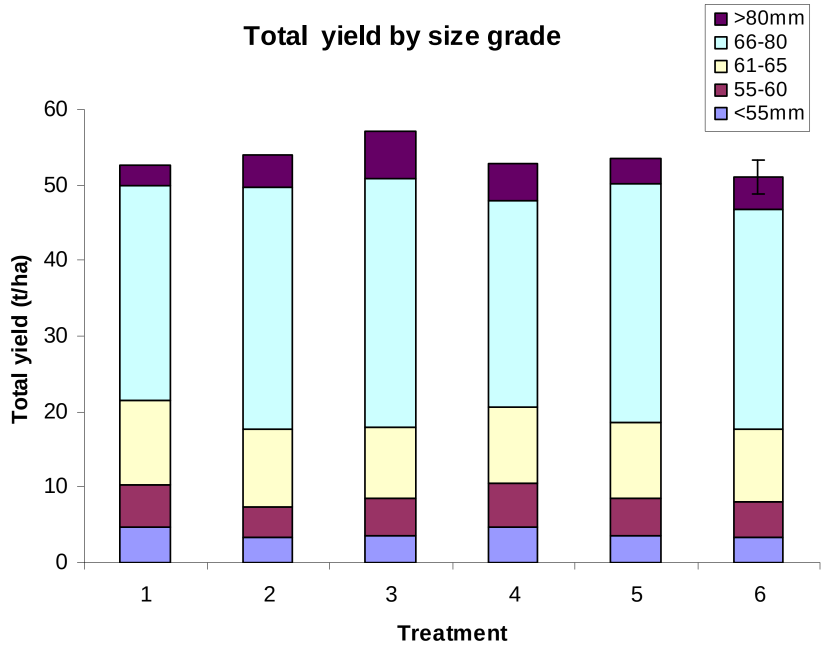
Note that crop nitrogen uptake for August was estimated based on biomass estimate as described.



Error bars indicate LSD for each data series ($p<5\%$).

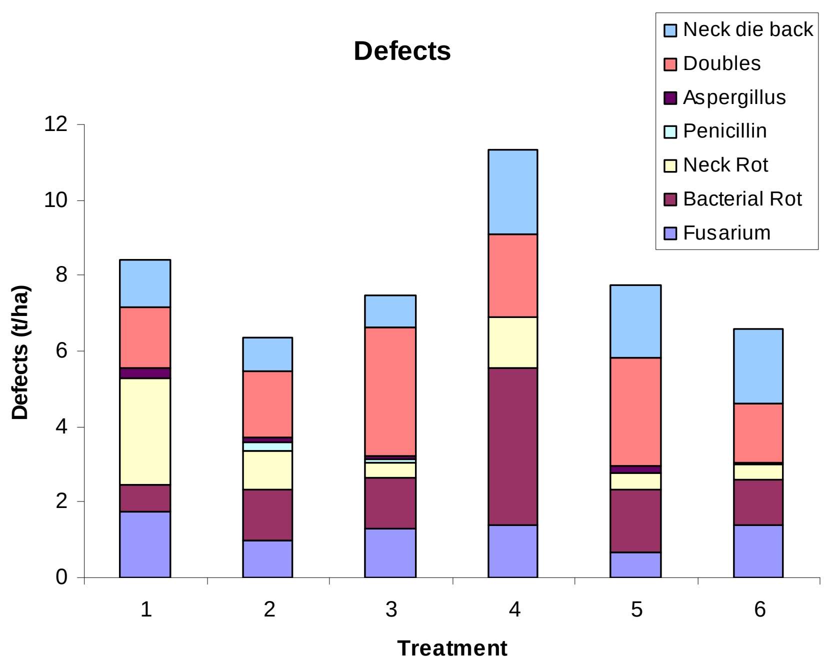
Appendix 1J: Cash crop yield and quality

Total yield by size grade



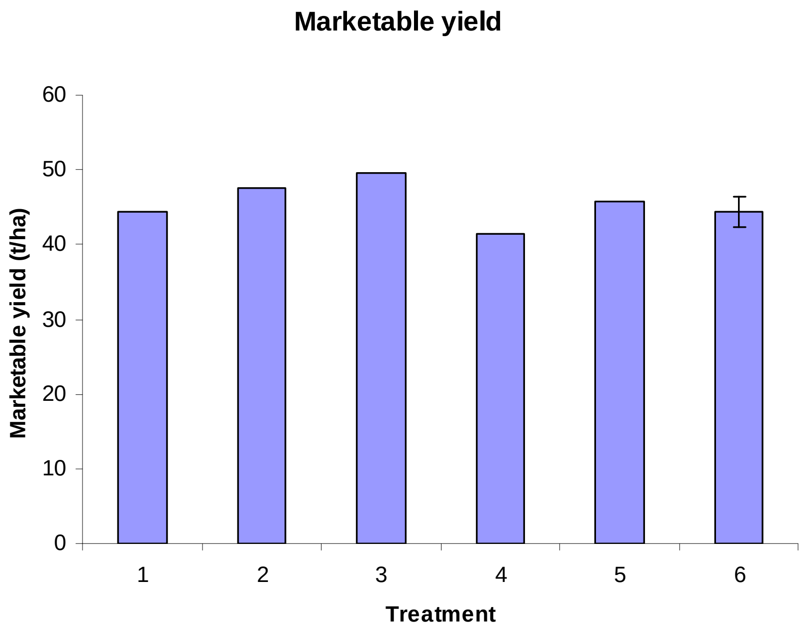
Error bar indicates LSD (p<5%) for total yield (all size grades)

Defects



Note: data slightly skewed due to one sample in treatment 4 with atypically high bacterial rot

Marketable yield



Error bars indicate LSD for each data series (p<5%).

Appendix 1K: Weed observations

Weed observations in mid-May

	Weeds												
Trt	AMG	Nettle	Flix	Cleavers	Fat Hen	Vol. Potatoes	Redshank	Fools Parsley	Clover	Sow thistle	Chickweed	Groundsel	ALL WEEDS
1	0	1.67	0.33	0	1	2	2.67	0.33	0.33	0	0		0.69
2	0	1.33	0	0.33	0.67	2.67	3	0.67	1	0	0	0	0.81
3	1	1.67	0.33	0	0.67	1.67	2	0.67	0	0	0	0	0.67
4	1	3.33	0.33	0	0.67	2.33	2.33	1	1.33	0	0	0	1.03
5	0.67	2.33	1	0	1	2.33	2.33	1	0.33	0	0.33	0	0.94
6	1	3	0.33	0	0	2.33	3	0.33	0.33	0.33	0	0.67	0.94

Key

0	(0-0.5)	**No weed**
1	(>0.5-1.5)	**Low**
2	(>1.5-2.5)	
3	(>2.5-3.5)	**Moderate**
4	(>3.5-4.5)	
5	(>4.5-5.0)	**High**