Improving Paddock Productivity using Renovation Cropping Techniques (DAW628)

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1.0 Introduction

Intensive cropping has led to a number of problems that may threaten the long-term sustainability of cropping in Western Australia. In many areas of the state, declining soil fertility, soil compaction, herbicide resistance and low returns from pulse production in marginal cropping areas are becoming more critical to the sustainability of current farming systems. Growers are now looking for alternative options to increase organic matter; improve soil properties and provide additional non-chemical control options for weed management, whilst providing a break crop effect. International studies indicate renovation techniques such as green and brown manure crops are often associated with the amelioration of poorly structured soils, improved soil nutrition, integrated weed management and increased productivity.

In Australia, yield and protein increases following a green manure phase have been supported by field trials in South Australia where cereal crops following a green manure phase increased grain yields by 34% over a harvested vetch and increased grain protein by 1.8%. The combined value of these benefits can tip the economics in favour of green manure crops, for some soils in some areas. There appears to be little information available on the performance of these techniques in Western Australia, and limited data available from elsewhere in Australia. Much of the literature available results from international work in tropical or semi-tropical climates, which often afford two cropping phases each season. Research to target these priority areas and develop a viable cropping system for growers throughout the state is essential. Part of this integrated approach to farming systems, will be to determine the economic and long term feasibility for a green manure phase under current cropping systems. A review of current and past work relevant to assessing the role of green manure crops in Australia has been carried out; the results of which are summarised here.

Definition of Terms

'Aerobic':	Occurring in the presence of oxygen
'Aggregate':	Group of 'bound' mineral and organic soil particles that operate as a unit. These consist primarily of soil particles (clay, silt and sand) that cohere to each other more strongly than to other surrounding particles.
'Allelopathic':	An inhibition effect of one organism on another.
'Anaerobic':	Occurring in the absence of oxygen
'Anthesis':	Flowering
'Biofumigant':	Plant residues/organic matter containing naturally occurring biocidal chemicals
'Brown manure':	Dessication of the crop at flowering, allowing it to remain standing
'Bulk density':	Ratio of dry soil mass to its bulk volume (relates to available pore space: the lower the bulk density, the more available pore space for water and nutrient storage).
'C:N' ratio:	Ration of carbon to nitrogen content of plant residues
'Green manure':	Incorporation of green plant residue into the soil using a disc or plough.
'Mulch':	Mowing or slashing of a green manure crop, so that the plant residue is left laying on the soil surface.
'Immobilisation':	The fixation of nitrogen and other nutrients by microorganisms
'Mineralisation':	Process of conversion (oxidation) of nitrogen and other nutrients from an organic form to an inorganic (available nitrogen) form.

'Nitrification': Process of conversion of ammonium to nitrate.
'Non-wetting': Water repellant
'Volatilisation': Loss of nutrients through gas exchange (vapour) from soils and plants. For example the conversion of NH^4 ions to ammonia gas (NH^3) which is lost to the atmosphere. Higher rates are more likely to occur on alkaline soils.

2.0 Literature Review: Research findings on the role of green manure crops within current farming systems in Australia

2.1 What is a green manure crop?

Green manure crops are defined for our purpose as a crop grown with the principle aim of returning it to the soil. This method has been used in the past by growers, and is experiencing renewed interest as a tool to increase organic matter; improve the physical, biological and chemical properties of soil and as an integrated weed management tool. Other potential benefits associated with the implementation of a green manure crop include a reduction in the level of chemical inputs required in the farming system, the conservation of soil moisture and a potential biofumigation or 'break' crop effect for the control of root disease and pests in subsequent crops.

Renovation cropping techniques refer to a range of incorporation methods utilised for green manure crops and may preclude soil disturbance, where erosion is a risk by utilising non-destructive methods such as brown manuring (dessication) or mulching (mowing/slashing) of plant material. Due to differences in the amount of soil contact associated with each of these methods, it is likely that potential changes in the amount, or pattern of decomposition will be observed for different crops and environments.

2.1.1 Green Manure

Conventional green manure crops incorporate green plant material into the soil using discs or a plough (Plate 1). The optimal time for incorporation is at, or soon after flowering and prior to grain filling. Incorporation after this time can still be achieved, but plant material may need to be further 'chopped up' to ensure the breakdown of residue that has become more 'woody'. Later incorporation is likely to increase potential problems associated with volunteer 'weeds' in the following crop and increase the potential for weed seed set.

Plate 1. Green manure vetch crop incorporated by ploughing, Western Australia

Green manuring is most effective when done under adequate soil moisture, with plant decomposition accelerated by additional rainfall and continuing moist conditions. Plant decomposition is largely a result of microbial soil processes and therefore the optimal depth for incorporation should be between 5 and 7cm, and no deeper than 10cm. Deeper incorporation may result in slow residue breakdown, due to anaerobic conditions and reduced microbial activity at depth.

To reduce the risk of erosion, aim to retain approximately 30 percent of the plant material on the soil surface. This is particularly important on lighter soils.

Green manure crops may have a knockdown herbicide applied prior to incorporation to ensure no weed seed set takes place and to minimise the chances of crop re-growth with late spring rainfall. The machinery employed to green manure is primarily restricted by what is 'on-farm' and may range from scratching in the residue, to complete incorporation using a moulbord plough. In Western Australia, growers have experienced relatively good success using offset scalloped discs, which aid in chopping up residue and achieve good burial with approximately 20 to 50 percent of material left on the surface.

Crop habit can influence the extent to which residues can be managed. Incorporation of 'trailing' crops such as field peas or serradella is sometimes difficult due to the tendency for these crops to entwine and resist breaking. These crop types can often form a mat on the soil surface, particularly when soil is dry. Crops producing high amounts of organic matter or biomass, are likely to experience problems associated with poor levels of incorporation, whilst low biomass crops can result in low levels of residue retention on the soil surface. Low incorporation is unlikely to result in problems, but care should be taken when managing low biomass crops to minimise erosion risk.

Soil type must be considered when making decisions on the method of renovation and careful cultivation is recommended to minimise damage to soil structure. Lighter soils at risk of erosion should be treated with care, and mulching or brown manuring are the preferred management option.

2.1.2 Brown Manure

'Brown manuring' involves dessication of the crop using a broad-spectrum herbicide at flowering, (Plate 2) and is considered safe to use on lighter soils where the potential for erosion is high.

Significantly less soil: plant contact is associated with this technique and consequently, the decomposition of plant organic matter will be slower. Often standing crops are associated with a greater potential loss of nitrogen benefits through volatilisation (Whitehead and Lockyer, 1989), so timing may be the key in maximising the potential returns with this method. Rainfall events directly following brown manuring will aid in the reduction of potential losses.

Plate 2. Brown manure Serradella (Cadiz) pasture dessicated at flowering, Western Australia

The benefits for this method are in minimising the level of soil disturbance, which can aid in water conservation through reduced evaporation levels and slower rates of nutrient release. Disadvantages may exist where a large amount of biomass is accumulated, and material is not broken down sufficiently prior to seeding to allow the passage of machinery. This may occur in some instances where insufficient summer and pre-seeding rainfall is experienced.

2.1.3 Mulch

'Mulching' involves the mowing or slashing the crop, so that plant residue is left laying on the soil surface (Plate 3), enabling better access to soil moisture and helping reduce evaporation. Material that is broken or shredded into smaller components is likely to be broken down more rapidly, therefore residue breakdown will be influenced by the type of machine used.

Plate 3. Mulched field pea crop, Western Australia

This method also has greater potential for losses to occur by volatilisation. Advantages for this method are associated with minimal disturbance of the soil structure, a reduced risk of erosion and potentially more rapid breakdown compared with brown manure. Herbicides may be employed either prior to or post slashing to ensure control of any smaller weeds present, or alternatively as a strategy for the control of crop and weed re-growth.

2.2 Plant species suited for use as a green manure crop

Green manure crops can offer advantages similar to a legume phase for improving grain yield and quality in subsequent crops, and additional benefits in improved soil health, increased weed control and control of soil-borne diseases and pests.

It is essential that growers should consider the major constraint limiting production prior to implementing a renovation phase, as this can influence the type of crop or pasture species chosen. Inappropriate crop choice or implementation of techniques in paddocks where grain yields are not constrained may result in little or no benefit. For example, anecdotal evidence from trial work in Western Australia suggests densely sown crops, or crops with early vigor such as oats and barley are more effective in controlling weeds and would be considered beneficial as part of an integrated weed management strategy. In paddocks with a high grass weed burden however, further benefit would be associated with seeding of large seeded forage legumes which are generally more vigorous than small seeded pasture legumes, and have been shown to be more competitive against grass weeds than either pasture legumes or lupins (Condon, 2000). Additional benefits in using legumes would be associated with the high nitrogen value of the plant residue.

When contemplating a new plant species as a green manure crop, evaluation of crop performance on a small area is recommended for adaptation to local soil and climatic conditions, as some of the recommendations made for other states of Australia, are either not suited or not available in Western Australia.

Legumes
Grain legume crops such as field peas, vetch and lupins are used predominantly in Western Australia for their rotational benefits, although it is also common to have mixes such as pea: canola ('peaola') and pea: oat crops being utilised for feed. Pasture legumes are also common in mixed farming systems, and are used both for increasing animal productivity as well as grain production. Legume crops to be used as a green manure, should be managed to produce a maximum amount of biomass and incorporated whilst still green and prior to grain filling. Large seeded legumes are generally more competitive against grass weeds, whilst pasture legumes are generally slower in accumulating biomass, and therefore provide less competition against early germinating weeds.

Brassica's
Plants such as canola (*B. napus*), mustard (*B. juncea*) and turnip weed (*Rapistrum spp.*) are currently promoted as biofumigants because they contain glucosinilate's (GSL's) throughout their plant tissue. When broken down, these GSL's produce isothiocyanates (ITC's) which in turn release naturally occurring biocidal compounds similar to metham sodium, a commercial chemical currently widely used throughout the world as a soil fumigant (Matthiessen *et al.* 1995).

Research suggests these compounds (or the combined action of the compounds) can be toxic to groups of soil fungi including *Rhizoctonia*, *Pythium* (Manici et al. 1997), *Take-all* (Angus et al. 1991), *Fusarium* and may also be associated with the suppression of a range of nematodes (Kirkegaard and Matthiessen, 1999).

The use of Brassica crops as a green manure crop is therefore largely associated with the control of cereal root diseases (Matthiessen and Kirkegaard, 1997), as they contribute only a small amount of mineral nitrogen per ton of dry matter, and have a slower decomposition period than high nitrogen crops. Primary benefits are associated with paddocks in which there is a high root disease carry over and as previously discussed, may be sown in combination with a legume crop such as field pea or vetch to provide higher levels of residue nitrogen.

Cereals
Cereal or non-legume crops may be an appropriate choice where nitrogen conservation is desired, such as on lighter textured soils prone to leaching or on soils where high levels of nitrogen already exist. Their purpose in this scenario would be to immobilise nutrients and prevent them from leaching. Cereal crops such as oats and barley are also suited to the control of germinating weeds, due to their rapid biomass production and competitive habit. As discussed with brassica species, these may be intersown with a legume if desired.

2.3 Management of green manure crops

To date the adoption of green manure crops in Western Australia is largely a response to either seasonal factors where yield is constrained by low rainfall, disease and frost; or where long term problems have been identified such as continued fertility decline or high weed burdens. Consequently, the management of green manure crops can vary from 'high' to 'low' inputs depending on whether implementation of a renovation phase has been planned. Management can and generally should include the use of fertiliser, insect and disease, and weed control measures.

Renovation to increase production of grain crops on low fertility soils is likely to require normal fertiliser use and appropriate weed and pest management in the year of renovation to maximise crop biomass, and optimise subsequent nitrogen availability. Similarly, renovation to build soil organic matter requires a significant input of plant residue which will rely on normal inputs and management practices. Failure to use appropriate seed dressings and fertiliser for example, could result in poor crop germination and establishment or plant vigor, resulting in poor biomass production and hence limiting potential benefits to the following crop.

Control of weeds using renovation crops should incorporate management techniques that increase the competitive ability of the crop in competing for nutrients, water and space. Where root disease is not a factor and high weed burdens are not a factor, it is possible to reduce herbicide inputs and particularly the use of selective herbicides for the control of weeds. Where herbicide resistance is not an issue, selective herbicides may be used in crop for the control of high grass weed burdens to reduce the potential for cereal root diseases. The primary aim in using any of these methods is to ensure no viable weed seed is returned to the system, hence timing is extremely important.

The use of a knockdown herbicide prior to renovation cropping ensures maximum control of weeds. Other tactics such as delayed seeding, rotational grazing and effective application of knockdown chemicals to control early weed germination can also increase the efficacy of early weed control. Where possible, plan crop sequences to allow a rotation of chemical groups to reduce the risk of herbicide resistance. For effective long-term management of weeds, techniques should achieve 100% seed set control of weeds at flowering. Timing is therefore critical.

Planned green manure crops should therefore be managed in a similar way to a grain crop if maximum benefits are to be achieved. Lower inputs can however be considered when assessing a salvage option for a 'failed' crop, or where root disease is not a major constraint to production.

2.3.1 Managing crop residues

Consideration should be given to the level of plant residue likely to remain at seeding and management of the seedbed in regard to the capacity of available machinery in handling these, given the incorporation of residues may have resulted in an uneven soil surface. Normal seeding preparation applies to the preparation of the seedbed, but where large clods have resulted from incorporation, the use of a bar harrow with minimal soil disturbance is generally sufficient.

In most soils the decomposition of plant residues is a microbially mediated process, with the primary aim of obtaining energy for respiration. Decomposition of residues is likely to be influenced by the microbial structure of the population, the chemistry of the residue and soil factors driving microbial activity, such as fertility and moisture. Decomposition of green legume residues can generally be expected to be rapid, with up to 40% of residue mineralised within 12 months (Ladd *et al.*, 1985; Fillery, 2001). A slower rate of decomposition should be anticipated for cereal or brassica residues, and older plant residues that possess a wider C:N ratio and high amounts of recalcitrant materials such as lignin and cellulose. Limiting contact of organic material with the soil surface is also likely to result in slower mineralisation of residues.

The application of a food or energy source to stimulate microbial activity has been used in the past to enhance stubble decomposition, but is generally limited in use to when soil conditions are considered adequate to sustain microbial activity. Cultivation on opening rains can also stimulate microbial activity and breakdown of residues but is not a preferred practice for low tillage farming systems and depending on the quality of residue, may result in either a faster rate of mineralisation (resulting in nitrogen being more subject to leaching), or an immobilisation of soil nitrogen (often reflected in poorer establishment and plant growth of the subsequent crop). Normal fertiliser application would be required in the latter case, primarily to buffer the effect of nitrogen immobilisation from the soil by microbes, particularly on soils with low or marginal nitrogen levels.

Stubble burning will effectively reduce stubble loads, but will result in the loss of organic matter and potential longer-term benefits. Seeding practices are therefore most likely to result in mutual benefit from appropriate management of plant residues and application of fertilisers, such as the use of seeding discs, or the use of coulter discs to cut, move aside, or lift undecomposed plant material. If cultivation prior to sowing is genuinely required, this should be done as close to seeding as possible to avoid early loss of nitrogen.

2.3.2 Allelopathy

Allelopathic effects are sometimes associated with the residues of crops and weeds such as blue lupins (*L. angustifolius*) and Goosefoot (*Chenopodium pumilio*), reportedly resulting in a reduction in germination of crops following weed control in the weeks prior to seeding, or following the incorporation of stubble. Poor germination and establishment (reduced vigor), or a potential reduction in nutrient availability to the crop through immobilisation of soil nitrogen can result in reduced biomass production and grain yields of cash crops, hence limiting the potential benefits associated with retention of organic matter. However, management strategies implemented at least six weeks prior to seeding should effectively minimise any risks to crop production.

2.3.3 Biofumigation

The potential for improvements in crop productivity using a range of *Brassica* crops as biofumigants has been identified in Australia (Matthiessen and Kirkegaard, 1997). The level of phenylethyl isothiocyanate produced for example, appears to be related to the suppression of both fungal and nematode populations, particularly root lesion nematodes (*Pratylenchus spp*.) in the soil (Eds. Kirkegaard and Matthiessen, 1997).

The effectiveness of biofumigant crops can vary depending on the crop type and the part of the plant used (Kirkegaard, 1995). A large proportion of the ITC's produced by the breakdown of canola and mustard residues for example, are produced almost exclusively from the root biomass, despite shoot residues containing twice the potential amount of ITC as a result of greater biomass (Eds. Kirkegaard and Matthiessen, 1999). It is therefore likely that plant 'roots may play a more prominent role than shoots, in contributing allelochemicals' which have a biofumigation effect (Eds. Kirkegaard and Matthiessen, 1999).

Recent studies (Kirkegaard *et al.* 1996) also indicate the type and age of the residue will influence its effectiveness. The concentration of GSL's in root residues for example, have been found to vary for different crop species, mustard generally being more suppressive than canola tissue; whilst mature tissue is also less effective than green tissue at suppressing a range of soilborne pathogens (Kirkegaard *et al.* 1996). Disease suppression is therefore related to the concentration and type of ITC's released (which varies with tissue type and species), and the sensitivity of the pathogen (Kirkegaard *et al.* 1996). Therefore the growth stage, as well as the plant species will influence the potential for biofumigation through the release of ITC's.

Brassica crops have been shown to suppress a range of fungi (Chan and Close, 1987), nematodes (Mojtahedi *et al.* 1991) and wireworms (Brown *et al.* 1991), providing superior break crop effects (Kirkegaard *et al.* 1994) compared to other crops. It is also important to consider that although the potential to use GSL containing plants for pest control has been recognised, little is known about the formation of toxic allelochemicals in soil (Eds. Kirkegaard and Matthiessen, 1999) and their effect on a range of beneficial fungi such as Vesicular-arbuscular mycorrhizal (VAM) fungi. To date, the benefits of incorporating residues as a green manure crop have not yet been clearly demonstrated in Western Australia.

2.4 Integrated Weed Management

An important aspect of effective weed management is the potential for control strategies to both prevent the build up of weed seeds, as well as reduce the weed seed bank over time. A number of management options such as hay cutting, incorporation of rotational crops and pasture phases, have been shown to be effective strategies in controlling weeds (Craddock *et al.* 1995), and the value of alternative control strategies such as green or brown manure crops must be assessed relative to these.

Little quantitative evidence exists on the level of weed seed carry over associated with green or brown manuring and the subsequent impact on seed bank dynamics. However, a number of studies in Western Australia (Hoyle, 2002; Revell and Hudson, 2001; Newman *et al.* 2001; Roy, 2001) indicate a significant reduction in weed numbers is possible when these techniques are imposed (see Table 1, Plate 4).

Table 1. Density of in-crop annual ryegrass (Lolium rigidum), grain yield and protein of wheat cv. Westonia grown in 1999 after a range of pasture treatments were imposed at Cunderdin, Western Australia in 1998 (Data are a subset of those given in Revell and Hudson, 2001).

Treatment	In crop ryegrass (plants/m2)	Grain yield (t/ha)	% Yield of control	Protein (%)
Untreated control	1925	2.03	100	9.5
Green manure	163	2.97	146	9.4
Brown manure	150	4.14	204	9.6
Green mulch	238	2.93	144	8.9

Plate 4. Wheat crop following a green manure treatment (on left) and harvested treatment (on right) imposed on field peas in the previous year at Bindoon in Western Australia (Hoyle, 2002)

A number of options are available for the control of weeds in current farming systems. A relative comparison of different methods in controlling annual ryegrass for Western Australia (Table 2) indicates renovation techniques are likely to provide an effective option for weed control in an integrated weed management (IWM) strategy.

Table 2. A comparison of the reduction in in-crop annual ryegrass density after green manure cropping against conventional weed control strategies at a range of sites in Western Australia

Method	Effective reduction in annual ryegrass density
Green manure	95-100% (F. Hoyle 2000; A. Douglas, 2002; V. Stewart, 2002)
Brown manure	90-92% (V. Stewart, 2002)
Burning	95% (A. Douglas, 2002)
Hay cutting	85-89% (V. Stewart, 2002)
Crop topping	82-85% (V. Stewart, 2002)
Seed/chaff carting	40-75% (V. Stewart, 2002; Walsh and Parker, 2002)
Increased seed rates	50-55% (V. Stewart, 2002; A. Douglas, 2002; D. Minkey, 2002)
Trifluralin	92% (Newman *et al.* 2001)
Hayfreezing pastures	55-80% (Blake and Lauritsen, 2002)
Grazing	0-95% (Blake and Lauritsen, 2002; Revell and Glasson, 2002)

The impact of different control strategies on both short and long term economics must be considered, particularly where utilising tools such as green or brown manure crops, as this will have a significant impact on cash flows in the short term. In New South Wales, a comparison of different cropping rotations indicates both green manure and silage treatments cut prior to seed set were most effective in reducing grass weeds (Condon, 2000). However, the green manure phases provided a relatively low economic return over 3 years when compared to the silage treatments, despite significantly higher wheat grain yields (Condon, 2000). This indicates that green manure crops in this situation may be profitable only where the weed population is high, or where herbicide resistance to a range of chemicals exists.

2.4.1 Phase management

For most farmers the best way to manage herbicide resistance when it develops is to change their rotation. Successful management for herbicide resistance generally requires a minimum of at least two consecutive years where farmers must control seed set, and usually requires at least one non-crop year (Payne and Wurst, 1995).

Growers will often consider including two or more years of consecutive pasture because there is generally a low cost of adoption, minimal risk and longer phases generally make it a more profitable option (Bathgate, 1992). The benefits of consecutive years in which weed seed set control is achieved, is demonstrated in an analysis of seed bank dynamics carried out on 31 paddocks over 5 years in South Australia (Craddock *et al.* 1995). This study indicated single year phase pastures reduced seed bank levels in 40 percent of paddocks surveyed, whereas longer pasture phases of 2 years or more resulted in lower seed bank levels in 88 percent of paddocks (Craddock *et al.* 1995).

This is supported in Western Australia, where anecdotal evidence indicates it may take up to three years on some soil types (non-wetting sands) to control weeds (Newman *et al.* 2001). This is likely to be due to a lower proportion of the seed bank germinating through time on this soil type. However, significant control - even on these difficult soil types can be achieved with two years of seed set control. The potential for these techniques to increase the control of ryegrass on these soil types is demonstrated in an unreplicated trial at Mingenew, in WA. Here, an initial ryegrass population of 300 plants/m^2 was increased by 470% (1433 plants/m^2) under harvested treatments, and reduced by 45% (163 plants/m^2) after brown manuring in a single year (Newman *et al.* 2001). This was further reduced with a second year of control (brown manure) to less than 25 plants/m^2 (Newman *et al.* 2001). Other trial data that support the control of at least two consecutive years of ryegrass populations using an integrated weed management strategy, include trials carried out in Dowerin, York and Corrigin (Roy, 2001).

The long-term financial value of green manure crops within an integrated ryegrass management system has been analysed using the Ryegrass Integrated Management (RIM) model (Pannell *et al.*, 1999). The focus for these analyses was a) how large a ryegrass seed bank needs to be before it is worth green manuring lupins, and b) how biological or economic variables affect this break-even weed density (Monjardino *et al.* 2000). Preliminary results suggest this practice provides effective weed control and that its value increases as the weed numbers increase in the system (Monjardino *et al.* 2000). The incorporation of complementary management tools such as two consecutive years of weed control, a knockdown herbicide application, a tickle and delayed seeding of the green manure crop also proved effective in increasing the success and subsequent profitability of this technique (Monjardino *et al.* 2000).

The impact of changing the weed population dynamics should also be given some consideration, as the opportunity for other weeds such as Brome grass (*Bromus spp.*) to become more dominant may be possible by reducing competition from annual ryegrass or other targeted weeds (Newman *et al.* 2001).

2.5 Soil organic matter, residue breakdown and nitrogen release

Soil organic matter (SOM) is the fraction of soil that originates from living organisms (Chaney *et al.* 1994), either alive or in various stages of decay. It is often associated with 'healthier' soils and changes in SOM are considered a valuable indicator of the 'sustainability' of cropping systems (Payne and Wurst, 1995). Soil organic matter is composed of several pools that differ in decomposition rate, due largely to the complex nature of organic residues which contain both readily decomposable and resistant material (Chaney *et al*. 1994). The incorporation of organic material into the soil is generally considered desirable, as it makes it available for processing by microbes and conversion to humus. This enhances the capacity of the soil to sequester or 'lock up' nutrients, and prevents them from leaching from the soil.

A combination of moist soil and high temperatures create the most favourable conditions for decomposition of organic matter (Chaney *et al.* 1994), therefore soils with a greater ability to retain moisture, would generally be considered to have a higher biological activity and more rapid turnover (Shields and Paul, 1973). It is logical then to consider that retention of plant residues on the soil surface, will influence the decomposition of organic matter and subsequent mineralisation of nitrogen by maintaining soil moisture levels for extended periods and, subsequently stimulating microbial activity (McCalla and Russell, 1948; Murphy, 2000). Retention of plant residues through mulching, or green and brown manuring should therefore potentially result in enhanced nutrient cycling and availability. Ultimately, the rate of decomposition is primarily dependent on rainfall (Reincke, 1996).

2.5.1 Management of soil organic matter in Western Australia

In Western Australia, recent research has attempted to quantify the capacity of the soil to build soil organic matter (OM) and as a consequence, improve soil physical and chemical fertility (Hamza, unpublished) through the retention of organic residues over three years. These trials indicate OM build up was generally not influenced by the sequence of crops as demonstrated on three soil types in the low rainfall areas of Western Australia (Table 3).

Table 3. Raw organic matter (t/ha of dry matter) contributed to different soil types soil at Merredin, Nungarin and Tammin (98ME155, 98ME 156, 98ME 157) between 1998 and 2000 (Hamza, unpublished).

	Total plant OM contributed (t/ha)		
	Sandy clay loam (Merredin)	Loam soil (Nungarin)	Loamy sand (Tammin)
Rotation 1 (faba: field pea: oat)	11.9	9.1*	11.8*
Rotation 2 (field pea: oat: faba)	13.0	12.0	14.7
Rotation 3 (oat: faba: field pea)	11.5	12.7	12.5

* Lupin used in place of faba beans at this site

Not surprisingly, increases in soil organic matter (SOM) were observed following incorporation of plant residues in the first two years of application (Table 4) during which both rainfall and soil water were adequate. In 2000, low rainfall combined with warm weather immediately preceding crop incorporation resulted in a sharp decline in dry matter production of the crop and led to rapid OM decomposition.

This resulted in a slight decrease in the soil organic matter in 2000. This confirms previous research indicating the loss of soil organic matter (SOM) is strongly dependent on the interaction between temperature and precipitation (Carter, 1996). Cool, wet conditions are generally favourable for slow turnover of organic material resulting in increased SOM accumulation, whilst moist, warm climates result in rapid decomposition and loss of SOM (Tate, 1992; Cole *et al*., 1993)

Table 4. Soil organic matter (SOM%) in soil measured at Merredin (98ME155), Nungarin (98ME156) and Tammin (98ME157), prior to treatments being imposed in April 1998 and following green manure treatments imposed in 1998-2000.

	Initial SOM (%)	*Average SOM (%) of all GM Treatments (Oats, field peas, faba beans)		
		1998	***1999***	***2000***
Sandy clay loam	1.30	1.56	1.94	1.87
Loam	1.61	1.97	2.32	2.22
Loamy sand	1.31	1.90	2.31	2.24

* Average treatment results are presented, as no significant difference in treatment effects were observed

In contrast to previous research (Campbell and Souster, 1982; Ladd *et al.*, 1981), the accumulation of soil organic matter was higher on soils with lower clay content and coarser texture (Table 4). This trend is most likely a result of higher soil fertility at this site, as demonstrated by increased dry matter production (Table 4) and yield gains of between 5 and 14 % (data not presented). Since we know that the rate of decomposition and potential nutrient turnover can be affected by soil type (Reincke, 1996), this data may suggest that the decomposition of organic matter was higher on soils with lower clay content. Coarse textured soils may result in more rapid decomposition of OM through better aeration (Reincke, 1996) or is perhaps associated with soil moisture levels as influenced by changes in soil texture (Myers *et al.* 1982; Stanford and Epstein, 1974; Reichman *et al.* 1966; Miller and Johnson, 1964).

Given it was considered unlikely that any significant gain would be measurable in the short term for soil organic matter in Western Australian soils, particularly on the coarse textured sands, the increase in SOM reported in 3 years is significant. Soil organic matter levels are influenced by agricultural practices including tillage, type and amount of plant residue added and crop rotation (Chaney *et al.* 1994). However, the primary influence of these factors in influencing the stability of the SOM and subsequent nitrogen availability is the rate of decomposition (Chaney *et al.* 1994) as affected by moisture. It is generally considered unlikely that any significant gain will be measurable in the short term for soil organic matter for Western Australian soils, unless soil physical properties are also improved to maximise soil water storage and fertility (Hamza, pers. comm.).

2.5.2 Decomposition of plant residue

Microbes require both carbon and nitrogen to grow, and the ratio of these within the plant is therefore very important in determining the rate of decomposition and potentially available nutrients (Chaney *et al.* 1994).

Decomposition of green legume residues is generally rapid, with up to 40% of residue mineralised within 12 months (Fillery, 2001). Due to rapid decomposition of low C:N residues, nitrogen may be in excess, resulting in greater potential losses of nitrogen from the system through leaching (Chaney *et al.* 1994) on highly fertile soils, and potential acidification of the soil. On poorly fertile soils, the addition of residues high in nitrogen (low C:N ratio) such as a legume crop may result in an initial tie up of nitrogen, but this is generally followed by a rapid release of nitrogen through continued mineralisation of organic matter and remineralisation from the microbial biomass (Bowden *et al.* 1985).

The addition of high C:N material such as wheat stubble or cereal residues, stimulates microbial activity and increases the demand for nitrogen (Chaney *et al.* 1994). Where insufficient nitrogen is available from decomposition of the residues, nitrogen will be immobilised from the soil (Sims and Frederick, 1970; McCalla and Russell, 1948; Reincke, 1996) making it temporarily unavailable to plants. The impact of this immobilisation can be on poorer establishment and plant growth and reduced grain yields, and therefore has greater implications for nitrogen management in subsequent grain crops.

Immobilisation of soil nitrogen may vary with the amount of residue added or duration of incubation (Reincke, 1996), particularly for residues with low N content (Smith and Douglas, 1969; Jenkinson, 1977). It is possible that these effects may be counteracted later in the growing cycle following deeper root exploration, or through an increased rate of mineralisation of soil nitrogen (Bowden *et al.* 1985). It is likely however, that any gains in grain yield observed for low nitrogen residue treatments, may be more closely associated with other factors such as better moisture retention or improved soil structure.

Inorganic nitrogen accumulation following a legume phase can often reach up to 75-150 kg N ha after a summer fallow period (Fillery, 2001) as demonstrated by Anderson *et al.*, 1998*a* in Western Australia. The size of this response is largely influenced by seasonal factors and paddock history, and hence nitrogen availability to the subsequent crop can be highly variable (Bowden *et al.* 1985), making it difficult to interpret direct nitrogen effects resulting from the addition of green manure residues. Combine with this changes to soil structure, penetrability, nutrient content, seed bed conditions, residual moisture levels, weed burdens and disease levels resulting from the addition of plant residues (Bowden *et al.* 1985) and it becomes increasingly difficult to attribute responses in grain yield to changes in soil nitrogen status.

Potential availability of mineral nitrogen two weeks after incorporation may be predicted for WA soils, based on a linear correlation between the amount of mineral nitrogen in soil and the nitrogen concentration (N%) of plant residue for a wide range of soil types (Reincke, 1996) as follows.

*Mineral nitrogen = [0.9 * mineral nitrogen (sieved soil)] - [(10.5 * residue dry matter (t/ha)] + [(4.3 * residue dry matter * residue N concentration as a %)]*.

The chemical composition of plant residue changes over summer as the plant tissue breaks down, the above ground fractions losing nitrogen through time. Green residue for example, is mineralised more rapidly than dry material with a similar carbon to nitrogen (Van Schreven, 1964). This infers that the release and subsequent uptake of nitrogen during the growing season is largely influenced by the characteristics of the residue, which in turn is associated with changes in the rate of microbial mineralisation and/or immobilisation as described by Van Schreven (1964).

The influence of plant residue characteristics (C:N ratio) on mineral N in Western Australia is demonstrated by Reincke (1996), wide C:N ratios resulting in lower availability of mineral N and resulting in net immobilisation when applied at higher rates (Table 5). The addition of higher amounts of plant residues with a narrow C:N ratio, resulted in increased levels of mineral N, suggesting faster mineralisation rates associated with high N residues.

Table 5. Plant residue characteristics of whole tops at late flowering and soil mineral nitrogen for two sites (Wongan Hills and Avondale) in Western Australia when applied at 3 and 6 t/ha plant biomass (Reincke, 1996).

	%C	%N	C:N ratio	Mineral N (mg/kg)			
				Wongan Hills		Avondale	
				3 t/ha	6 t/ha	3 t/ha	6 t/ha
Rose clover	40.8	2.06	19.8	16	18	20	17
Medic	41.3	1.87	22.0	13	18	22	20
Capeweed	39.1	2.00	19.5	17	18	13	6
Wire weed	44.9	1.84	24.4	6	0	6	0
Wild radish	43.6	2.58	16.9	37	35	31	39
Field pea (leaf only)	42.1	3.52	11.9	31	48	38	46
Blue lupin (leaf only)	42.9	1.77	24.2	15	7	14	4
Narrow leaf lupin (leaf only @ early flowering)	42.8	3.56	12.0	51	79	43	64

2.5.3 How nitrogen becomes available: Nitrogen pool dynamics

Soil nitrogen cycling and supply is driven by three distinct pools (Bowden *et al.*, 1985).

Pool 'A' consists of inorganic nitrogen forms such as ammonium (NH^{4+}) and nitrate (NO_3^-) which exist in solution or exchange complexes. In general, NO_3^- forms are immediately plant available and therefore subject to leaching from fresh organic matter and turnover of soil microorganisms, while NH^{4+} is usually adsorbed onto soil colloids.

Pool 'B' is considered 'potentially plant available' and includes the labile organic nitrogen sources such as soil biomass, as well as high nitrogen residues considered to be a source for microbial metabolism, which, after conversion during the growing season, are subject to leaching.

Pool 'C' is made up of 'stable' organic nitrogen which turns over slowly at a rate of only 1-2 percent of content each year and is subsequently made available through pools A and B.

In WA's most leaching environments, Pool 'A' is unlikely to be a significant source of inorganic nitrogen, as these soils have low water holding capacity and are generally subject to high winter rainfall, therefore providing little residual value (Bowden *et al.* 1985). A green manure crop could be used as a 'catch' crop in this scenario, taking up freely available nitrogen and making it unavailable for leaching during high winter rainfall periods; providing a slower release of nitrogen upon decomposition of the residue ('Pool B'). This would be most effective if done during the summer fallow period to 'trap' nutrients released from residues (Murphy, 2000), but is counterbalanced by a relatively high risk of crop failure due to moisture stress in Western Australia with few exceptions. Alternately, growers may consider planting a winter crop with a wide C:N ratio on highly fertile soils, which will take longer to decompose and release nutrients due to the immobilisation of available nitrogen in the microbial biomass.

The potential loss of mineralised residue N through NO_3^- leaching is generally considered small for Mediterranean-type climates, with the greatest risk of loss associated with low demand for mineralised nitrogen at the onset of seeding when crop demand is low (Fillery, 2001). The use of green and brown manure crops as nitrogen 'traps' on a range of soil types may therefore enhance the utilisation or timing of release, more suited to the uptake of nitrogen in subsequent crop phases. Establishment of perennial grasse or weeds (i.e. capeweed) over summer fallow periods may also reduce potential N loss by acting as a 'sink' for nitrogen uptake.

2.5.4 Soil and plant recovery of nitrogen

The soil organic matter pool is the main sink for N in legume residues (Fillery, 2001). This is demonstrated by Mayfield and Amato (1996) where the application of biologically fixed nitrogen (legume residues) was found to largely offset the soil derived N removed in subsequent wheat crops as grain, with less than 10 percent uptake measured in the following wheat crop. The utilisation efficiency (nitrogen uptake) of the subsequent crop in using this nitrogen may be altered by residue quality (Ladd *et al*., 1983; Reincke, 1996) and rainfall, with increased uptake efficiency often associated with increased summer rainfall (Condon, 2000) and lower growing season rainfall (Anderson *et al*. 1998*b*).

Generally, the nitrogen immobilisation and mineralisation potential of the residue is limited by the extent to which organic material is in contact with the soil surface (Sain and Broadbent, 1977; Parker, 1962; Mayfield and Amato, 1996). Low contact levels resulting in slower mineralisation of residues, is likely to result in potentially greater losses of N through volatilisation, particularly in areas with low rainfall. Residues mixed in with the soil (green manured) will increase the level of contact between organic material and soil microorganisms, and should result in more rapid decomposition and mineralisation. This is demonstrated by Bowden *et al.* (1995) in Western Australia where increased plant uptake of nitrogen from lupin residues, reflects higher mineral N levels on green manure treatments (Table 6).

Table 6. Soil mineral nitrogen measured after different treatments were applied to lupins in Western Australia (Data is a subset of those presented in Bowden et al. *1985).*

	Mineral soil N (ppm)	Total N input	Predicted N Equivalent	Tissue N uptake Early	Tissue N uptake Late
Harvest	2	21	5	18	18

Brown manure	16	102	39	44	60
Green manure	38	102	39	>80	>80

Similarly, in New South Wales (NSW) and South Australia (SA), a higher rate of release of soil inorganic nitrogen was observed under incorporated (green manured) treatments compared to surface applied residue (Condon, 2000; Mayfield and Amato, 1996).

Increasing the amount of contact between soil and plant material is therefore likely to result in greater potential for loss of N under high rainfall conditions (Bowden *et al.* 1985). This is balanced by the ability for SOM to hold and release nutrients relatively slowly however, indicating that compared to inorganic sources of nitrogen, there is potential for a higher efficacy of supply in a leaching environment (Diggle, 1987) due to a more favourable pattern of release.

2.5.5 Influence of farming practices on mineral N

Continuous cropping farming systems, generally result in an exponential decay of soil nitrogen levels (Tuohey and Robson, 1980); largely due to plant removal (Clarke and Russell, 1977), nitrogen leaching and denitrification (Reincke, 1996) under the crop. In a fallow-wheat rotation, N losses are also similar to, or larger than the nitrogen removed under continuous cropping to cereals (Clarke and Russell, 1977). Therefore the benefits most commonly attributed to increased grain yields under fallow (which is commonly practiced in Australian farming systems), are those associated with an increase in stored water (French, 1978a; Schultz, 1972; Tuohey *et al.* 1972).

These losses may be counteracted to some extent under these systems in years where water is not a limiting factor (>440mm), as a result of longer periods of mineralisation and potentially longer access to soil moisture, with short term grain yields observed due to increased nitrogen (French, 1978b).

In many cases the influence of farming practices on grain yield is complex, involving a number of primary drivers, which interact with both season and site. For example, incorporation of a pasture phase resulting in increased SOM content (Donald and Williams, 1954; Williams and Donald, 1957; Russell, 1960, 1961; Mullaly *et al.* 1967; Barrow, 1969), is likely to result in improved soil structure by aggregating soil particles (Greenland, 1971), lowering soil bulk density (Russell, 1960), and increasing both water infiltration (Logan, 1960) and water holding capacity (Russell and Shearer, 1964). It is therefore difficult to identify the sole or primary factor driving increased grain yields, as a combination of factors have resulted in the removal of yield constraints.

Animal production can also have a pivotal role in reducing organic matter and the transformation of N in residues (Fillery, 2001), particularly grazed pastures. Grazing can negatively affect soil structure by reducing organic matter and increasing compaction associated with 'traffic'; and influence the release of nitrogen excreted in faeces and urine (Watson and Lapins, 1969), resulting in the transfer of large quantities of nitrogen within paddocks and increased loss of N through volatilisation. The quantity, quality and composition of pasture and legume residues can also likely to be influenced, resulting in changes to mineralisation rates. A grassy pasture for example may release 34 kg/ha/year N, whilst a legume dominant pasture may release up to 155 kg/ha/year (Greenland, 1971).

Changes to stubble residue management can also influence the amount of nitrogen returned to the soil. Stubble burning for example may result in the loss of significant amounts of nitrogen (27-73%) and sulphur contained in OM, as gases (Biederbeck *et al.* 1980). It can also reduce microbial populations significantly (Biederbeck *et al*. 1980) and may leave the paddock more susceptible to erosion. Retention of stubble by incorporating it into the soil is less likely to result in losses, as the nitrogen released is generally immobilised by microorganisms or sorbed as ammonium by soil colloids. Stubble mulching is unlikely to provide the same level of nitrate depression as incorporation (McCalla, 1961), but can provide similar benefits by depressing N mineralisation over a longer period of time and can also result in moisture retention of the soil. Depending on the type of residue however, this may increase the risk of disease and pest build up. The level of immobilisation as discussed previously, is likely to be dependent on both rainfall and the amount of carbon in the residues (Knapp *et al.* 1983, Reinertson *et al.* 1984).

The amount of nitrogen fixed from a crop is therefore likely to vary significantly with soil type, environment, nutrition and management factors.

2.5.6 Influence of climate on N mineralisation

The decomposition of plant residues is dependent on temperature and moisture availability influencing both enzyme and microorganism activity (Waksman and Gerretsen, 1931; Bartholomew and Norman, 1946; Nommik, 1962). Wetting and drying of soils is critical to the pattern of nitrogen release and availability. In general, the longer a soil is kept dry prior to being moistened, the greater the amount of C and N is mineralised (Birch, 1959) upon wetting. This is likely to be the predominant pattern associated with N mineralisation in Western Australia.

Repeated wetting drying cycles contribute to more rapid decomposition of plant residue compared to continually moist conditions when residues are generally slow to decompose, resulting in a steady slow release of nitrogen (Birch, 1958; Birch, 1964; Senevirantre, 1985). Therefore summer periods during which frequent rainfall events are experienced, may result in higher accumulation of mineral N which is then subject to leaching, particularly for high nitrogen residues. Decomposition rates will be influenced by the rate of drying of residues and soil.

The effect of temperature is thought to be more important than wetting and drying cycles in N mineralisation, with slower decomposition rates observed at low temperatures (Reincke, 1996). Nitrification is primarily influenced by temperature, optimal conditions for accumulation of nitrates occurring at approximately 30°C, whereas the accumulation of ammonium appears less constrained by temperature and occurs at both low (Campbell *et al.* 1971) and high temperatures, up to an optimum 50°C (Myers, 1974). This is also influenced by soil type, a more rapid response to temperature observed on sandy soils compared to loam or clay soils (Campbell *et al*. 1984), supporting previous observations that soil type is likely to influence both the rate of decomposition and N mineralisation.

2.6 The influence of organic matter on physical soil properties

Recent research attempting to quantify the capacity of the soil to build SOM and identify improvements in soil physical properties resulting from the retention of organic matter, has resulted in the development of initial indicators for soil quality in Western Australia (Hamza, unpublished).

2.6.1 Bulk density (p_b)

Bulk density is a measure of the available pore space within a soil for storage of water and nutrients. Reductions in soil bulk density reflect an increased capacity for storage, but is limited in its ability to determine changes in soil structure due to the potential for large fluctuations in the range of values for surface soils both during, and between seasons. Increasing pore space will result in an environment more suited to microbial activity, and therefore likely to result in faster decomposition of organic matter and more rapid N mineralisation. Plant availability of nutrients should also be greater, due to increased storage capacity.

2.6.2 Soil pH

Soil pH measures soil acidity with low values (pH<4.5) indicating strongly acidic soils considered critical for the growth of many crops, and high values indicating the potential 'lock up' of soil nutrients and level of sodicity. Increases in soil pH have been associated with the application of organic matter to a range of soils (Hamza, unpublished). However, other studies have demonstrated reductions in soil pH associated with the retention of organic residues, particularly residues high in nitrogen.

2.6.3 Cation exchange capacity (CEC)

Cation exchange capacity (CEC) indicates the total capacity of a soil to hold exchangeable cations (Rengasamy and Churchman, 1999), and refers to the nutrient storage capacity of the soil. Increasing cation exchange capacity is likely to result in increased uptake of plant available nutrients, hence increasing yield potential.

2.6.3 Water Infiltration

Change measured in the sorptivity or infiltration of a soil, reflect the ability of a soil to allow rapid entry of water into the soil profile (i.e. ability to 'wet up') and for the capacity of that soil to hold water once saturated (steady state flow). The soil type will influence whether a reduction in steady state flow is beneficial or not - a soil prone to waterlogging for example is likely to benefit from a more rapid movement of water through the profile and away from the plants rooting zone. A lighter textured soil however, would tend to benefit from a slower rate of movement, which will help reduce moisture stress and leaching of plant nutrients away from the rooting zone. Although a good indicator of soil structure, results can be highly variable and it can be difficult to assess treatment responses.

2.7 What changes in subsequent crop management are necessary with implementation of renovation cropping techniques?

2.7.1 Fertiliser inputs

The application of nutrients to ensure optimal plant growth will be influenced by the quality and quantity of organic residues retained. However, basal nitrogen fertiliser should be applied at seeding as normal, with top-dressing applications delayed until able to make further assessments based on potential yield and nitrogen supply. The use of crops with a wide C:N ration which have slow decomposition rates may require additional nitrogen at seeding to assist in the break down of remaining plant residue and reduce the potential immobilisation of soil nitrogen by microbes. This will be particularly evident where a lack of summer rain has resulted in low levels of crop residue breakdown.

More accurate assessment of fertiliser inputs can be calculated using background soil nitrogen and an estimate of plant available nitrogen resulting from the green manure crop (TOPCROP Nitrogen Calculator, SYN model). The employment of split fertiliser applications may be useful in reducing fertiliser costs based on estimates of plant available nitrogen and growing season rainfall to ensure early crop vigour, with later nitrogen applications applied to maximise grain yield potential and quality based on rainfall.

Demonstrated treatment responses to renovation cropping methods have been observed resulting from plant residues measured at three sites in WA (Bowden *et al*., 1985). This data suggests the grain yield response observed is unlikely to result from increased mineralisation of N, as plant uptake at these sites does not appear to differ markedly between treatments (Table 7). Nitrogen at this site does not appear to be limiting as indicated by unchanged grain yields with the application of 80kg N ha^{-1} on control treatments (Table 7). Yet, grain yields continue to increase on renovation treatments, with only one exception. This suggests that limiting factors other than nitrogen were influencing yield.

Table 7. Trial data from three sites established in 1982 at East Hyden (sandy loam over gravel), Newdegate (Mallee, sand over gravel) and Dowerin (deep loamy sand) from Bowden et al. 1985.

Site	Treatment	N Input		Tissue N uptake		Biomass	Grain
		Mineral N	Residue N	6-8 weeks	Anthesis	maturity (t/ha)	Yield (t/ha)
East Hyden	Harvest	12	30	2.1	25	3.1	1.6
	80kg/ha N*			2.5	51		1.5
	Brown manure	25	102	2.3	33	4.3	2.2
	Green manure	35	102	4.2	58	5.4	2.7
Newdegate	Harvest	39	36	3.9	62	5.4	2.4
	80kg/ha N*			4.7	68		2.5
	Brown manure	53	91	4.6	64	6.8	3.1
	Green manure	66	91	4.5	68	6.8	3.0
Dowerin	Harvest	8	65	3.7	28	3.9	1.9
	80kg/ha N*			4.1	37		1.9
	Brown manure	15	112	2.8	29	2.6	1.3
	Green manure	39	112	4.3	35	4.9	2.0

* Fertiliser N applied as ammonium nitrate (NH^{4}_{+} NO_{3-})

Rotational management should remain unchanged from normal management of continuous cropping systems, with appropriate rotation of crops to reduce disease incidence and maximise yields.

Strategic implementation of these techniques should result in reduced weed burdens and increasing soil fertility, with medium to long term gains possible through the reduction of herbicide use in all phases of the rotation, and optimal nutrient supply developed through enhanced timing of supply.

2.8 Economics

The impact of different cropping strategies on short and long term economics must be considered, particularly where utilising tools such as green or brown manure crops, as these will have a significant impact on cash flows in the short term. It is timely to suggest that the impact of these techniques on both profitability and long term viability will vary with site and season and that in many cases, a number of alternative solutions may be available. In the studies discussed below, the implications where quantified, are primarily economic. Justification for the use of these techniques may have greater impact when discussing the triple bottom line including social, economic and environmental impacts.

The cost of a renovation phase will depend on a number of factors including fluctuations in the price of grain, lost harvest returns, the cost of renovation and grain yield in the subsequent year. It is therefore difficult to estimate the likely success rate, as benefits such as increased grain yields can be offset in years where low grain prices are a factor. Increasing seed and fertiliser costs can significantly influence the impact of a legume green manure phase, increasing the cost in the renovation phase and potentially decreasing the cost in subsequent rotations. However, the most significant change in costs is likely to be associated with the price of grains in both the year production is sacrificed and in the subsequent years following renovation. For example, based on a renovation cost of $140/ha in Year 1, the percentage grain yield increase required to offset the cost of renovation is dependent on yield level, assuming no longer term benefits and based on current wheat prices (Table 8).

Table 8. Yield required to break even after renovation phase, based on potential grain yield for a set renovation cost.

Potential Yield Level (t/ha)	Yield Level required to break even (t/ha)	Percentage (%) yield improvement required to break even*
1.0	1.5	50%
2.0	2.5	25%
3.0	3.5	16%
4.0	4.5	13%

* Yield increase (%) required, based on wheat delivered into AH at 11% protein and 1% screenings, price $286/tonne.

The cost of a renovation phase can be significantly reduced by the use of on-farm seed as a green manure crop and by integrating other management programs such as lime or trace element application. Profitability of subsequent crops is also likely to be higher where the value of this crop is high, such as durum wheat, Australian Hard wheat or canola.

The economics of these techniques can also be significantly influenced by climatic conditions in following crop phases, low yielding crops potentially unable to capture the direct benefits gained from a renovation phase. An average yield improvement of 15 percent for example will have significantly more impact on cost recovery when the potential yield of a grain crop is high. For example, a wheat crop yielding 1.5t/ha and paid at $250/t would return an extra $56/ha with a 15% yield gain, whereas a 4t/ha crop would return an extra $150/ha. This indicates that relative values will be influenced significantly by potential yield in subsequent cropping phases.

Studies focusing on short term economic gains are unlikely to capture the full benefits of these techniques due to longer term benefits that may arise from more effective weed control and improvements in soil health. The economic value of green manure crops may become more attractive with developing resistance to a range of herbicide groups and under high weed burdens.

2.8.1 Economic viability in New South Wales

In New South Wales, an economic analysis of different cropping rotations resulted in an on-farm income of approximately $580/ha for a three year rotation of pasture (green manure):wheat:wheat, compared to a pea:wheat:wheat rotation at approximately $630/ha (Condon, 2000). This suggests the green manure phase provided a relatively low economic return over 3 years despite significantly higher wheat grain yields (Condon, 2000). In this study, the impact of different techniques on the same crop type has not been measured and differences may be due to plant specific attributes. However, these results are similar to other studies in this state and suggest the economics of implementing a green manure phase is unlikely to be viable in a high yielding environment (Fettell, 2001). Results also indicate that green manure crops resulted in the lowest grass weed emergence the following year and gave the greatest increase in soil organic nitrogen (Condon, 2000) which may indicate longer term benefits outside those assessed in this scenario.

2.8.2 Economic viability in South Australia

A number of studies have been carried out in South Australia on the relative merit of green manure treatments compared to alternative weed management options, largely as a result of increasing levels of herbicide resistance.

Trial data largely supports grower experience, wheat sown under green manure vetch treatments yielding between 34 and 48% more than following harvested vetch in a dry year at two sites, with protein gains of between 0.3 and 1.8% (Mayfield, 1995). The resulting net cash return over two years, was slightly lower for the green manure treatments compared to harvested vetch by approximately $29/ha (Mayfield, 1995).

Green manure treatments were also determined to be a relatively high cost option for weed control in South Australia compared to spray-topped peas, oaten hay or a high legume content pasture over a two year rotation (Payne and Wurst, 1995). These trials were carried out on a soil with a low fertility (0.6% SOC), not significantly different to many of the soils in Western Australia. A range of other sites in South Australia, resulted in average grain yield increases of between 24 and 29% for green and brown manure treatments compared to harvested legumes (Mayfield and Amato, 1996).

Economic returns may be more closely aligned if reduced costs associated with reduced herbicide usage, herbicide resistance management, lower inputs and potential long-term benefits were included This may provide sufficient cause for implementing green manure techniques in some paddocks in some years (Mayfield, 1995). Returns will be highly dependent on weed burdens, grain and fertiliser prices (Mayfield, 1995) as previously discussed, with higher input prices leading to greater levels of profitability for green manure crops.

2.8.3 Economic viability in Victoria

Results from a series of trials conducted by the Birchip Cropping Group, indicates green manure legumes resulted in improved wheat yields and protein compared to harvested treatments, but gains were not sufficient to compensate for the loss of production in the previous year (Green manuring: what are the benefits? Groundcover summer issue 1999). These trials were located on a range of soil types including Wimmera clay, Mallee clay loam and red brown earth, and may have started with inherently higher SOM and background nitrogen status, resulting in lower potential gains.

2.8.4 Economic viability in Queensland

Reports of significant yield gains from organic production systems have indicated mung beans, fenugreek and cow pea have potential as green manure crops in Queensland for the production of organic wheat. Little information is currently available on the economics of these farming systems in this region.

2.8.5 Economic viability in Western Australia

Early research in a low rainfall environment at Salmon Gums in Western Australia, demonstrated green manure peas out-yielded harvest treatments by up to 24% in the subsequent wheat crop (Table 11).

Table 11. Soil and plant attributes measured on wheat plots following harvested and green manure field pea treatments imposed in the previous season at Salmon Gums in Western Australia (M. Seymour, pers. comm.).

	Soil			*Plant*	
	N (total %)	NO_3^- (ppm)	SOC (%)	Biomass @ Ear emergence (t/ha)	Yield (t/ha)
Harvest peas	0.057	6	0.74	5.99	2.21
Green manure peas	0.067	10	0.85	8.60	2.75

* This trial was influenced by poor October rainfall

Similarly, on a yellow sandy loam at Hyden in Western Australia, early trial results indicate green or brown manured lupins were significantly (P=0.05) higher yielding than harvested lupins, treatments yielding 57% and 33% more than harvested plots respectively (G. Knell, *pers. comm.*).

Current research has resulted in mixed benefits over a range of sites. Results obtained on a red clay loam at Mullewa, indicate it is possible to recover costs over a three year rotation, depending on the crop species used (Hoyle, 2001). In this study, the three year income for a 'field pea:wheat:wheat' rotation was not significantly different to a 'green manure field pea:wheat:wheat' rotation and was lower than a 'green manure *Lathyrus*:wheat:wheat' rotation (Hoyle, 2001). Therefore the economics of using a large seeded legume producing adequate biomass resulted in costs being offset in the two cropping phases following implementation of treatments. Where non-legume crops were used at this site, the economic benefits were not sufficient to offset costs in the medium term.

A trial conducted on a deep sandplain at Yuna using Cadiz serradella, was also able to demonstrate significant gains in wheat production for a single year but was unable to demonstrate benefits in the following canola crop, which had been badly affected by grubs. It was therefore considered less likely that the economics of green manure crops on lighter textured soil types would be economically viable in the short term based.

The impact of commodity prices should again be considered when evaluating the relative benefits of a green manure crop. An economic evaluation of research conducted at Katanning on green manure crops in 1999 indicated a loss in net income with the implementation of these techniques. However, further analysis using current prices for grain and fertiliser inputs suggests commodity prices are likely to have a significant impact on cost recovery.

Anecdotal evidence exists at some sites in Western Australia where either the type of residue used or the soil type has resulted in the second cropping phase being more productive than the first. This indicates that the economics of these systems requires more than a single cropping year (or even two) to establish the cost recovery resulting from the implementation of a green manure phase.

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3.0 Introduction and Background to DAW628

In many areas of the state, soil fertility and structure is declining; herbicide resistance issues are becoming more important; and in low rainfall marginal cropping areas and under continuous cropping systems, returns from pulse break crops are low. Yield and protein increases following a green manure phase have been supported by field trials in South Australia where cereal crops following a green manure phase increased grain yields by 34% over a harvested vetch and increased grain protein by 1.8%. The combined value of these benefits can tip the economics in favour of green manuring for some soils in some areas. Research to target these priority areas and develop a viable cropping system for growers throughout the state is essential. Part of this integrated approach to farming systems, will be to determine the economic and long term feasibility for a green manure phase under current cropping systems.

The development of renovation cropping techniques in Western Australia is primarily aimed at rejuvenating poorer performing areas of the farming system, where the viability and continuing production of grain crops is at risk due to limitations imposed by physical, biological or chemical constraints. Previous research has confirmed the advantages of green manure crop as a tool in integrated weed management and in improving productivity. Additional advantages are in maintaining and improving soil organic matter, nutrient availability and physical qualities of soil.

This research determines to assess the benefits (economic and environmental) of a green manure phase under current cropping systems. The aim of this trial is to evaluate crop types and incorporation techniques to rejuvenate poor performing soils, assess the environments suited to these techniques, as well as to identify and evaluate the potential longevity of benefits. Green manure crops will be investigated within a farming systems context, to develop strategies for the sustained production of cash crops and increased viability of the farm business.

4.0 Methods

A total of 32 experiments were conducted in various agricultural regions of Western Australia over five years in 1998, 1999, 2000, 2001 and 2002. Trials were conducted in the high (>450 mm annual rainfall), medium (325-450 mm) and low rainfall zones (< 325 mm) and chosen on the basis of soil type. Sites were typically 'poor performing paddocks' with an unidentified constraint to yield. Typically, experiments were carried out for a minimum period of two years, with longer term experiments continued for up to five years.

Rainfall was monitored at most sites, crop growth stage recorded (Zadoks *et al.* 1974), and grain harvested and analysed for grain quality parameters. Where local rainfall data was not collected, climatic information was gathered where possible, from automatic weather stations located nearest the site (see Appendix 1).

Trials were conducted either as small plot experiments, or as large scale replicated farmer trials. In small plot experiments at each location, trials were seeded in either eight or sixteen row plots (18cm inter-rows), and a minimum 20m in length. Trial design was generally in a split plot, randomised block design with three replicates. Plots were sown (direct drilled) with a basal fertiliser at seeding and seed rate adjusted for seed size and germination percentage.

4.1 Calculating growing season rainfall

Growing season rainfall (GSRF) was calculated using the French and Schulz method (French and Schulz,). GSRF was calculated using 25% of rain received from January to March, plus growing season rainfall (April-October), minus 110mm for water losses. This was used for all sites and seasons to provide relative comparisons across sites in response to treatments.

4.2 Assessing physical soil properties

Soils were sampled randomly and characterised for physical properties at the site prior to the implementation of treatments to identify and assess constraints to production. Composite samples (0-10, 10-30, 30-50 cm, >50cm) of soils were collected using an auger prior to seeding in each year, sieved (<2 mm) and weighed at field moisture. Soils were then oven dried at 110°C and reweighed to calculate gravimetric water content as indicated below.

In selected trials bulk density, volumetric water and infiltration were also measured. Physical soil parameters were difficult to estimate for treatments, particularly for water infiltration and steady state flow rates.

Water Infiltration (mm/hr)
Disc permeameters measure the in-situ hydraulic properties of field soils, allowing the measurement of infiltration rate, sorptivity and hydraulic conductivity with minimal soil disturbance. Measurements were replicated four times in each plot and treatments replicated 3 times in an effort to reduce the errors associated with variable results. Sorptivity was measured at a slight suction of approximately -5 cm to eliminate the effect of macropores, and was adjusted for soil type. A thin layer of sand was used to ensure good contact between the porous plate of the disc permeameter and the soil, and a metal ring driven into the soil to restrict lateral water flow. Sorptivity is determined from the slope of the water level - square root of time relationship (Philip, 1969), for the early stage of infiltration after the sand cap is fully wetted. The steady state flow rate is equal to the slope of the straight line between water level and time towards the end of the infiltration run, where the rate of infiltration becomes constant.

Gravimetric soil water content (%)
Gravimetric water (θ_m) provides a basic estimate of water content by mass, defined as θ_m = weight of water/dry weight of soil * 100. This was calculated for both initial (θ_{m0}) and post (θ_{m1}) water content where infiltration measurements have been undertaken.

Volumetric soil water content (%)
Further information is required to determine the depth of water in the field as determined by the depth of soil. Volumetric soil water content (θ_v) = weight of water/volume of soil * 100. This was calculated

for both initial (θ_{v0}) and post (θ_{v1}) where infiltration measurements have been undertaken. Therefore if 10mm of water was found in 100mm of soil θ_v=0.1.

Bulk Density, p_b (g/cm^3)
Soil bulk density (p_b) was measured by collecting a known volume of soil and drying the soil to get the mass of dry soil. Bulk density was then calculated where p_b = dry weight of soil/volume of soil. (Hanks, xxxx). Bulk density is limited in its ability to determine changes in soil fertility structure due to the potential for large fluctuations in the range of values for surface soils both during, and between seasons.

Total soil porosity (Mg/m^3)
The volume of air per unit volume of dry soil (Mg/m^3) can be calculated, where total porosity (TP) = 100-(38*bulk density).

4.3 Assessing chemical soil properties

Soil chemical properties were analysed primarily through CSBP unless otherwise stated.

Plant available nitrogen [Nitrate (NO^{3+}) and ammonium (NH^{4+})]
Available nitrogen (nitrate and ammonium) extracted with 2M potassium chloride (KCl) solution (1:5) at 25ºC. Available nitrogen (mg/kg) is measured simultaneously for nitrate and ammonium by using a Lachat Flow Injection analyser (Searle, 1984). The ideal range for nitrogen is dependent on purpose but is generally considered to be between 90 and 120 kg N ha^{-1}. Nitrate and ammonium are considered ideal when soil concentration is between 10 and 20 mg/kg.

Phosphorous (P)
Phosphorous (mg/kg) extracted with 0.5M $NaCHO_3$ at 25ºC (pH 8.5, 1:100 soil/solution ratio, Colwell procedure). Low, moderate and high values have been based on <10 mg/kg, 10-30 mg/kg and >30 mg/kg respectively (Purdie, 1995). Low values indicate a response to fertiliser P is likely, moderate values indicate a possible response, whilst high values suggest no response is likely to be observed.

Potassium (K)
Potassium (mg/kg) extracted with 0.5M $NaCHO_3$ (pH 8.5, 1:100 soil/solution ratio, Colwell procedure). Concentration determined using a flame atomic absorption spectrophotometer (Rayment and higginson, 1992). Ideal levels vary depending on farming systems, but should be in the range of 150-300 kg ha^{-1}. Low, moderate and high values have been based on <70 mg/kg, 70-200 mg/kg and >200 mg/kg respectively (Purdie, 1995). Values greater than 100 mg/kg are considered high for sandplain soils (Purdie, 1995).

Sulphur (S)
Sulphur (mg/kg) extracted by 0.25M potassium chloride (KCl) solution at 40ºC and sulphate measured by ICP (Blair *et al.*, 1991). The ideal range for sulphates is considered to be between 15 and 40 ppm.

Organic carbon (OC)
Organic carbon (Walkley and Black, 1934) is measured on finely ground soil (<2mm) using CSBP method. Soil organic carbon is generally expressed as a percentage of the total soil mass: OC % = (g C/kg soil)/10. Organic carbon levels are determined to be low when below 1% in the A horizon, medium when between 1 and 2%, and high when greater than 2% (Purdie, 1995).

Iron (Fe)
Reactive iron (mg/kg) extracted on a 1:33 solution of soil and Tamm's Reagent (oxalic acid/ammonium oxalate) solution, concentration measured by flame atomic absorption spectrophotometer. The ideal range for iron is considered to be between 100 and 400 ppm (Australian Perry Ag Lab Soil Audit).

Aluminium (Al)
Aluminium is extracted on a 1:5 solution of soil and 0.01M calcium chloride ($CaCl_2$) solution, and concentration measured by ICP-AES (Bromfield, 1987). This has only been measured on sites considered at risk (pH in $CaCl_2$<4.5). Low values are below 1 mg/kg, moderate when between 1 and 10 mg/kg, and high when above 10 mg/kg (Purdie, 1995).

Electrical Conductivity (EC, 1:5)
Electrical conductivity (Ds/m) is measured by using a conductivity meter at 25ºC, on a 1:5 suspension of soil in deionised water. EC provides an indication of salinity levels, which may constrain plant growth. Low, moderate and high levels will depend on plant species and salts present in solution but are estimated at <0.05, 0.05-2.0 and >2.0 dS/m (Purdie, 1995).

Soil pH
Soil pH of a 1:5 (soil in deionised water) extract is measured using a combination pH electrode calibrated against 0.01M KCl (Rayment and Higginson, 1992). Calcium chloride ($CaC1_2$) solution is added to produce a concentration of 0.01M $CaC1_2$ and pH is again determined using a combination pH electrode. Soil pH ($CaC1_2$) measures soil acidity when soil is present in solution (1:5 suspension) with 0.01 M $CaCl_2$ and refers to the concentration of hydrogen ions (H+) in the soil solution. Neutral solutions have a pH of 7.0. Low values (pH<4.5) indicate strongly acidic soils considered critical for many crops.

Cation exchange capacity (CEC)
CEC is measured using the Gilman and Sumpter method (Rayment and Higginson, 1992) on a 0.1M $BaCl_2$/0.1M NH_4Cl extraction of exchangeable bases, and concentration measured by ICP-AES. Cation exchange capacity (CEC) indicates the total capacity of a soil to hold exchangeable cations (Rengasamy and Churchman, 1999). In most soils, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+) comprise the primary cations present in exchangeable form, with the exception of acid soils where exchangeable aluminium ions can account for a significant proportion of the total CEC (Rengasamy and Churchman, 1999).

CEC is commonly calculated as the sum of basic cations (CEC by ∑bases) and is estimated to be low when below 3 cmol/kg, medium when between 3-10 cmol/kg and high when above 10 cmol/kg (Purdie, 1995).

The ideal range for total exchange capacity (TEC) is 10-18 milliequivalents, with calcium comprising 60-70% of this, magnesium 10-20%, potassium 2-5% and sodium 0.5-3%. Ideal levels for Aluminium (Al) are considered to be less than 2.0 ppm.

4.4 Assessing biological soil properties

Microbial Biomass-C
Microbial biomass-C (MBC) was determined by fumigation extraction as described by Vance et al. (1987) except that total oxidisable C was measured by low temperature persulphate oxidation (Shimadzu Model 5050).

4.5 Assessing plant properties

Plant establishment
Weed numbers were measured both prior to and after herbicide treatments to assess treatment effects on weed dynamics, whilst crop establishment was generally measured four to six weeks after sowing. Plant numbers were measured by counting all germinated plants within randomly placed quadrats. One of two methods was used, with counts being undertaken on either two quadrats totalling an area of 0.72 m^2 measured, or three quadrats totalling 0.99m^2 taken within each plot. Plant number was expressed as the number of plants per square metre.

Plant biomass
Crop and weed biomass were measured by harvesting (cutting) all plant residue within randomly placed quadrats. One of two methods was used, with either two cuts totalling an area of 0.72 m^2 measured, or three cuts totalling 0.99m^2 taken within each plot. On arrival in the laboratory, separation of weed and crop residue was undertaken and each component weighed, oven dried and reweighed for plant dry matter. Plant dry matter was then converted to tonnes per hectare.

Crop development was assessed using the Zadok's growth scale (Zadoks et al., 1974). Crop dry matter was assessed for selected trials at stem elongation (Z31), and for all trials at anthesis (Z65) and physiological maturity (Z91).

Grain yield
Potential grain yield was calculated using the GSRF for the site and using a multiplication factor of 20kg of grain produced for each mm of rainfall received.

For mechanically harvested small plot trials, all eight rows in each plot were harvested with an experimental harvester, after trimming to a length of 18m at all sites. Hand harvest estimates were also undertaken in conjunction with biomass assessments at harvest, and grain yield components (harvest index, head number, average grain weight) determined where possible.

Grain protein (%)
Grain protein percent was measured from bulk grain samples after cleaning over a 1.5mm screen, using an Infratech whole grain analyser and adjusted to 11% grain moisture.

Hectolitre weight
Grain weight by volume was assessed from bulk grain samples after cleaning over a 1.5mm screen, using a half litre chondrometer and presented as weight of grain per hectolitre (kg/hl).

Small grain screenings (%< 2 mm)
Small grain screenings are calculated from bulk grain samples, using a Carter Dockage Tester by placing grain samples initially over a 1.5mm screen to clean the sample, and subsequently over a 2mm screen. Grain falling through the 2mm screen is collected and assessed for % whole and broken grain.

4.6 Trial design and statistical analysis

Trial design was verified with biometrics prior to implementation. Analysis of variance (ANOVA) was conducted to determine significant treatment effects using GENSTAT 5 Release 6.1. Trials unable to be analysed using ANOVA, were analysed using REML after consultation with biometrics. Regression analysis was used to determine factors associated with grain yield and quality trends.

4.7 Economics

Calculation are presented per hectare and represents the return on actual crop yields based on AWB pool prices (Golden Rewards) for relevant years, including protein payments and inclusion of any dockages applicable for grain screenings and black point. Prices for field peas and lupins have been taken from actual pool prices in relevant years. Input costs for growing a crop have been estimated using the 2002 Gross Margin Guide (Department of Agriculture, Western Australia).

5.0 Results

Please find detailed trial results as follows:

5.1 98MW31
5.2 98GE110
5.3 99TS01
5.4 99TS02
5.5 99TS06
5.6 99TS07
5.7 99WH01
5.8 00AD68
5.9 00ES98
5.10 00ME103
5.11 00WH62
5.12 00WH63
5.13 01AD44
5.14 01ES64
5.15 01ES65
5.16 01GE77
5.17 01GE78
5.18 01GS59
5.19 01WH45
5.20 01WH46
5.21 01WH47
5.22 Grower trial: Ford
5.23 Grower trial: Fretwell
5.24 Grower trial: West
5.25 Grower trial: McTaggart

A number of other trials and grower demonstrations were initiated but due to seasonal conditions, were terminated prior to the completion of research and have therefore not been presented.

6.0 Economics

6.1 The role of green manure crops in renovating poor performing paddocks: What's it worth?

Initial investigations estimated a yield gain of approximately 20% would be required for green manure techniques to be practical in terms of their economic benefit, although this is likely to be influenced by the level of constraint.

In 54% of trials assessed to date in this project (29 trials in total), a green manure phase (GM) resulted in a yield gain of greater than 20% (Table 6.1), when comparing the best legume GM to the same harvested legume. In cases where yield gains were not greater than 20%, this could either be associated with soil type, crop type, trial management or inappropriate choice of paddock.
The influence of soil type was variable when viewed across sites and seasons (Table 6.1) and in many cases, was influenced by adaptation of crop type to a range of soils.

Table 6.1. Wheat yield increase (%) resulting from imposing a 'best bet' green manure treatment compared to a harvested legume treatment in the year prior. Data are the average percentage increase measured over three incorporation techniques (green manuring, brown manuring, mulching). Data in brackets are the number of trials averaged for best treatment.

Soil type	1999	2000	2001	2002
Sand, Loamy sand	16 (1)	29 (2)	87 (1)	31 (7)
Sandy loam, Loam	20 (1)	15 (5)	9 (3)	11 (2)
Clay loam, Clay	*	38 (2)	61 (1)	77 (1)

To determine the effect of soil type, a set of three trials was established in 2001 at Wongan Hills across three soil types to provide an indication of the difference in potential benefits resulting from changes in soil properties. These trials indicated the potential yield gain from a mulch treatment (field peas) ranged from 12% on a sandy loam, to 23% on a shallow duplex and 45% on a clay loam soil (data not presented) compared to a harvested field pea crop.

Similarly, constraints limiting yield production such as high weed populations have a significant influence on the level of benefits gained and subsequently the economics of imposing such a strategy. Two trials conducted at Bindoon in 2000 highlight the influence that identification of appropriate paddocks can have on the profitability of imposing a green manure phase (Table 6.2), and hence the importance of identifying constraints to yield when considering these techniques.

Table 6.2. Grain yields and protein of a wheat crop in 2001, following treatments imposed in 2000 at Bindoon on two soils with contrasting weed burdens.

Soil type	Treatment	Weed burden (weeds/m^2)	Wheat yield (t/ha)	Protein (%)
Sandy Loam	Field Pea (Harvest)	158	2.15	10.1
	Field pea (GM)	3	4.15	11.0
Loam	Field Pea (Harvest)	0	2.44	10.5
	Field pea (GM)	0	2.86	11.2

This data indicates the heavier soil to be higher yielding, but demonstrated a poor economic response to implementation of a green manure phase, grain yield benefits assessed as lower than the cost of implementation (data not presented). The lighter textured soil was identified as having a significant yield constraint imposed by a heavy weed burden and in this case, a green manure phase has resulted in significant control of weeds, and subsequently a higher cumulative return (Table 6.3).

Table 6.3. Average annual income based on returns in 2000, 2001 and 2002 following treatments imposed at Bindoon in 2000 on a sandy loam soil. Data is the average of all treatments.

2000 Treatment	2000* ($/ha)	2001** ($/ha)	2002*** ($/ha)	2000-2002 Average annual income ($/ha)
Field pea (Harvest)	6	346	131	161
Field pea	-130	876	406	384

* Costs for growing a crop in 2000 was estimated at $130/ha. This may have varied for different crops but for this example has been assumed to be the same.

** Costs for production of wheat has been estimated at $170/ha

*** Costs for production of wheat has been estimated at $170/ha, price has been based on 10.5% protein and 1% screenings as grain quality was not assessed

Longer-term research also indicates that potential returns may need to be assessed over a longer time period, depending on soil type. A trial site in Mullewa established in 1998 for example, indicates harvested field pea treatments continued to achieve significantly lower grain yields than GM treatments for approximately three years, indicating the benefits of renovation techniques may be maintained for longer than a single season (Table 6.4). In this example, green manure field peas have proved an economically viable alternative to harvested legume and a chemical fallow (Table 6.4).

Table 6.4. Total income of a five year rotation (GM: wheat: wheat: peas: wheat) following green manure crops treatments imposed at Mullewa in 1998 on a clay loam soil. Data is the average of all treatments.

Green manure Crop	1998 Wheat Yield	1999 Wheat Yield	2000 Wheat Yield	2001 Pea Yield	2002 Wheat Yield	* 4 year average Income 1998-2001	* 5 year average Income 1998-2002
Fallow (Chemical)	0	2.1	1.2	3.1	0.44	$225	$167
Field pea (Harvest)	1.23	1.8	1.1	2.4	0.47	$239	$180
Field pea	0	2.2	1.9	2.9	0.49	$263	$201
Lathyrus	0	2.2	2.0	3.1		$282	
Vetch	0	2.0	1.8	2.8		$233	
Canola	0	1.9	2.0	3.0		$253	
Mustard	0	1.9	2.0	2.9		$248	
Oat	0	1.6	2.0	2.6	0.46	$221	$165
Oat:vetch mix	0	1.9	1.8	2.7		$222	
LSD (P=0.05)		*0.1*	*0.2*	*NS*			

* This calculation is presented as average annual income per hectare and represents the return on actual crop yields based on AWB pool prices for relevant years, including protein payments and inclusion of any dockages applicable for grain screenings.

** Costs for production of wheat has been estimated at $170/ha and field peas at $130/ha

This is not always the case however, particularly for lighter textured soils, which often demonstrate shorter term benefits. On these soils, maximising benefits in the first crop phase is essential to economic viability and thus can be significantly influenced by climate.

In general, there were no significant differences (or small differences) in grain yield or protein under the different incorporation techniques such as green manuring, brown manuring or mulching in either year. This indicates the potential for techniques such as mulching and brown manuring under no tillage farming systems and on lighter soils where the risk of erosion excludes the use of green manuring.

The cost of a renovation phase will depend on a number of factors including fluctuations in the price of grain, lost harvest returns, the cost of renovation and grain yield in the subsequent year. It is therefore difficult to estimate the likely success rate, as benefits such as increased grain yields can be offset in years where low grain prices are a factor. For example, based on a renovation cost of $140/ha in Year 1, the percentage grain yield increase required to offset the cost of renovation is dependent on yield level, assuming no longer term benefits and based on current wheat prices (Table 6.5).

Table 6.5. Yield required to break even after renovation phase, based on potential grain yield for a set renovation cost.

Potential Yield Level (t/ha)	Yield Level required to break even (t/ha)	Percentage (%) yield improvement required to break even*
1.0	1.5	50%
2.0	2.5	25%

3.0	3.5	16%
4.0	4.5	13%

* Yield increase (%) required, based on wheat delivered into AH at 11% protein and 1% screenings, price $286/tonne.

The cost of a renovation phase can be significantly reduced by the use of on-farm seed as a green manure crop and by integrating other management programs such as lime or trace element application. Profitability of subsequent crops is also likely to be higher where the value of this crop is high, such as durum wheat, Australian Hard wheat or canola.

Tactical implementation of renovation cropping can also improve the likelihood of an economic benefit to the grower, where yield level of the sacrificed crop is low, or when the following yield is high. The latter is particularly difficult to determine! Therefore the role of renovation cropping may be particularly important when considering options for crop salvage as a result of low rainfall, disease, frost, high weed burdens, etc.

In the medium to long term, the use of renovation cropping techniques strategically to ameliorate soil conditions is unlikely to be profitable in the majority of seasons, unless significant constraints to yield are present.

Key Elements to an economically viable green manure crop

- Identify the type and level of constraint present in a paddock, and choose an appropriate crop type designed to overcome this constraint. Grain legumes are generally the best choice for maximising returns on medium-heavy soils, with species influenced by soil type and climate. Field peas were estimated to be a relatively good option due to their adaptability to a broader range of soil types and competitive ability.
- Assess potential yield based on dry matter production at anthesis and determine the likely economic benefit based on current grain prices
- Assess the likely longevity of benefits based on soil type
- Fallow treatments often return similar levels of benefit, particularly when a dry season follows implementation of techniques. Consider your goals.
- If implementation of a renovation phase is in response to a highweed burden or resistant population, timing of application is critical.
- Consider integrating other farm management practices to reduce application cost.
- The cost of seeding and maintenance of a green manure crop, can significantly influence the gains or losses experienced.
- Tactical implementation where seasonal factors suggest low crop yield potential is more likely to result in economic benefit.

6.2 Making a tactical decision to green manure

Delayed seeding and subsequent crop etablishment problems experienced in many areas for a range of crops, have highlighted the potential for these crops to be utilised as a cover crop, due to probable low returns from grain yields in some areas. Grain yield potential may also be reduced with low growing season rainfall, high disease incidence, frost or other climatically induced constraints.

The basis for decision making in regards to appropriate management for a specific paddock should focus on a number of issues. These include past productivity and reliability of the paddock, current yield estimates based on plant population and development, opportunity for renovating the paddock, identifying future needs and not least, ensuring cash flows are appropriately managed.

Harvest
The cost:benefit ratio of harvesting grain will vary according to the current market prices of grain and as costs associated with harvest operation change. Two primary calculations are appropriate when looking at the cost of harvesting grain this season: the harvest break-even point (minimum required to cover costs of harvesting alone) and the break-even yields required to cover the costs of seeding, maintenance and harvesting (including transport) (Table 1).

Table 1. Harvest break-even point (t/ha) and break-even yields (t/ha) for lupin, field pea and wheat

	Lupin	Field pea	Wheat
Break-even yield (t/ha)	1.00	0.83	1.08
Harvest Break-even	0.22	0.17	0.15

Harvesting provides the potential for recouping some of the cost of seeding and subsequent management, but a decision not to harvest may be made based on the weed burden of the paddock, carryover of any nutrients and subsequent crop rotations.

Advantages for harvesting crops are pursuing income to increase cash flow, removing grain from the paddock to minimise potential for 'weed' problems in the following season and stubble management. Some disadvantages are increasing the risk of reduced return on investment (cost for harvesting minimum $15-20/ha) and poor control of weeds.

Hay
Advantages in considering grain crops for hay are the potential income/feed value, additional non-chemical weed control, grain removal and stubble management. Disadvantages include the high cost of making hay (minimum $30-40/ha), nutrient export ($) and potentially, poor quality.

Current estimates suggest a crop biomass of at least 2t/ha is required to break even (all costs) or about 0.5t/ha biomass to cover hay making costs (Bill Roy, Agricultural Consulting & Research Services Pty. Ltd.). Additional to these costs are the potential losses associated with nutrient export and cost of replacing these. An example calculation of the cost of replacing potassium after a 2t/ha hay crop is provided below (Bill Bowden, Kari-Lee Falconer).

Example calculations of the cost of replacing potassium after a hay and stubble crops:

A 2t/ha hay crop will remove 24kg/ha of potassium from the paddock. The cheapest source of K, is muriate of potash of which 49.5% is potassium. To replace the K removed, 48 kg/ha of muriate of potash needs to be applied. At $0.77/kg K, it would cost about $18.50/ha (24 by 0.77 = $18.50) to replace the potassium exported in hay.

The short-term implication of not adequately replacing nutrients in the soil after hay crops is, that soils which are marginal in nutrients will run the risk of future crops and pastures becoming deficient and therefore reducing potential profit.

Grazing
Advantages in grazing crops are associated with the potential feed value, reducing weed seed set, some grain removal, easing pressure on pastures, agistment opportunities and stock retention. Disadvantages may be associated with not having sufficient stock to maximise opportunity, potential grain carry over, stubble condition at seeding and increasing erosion pressure (requires 40-50% ground cover). Additional costs associated with supplementary feed being required when grazing cereal crops and general sheep health including an increased risk of lupinosis should also be considered.

Green and brown manure crops
Green manure crops or renovation crops provide an alternative to grain crops to rejuvenate poor performing paddocks, improve soil nitrogen levels, manage herbicide resistance, improve soil health, enhance moisture availability, and improve profitability and flexibility

Advantages for renovation include effective weed control (timing important), recycling of plant nutrients, retention of organic matter, moisture retention and increasing flexibility for future use (graze option on brown manuring). A number of techniques have proved effective in trial work for increasing productivity in current farming systems, including green manuring (GM), brown manuring (BM) and mulching (MU). There is less risk for erosion associated with the latter two options on light textured soils, and the flexibility to utilise these for late feed options. On lighter textured soils they may also provide slower nutrient recycling, minimising the potential losses from summer rains on leaching soils.

Average grain yield increases from trial work to date indicate productivity gains of approximately 15-20% with increases in grain protein also observed. Implementation requires correct timing and soil moisture. Tactical implementation where seasonal factors suggest low crop yield potential due to low rainfall, disease, frost etc is more likely to result in highest economic gain. Other disadvantages may be associated cash flow, access to appropriate machinery, increased erosion risk (GM only) and potential stubble condition at seeding (BM/MU).

Legume crops used in renovating paddocks can improve grain yield and protein significantly, and whilst benefits on heavy soils appear to be maintained in the medium term following renovation, shorter term benefits are anticipated for sandplain soils. Mulching and brown manuring may be used as an alternative to green manuring where erosion hazard is high, in no till farming systems or to maintain soil structure Integration of other farm practices such as liming and deep ripping to reduce costs and maximise efficiency. Renovation cropping can be an effective tool in an IWM package

Summary

The opportunity to maximise future income can be influenced by decisions made seasonally, particularly for paddocks that have proven reliable and profitable in the past. Setting up optimal conditions for the next cropping season should not be overlooked, given there may be limited resources.

7.0 Discussion

Essential plant growth requirements including nutrients and water are influenced by the capacity of the soil to both store and supply these elements. Infiltration of water into soil and the ability for soils to retain water are processes fundamentally important for soil productivity. Management strategies that increase the rate of water infiltration into soils are likely to improve the potential of the soil to capture larger amounts of water. The rate of movement through the soil profile however, may be more important for crop production in terms of influencing the ability of plants to utilise this water.

The advantages of incorporating a pasture legume or green manure phase into the farming system are associated with increasing flexibility and providing a diverse range of options to growers, such as grazing, strategic weed management, hay cutting, seed production, profitability and risk management, or a combination of these. The value of *legumes* in crop rotations is evident in Western Australian farming systems, where diversified rotational sequences incorporating these plants have resulted in higher contributions of mineral nitrogen to the soil, increased levels of organic matter and improved soil structure. In addition, legumes may act as a 'break' crop in disease and pest cycles, allow effective grass control and rotation of herbicide groups in the farming system.

Green manure crops are rapidly becoming an option in areas where a build up of herbicide resistance has been identified, to lift and maintain soil fertility, and in some areas because of low returns on pulse crops (Mayfield, 1995). Often, for growers in continuous cropping systems or in no till farming systems, grazing is not a practical solution. In a farmer review of 'green manure techniques', the primary reasons for adoption were many and varied (Mayfield, 1995). Amongst the reasons listed were increased cereal yields and grain protein, increased long-term soil fertility, control of weeds, reduced risk of herbicide resistance, reduced costs for spraying in subsequent years, control of cereal root diseases and reduced risk compared to growing grain legumes in marginal areas (Mayfield, 1995).

Where the production of conventional legume crops is limited by soil type and growing conditions, other options such as the use of 'phase' pastures may provide an alternative solution to improving chemical fertility. Pasture species such as Cadiz (*French Serradella*) can provide attributes such as soft seededness, high biomass production in a single year and may be integrated with sheep management where required. High biomass legume and pulse crops that are utilised as a source of nitrogen, may be a more effective option for rotational sequences where we expect to see large gains in subsequent cereal crops. This is particularly evident where currently grain legumes used in rotation with cereal crops, result in significant increases in wheat yield and grain quality.

Effective management must include the appropriate choice of crop to achieve a specific goal. A high vigor crop would provide advantages in weed control and herbicide resistance management. Combined with late seeding enabling the effective use of knockdown herbicides, this provides an ideal start for a quick growing, high biomass crop (high vigor) crop to compete effectively against further germination of weeds. Subsequent use of in-crop selective herbicides may then be reduced. Many highly competitive crops such as oats, cereal rye or triticale may be paired with other crops to maximise grain yield. High biomass crops are likely to maximise gains in soil organic carbon and as a result improve the biological health of the soil. These crops may also provide greater potential to alleviate soil structural problems, increasing the potential for better soil water holding capacity.

There has been a wide range of benefits observed from the use of green manure crops in Western Australia. It is often difficult to determine exactly what benefits have been derived from the green manure but average yield benefits have generally been in the order of 20-30%, with an associated increase of approximately 0.5% to 1% in grain protein. Benefits associated with improvements in soil health, reduced disease levels, improved weed management and as a tool in combating herbicide resistance are harder to associate with direct contributions in terms of production gains and hence profitability. These factors however, may result in increasing profitability through higher yields and grain protein, as well as improving the viability of current farming systems.

One of the primary factors in adopting a manure phase is to combat the risk of developing herbicide resistance, or as a tool in managing populations where resistance has already been identified. A green manure phase, if managed properly, should result in 100% seed set control of weeds. Combined with integrated management options such as delayed seeding of wheat phase, application of an early knockdown, high seeding rates and seed catching; then a canola or barley crop (swathed), we are able to approach the problem of resistance with a number of different mechanical and herbicide options.

The magnitude of these benefits will be affected by the current status of the paddock, poorer paddocks obviously having a greater potential for improvement. The benefits observed will also be dependent on whether the type of manure crop chosen is appropriate for the situation. Where weed management is effective for example, the potential increase may be more from the reduced competition for nutrients and soil water, than from other benefits. The importance of correctly identifying the restricting factors currently influencing yield, will help determine the extent of potential benefits and the type of manure crop most suited. Other events that may influence the benefits realised from a manure crop, depend on the events that influence the availability of organic matter and nitrogen, typically climatic events.

The adoption of green manuring, may be most profitable where a ‘tactical’ approach is taken in response to a seasonal event or problem, as the costs involved here are minimal. Initial analysis suggests this may occur in a low-income year or where a crop fails (Bathgate and Moerch, unpublished). Strategic use of manure crops may be employed where problems exist that have resulted in a yield decline of 20% or more (Bathgate and Moerch, unpublished) and represent part of a long-term systems approach to resolving specific issues.

Other management options could be incorporated with a manure phase, such as liming or applying gypsum on top of the crop to be manured and incorporating it at the same time. This can help in reducing management costs.

Costs and Risks

The cost of a green manure phase is associated with the loss of income required to grow and subsequently ‘sacrifice’ a crop. The level of cost involved is largely determined by the relative opportunity cost of that crop. Where a manure crop is adopted due to declining profitability for example, the opportunity cost declines (Bathgate and Moerch, unpublished). Associated with this opportunity cost, is the more variable risk of the likely benefits returned from growing a manure crop. Nitrogen recovery following a green manure crop likely to vary due to soil type, environment, crop type or management; quality and yield potential realised dependent on the percentage of residue decomposed (Badaruddin and Meyer, 1990).

It is possible that climatic events may restrict the level of benefits observed by affecting the breakdown of plant residues, or reduce the subsequent yield of crops where conditions are not favourable. Where the breakdown of the residue has not been sufficient, some problems at seeding may develop with the handling of that material. Disease implications have not been fully investigated at this time.

Risk may also be associated the adoption of these techniques where a perceival that a single green manure crop may be sufficient to ‘fix’ a problem that requires a long-term, integrated approach. Unreasonable expectations will generally lead to frustration and disappointment for growers, particularly where an element of risk exists. Current research will focus on providing information on the benefits and economics of a green manure crop and identification of any associated risks.

8.0 References

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8.0 Appendices

Examples of research and extension material generated from this project are attached below. Numerous articles have been produced for field days attended by growers, agribusiness, consultants and other research providers; news articles and media releases; GRDC publications, Crop Updates. Presentation of research results has been made to an average 1500 growers annually through speaking at seminars, field days and conferences throughout the course of the project.

8.1 Chapter for Integrated Weed Management Manual

Microsoft Word Document

8.2 Harvest, hay, graze or green manure?????

Microsoft Word Document

8.3 Conference paper: Green manure as IWM tool (Italy, 2002)

Microsoft Word Document