GRDC Grower Solutions Project
Central Queensland

Crop Nutrient Management trials report 2011-2015

Queensland Department of Agriculture and Fisheries

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Executive summary

The Central Queensland Grower Solutions project (CQGS) was designed to address short term development and extension (D&E) needs for the central Queensland (CQ) grains industry. Through industry consultation processes over the duration of the project, several crop nutrition / soil fertility D&E questions were identified of which three were selected for field trials:

Is there a yield advantage in applying bag nitrogen fertiliser to mungbean?

Five trials comparing different fertilisers and rates were conducted. These trials found no advantage from applying nitrogen (N) to mungbean crops, even in high yielding situations. One of the few significant treatment differences was a significant yield penalty in plots where inoculum was not used, which reinforces the need to inoculate mungbean correctly. Fertiliser impacts on nodulation were also assessed in one trial which found high N rates inhibited nodule development.

What are the benefits of chickpea-wheat rotations in CQ?

Eight trials were conducted to quantify the benefits (if any) of rotating chickpea into a cereal dominated CQ farming system. Benefits of the chickpea crop to a following wheat crop included extra N, higher yields, higher grain proteins, cereal disease suppression and greater profitability compared to sequential wheat crops.

These trials also found returns on investment of N fertiliser often exceeding 2:1 in low soil N situations. Significant yield increases to phosphorous (P), potassium (K) and sulphur (S) fertiliser inputs were also observed at deficient sites and chickpea appeared to be more responsive to PKS fertiliser than wheat.

How do CQ farmers and advisors use fertilizers effectively to manage soil fertility decline and complex soil macronutrient deficiencies?

Ten trials were established across CQ to validate deep fertiliser placement technology, assess the predictive accuracy of soil tests for P, K and S and find profitable strategies to overcome a yield ‘ceiling’.

Seven trials were harvested in 2014; there were several significant findings despite several being impacted by drought.

It is relatively easy to place fertiliser bands 15 - 20 cm deep; travelling along tram tracks after a light shower minimised soil surface disturbance.

Soil moisture can be lost when applying fertiliser at depth, strategically applying fertiliser early in the fallow will minimise this risk.

Soil tests correctly identified P deficiency at one site and perhaps at a second. Deep applied P can be profitable, with the cost of 30 kg P/ha recovered in the yield response of the first crop at one site. This is encouraging given 5 years/crops worth of P was applied.

Low grain proteins indicate that the current N management strategy is failing to meet crop requirements; N fertiliser use needs to be budgeted to meet yield expectations.

Expected response to P, K or S fertiliser application may not be realised unless there is sufficient N available to support the increased yield potential.

1.0 Background

Many CQ soils are deficient in one or more crop macronutrients - N, P, K and S; this has been identified as being one of the major reasons for stagnant cereal and pulse crop yields, and diminishing profitability of cropping enterprises. Widespread and seasonally variable N deficiency in CQ soils has been the most visible evidence of this fertility decline, with general acceptance of the need to apply N fertiliser. In addition to being N deficient, many CQ soils are now also likely to be deficient in one or more of the other key macronutrients, viz, P, K and S, which may be limiting yields and returns on fertiliser N investment.

Often faced with complex nutrient management decisions, CQ grain growers are grappling with a number of practical nutrient management issues including but not limited to (a) optimizing nutrition programs to maximize the productivity of individual crops and crop rotations, and (b) the development of on-farm, paddock/soil type specific fertiliser application strategies for longer term management of negative nutrient budgets and diminishing soil fertility reserves.

Over the last five years a combination of improved varieties, high prices and usefulness as a rotation crop for grass weed management have all contributed to mungbean evolving from a minor crop to potentially competing with maize as the second largest dryland summer crop (following sorghum) in area planted. Data collected by the Grains Research and Development Corporation (GRDC) in 2011 showed that after the release of new mungbean varieties in 2008, planting area increased from around 45,000 ha to 66,000. A survey of 71 CQ grain growers by the GRDC CQGS in 2011 showed that 47% regularly grew mungbean. The short duration of this crop also enables double cropping opportunities which could not otherwise occur. Mungbean is very important to the high cropping frequency farming systems of the Callide valley. Grain prices have ranged from $600 to $1300/t (often above $800 for Processing No. 1 beans). Mungbean can also be planted beyond the optimum sorghum planting window for CQ and provide a late February cropping option. Mungbean is now planted as a late summer option instead of sunflower when it is too late for sorghum. Given the increasing importance of mungbean in CQ, growers were interested in ways and means to maximize productivity. Anecdotal observations seemed to suggest the potential for significantly higher mungbean yields with the application of N fertiliser compared to the traditional practice in CQ wherein legumes are not fertilized with bag N.

Previous research highlighting the productivity and system health benefits of cereal/legume rotation (including wheat/chickpea rotations in southern Qld and elsewhere in the northern Australian grain belt) triggered renewed interest in evaluating the benefits of chickpea/wheat rotations in CQ. Wheat is the most important winter crop in CQ, valued nearly as much for the stubble cover it provides as for its productivity in the zero-till, water limited opportunity cropping systems of the region. Stubble retention is a key tactic in maximizing summer fallow efficiency, decreasing the potential for soil erosion and increasing soil biological activity. Desi chickpea (*Cicer arietinum* L.) is the second most important winter crop (after wheat), valued for nitrogen fixing capabilities and as a break crop in the cereal dominated broadacre cropping systems in the region. In recent years, good market prices for chickpea have made this an important crop in its own right. However, many farmers are unsure about the N fixing contribution of chickpeas under CQ conditions, an increasingly important issue as native nitrogen fertility levels decline.

The need to apply multiple nutrients in the form of bag fertiliser to address stagnant or declining grain productivity on their farms is forcing CQ grain growers to re-evaluate their soil/crop nutrient management strategies. It is no longer uncommon to find moderate to severe depletion in one or more soil macronutrients (N, P, K, and/or S) in many CQ grain paddocks. Macronutrient research has been underway for several years – some key nutrients are very well understood (eg. N), there is a better understanding of others (eg. P), whereas some are still being researched (eg. K and S). The development of definitive guidelines for remediating P, S and K nutrient deficiencies from the on-going research effort may be some years away. Whilst some progressive CQ farmers recognize the link between fertility rundown and stagnant or declining yield profiles on their farms and are proactively seeking solutions, many still do not appear to have sufficient knowledge of the relationship between nutrient inputs and grain output so as to manage their fertiliser inputs effectively. The virtual absence of on-farm yield benchmarking has precluded a significant number of CQ farmers from gaining a fundamental understanding of productivity in relation to soil fertility and unachieved yield potential on their farms. Whilst the knowledge gaps in macronutrient management are being addressed through research, many CQ farmers continue to suffer significant yield penalties and loss of income as a result of inadequate or inappropriate fertiliser use. The development of a practical, on-farm diagnostic (strip-trials) guide for farmers to identify the most profitable fertiliser program and appropriate application technique on individual paddocks or farms using current crop nutrition knowledge is a high priority in CQ

Through the mechanism of biannual grain grower and industry stakeholder engagements run by the CQGS team, the following nutrition priorities and research questions related to the topics discussed above were identified during the period 2011-2015 for actioning through on-farm trials:

Nutrition priority (2010-2012):
Measuring the impact of nitrogen, phosphorus or zinc fertiliser on mungbean yield

Nutrition priority (2011-2013):
Measuring the benefits of chickpea-wheat rotations in CQ grain production systems

Nutrition priority (2014-2015):
Development of fertiliser application strategies to manage complex soil macronutrient deficiencies

The following sections report on trials conducted under the auspices of each nutrition priority listed above.

2.0 Mungbean fertiliser trials (Nutrition priority 2010-2012)

Objective

To compare the yield responses of mungbean to different combinations of N, P, S, zinc (Zn) and inoculum.

Research questions

- What is the effect of applying N, P, S and Zn fertiliser singly or in combination on biomass production, nodulation and grain yield of mungbean?
- Given that mungbean is a quick maturing crop, is grain yield limited by an inability to fix sufficient N for top end yields?

Methodology

Five trials were conducted on a range of commonly farmed CQ soils (Tables 2.0.1, 2.0.2). Planting and fertilizing was done with two runs of a seven row cone plot planter, with tines at 25cm spacing. The plots were planted via the bulk seed box in rows 1, 3, 5 & 7 to achieve planted row spacing of 0.5 m. Fertiliser was applied to a depth of 5-10 cm through the cone down all seven rows such that 57% was applied with the four seed rows (rows 1, 3, 5, 7) and 43% applied in the interspace - three rows (rows 2, 4, 6). Inoculation was done via water injection at planting on all treatments except 'No-inoculum' treatment.

Table 2.0.1. Trial site metadata

Trial ID	Location	Property	Co-operator	Soil Type
MFT-1010-WOW1	Wowan	Alma park	Neal Johansen	Brigalow Scrub
MFT-1010-BIL1	Biloela	Biloela Res. Stn.	Gavin Lotz	Callide Alluvial
MFT-1010-THE1	Theodore	Wongalee	Brendan Conway	Brigalow Scrub
MFT-1101-CAP1	Capella	Werrina Downs	Mark Basford	Open Downs
MFT-1102-KIL1	Kilcummin	Tarvellon	David Daniels	Open Downs

Table 2.0.2. Key soil characteristics for each site.

Variable	WOW1	BIL1	THE1	CAP1	KIL1
Organic Carbon (OC) 0-10 cm	1.06	-	0.87	0.68	0.83
Nitrate (kg/ha) to 90 cm	65	20	13	22	46
Colwell P (mg/ha) 0-10 cm	72	140	10	21	32
pH 0-10 cm	6.9	6.4	7.7	8.4	7.7
Cl (mg/kg) 60-90 cm	426	98	162	< 20	< 20
EC (dS/m) 60-90 cm	0.63	0.21	0.44	0.33	0.11

Treatments

14 combinations of N, P, S and Zn fertiliser treatments were used in these trials. Fertiliser treatments and their respective nutrient levels are listed in Table 2.0.3. The nutrient percentages of the fertiliser products used are given in Table 2.0.4.

Table 2.0.3. Fertiliser treatments with their respective nutrient rates (kg/ha).

Treatment ID	Products used	N	P	S	Zn
No inoculum					
Control	Inoculum				
5 Silver N	Inoculum + Silver N	5			0.11
10 Silver N	Inoculum + Silver N	10			0.22
20 Silver N	Inoculum + Silver N	20			0.44
2.5 P	Inoculum + Triple Superphosphate		2.5	0.12	
5 P	Inoculum + Triple Superphosphate		5	0.24	
10 P	Inoculum + Triple Superphosphate		10	0.48	
10 N	Inoculum + Urea	10			
20 N	Inoculum + Urea	20			
40 N	Inoculum + Urea	40			
Urea + MAP	Inoculum + Urea + MAP	10	5	0.34	
Urea + Granulock	Inoculum + Urea + Granulock Supreme Z	10	5	0.34	0.23
Granulock	Inoculum + Granulock Supreme Z	2.7	5	0.97	0.24

Table 2.0.4. Nutrient composition of fertiliser products used.

Fertilisers	N (%)	P (%)	S (%)	Zn (%)
Urea	46.0	-	-	-
Granulock Supreme Z	11.0	21.8	4.0	1.0
Silver N	45.4	-	-	1.0
MAP	10.0	21.9	1.5	-
Triple Superphosphate	-	20.7	1.0	-

Trial design

The trials had four replicates arranged in a randomised block design. Trial plot areas were 20m x 4m with a datum area approximately 30-34m^2 (15-17m x 2m). Trials were planted and fertilised with a tyned 2m wide small plot planter. The target planting rate was 250,000 plants/ha (22kg/ha assuming seed weight of 14,000/kg). Water injected peat inoculum was used. The trials were planted on 50cm row spacing with fertiliser applied during planting at 25cm bands (some with the seed and remainder applied inter-row).

Sampling protocols

Soil sampling was done at 0-10 cm, 10-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm intervals for nitrate at planting and site characterisation by collecting eight soil cores per trial and bulking and sub-sampling.

Plant counts

Two samples were taken from each plot and averaged to provide a plot plant count. Each sample was 1 m long by four rows (2m^2). Plant counts were taken at 14-21 days after planting.

Biomass

Two samples were taken from each plot and averaged to provide a plot dry matter estimate. Each sample consisted of 2 crop rows by 1m long (1m^2). Samples were cut off at ground level with secateurs. Samples were dried in drying ovens at 60^{o}C for at least 5 days until they were air dried, then weighed.

Nodulation

This was done only at the WOW1 trial site; the roots of two plants were dug up in each plot. The roots and associated soil was soaked and treated with clay deflocculate. The soil was carefully washed from roots (on top of a fine mesh). The root system was then assessed for nodulation. Nodules were separated from roots, dried and weighed.

Grain yield

The central 2m from each plot was harvested with a small plot combine harvester. Length of harvested plot was measured to within 10cm. Grain samples were collected for each plot. Grain weights were adjusted for moisture to maximum receival standards (12%).

Results

2.1 MFT-1010-WOW1

- Previous crop was wheat
- Soil water at planting = 120 mm
- Planted on 7/10/2010
- In-crop rain = 512 mm

Soil N

At planting soil N averaged 65 kg/ha.

Plant population

Plant population density within the experimental plots was assessed on 21/10/2010. There were significant (P<0.01) differences in mungbean plant population (Table 2.1.1). Generally lower plant populations occurred in treatments with 10-40 kg N/ha compared to those with little or no N fertiliser applied.

Table 2.1.1. Mean plant population density in the Wowan (WOW1) trial.

Treatment	Plant Population (plants/ha)		Difference from control (%)
2.5 P	360,000	a	8
5 P	356,250	ab	7
Urea + Granulock	347,500	abc	5
10 P	347,500	abc	5
Control	332,500	abcd	0
10 Silver N	327,500	abcd	-2
No inoculum	320,000	abcd	-4
5 Silver N	291,250	abcd	-12
Granulock	283,750	bcd	-15
20 N	283,750	bcd	-15
40 N	277,500	cd	-17
Urea + MAP	262,500	de	-21
10 N	260,000	de	-22
20 Silver N	190,000	e	-43
lsd	76,032		

Nodulation

Nodulation was assessed on 1-3/12/2010. There was a significant difference in nodulation scores (see Table 2.1.2) with 20 N and 40 N having less nodules than ‘No inoculum’.

Urea and high P rates significantly reduced nodule dry weights per plant.

20 N and Granulock significantly increased root dry weight production while high P rates and non-fertiliser treatments had lower root biomass.

Table 2.1.2. Mean nodulation score, nodule and root dry weights for selected treatments in the Wowan (WOW1) trial.

Treatment	Nodule Score		Nodule Dry Weights (g) per plant		Root Dry Weights (g)	
Granulock	1.98	ab	0.024	abcd	1.176	a
40 N	1.52	b	0.017	cd	0.970	bc
20 N	1.41	b	0.017	cd	1.126	ab
10 N	1.81	ab	0.013	d	0.977	abc
10 P	2.10	ab	0.020	bcd	0.906	c
5 P	2.20	ab	0.015	d	0.876	c
2.5 P	1.99	ab	0.032	abc	0.944	bc
Control	2.03	ab	0.037	a	0.878	c
No inoculum	2.21	a	0.034	ab	0.825	c

Biomass

Plant biomass samples were collected on 3/12/2010. Biomass averaged 3,223 kg/ha with no significant difference between treatments (P>0.05; Fig. 2.1.1).

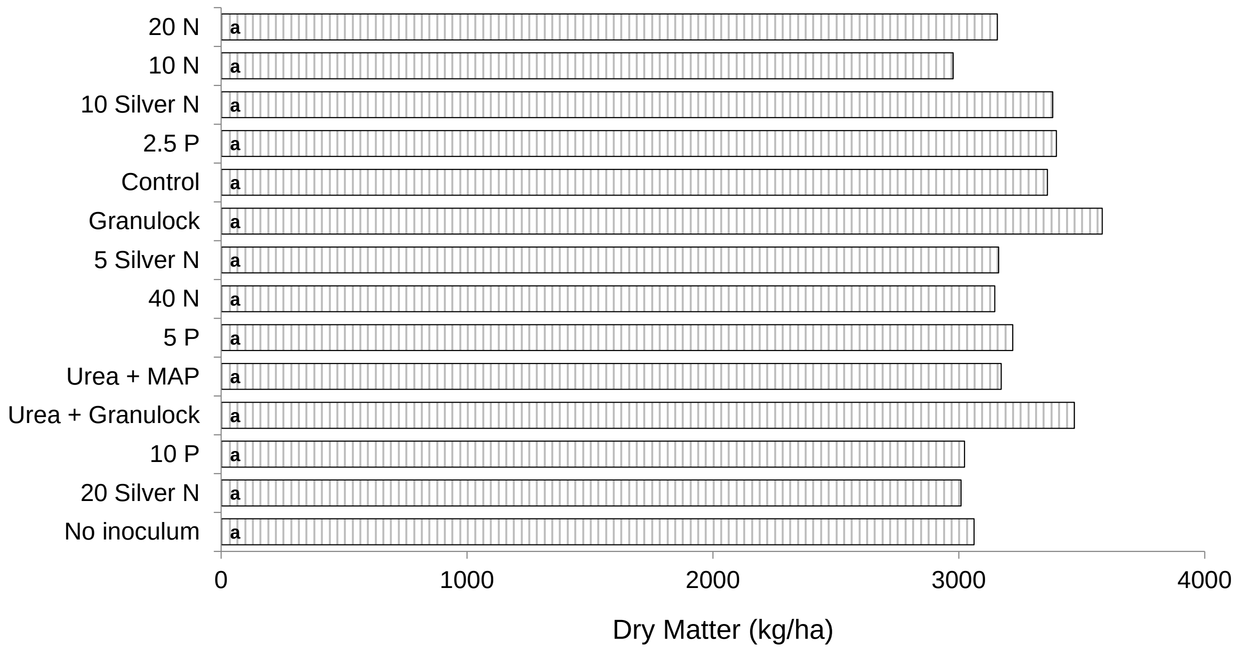

Fig. 2.1.1. Mean dry matter (biomass) accumulated by mungbean test crops in response to treatment with various fertiliser combinations at Wowan (WOW1). Means sharing the same alphabet are not significantly different (P>0.05).

Yield

The trial was harvested on 13/01/2011. Yield varied significantly among treatments (P<0.05; Fig. 2.1.2). There was a significant yield decrease when mungbean was not inoculated.

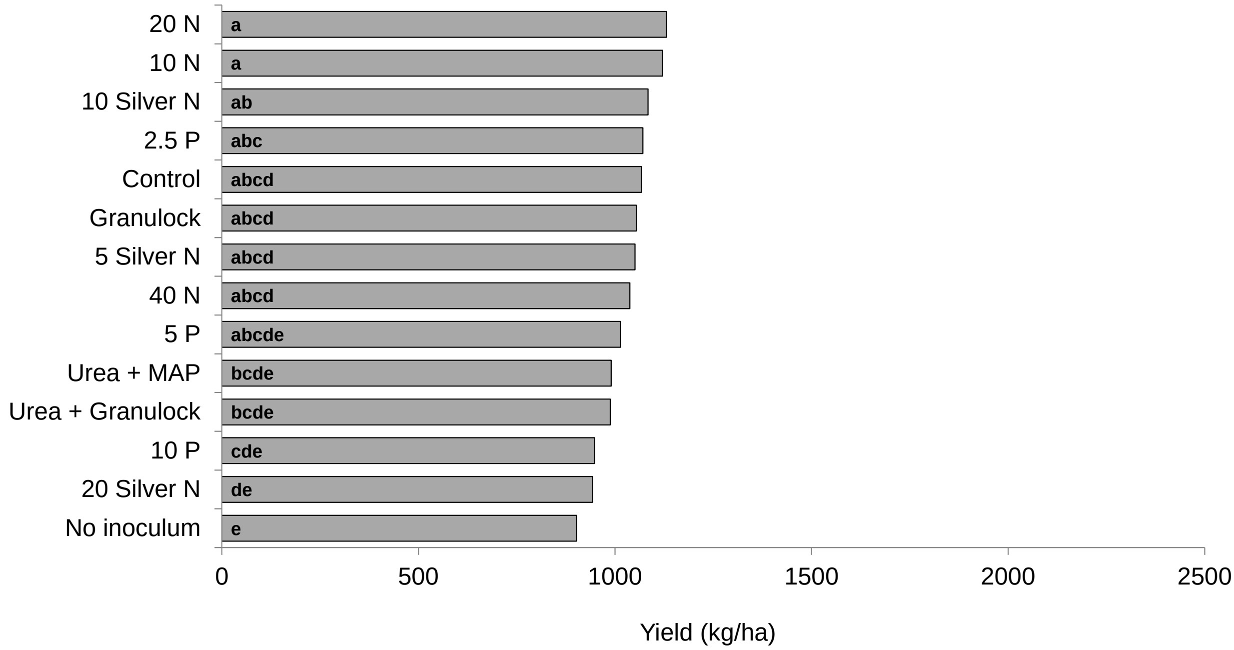

Fig. 2.1.2. Mean yield of mungbean test crops in response to treatment with various fertiliser combinations at Wowan (WOW1). Means sharing the same alphabet are not significantly different (P>0.05).

2.2 MFT-1010-BIL1

- Previous crop was sorghum in summer 2009/2010
- Soil water at planting = 150 mm
- Planted on 6/10/2010
- In-crop rain = 604 mm

Soil N

At planting soil N averaged 20 kg/ha.

Plant population

Plant population density within the experimental plots was assessed on 21/10/2010. Mungbean averaged 243,000 plants/ha. There was no significant difference (P>0.05) in plant density among treatments.

Biomass

Plant biomass samples were collected on 08/12/2010. Biomass averaged 3,390 kg/ha with no significant difference between treatments. There was a trend (P=0.075) for treatments with added N to produce greater biomass than those without (Fig. 2.2.1).

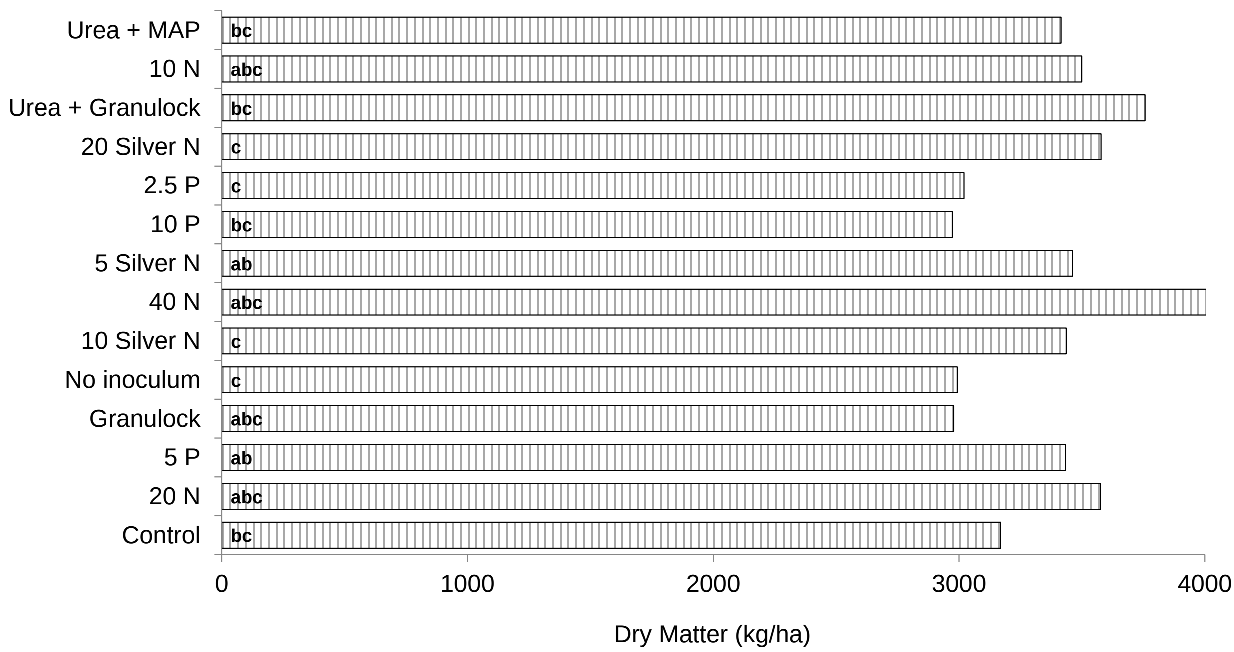

Fig. 2.2.1. Mean dry matter (biomass) accumulated by mungbean test crops in response to treatment with various fertiliser combinations at Biloela (BIL1). Means sharing the same alphabet are not significantly different (P>0.05).

Yield

The trial was harvested on 25/01/2011. Yield averaged 2,212 kg/ha with no significant differences among treatments (P>0.05; Fig. 2.2.2).

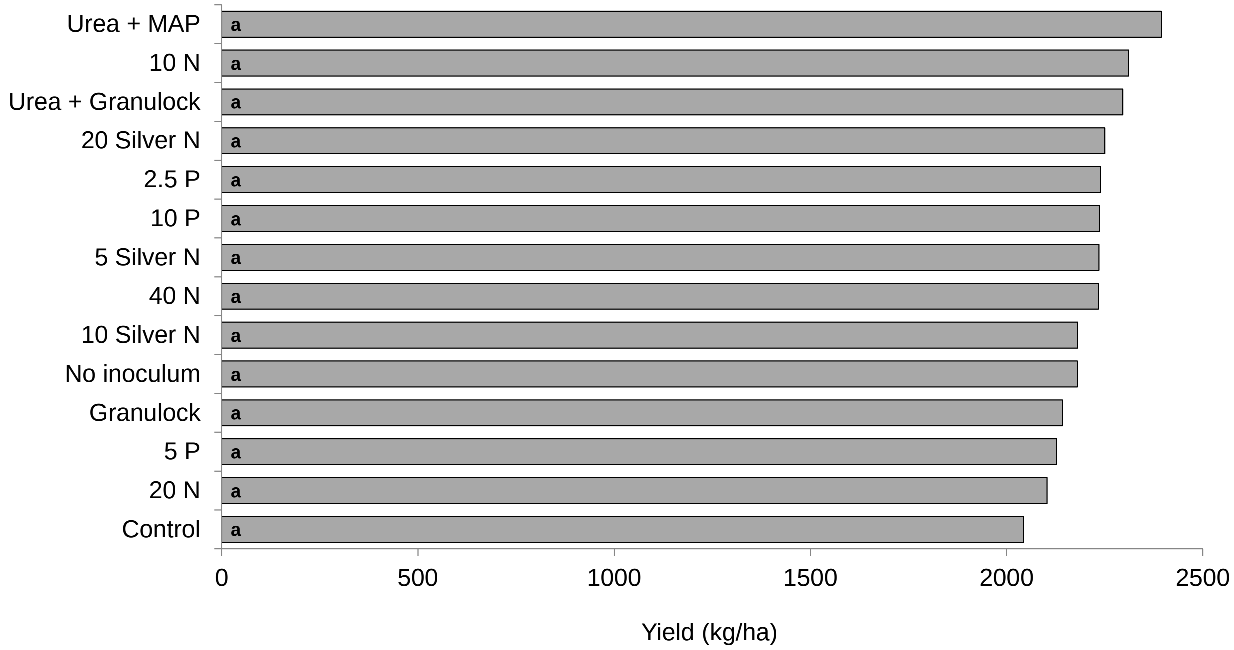

Fig. 2.2.2. Mean yield of mungbean test crops in response to treatment with various fertiliser combinations at Biloela (BIL1). Means sharing the same alphabet are not significantly different (P>0.05).

2.3 MFT-1010-THE1

- Previous crop was sorghum in summer 2009/2010
- Soil water at planting = 180 mm
- Planted 11/10/2010
- In-crop rain = 619 mm

Soil N

At planting soil N averaged 13 kg/ha.

Plant population

Plant population density within the experimental plots was assessed on 21/10/2010. Mungbean averaged 297,000 plants/ha. There was no significant differences (P>0.05) in plant population density among treatments.

Yield

The trial was harvested on 25/01/2011. Yield averaged 689 kg/ha with significant (P<0.05) differences between treatments (Fig. 2.3). There was a 27% yield decrease when inoculum was not used. 'Granulock' and 'Urea + MAP' gave the greatest yields.

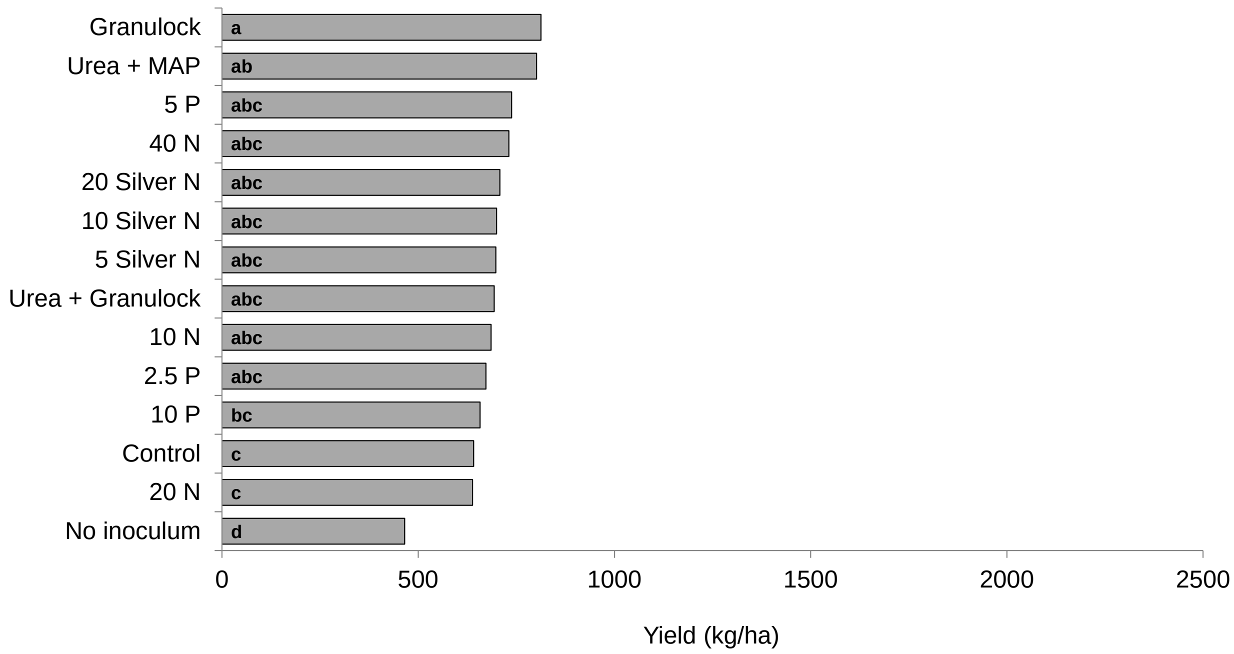

Fig. 2.3. Mean yield of mungbean test crops in response to treatment with various fertiliser combinations at Theodore (THE1). Means sharing the same alphabet are not significantly different (P>0.05).

2.4 MFT-1101-CAP1

- Previous crop was sorghum in summer 2009/2010
- Soil water at planting = 180mm
- Planted on 27/01/2011
- In-crop rain = 372 mm

Soil N

At planting soil N averaged 46 kg/ha.

Plant population

Plant population density within the experimental plots was assessed on 14/02/2011. Mungbean averaged 326,000 plants/ha. There was a trend towards lower plant densities (P=0.057) in treatments with higher rates of N (Table 2.4).

Table 2.4. Mean plant population density in the Capella (CAP1) trial.

Treatment	Plant Population (plants/ha)		Percent difference to control (%)
Granulock	325,000	abcd	-13
Urea + Granulock	315,000	bcd	-16
Urea + MAP	317,500	bcd	-15
40 N	302,500	cd	-19
20 N	283,750	d	-24
10 N	325,000	abcd	-13
10 P	321,250	bcd	-14
5 P	343,750	abc	-8
2.5 P	357,500	ab	-5
20 Silver N	311,250	bcd	-17
10 Silver N	298,750	cd	-20
5 Silver N	348,750	abc	-7
Control	375,000	a	0
No inoculum	336,250	abc	-10
lsd	50,596		13

Biomass

Plant biomass samples were collected on 14/03/2011. Biomass averaged 3,218 kg/ha with no significant differences between treatments (P>0.05; Fig. 2.4.1).

Yield

The trial was harvested on 13/05/2011. Yield averaged 1,375 kg/ha with no significant differences among treatments (P>0.05; Fig. 2.4.2).

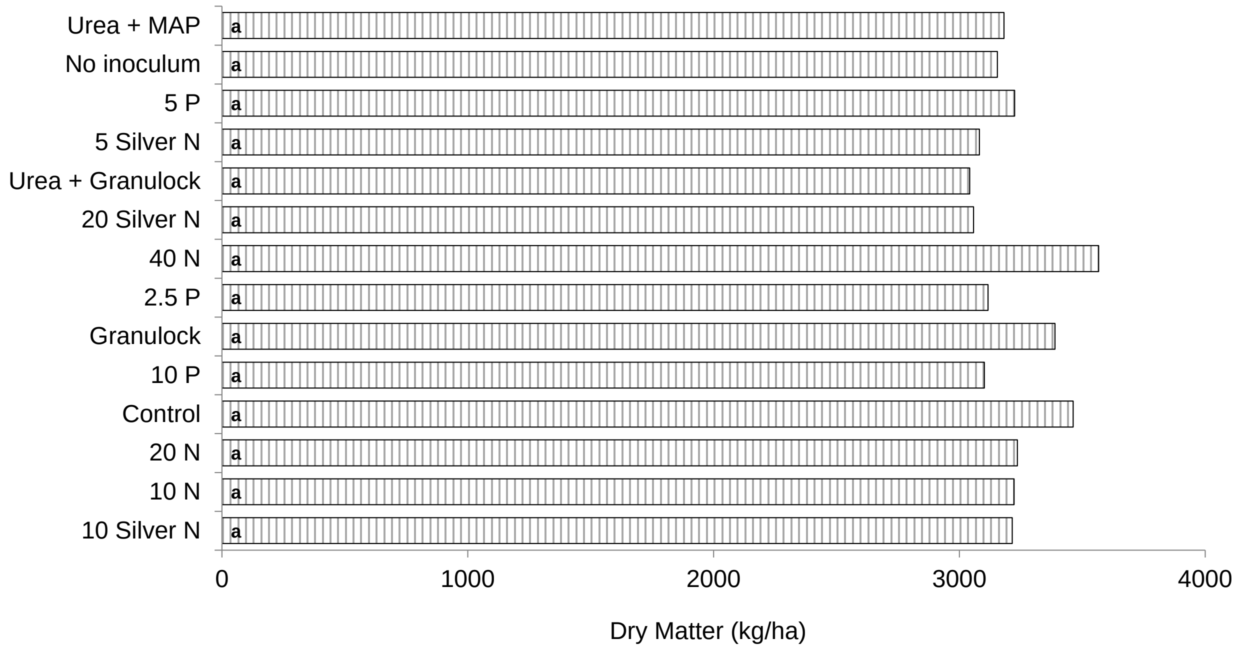

Fig. 2.4.1. Mean dry matter (biomass) accumulated by mungbean test crops in response to treatment with various fertiliser combinations at Capella (CAP1). Means sharing the same alphabet are not significantly different (P>0.05).

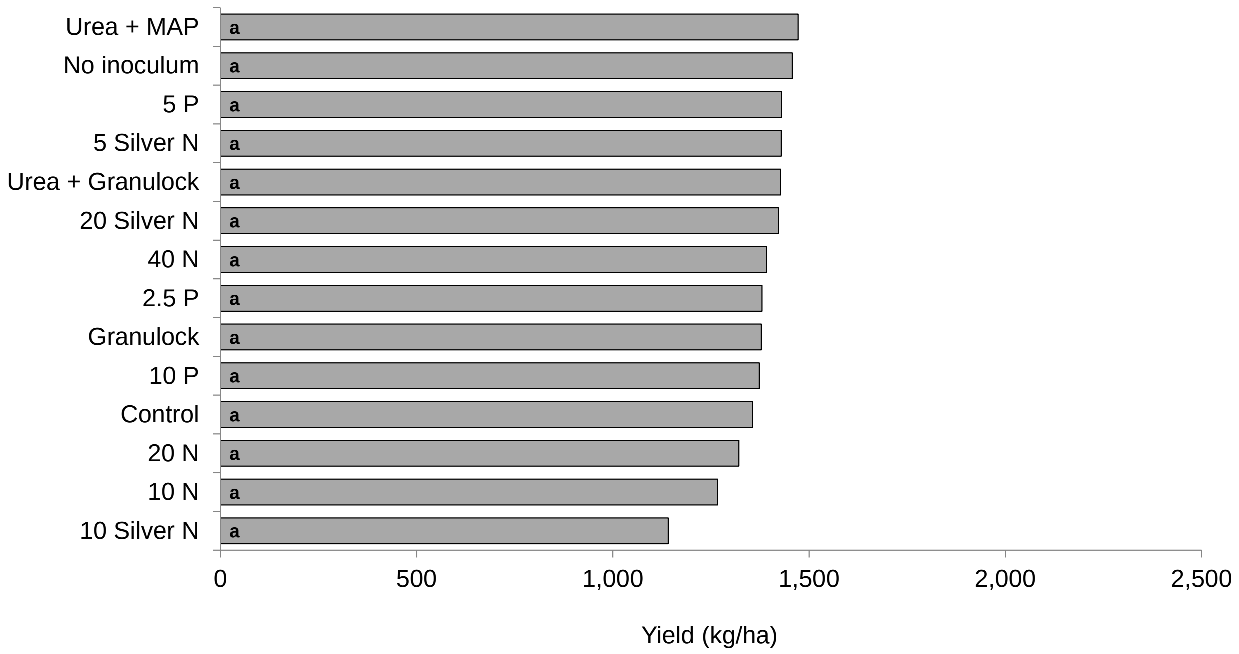

Fig. 2.4.2. Mean yield of mungbean test crops in response to treatment with various fertiliser combinations at Capella (CAP1). Means sharing the same alphabet are not significantly different (P>0.05).

2.5 MFT-1102-KIL1

- Previous crop was wheat in 2010
- Soil water at planting = 160 mm
- Planted on 9/02/2011
- In-crop rain = 210 mm

Soil N

At planting soil N averaged 22 kg/ha.

Plant population

Plant population density within the experimental plots was assessed on 23/02/2011. Mungbean averaged 320,000 plants/ha. There were no significant differences in plant population density among treatments (P>0.05).

Biomass

Plant biomass samples were collected on 06/04/2011. Biomass averaged 3,697 kg/ha with no significant differences between treatments (P>0.05; Fig. 2.5.1).

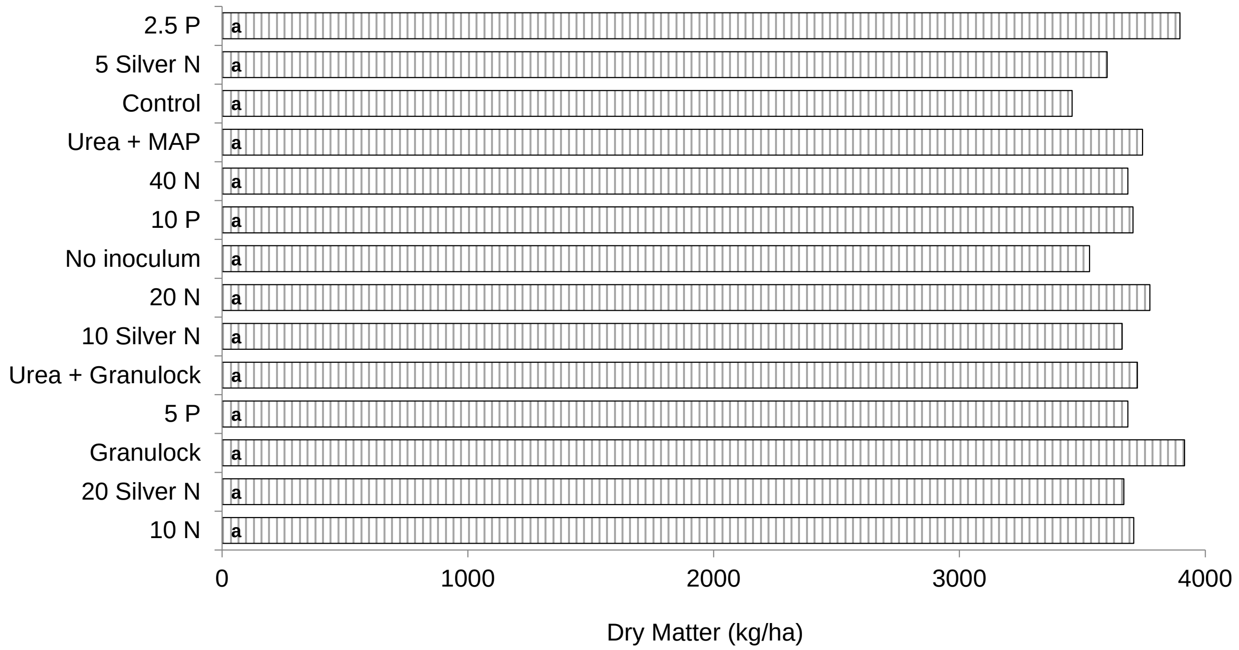

Fig. 2.5.1. Mean dry matter (biomass) accumulated by mungbean test crops in response to treatment with various fertiliser combinations at Kilcummin (KIL1). Means sharing the same alphabet are not significantly different (P>0.05).

Yield

The trial was harvested on 27/05/2011. Yield averaged 1,447 kg/ha with no significant differences between treatments (P>0.05; Fig. 2.5.2).

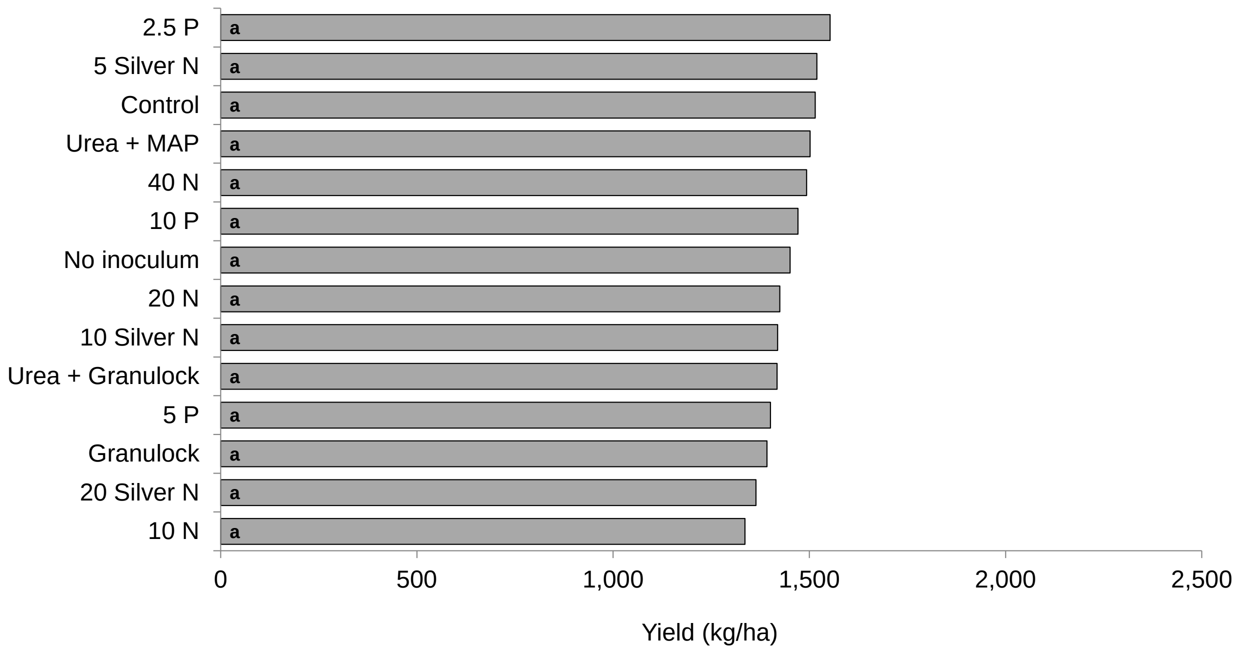

Fig. 2.5.2. Mean yield of mungbean test crops in response to treatment with various fertiliser combinations at Kilcummin (KIL1). Means sharing the same alphabet are not significantly different (P>0.05).

Discussion

There was no evidence of any significant yield response to bag N fertiliser in the trials reported here except in situations where root nodulation might have been sub-optimal due to the absence or paucity of inoculum (ie. WOW1 and THE1 trials). This result is consistent with prevailing conventional wisdom that legumes will usually fix nitrogen in relation to their needs and existing soil nutrient levels. Significant treatment effects for dry matter at one site can also be explained primarily on the basis of inoculum effects.

One of the few significant treatment differences from these trials was reduced yield when inoculum was not used, at WOW1 (-12%) and THE1 (-27%). At the other three sites there was no significant yield impact. Positive yield responses at two sites indicate inoculation may benefit mungbean in some circumstance. On the other hand, a lack of yield response at three sites indicates that inoculum should not be expected to provide a benefit in every situation. Nevertheless, it is important to use inoculum because it can provide substantial benefits to crops for minimal investment.

Constraints on responses to applied bag N when other nutrients are limiting (eg. P, K or S) cannot be ruled out. In the trials reported here, all fertiliser treatments were applied in the top 10 cm of the profile using current knowledge as per industry practice in 2010-11. Since then P and K knowledge and fertiliser management has advanced and deep application is now recognised as being important. It is possible that N fertiliser responses could have been different and perhaps more apparent if PKS had been applied 15-20 cm deep on sites where one or more of these macronutrients are deficient (eg. THE1).

Nodulation scores at WOW1 found nodulation was reduced by high N treatments (20 N and 40 N). This provides supporting evidence that high N fertiliser rates may inhibit nodule development.

Three of the five sites had above-average to high yields; BIL1, CAP1 and KIL1. There was no significant yield difference between treatments for any of these sites. These trials have found no evidence to support the claim N fertiliser is required to achieve top end yields. Instead these trials results provide evidence which supports the need for inoculation to maximise yield potential and found N fertiliser does not increase mungbeans yields, economically or otherwise.

3.0 Chickpea-wheat rotation trials (Nutrition priority 2011-2013)

Objective

To compare the yield responses of wheat followed by wheat (W/W) and chickpea followed by wheat (C/W) crop sequences with and without added bag fertiliser

Research questions

- What is the contribution of chickpea to the following wheat crop in terms of increased grain yield, N fixation and/or availability?
- What are the potential impacts of rotating wheat with chickpea on soil water, fertiliser use, disease prevalence and other system variables?

Methodology

Eight crop sequence comparisons (trials, hereafter) were conducted on soils with known low to moderate N fertility levels on four farms spread across CQ. Each farm hosted two trials in different paddocks; the first (ROT-11) started in 2011 and finished in 2012; the second (ROT-12) started in 2012 and finished in 2013.

Table 3.1 summarises the locations and soil types for each trial; Table 3.2 summarises key soil characteristics for each site. Comprehensive soil characterisation information for each site can be found in Appendix 5.1 and 5.2.

Table 3.1. Crop rotation trial site metadata.

Trial ID	Co-operator	Property	Location	Soil Type
ROT-1105-CLE1	Brendon Swaffer	Bungarra	Clermont	Flooded Coolabah
ROT-1105-GIN1	Andrew Bate	Shalimar	Gindie	Open Downs
ROT-1105-THE1	Brendan Conway	Wongalee	Theodore	Brigalow Scrub
ROT-1105-JAM1	Ian Hutchings	Lorraine	Jambin	Callide Alluvial
ROT-1205-CLE2	Brendon Swaffer	Bungarra	Clermont	Open Downs
ROT-1205-GIN2	Andrew Bate	Shalimar	Gindie	Open Downs
ROT-1205-THE2	Brendan Conway	Wongalee	Theodore	Brigalow Scrub
ROT-1205-JAM2	Ian Hitchings	Lorraine	Jambin	Callide Alluvial

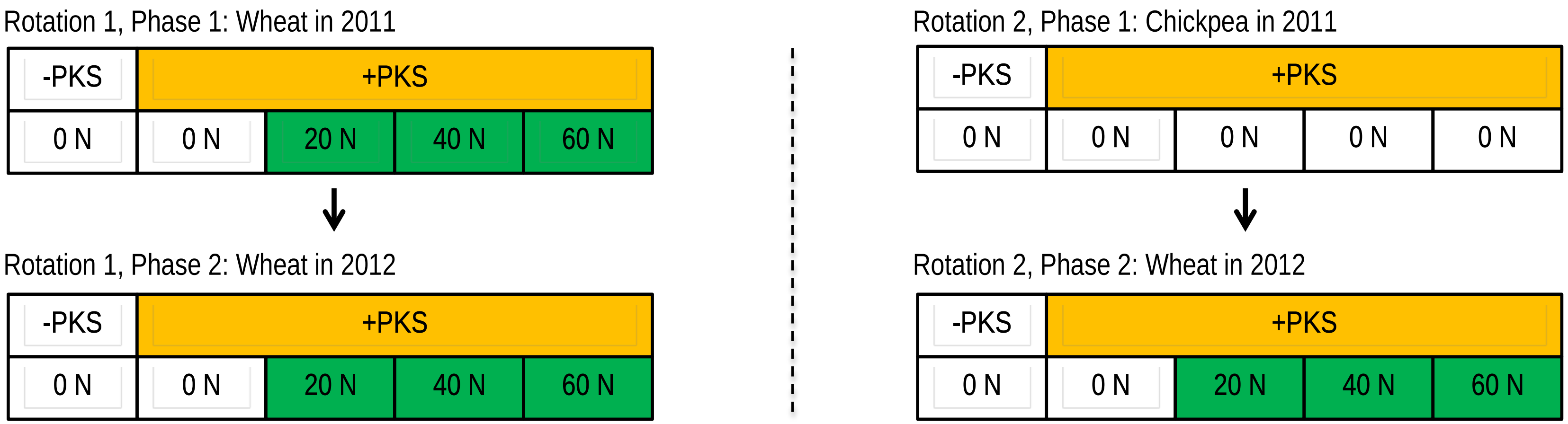

Fig. 3.0.1. Design of chickpea – wheat rotation trials conducted at Clermont (CLE1), Gindie (GIN1), Theodore (THE1) and Jambin (JAM1); Treatments included +/- N and +/- PKS fertiliser blend. See text for details.

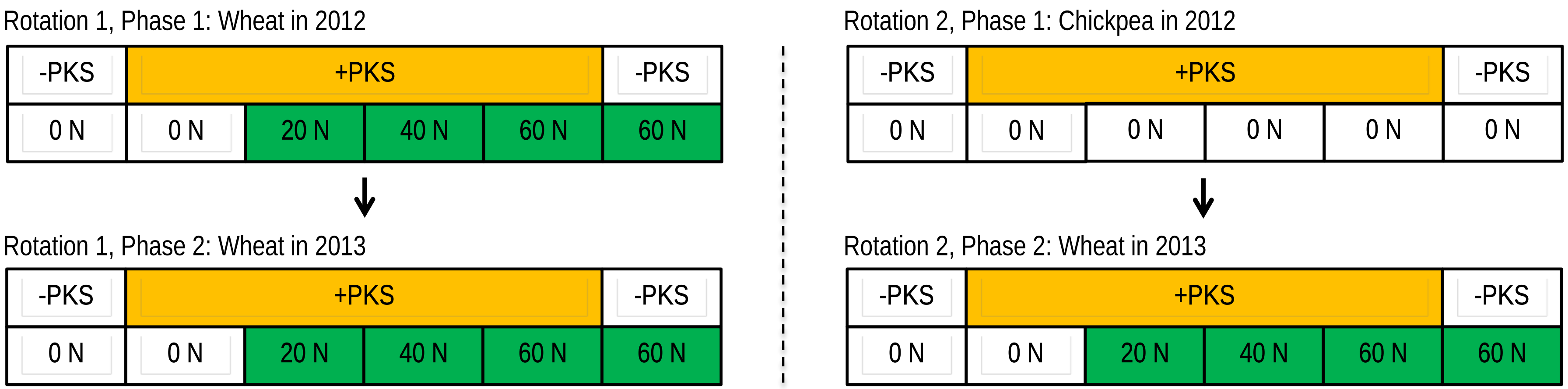

Fig. 3.0.2. Design of chickpea – wheat rotation trials conducted at Clermont (CLE2), Gindie (GIN2), Theodore (THE2) and Jambin (JAM2); Treatments included +/- N and +/- PKS fertiliser blend. See text for details.

Table 3.2: Key soil characteristics for crop rotation trial sites.

Variable	CLE1	CLE2	GIN1	GIN2	THE1	THE2	JAM1	JAM2
Organic Carbon 0-10 cm	0.55	0.91	0.65	0.67	0.89	0.87	1.03	1.29
Nitrate (kg/ha) 0 - 90 cm	51	33	38	20	21	58	76	106
Colwell P (mg/ha) 0 -10 cm	14	16	39	26	8	29	28	46
pH (0-10 cm)	8.9	8.5	7.0	7.5	8.2	8.5	7.7	7.9

Table 3.3: Fertiliser application in relation to trial phase and treatment for all crop rotation trials.

Phase 1 crop	Treatments	Phase 1		Phase 2	
		Urea (kg/ha)	PKS Applied	Urea (kg/ha)	PKS Applied
Wheat	0 N – PKS**	0	-	0	-
Wheat	0 N + PKS	0	+	0	+
Wheat	20 N + PKS	43.48	+	43.48	+
Wheat	40 N + PKS	86.96	+	86.96	+
Wheat	60 N + PKS	130.43	+	130.43	+
Wheat	60 N - PKS	130.43	-	130.43	-
Chickpea	0 N – PKS**	0	-	0	-
Chickpea	0 N + PKS	0	+	0	+
Chickpea	20 N + PKS	0	+	43.48	+
Chickpea	40 N + PKS	0	+	86.96	+
Chickpea	60 N + PKS	0	+	130.43	+
Chickpea	60 N - PKS	0	-	130.43	-

** Untreated control

Trial design

The trials were located within a large rectangular area with a W/W rotation in one half and a C/W rotation in the other (Fig. 3.0.1 & 3.0.2). The two rotation areas were separated by a crop buffer of 8m. Within each rotation area, the treatments (Table 3.3) were laid out as a randomised block design with five treatments in ROT-11 and six treatments in ROT-12; THE1 and JAM1 had five replicates whereas all others had four replicates. All plots were 4 m wide by 20 m long, fertilised and planted with a tyned 2m wide small plot planter.

Fertiliser treatments

Nitrogen was applied as granular urea (46% N) at four rates 0, 20, 40 and 60 kg/ha N (Table 3.3). The PKS mix consisted of triple superphosphate (20.1% P and 1% S) and Sulphate of Potash (41% K and 18% S). A mixture of P, K and S fertiliser (PKS hereafter) was applied at 21.8 kg/ha P, 17.5 kg/ha S and 37.5 kg/ha K to buffer out any deficiencies of these nutrients. N fertiliser (from pre-weighed bags) was applied via a trip cone. The PKS mix was applied (from a separate box) down the same tyne as planting seed. In the phase 1 of each trial all fertiliser was applied at planting and in phase two N and PKS fertiliser were applied in fallow with starter only applied at planting. Wheat and chickpea were planted on 50cm row spacing into moist soil.

Sampling Protocols

Soil Sampling

Soil samples were collected using a hydraulic soil corer. Sample increments were 0-10 cm, 10-30 cm, 30-60 cm, 60-90 cm. Soils were sampled for site characterisation, soil N and soil water. One soil core was collected from each plot, with cores from the same treatment bulked together for analysis. Nitrogen sampling included three additional 10 cm deep foot-stomps per soil core; bulked with the 0-10 cm increment from hydraulic cores. Soil water sampling took place at planting and harvest; Nitrogen sampling took place at planting and harvest. Site characterisations were taken before the start of the first crop at each trial site. Water samples were oven dried at 105^{o}C for at least three days for dry weights. Nitrogen samples were oven dried at 40^{o}C for at least 3 days before being ground finer than 2 mm and sent to Australasian Soil and Plant Analysis Council (ASPAC) accredited laboratories for nitrate and ammonium analysis

Plant Counts

Two samples were taken from each plot and averaged to provide a plot plant count. Each sample was 1 m long by two rows (1m^2). Plant counts were taken at 14-21 days for wheat plots and around V2-V5 for chickpeas.

Biomass

Two samples were taken from each plot and averaged to provide a plot dry matter estimate. Each sample consisted of 2 crop rows by 1m long (1m^2). Samples were cut off at ground level with dagging shears for wheat and secateurs for chickpeas. Samples were dried in drying ovens at 40^{o}C for at least 3 days until they were air dried, then weighed.

Grain Yield

The four middle rows in each plot were harvested with a small plot combine harvester. Length of harvested plot was measured to within 10 cm. Grain samples were collected for each plot. Grain moisture was analysed for every plot. Grain moisture was used to adjust all yield values to maximum receival standards at CQ depots (12.5% for wheat and chickpea). Grain protein was analysed for all wheat treatments and the chickpea treatments ‘0 N – PKS’ and ‘0 N + PKS’.

Statistical analysis

Data from individual trials were analysed using the General Analysis of Variance procedure in GENSTAT 16th Edition (VSN International 2013). Data from the two rotations within each trial were analysed separately. Fisher's Protected Least Significant Difference test was used to test for differences between means at *P*=0.05. Where normality of the data distribution was in doubt, an appropriate transformation (arcsine, angular or log) was used prior to analysis. Treatment means and the statistical significance of multiple comparisons among means shown in each graph in the following section are given in in Tables 5.4.1a to 5.4.8b (Appendix 5.4).

Profitability

The net profitability of N application in wheat following chickpea compared to wheat following wheat was calculated by using representative grain prices ($/t) for delivery at the local depot of each trial for the month of harvest each year and yields from selected W/W and C/W treatments in phase 2 of each trial. Profit is defined as the difference in gross margins between a given N fertiliser treatment and the '0 N + PKS' treatment after the cost of fertiliser has been deducted. Grain prices were calculated by deducting local depot freight costs from an advertised price for the relevant port. Port prices were sourced from historical Pentag Nidera daily bid sheets and freight costs were sourced from 'Grain Traders Australia' 2011. Full details of port and local depot grain prices for chickpea and each wheat grade can be found in Appendix 5.3.

A granular urea price of $650/t was used in calculating the profitability of the various N fertiliser treatments; this price was commonly quoted by various reseller agronomists over the three years of the trial period and is relatively representative of the urea price over the duration of these trials.

PKS fertiliser prices were sourced in September 2014 for Emerald for Triple Superphosphate and Sulphate of Potash.

Results

3.1 ROT-1105-CLE1

Phase 1 (2011)

- Previous crop - wheat in 2010
- Planted on 23/05/2011
- In-crop rain = 99 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.1a. Statistical comparisons of treatment means are valid only within crop/rotations.

Soil N
At planting soil N averaged 48 kg/ha. At harvest, soil N was 37 kg/ha after chickpea; 25 kg/ha after '0 N-PKS' wheat and 23 kg/ha after '60 N + PKS' wheat.

Soil Water
Not measured

Plant population
Plant population density within the experimental plots was assessed on 13/07/2011. Chickpea averaged 190,000 plants/ha and wheat averaged 1,270,000 plants/ha. There were no significant differences in plant population density among treatments within crops ($P>0.05$).

Biomass
Biomass samples were collected on 12/09/2011. Chickpea biomass averaged 3,873 kg/ha. Wheat biomass ranged from 2,636 kg for '0 N – PKS' to 4,434 kg/ha for '60 N + PKS'. Wheat biomass increased significantly with increasing rate of N fertiliser ($P<0.001$). PKS fertiliser alone produced no significant difference in chickpea or wheat biomass ($P>0.05$).

Yield
The trial was harvested on 24/10/2011. Chickpea yield averaged 2,692 kg/ha across the trial site. Wheat yields ranged from 1,669 kg for '0 N – PKS' to 2,397 for '40 N + PKS' (Fig. 3.1). PKS fertiliser alone produced no significant yield increases in wheat or chickpea ($P>0.05$). Wheat treatments with ≥20 kg/ha of N yielded significantly more that treatments without N ($P<0.05$).

Wheat grain protein increased from 10.6% to 12.9% (APW to AH) with increasing rates of N fertiliser.

Phase 2 (2012)

- Fallow rain between first and second crops = 719 mm
- Planted on 17/05/2012
- In-crop rain = 145 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.1b

Soil N
At planting, soil N in C/W plots averaged 59 kg/ha. Soil N in W/W plots was 32 kg/ha for '0 N – PKS'.

Soil Water

There was an average of 225 mm soil water at planting in C/W plots and 207 mm in W/W plots. This soil was above field capacity (saturated).

Plant Population

Plant population density was assessed on 03/07/2012. Population density of wheat in C/W plots averaged 669,000 plants/ha with 633,000 plants /ha in W/W plots. There were no significant treatment differences (P>0.05).

Biomass

Biomass samples were collected on 05/09/2012. Wheat biomass in C/W plots averaged 5,419 kg/ha for 0 N treatments and 6,601 kg/ha for N treatments. Biomass in all C/W plots with added N fertiliser was significantly (P<0.001) greater than 0 N treatments however biomass did not increase with the rate of N applied.

Wheat biomass in W/W plots averaged 5,091 kg/ha for 0 N treatments and 6,323 kg/ha for N treatments; 40 and 60 N fertiliser treatments produced significantly greater biomass (P<0.01) than 0 N treatments.

There was no biomass difference attributable to the use of PKS fertiliser.

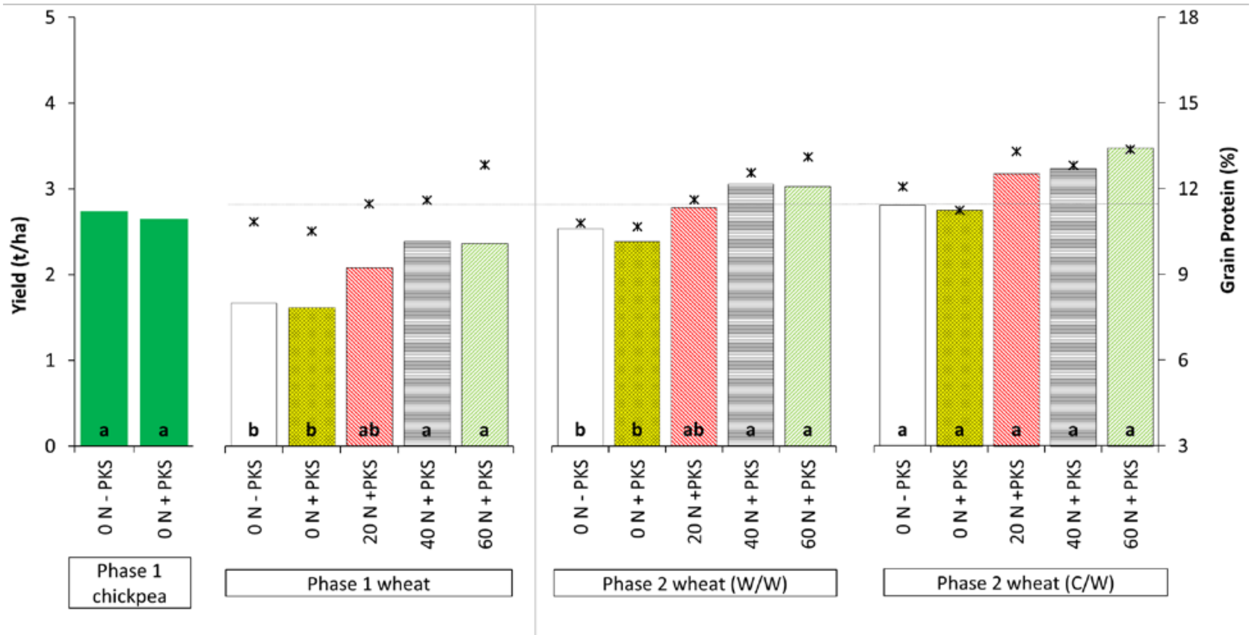

Fig. 3.1. Mean crop yield and grain protein responses to fertiliser application in phases 1 (2011) and 2 (2012) of a W/W and C/W crop sequence at Clermont (CLE1). The bars represent chickpea and wheat grain yield; symbols represent grain protein. The dotted grey line represents the benchmark value of 11.5% wheat grain protein. Means sharing the same alphabet are not significantly different (P>0.05). Statistical comparison of means is valid only within phases and crops within phases.

Yield

The trial was harvested on 24/10/2012. Wheat yield from C/W plots averaged 3,092 kg/ha; there were no significant differences among treatments ($P>0.05$) although yields from the +N treatments were, on average, higher than those from the 0 N treatments (Fig. 3.1). Grain protein was ≥1% higher in the treatments with added N than those without.

Wheat yield from W/W plots averaged 2,446 kg/ha for 0 N treatments and 2,935 kg/ha for N treatments (Fig. 3.1); 40 and 60 N fertiliser treatments were significantly ($P<0.05$) greater than 0 N treatments.

Wheat grain protein varied from 10.6% to 13.1% (APW to APH) and increased with increasing rates of N fertiliser.

3.2 ROT-1105-GIN1

Phase 1 (2011)

- Previous crop - wheat in 2010
- Planted on 24/05/2011
- In-crop rain = 41 mm
- This trial was moderately frost affected

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.2a. Statistical comparisons of treatment means are valid only within crop/rotations.

Soil N

At planting soil N averaged 39 kg/ha. At harvest, soil N was 16 kg/ha after chickpea; 14 kg/ha after '0 N-PKS' wheat and 18 kg/ha after '60 N + PKS' wheat.

Soil Water

Not measured

Plant population

Plant population density within the experimental plots was assessed on 25/07/2011. Chickpea averaged 166,000 plants/ha and wheat averaged 1,069,000 plants/ha. There was no significant difference between plant populations due to any treatments (P>0.05).

Biomass

Biomass samples were collected on 13/09/2011. Chickpea biomass averaged 4,777 kg/ha. Wheat biomass ranged from 3,255 kg/ha for '0 N – PKS' to 4,556 kg/ha for '60 N + PKS'. N fertiliser produced significant (P<0.05) increases in wheat biomass in the 40 and 60 N treatments. PKS fertiliser produced no significant difference in chickpea or wheat biomass (P>0.05).

Yield

The trial was harvested on 21/10/2011. Chickpea yields averaged 1,374 kg/ha. Wheat yields averaged 1,356 kg/ha. There were no significant differences (P>0.05) between treatments for either PKS or N fertiliser (Fig. 3.2).

Wheat grain protein increased from 9.0% to 13.1% (ASW to APH) with increasing N fertiliser rates.

Phase 2 (2012)

- Fallow rain between first and second crops = 633 mm
- Planted 17/05/2012
- In-crop rain = 170 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.2b.

Soil N

At planting, soil N following chickpeas averaged 30 kg/ha. Soil N following wheat was 21 kg/ha for "0 N – PKS' and 25 kg/ha for '60 N + PKS'.

Soil Water

Starting soil water averaged 203 mm following 2011 chickpea and 229 mm following 2011 wheat.

Plant Population

Data not collected

Biomass

Biomass samples were collected on 24/09/2012. Wheat biomass in C/W plots averaged 4,472 kg/ha for 0 N treatments and increased significantly (P<0.001) with increasing rates of N, up to 6,859 kg/ha for '60 N + PKS'.

Wheat biomass in W/W plots averaged 4,289 kg/ha for 0 N and rose to 6,590 kg/ha for '60 N + PKS'. There were significant (P<0.001) increases in wheat biomass observed for 20 and 60 N treatments compared to the 0 N treatments.

Addition of PKS fertiliser had no significant impact (P>0.05) on crop biomass in either rotation.

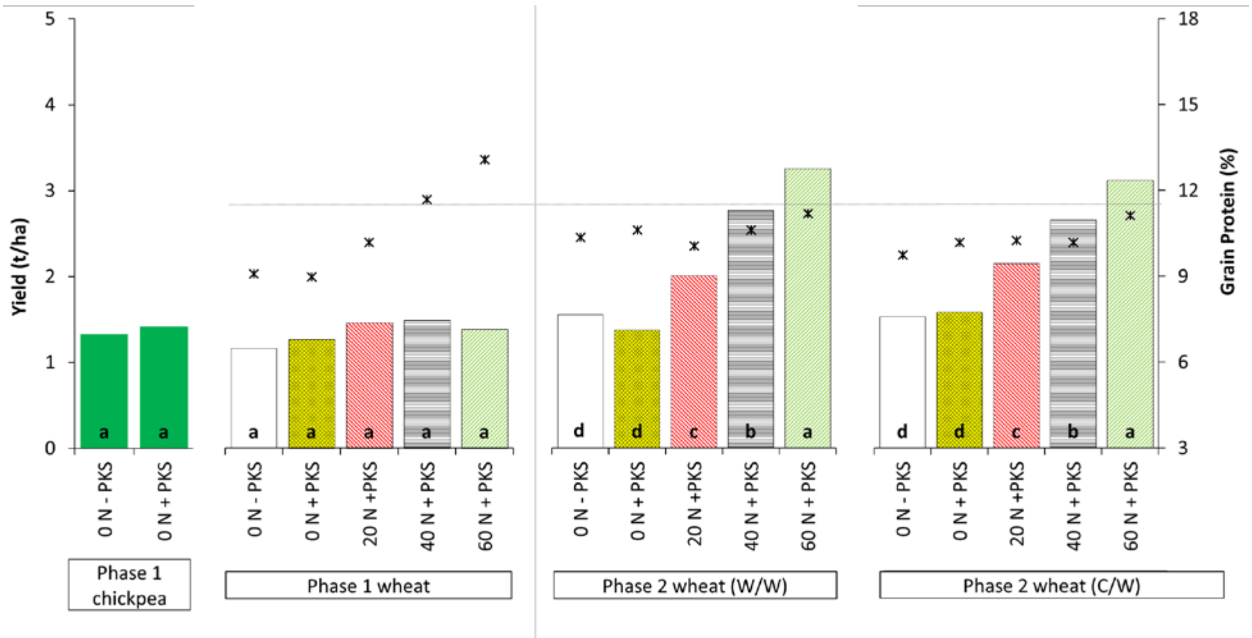

Fig. 3.2. Mean crop yield and grain protein responses to fertiliser application in phases 1 (2011) and 2 (2012) of a W/W and C/W crop sequence at Gindie (GIN1). The bars represent chickpea and wheat grain yield; symbols represent grain protein. The dotted grey line represents the benchmark value of 11.5% wheat grain protein. Means sharing the same alphabet are not significantly different (P>0.05). Statistical comparison of means is valid only within phases and crops within phases.

Yield

The trial was harvested on 13/10/2012. Wheat yields in C/W plots averaged 1,556 kg/ha for 0 N treatments and increased significantly (P<0.001) with increasing rates of N to 3,117 kg/ha for '60 N + PKS'. Grain protein ranged from 9.8% (ASW; 0 N – PKS) to 11.1% (APW; 60 N + PKS).

Wheat yields in W/W plots averaged 1,453 kg/ha for 0 N and increased significantly (P<0.001) with increasing rates of N to 3,237 for '60 N + PKS'. Wheat grain protein ranged from 10.3% for '0 N – PKS' (ASW) to 11.1% for '60 N + PKS' (APW).

PKS fertiliser had no significant impact (P>0.05) on wheat yield, following either 2011 chickpea or wheat.

3.3 ROT-1105-THE1

Phase 1 (2011)

- Previous crop - wheat in 2010
- Planted on 21/06/2011
- In-crop rain = 99 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.3a. Statistical comparisons of treatment means are valid only within crop/rotations.

Soil N
At planting soil N averaged 24 kg/ha. At harvest, soil N was 15 kg/ha after chickpea; 14 kg/ha after '0 N-PKS' wheat and 32 kg/ha after '60 N + PKS' wheat.

Soil Water
Not measured

Plant population
Plant population density within the experimental plots was assessed on 27/07/2011. Chickpea averaged 173,000 plants/ha and wheat averaged 865,000 plants/ha. Within the chickpea plots, mean plant population density was significant lower ($P<0.01$) in the treatments with PKS than in those without. Among the wheat plots, there was no significant difference in wheat plant population density as a result of PKS or N fertiliser user ($P>0.05$).

Biomass
Biomass samples were collected on 15/09/2011. There was a significant ($P<0.05$) increase in chickpea biomass with the use of PKS fertilisers, from 1,964 kg/ha for '0 N – PKS' to 2,573 kg/ha for '0 N + PKS'.

There was no significant difference ($P>0.05$) in wheat biomass attributable to PKS fertiliser. N fertiliser increased wheat biomass significantly ($P<0.001$) for 20 and 60 N treatments relative to 0 N.

Yield
The trial was harvested on 25/10/2011. Chickpea yields increased significantly ($P<0.01$) with the use of PKS fertiliser from 1,880 kg/ha for '0 N – PKS' to 2,463 kg/ha for '0 N + PKS'.

Wheat yields increased significantly ($P<0.001$) with the use of N fertiliser in the 20 and 60 N relative to the 0 N. PKS fertiliser had no significant impact on wheat yields ($P>0.05$).

Wheat grain protein rose from 10% (APW) for '0 N – PKS' to 12.8% (AH) for '60 N + PKS' with increasing rates of N fertiliser.

Phase 2 (2012)

- Fallow rain between first and second crops = 578 mm
- Planted on 14/05/2012
- In-crop rain = 208 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.3b.

Soil N

At planting, soil N following chickpeas averaged 70 kg/ha. Soil N following wheat was 55 kg/ha for '0 N – PKS'.

Soil Water

Starting soil water averaged 132 mm for the trial site with no measurable difference between the chickpea and wheat blocks.

Plant Population

Data not collected

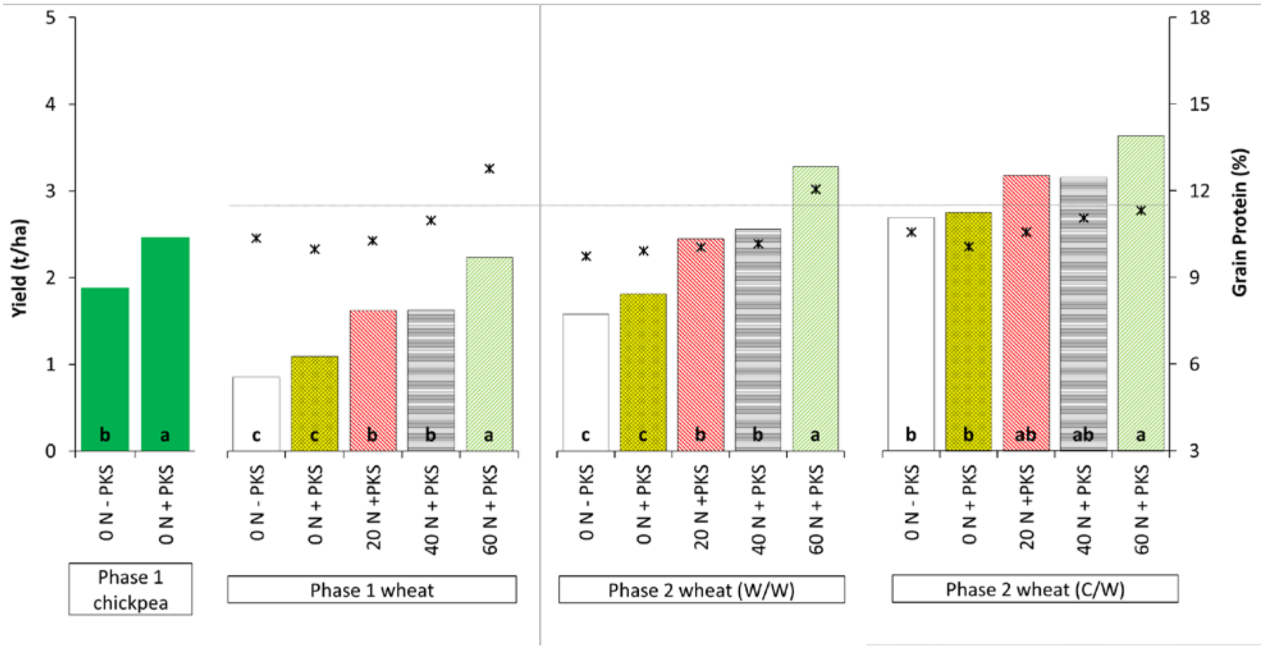

Fig. 3.3. Mean crop yield and grain protein responses to fertiliser application in phases 1 (2011) and 2 (2012) of a W/W and C/W crop sequence at Theodore (THE1). The bars represent chickpea and wheat grain yield; symbols represent grain protein. The dotted grey line represents the benchmark value of 11.5% wheat grain protein. Means sharing the same alphabet are not significantly different (P>0.05). Statistical comparison of means is valid only within phases and crops within phases.

Biomass

Biomass samples were collected on 28/08/2012. Wheat biomass in C/W plots varied significantly among treatments (P<0.001), ranging from 6,235 kg/ha for '0 N – PKS' to 9,258 for '40 N + PKS'. Biomass was significantly higher in all PKS fertiliser treatments than in '0 N – PKS'. Among the +PKS treatments, biomass was highest in the 40 N treatment (P<0.001) followed by the other N treatments.

Wheat biomass in the W/W plots ranged from 5,171 kg/ha for ‘0 N – PKS’ to 8,324 kg/ha for 60 N and increased with increasing rates of N (P<0.01).

Yield

The trial was harvested on 16/10/2012. Wheat yields in C/W plots averaged 2,723 kg/ha for 0 N with a significant (P<0.01) increase in yield for ‘60 N + PKS’ (Fig. 3.3). Grain protein was all APW with a trend towards higher proteins with increasing N fertiliser rate.

Wheat yields following 2011 wheat averaged 1,682 kg/ha for 0 N with significant (P<0.001) yield increases observed for 20 N and 60 N (Fig. 3.3). Grain protein ranged from 10.1% (‘0 N – PKS’; ASW) to 11.3% (‘60 N + PKS’; AH) and increased with higher rates of N fertiliser.

3.4 ROT-1105-JAM1

Phase 1 (2011)

- Previous crop - wheat in 2010
- Planted on 20/06/2011
- In-crop rain = 148 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.4a. Statistical comparisons of treatment means are valid only within crop/rotations.

Soil N
Soil N at planting averaged 82 kg/ha. At harvest, soil N was 19 kg/ha after chickpea; 24 kg/ha after ‘0 N + PKS’ wheat and 53 kg/ha after ‘60 N + PKS’ wheat.

Soil Water
Not measured

Plant population
Plant population density within the experimental plots was assessed on 2/08/2011. Chickpea averaged 192,000 plants/ha and wheat averaged 494,000 plants/ha. There was no significant difference ($P>0.05$) in plant density among treatments.

Biomass
Biomass samples were collected on 14/09/2011. There was a significant ($P<0.01$) increase in chickpea biomass with the use of PKS fertilisers from 3,250 kg/ha to 4,066 kg/ha.

There was no significant difference ($P>0.05$) in wheat biomass among treatments due to PKS or N fertiliser.

Yield
The trial was harvested on 2/11/2011. Chickpea yields averaged 3,471 kg/ha. Wheat yields averaged 3,497 kg/ha for 0 N with one significant ($P<0.01$) yield increase observed for ‘20 N + PKS’ only (Fig. 3.4). Wheat grain protein varied in a narrow range from 12.7% (AH) to 13.8 (APH).

Phase 2 (2012)

- Fallow rain between first and second crops = 332 mm
- Planted 16/05/2012
- In-crop rain = 160 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.4b.

Soil N
At planting, soil N following 2011 chickpeas averaged 82 kg/ha. Soil N following 2011 wheat averaged 106 kg/ha for 0 N treatments.

Soil Water
Starting soil water averaged 122 mm following 2011 chickpea and 140 mm following 2011 wheat.

Plant Population

Plant population density was assessed on 20/06/2012. Wheat population averaged 250,000 plants/ha density in C/W plots and 248,000 plants/ha in W/W plots. There was no significant difference between plant populations due to any treatments (P>0.05).

Biomass

Biomass samples were collected on 03/09/2012. Wheat biomass in C/W plots was quite variable, ranging from 5,738 kg/ha for '0 N – PKS' to 7,013 kg/ha for '60 N + PKS' but differences among treatments were not significant (P=0.088).

Wheat biomass in W/W plots averaged 6,250 kg/ha; differences among treatments were not significant (P>0.05).

Yield

The trial was harvested on 15/10/2011. Wheat yields averaged 3,144 kg/ha in C/W plots and 2,989 kg/ha in W/W plots. There were no significant yield differences among treatments within rotations at this site (Fig. 3.4). Wheat grain protein following chickpea and wheat ranged from 13.7% to 14.9% (APH).

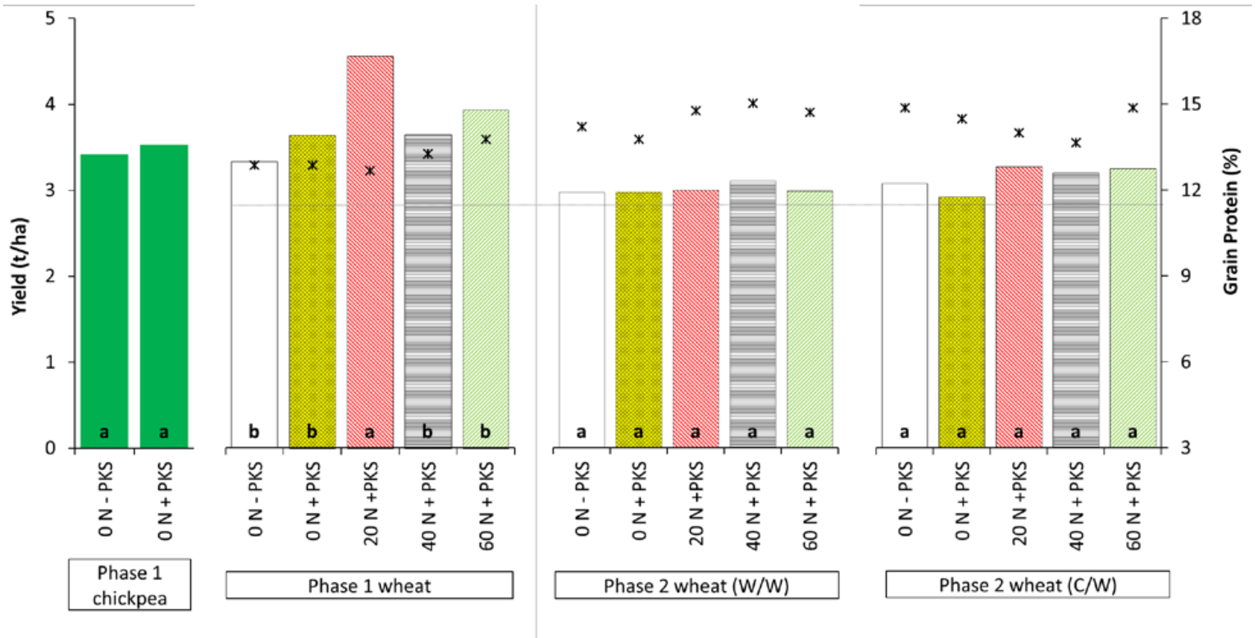

Fig. 3.4. Mean crop yield and grain protein responses to fertiliser application in phases 1 (2011) and 2 (2012) of a W/W and C/W crop sequence at Jambin (JAM1). The bars represent chickpea and wheat grain yield; symbols represent grain protein. The dotted grey line represents the benchmark value of 11.5% wheat grain protein. Means sharing the same alphabet are not significantly different (P>0.05). Statistical comparison of means is valid only within phases and crops within phases.

3.5 ROT-1205-CLE2

Phase 1 (2012)

- Previous crop - wheat in 2011
- Planted on 17/05/2012
- In-crop rain = 145 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.5a. Statistical comparisons of treatment means are valid only within crop/rotations.

Soil N
At planting soil N averaged 24 kg/ha. At harvest, soil N was 15 kg/ha after chickpea and 20 kg/ha after '0 N-PKS' wheat.

Soil Water
Starting soil water averaged 152 mm plant available water.

Plant population
Plant population density within the experimental plots was assessed on 3/07/2012. Chickpea averaged 252,000 plants/ha and wheat averaged 626,000 plants/ha. There was no significant difference in plant population density among treatments within crops (P>0.05).

Biomass
Biomass samples were collected on 05/09/2011. Chickpea biomass was significantly (P<0.001) increased by PKS fertiliser from 2,635 kg/ha for '0 N – PKS' to 3,252 kg/ha for '0 N + PKS'.

PKS fertiliser had no impact on wheat biomass. N fertiliser significantly (P<0.001) increased mean wheat biomass from 3,208 kg/ha for the 0 N treatments to 5,090 kg/ha across all +N treatments.

Yield
The trial was harvested on 24/10/2012. Chickpea yield was significantly (P<0.001) increased by PKS fertiliser.

PKS fertiliser had no impact on wheat yields. 60 N treatments yielded significantly (P<0.05) greater than other treatments. Wheat grain protein increased from 9.6% (ASW) to 13.1% (APH) with increasing rates of N fertiliser.

Phase 2 (2013)

- Fallow rain between first and second crops = 382 mm
- Planted on 11/05/2013
- In-crop rain = 29 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.5b

Soil N
At planting, soil N following chickpea averaged 59 kg/ha. Soil N following wheat was 48 kg/ha for 0 N.

Soil Water

Starting soil water averaged 140 mm after 2012 chickpeas and averaged 205 mm after 2012 wheat.

Plant Population

Plant population density was assessed on 29/05/2013. Plant population averaged 818, 000 plants/ha following 2012 chickpea and 663, 000 plants/ha following 2012 wheat. There was no significant difference in plant population among fertiliser treatments within rotations (P>0.05).

Biomass

Biomass samples were collected on 30/08/2013. Wheat biomass in C/W plots averaged 4,612 kg/ha with no significant treatment effects (P>0.05).

Wheat biomass in W/W plots averaged 3,435 kg/ha for 0 N treatments and biomass was significantly (P<0.001) increased to an average of 4,872 kg/ha with the use of N fertiliser.

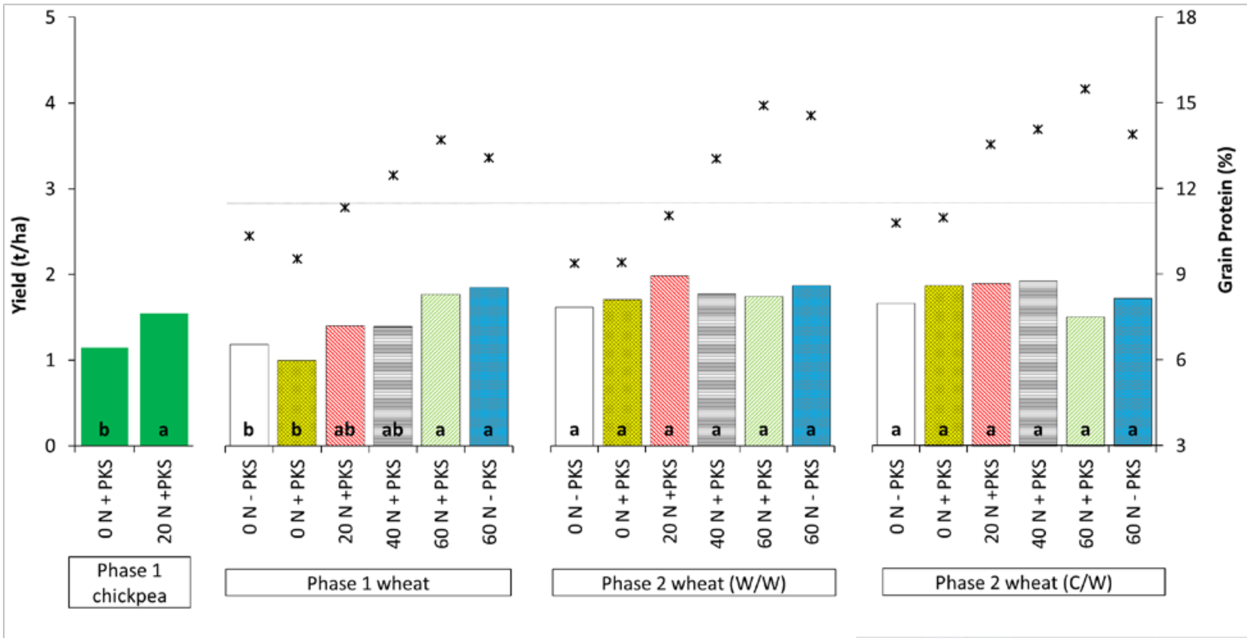

Fig. 3.5 Mean crop yield and grain protein responses to fertiliser application in phases 1 (2012) and 2 (2013) of a W/W and C/W crop sequence at Clermont (CLE2). The bars represent chickpea and wheat grain yield; symbols represent grain protein. The dotted grey line represents the benchmark value of 11.5% wheat grain protein. Means sharing the same alphabet are not significantly different (P<0.05). Statistical comparison of means is valid only within phases and crops within phases.

Yield

The trial was harvested on 30/09/2013. There was no significant difference in wheat yields among C/W treatments (Fig. 3.5) but grain protein increased from 10.8 (AH) to 15.5 (APH). The rank order of grain protein was 0 N < (20 N = 40 N = '60 N – PKS') < '60 N + PKS' (P<0.001).

There was no significant difference in wheat yields among W/W treatments (Fig. 3.5) but grain protein increased from 10.8 (AH) to 15.5 (APH). The rank order of grain protein was 0 N < 20 N < 40 N < 60 N (P<0.001). The effect of PKS fertiliser was not significant in either rotation (P>0.05).

3.6 ROT-1205-GIN2

Phase 1 (2012)

- Previous crop - wheat in 2011
- Planted on 17/05/2012
- In-crop rain = 170 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.6a. Statistical comparisons of treatment means are valid only within crop/rotations.

Soil N
At planting soil N averaged 28 kg/ha. At harvest, soil N was 13 kg/ha after chickpea and 11 kg/ha after '0 N - PKS' wheat.

Soil Water
At planting soil water averaged 158 mm plant available water.

Plant population
Plant population density within the experimental plots was assessed on 02/07/2012. Chickpea averaged 267,000 plants/ha and wheat averaged 539,000 plants/ha. There was no significant difference in plant population density among treatments within crops (P>0.05).

Biomass
Biomass samples were collected on 27/08/2012. Chickpea biomass averaged 4,767 kg/ha with no significant treatment effect (P>0.05).

Wheat biomass averaged 4,267 kg/ha for 0 N and was increased by the addition of N fertiliser with significant (P<0.001) increases observed at 20 N and another significant increase at '60 N + PKS'.

Yield
The trial was harvested on 13/10/2012. There was no significant difference in chickpea yields between PKS treatments (P>0.05).

Use of N fertiliser increased wheat yields with significant (P<0.001) yield increases observed for 20, 40 and 60 N (Fig. 3.6). There was no significant impact from the use of PKS fertiliser on wheat yields. Wheat grain protein varied from 8.4% (FED1) to 12.6% (AH). The rank order of grain protein was 0 N < (20 N = 60 N – PKS) < 40 N < 60 N (P<0.001).

Phase 2 (2013)

- Fallow rain between first and second crops = 404 mm
- Planted 3/05/2013
- In-crop rain = 42 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.6b.

Soil N

At planting, soil N following chickpeas averaged 74 kg/ha. Soil N following wheat was 68 kg/ha for '0 N – PKS'

Soil Water

At planting soil water averaged 170 mm with no difference between the chickpea and wheat plots.

Plant Population

Plant population density within the experimental plots was assessed on 21/05/2013. The wheat population following 2012 chickpea averaged 594,000 plants/ha and 634,000 plants/ha following 2012 wheat, there were no significant treatment differences (P>0.05).

Biomass

Biomass samples were collected on 15/08/2013. Wheat biomass in C/W plots ranged from 5,799 kg/ha for '0 N – PKS' to a mean of 6,752 kg/ha for N + PKS treatments. 40 N and 60 N (in the presence of PKS) significantly (P<0.05) increased wheat biomass, other N treatments were no different to 0 N (P>0.05).

Wheat biomass in W/W plots averaged 5,360 kg/ha for 0 N treatments and averaged 6,402 for N + PKS treatments. N fertiliser (in the presence of PKS) significantly (P<0.001) increased biomass, '60 N – PKS' was no different to 0 N (P>0.05).

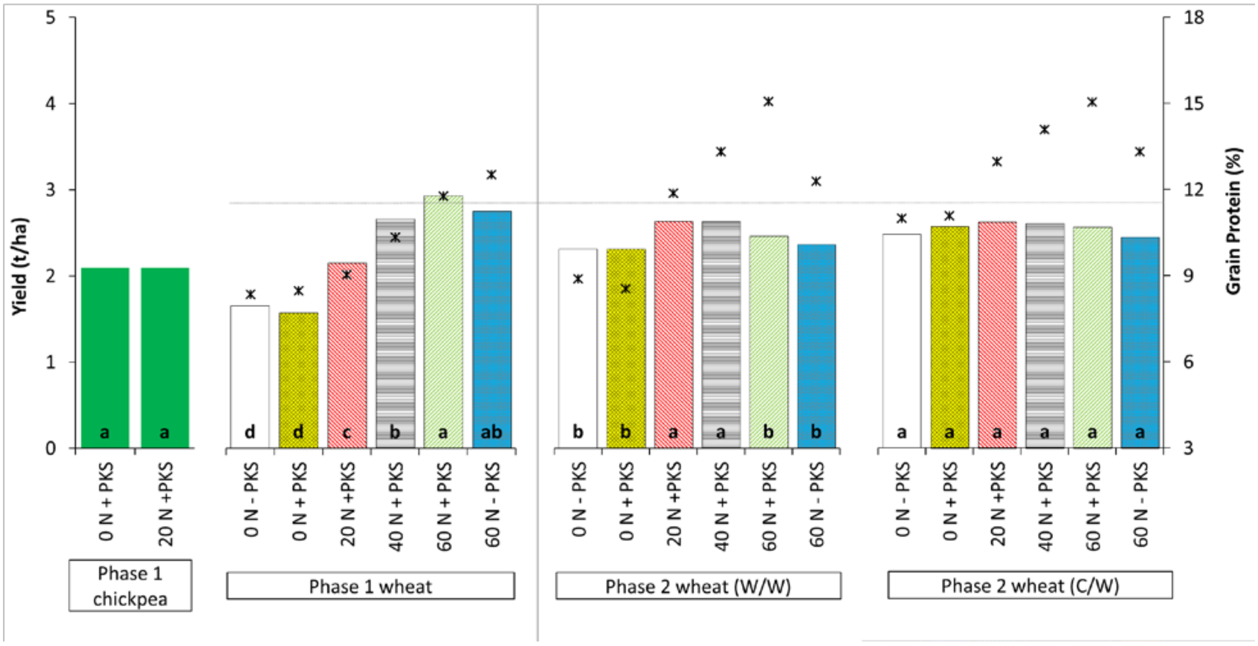

Fig. 3.6. Mean crop yield and grain protein responses to fertiliser application in phases 1 (2012) and 2 (2013) of a W/W and C/W crop sequence at Gindie (GIN2). The bars represent chickpea and wheat grain yield; symbols represent grain protein. The dotted grey line represents the benchmark value of 11.5% wheat grain protein. Means sharing the same alphabet are not significantly different (P>0.05). Statistical comparison of means is valid only within phases and crops within phases.

Yield

The trial was harvested on 17/09/2013. There was no significant difference in wheat yields among C/W treatments (Fig. 3.6) due to PKS or N fertiliser. Grain protein varied from 11% (APW) to 15.1% (APH). The rank order of grain protein was 0 N < (20 N = 60 N – PKS) < 40 N < 60 N + PKS (P<0.001).

PKS fertiliser did not produce any significant wheat yield differences among W/W treatments. 20 N and 40 N treatments significantly (P<0.001) out-yielded all other treatments (Fig. 3.6). Grain protein varied from 8.5% (ASW) to 15.0% (APH). The rank order of grain protein was 0 N < (20 N = '60 N – PKS') < 40 N < '60 N + PKS' (P<0.001).

3.7 ROT-1205-THE2

Phase 1 (2012)

- Previous crop - wheat in 2011
- Planted 14/05/2012
- In-crop rain = 201 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.7a. Statistical comparisons of treatment means are valid only within crop/rotations.

Soil N
At planting soil N averaged 57 kg/ha. At harvest, soil N was 31 kg/ha after chickpea; 34 kg/ha after '0 N-PKS' wheat.

Soil Water
At planting, soil water averaged 139 mm across the trial site.

Plant population
Plant population density within the experimental plots was assessed on 19/06/2012. Chickpea averaged 67,000 plants/ha and wheat averaged 198,000 plants/ha. There was no significant difference in plant population density among treatments (P>0.05).

Biomass
Biomass samples were collected on 28/08/2012. Chickpea biomass averaged 3,898 kg/ha. Wheat biomass averaged 6,024 kg/ha with no significant treatment effects (P>0.05).

Yield
The trial was harvested on 16/10/2012. There was no significant difference in chickpea yields among PKS treatments (P>0.05).

Wheat yields were significantly (P<0.096) increased by N fertiliser treatments in the presence of PKS fertiliser (Fig. 3.7). Wheat grain protein increased from 10.8% (APW) to 13.4% (APH) with increasing rates of N fertiliser.

Phase 2 (2013)

- Fallow rain between first and second crops = 419 mm
- Planted late/05/2013
- In-crop rain = 26 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.7b.

Soil N
At planting, soil N following chickpeas averaged 86 kg/ha. Soil N following wheat was 77 kg/ha for '0 N – PKS'.

Soil Water

At planting soil water averaged 151 mm with no measurable difference between the chickpea or wheat blocks.

Plant Population

Data not collected

Biomass

Biomass samples were collected on 10/09/2013. Wheat biomass following 2012 chickpea averaged 6,778 kg/ha with no significant treatment effects (P>0.05).

Wheat biomass following 2012 wheat averaged 6,481 kg/ha with no significant treatment effects (P>0.05).

Yield

The trial was harvested on 11/10/2013. Wheat yields in C/W plots averaged 3,104 kg/ha with no significant treatment effects (Fig. 3.7). Wheat grain protein increased from 12.0% (AH) to 14.1% (APH) with increasing rates of N fertiliser but the differences among treatments were not significant (P>0.05)

Wheat yields in W/W plots averaged 2,761 kg/ha with no significant treatment effects (Fig. 3.7). Wheat grain protein ranged from 10.6% (APW) to 15% (APH) with the lower protein levels being found in the 0 N treatments (P<0.001).

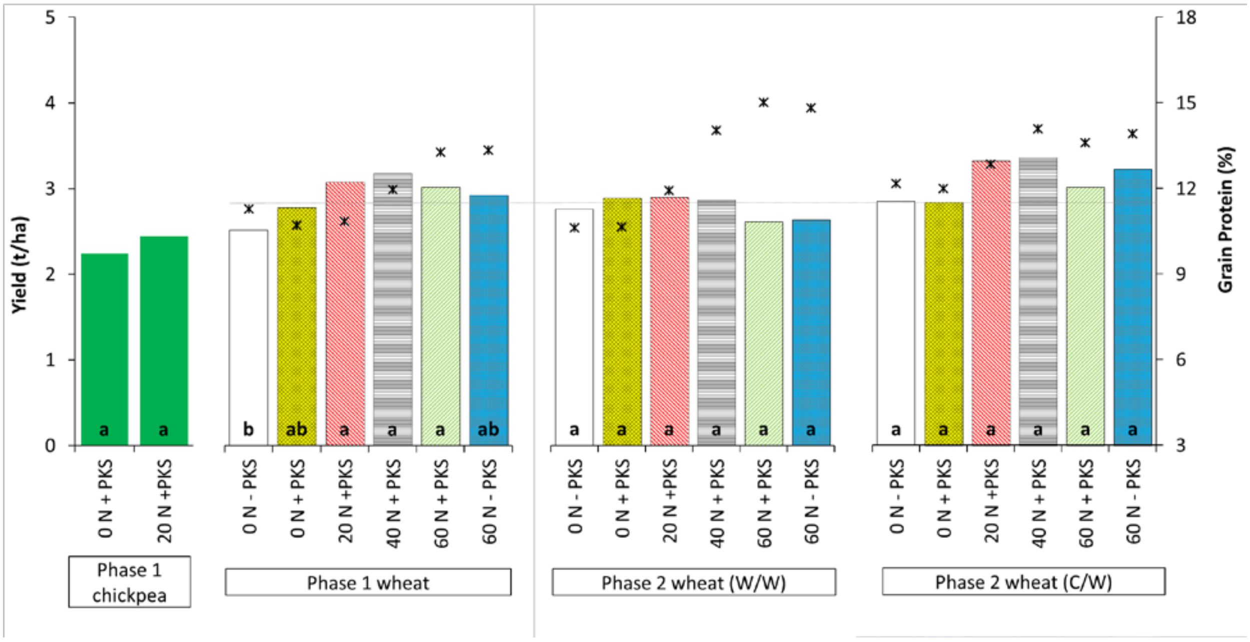

Fig. 3.7. Mean crop yield and grain protein responses to fertiliser application in phases 1 (2012) and 2 (2013) of a W/W and C/W crop sequence at Theodore (THE2). The bars represent chickpea and wheat grain yield; symbols represent grain protein. The dotted grey line represents the benchmark value of 11.5% wheat grain protein. Means sharing the same alphabet are not significantly different (P>0.05). Statistical comparison of means is valid only within phases and crops within phases.

3.8 ROT-1205-JAM2

Phase 1 (2012)

- Previous crop wheat in 2011
- Planted 16/05/2012
- In-crop rain = 160 mm

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.8a. Statistical comparisons of treatment means are valid only within crop/rotations.

Soil N
At planting soil N averaged 128 kg/ha. At harvest, soil N was 43 kg/ha after chickpea and 48 kg/ha after '0 N - PKS'.

Soil Water
At planting, soil water averaged 130 mm across the trial site.

Plant population
Plant population density within the experimental plots was assessed on 20/06/2012. Chickpea averaged 168,000 plants/ha and wheat averaged 372,000 plants/ha across all treatments. There was no significant difference in plant population density among treatments (P>0.05).

Biomass
Biomass samples were collected on 03/09/2012. Chickpea biomass averaged 4,480 kg/ha and wheat biomass averaged 5,528 kg/ha with no significant treatment effects (P>0.05).

Yield
The trial was harvested on 15/10/2012. There was no significant difference in chickpea or wheat yields due to fertiliser treatments (P>0.05). Wheat grain protein was ≥15.3% in all treatments (APH).

Phase 2 (2013)

- Fallow rain between first and second crops = 695 mm
- Planted 20/05/2013
- In-crop rain = 33 mm
- W/W plots were heavily infected with yellow spot disease; relatively little disease in C/W plots

Treatment means and statistical findings for plant counts, biomass and grain yield can be found in Appendix 5.4.8b.

Soil N
At planting, soil N following 2012 chickpeas averaged 78 kg/ha. Soil N following 2012 wheat was 76 kg/ha for '0 N – PKS'.

Soil Water
At planting, soil water averaged 152 mm for the trial with no measurable difference between the chickpea and wheat blocks.

Plant Population

Plant population density was assessed on 01/07/2013. Wheat population density averaged 423,000 plants/ha in C/W plots and 380,000 plants/ha in W/W plots, there were no significant treatment effects within rotations.

Biomass

Biomass samples were collected on 09/09/2013. Wheat biomass in C/W plots averaged 9,509 kg/ha with no significant treatment effects (P>0.05).

Wheat biomass in W/W plots averaged 6,933 kg/ha with no significant treatment effects (P>0.05).

Yield

The trial was harvested on 02/10/2013. There was no significant difference among treatments in wheat yields following either chickpea or wheat (Fig. 3.8). In the C/W plots, wheat grain protein was ≥ 13% but differences among treatments were not significant (P>0.05). By comparison, in the W/W rotation grain protein was significantly higher (P<0.01) in treatments with ≥40 N (≥14.2%; APH).

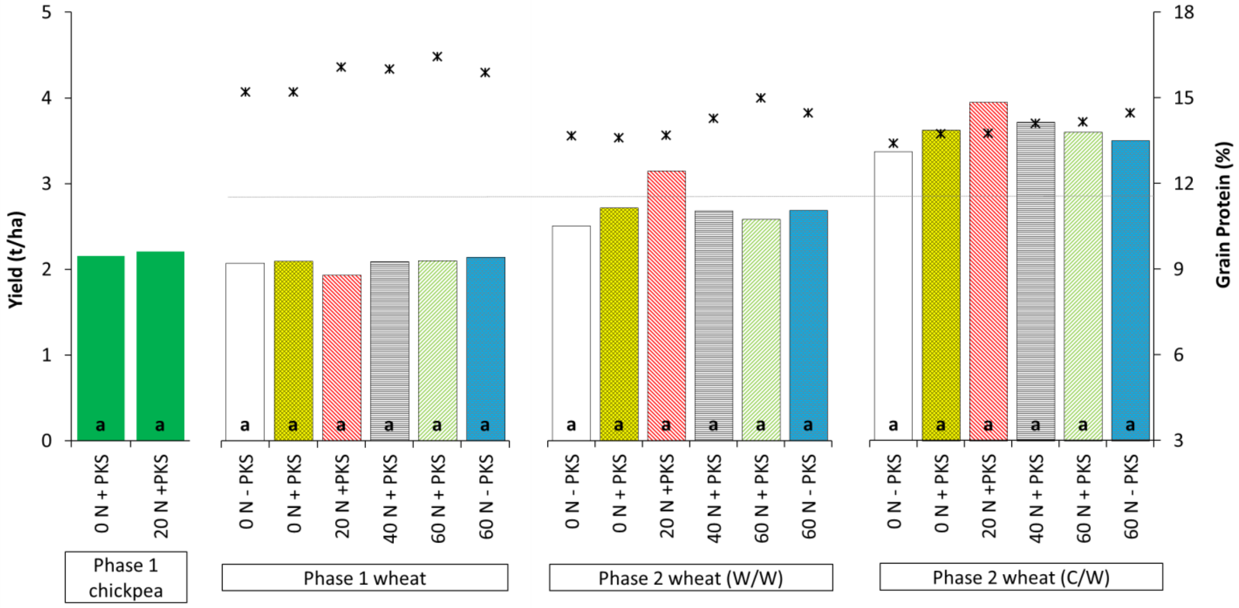

Fig. 3.8. Mean crop yield and grain protein responses to fertiliser application in phases 1 (2012) and 2 (2013) of a W/W and C/W crop sequence at Jambin (JAM2). The bars represent chickpea and wheat grain yield; symbols represent grain protein. The dotted grey line represents the benchmark value of 11.5% wheat grain protein. Means sharing the same alphabet are not significantly different (P>0.05). Statistical comparison of means is valid only within phases and crops within phases.

General Discussion

One strength of the eight trials reported here is that the trial design allows robust comparisons among treatments (N rates) within crops. A weakness is the lack of replication of the crop factor within sites (ie, each trial had only one large block of wheat and one of chickpea) for logistical and other reasons which precludes direct (statistically valid) comparisons of wheat and chickpea treatment means. Nevertheless, graphical and other informal comparisons allow reasonable conclusions to be inferred on various aspects of relative performance of the C/W and W/W rotations.

Where plant available water was not significantly limiting, the results of the eight rotation trials clearly show improved productivity of wheat following chickpea compared to wheat following wheat (ie. a rotation benefit) and responsiveness to N fertiliser application in soils that are representative of the range of low N fertility soils typically found in large parts of CQ. The trial results also indicate the potential for other 'system benefits' that include, but may not be limited to, the positive impacts of the rotation on cereal disease level.

Rotation benefits

Wheat following chickpea benefited from increased yield, higher grain proteins, greater profits and potentially higher soil N/increased N availability (Fig. 3.9, Table 3.4).

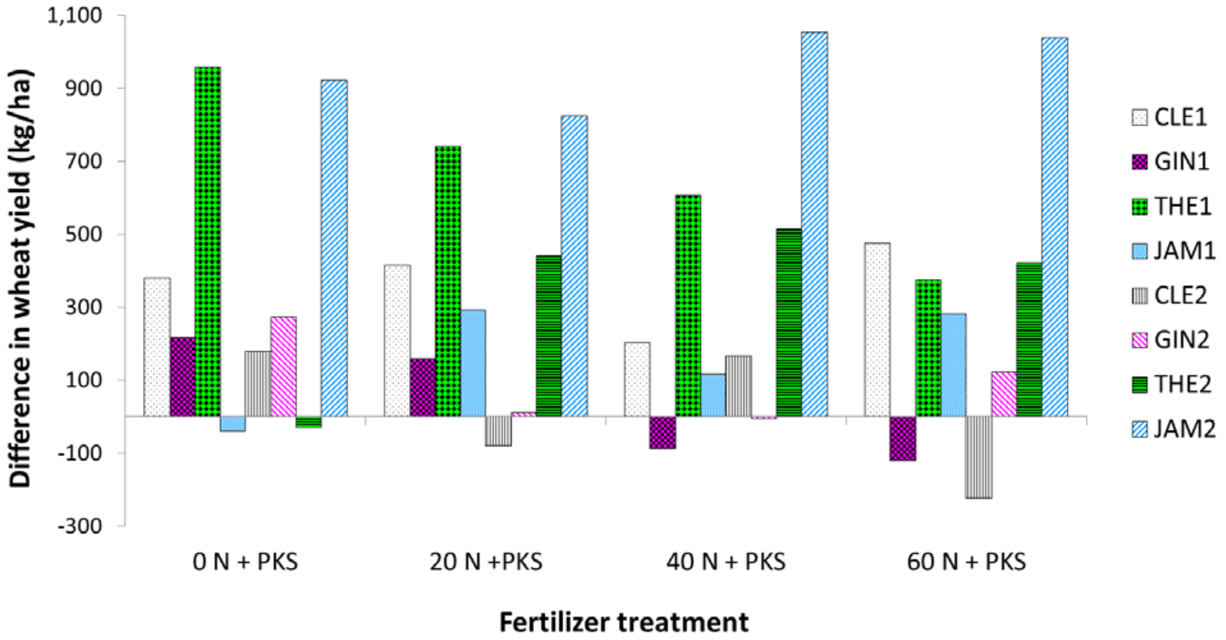

Fig. 3.9. Change in productivity of wheat following chickpea (C/W) compared to wheat following wheat (W/W) estimated as the difference between corresponding C/W and W/W treatment means at eight trial sites in CQ. See Table 3.4 for site details.

Table 3.4. Differences in the mean yield and profitability between corresponding '0 N + PKS' treatments in wheat following chickpea (C/W) and wheat following wheat (W/W) rotations across eight trials in CQ.

Trial ID	C/W yield (kg/ha)	W/W yield (kg/ha)	Yield (kg/ha)	Yield (%)	$
ROT-1105-CLE1	2,754	2,374	380	16%	$ 102.86
ROT-1105-GIN1	1,584	1,367	217	16%	$ 55.47
ROT-1105-THE1	2,757	1,799	958	53%	$ 265.37
ROT-1105-JAM1	2,917	2,958	-41	-1%	-$ 12.24
ROT-1205-CLE2	1,871	1,694	177	10%	$ 58.83
ROT-1205-GIN2	2,572	2,299	273	12%	$ 69.27
ROT-1205-THE2	2,842	2,872	-30	-1%	$ 21.13
ROT-1205-JAM2	3,624	2,703	921	34%	$ 243.60

Increased productivity - additional and/or more available organic soil N

From the eight trials, six showed a C/W rotation yield improvement compared to the W/W rotation (Fig. 3.9; Table 3.4) with large yield differences in two of these (THE1 and JAM2). At the remaining two sites there was no appreciable difference between the rotations. The very high yield benefit at THE1 was primarily due to increased N availability in the C/W rotation whereas the very high yield increase for JAM2 was likely attributable to a disease suppression effect.

At five of the eight trial sites, soil N at planting of Phase 2 wheat was ≥10 kg/ha greater following chickpea compared to wheat. Four of the five sites had low/moderate starting soil N and a well grown chickpea crop with large biomass, both factors considered to encourage N fixation.

At the JAM1 site, soil N at planting of Phase 2 wheat was 24 kg/ha lower after chickpea compared to wheat. At this high native soil fertility site, an abundance of soil N at planting would have negated the need for fixation thereby inducing the plant to utilise the available N. Higher soil N fertility may also explain the lack of starting Phase 2 soil N difference at the JAM2 site.

The benefits of C/W compared to W/W can be the equivalent of 20 to 40 kg/ha inorganic N fertiliser.

- 20 N benefit at CLE1: 2,810 kg/ha from '0 N – PKS' (following chickpea) requiring 20 N to achieve similar yield of 2,763 kg/ha following wheat. Also 3,178 kg/ha from 20 N (following chickpea) with 40 N and 60 N unable to march this yield following wheat.
- 20 N benefit at GIN1: 2,152 kg/ha from 20 N following chickpea required 40 N to meet (and exceed) this yield following wheat
- 20 to 40 N benefit at THE1: 2,689 kg/ha from '0 N – PKS' (following chickpea) requiring 40 N to achieve 2,548 kg/ha following wheat. Also 3,178kg/ha from 20 N (following chickpea) requiring 60 N to achieve 3,256 kg/ha following wheat. This trial was observed to be visually N deficient.

The THE1 data suggests that the benefit may be larger in more acute N deficient situations while the other sites suggest 20 N may be more commonly expected (where N deficiency is not so severe). This difference was not apparent in trials initiated in 2012 as 2013 was a drought year with lower yield potentials and reduced crop N demands as indicated by the grain proteins (cf. Figs. 3.5 to 3.9).

Fertiliser responsiveness

Significant biomass and yield increases were observed in response to PKS fertiliser application at some sites:

- Four sites demonstrated a significant PKS increase in crop biomass; THE1 chickpeas, JAM1 chickpeas, THE1 wheat following chickpeas and CLE2 chickpeas. Responses were site specific and more common in chickpeas.
- Two sites demonstrated a significant PKS yield increase; THE1 chickpeas and wheat following chickpeas and CLE2 chickpeas. Responses were again site specific and more common in chickpea.

These results supports the assertion by researchers that some CQ soils have deficiencies in one or more macronutrients (P, K, S) which can increase yields if correctly fertilised. In the trials reported here, PKS was applied in the top 10 cm of the profile using current knowledge as per industry practice in 2011. Since then P and K knowledge and fertiliser management has advanced and deep application is now recognised as being important. It is possible that PKS responses could have been different and perhaps more prevalent if PKS had been applied 15-20 cm deep as there were several instances of apparent (but statistically non-significant) PKS responses in biomass and yields at some sites.

Overall, the trial data show significant biomass and yield responses to the application of N fertiliser at multiple trial sites over all three years. Where water was limiting or the crop experienced a dry finish, the early biomass differentials between treatments did not translate into yield differences.

Grain Proteins

Phase 2 wheat in the C/W rotation often generated greater wheat grain proteins compared to the W/W rotation. This was true for five sites where this trend towards higher proteins resulted in at least one higher wheat grade for the C/W compared to its W/W N treatment counterpart. At these five sites, about half (13/28) N treatments resulted in a higher protein grade due to the C/W rotation.

- CLE1 – site average of 0.9% greater protein with '0 N – PKS' and '20 N + PKS' treatments achieving a higher grade (and higher yields). This site was N deficient without N fertiliser and had additional N available following chickpea.
- THE1 – site average of 0.4% greater protein with both 0 N and 60 N treatments achieving higher grade (and higher yields). This site was N deficient and had additional N available following chickpea.
- CLE2 – site average of 1.1% greater protein with 0 N treatments achieving a higher grade and 20 N jumping up two grades (APW to APH). This site was N deficient without N fertiliser and may have had additional N available following chickpea.
- GIN2 – site average of 1.3% greater protein with both 0 N treatments and 20 N achieving a higher grade (and higher yields). This site was N deficient without N fertiliser and chickpea may have contributed some additional N by rapid breakdown and mineralisation of residues in crop (similar starting soil N).
- THE2 – site average of 0.3% greater protein with both 0 N treatments achieving a higher grade. This site was N deficient without N fertiliser and may have had additional N available following chickpea.

In the other three trials (GIN1, JAM1, JAM2) there were negligible protein differences between the rotations. Both JAM sites had better soil N fertility compared to all the other sites. GIN1 had mostly negligible yield and protein differences between the two rotations; this site had no soil N advantage from the C/W rotation but may have been impacted by frost.

Other system benefits - Increased yields by management of stubble borne cereal diseases

At the JAM2 site, yellow spot (*Pyrenophora tritici-repentis*) was observed at ‘damaging levels’, in W/W plots while a thorough search could only identify a few lesions in adjacent C/W plots. The incidence of yellow spot infection in the C/W plots also decreased with distance away from the W/W trial area. Comparison of biomass and yield between the rotations found an average 37% greater biomass in C/W and an average 34% higher yield (Table 3.4). The trend for greater biomass and yield in the absence of disease was consistent for all fertiliser treatments at this trial. The disparity in the prevalence of yellow spot between the two rotations at this site is indicative of a suppressive effect of the C/W rotation compared to the W/W rotation; this suggests that rotation with a legume may assist in the management of and reduction in the severity of stubble borne cereal diseases (where present).

Comparative profitability of C/W and W/W rotations

Phase 2 wheat in the C/W rotation was clearly more profitable more often. Assuming the cost of growing wheat is identical following chickpea or wheat, the often higher yields, often better grain proteins (plus some better wheat prices for higher grades) can result in higher profits. For example GIN2 had a 12% yield increase and a higher wheat grade for ‘0 N + PKS’ which resulted in an estimated profit of $69.27.

Out of the 82 fertiliser treatments where N was applied, 21 treatments (26%) had a significant yield increase which resulted in a minimum 2:1 (max. 7.5:1) return on investment (ROI) against the cost of urea and included 20, 40 and 60 N treatments. Nine of these treatments were in phase 1 wheat (Table 3.5), three were in wheat following chickpea and seven were in wheat following wheat (Table 3.6). There was an additional four significant yield increases (5%) which returned less than 2:1 against the cost of urea, these tended to be higher N rates (Table 3.5 and 3.6). Profitable yield increases to N fertiliser were more common in better yielding crops with low starting soil N.

A ROI of 2:1 was selected as a minimum acceptable return after consultation with CQ farmers. It should also be noted the rate of return and N fertiliser profitability values in Tables 3.5 and 3.6 only include fertiliser purchase price, not application or other costs. Actual farmer profits from N fertiliser may be lower than those presented.

Summary

- Wheat following chickpea was consistently more productive and profitable than wheat following wheat in a range of ‘typical’ CQ soils when starting soil N was low and plant available water was not limiting during the season.
- In low N situations, N fertiliser are highly likely to be profitable (ROI ≥ 2:1) unless yield is constrained by other factors (eg. PAW, other nutrient deficiencies)
- Responses to PKS fertiliser were location specific and more commonly occurred in chickpea crops.
- The soil N contribution of chickpea to a following wheat crop appears to be around 10-20 kg N/ha. This N contribution did not always occur and was more common in low N situations and higher wheat yield potential crops.
- The chickpea-wheat rotation can assist with management of stubble borne cereal diseases.
- Chickpea increases the grain protein of following wheat crops.
- The financial value of the chickpea-wheat rotation was always better than sequential wheat cropping

Table 3.5. Phase 1 N fertiliser treatment gross margins, N fertiliser return on investment (ROI) and overall N fertiliser profit for each '+ PKS' treatment for all sites.

Trial ID	Treatments	Gross margin ($/ha)	ROI	Profit §§ ($/ha)
CLE1	0 N + PKS	$322		
CLE1	20 N +PKS	$414	3.3	$64
CLE1	40 N + PKS	$541	3.9	$163
CLE1	60 N + PKS	$536	2.5	$129
GIN1	0 N + PKS	$191		
GIN1	20 N +PKS	$269	2.8	$50
GIN1	40 N + PKS	$315	2.2	$68
GIN1	60 N + PKS	$356	2.0	$81
THE1	0 N + PKS	$225		
THE1	20 N +PKS	$334	3.9	$81
THE1	40 N + PKS	$334	1.9	$53
THE1	60 N + PKS	$522	3.5	$212
JAM1	0 N + PKS	$860		
JAM1	20 N +PKS	$1,076	7.7	$188
JAM1	40 N + PKS	$1,080	3.9	$163
JAM1	60 N + PKS	$1,110	3.0	$165
CLE2	0 N + PKS	$248		
CLE2	20 N +PKS	$381	4.7	$104
CLE2	40 N + PKS	$386	2.4	$81
CLE2	60 N + PKS	$513	3.1	$180
GIN2	0 N + PKS	$357		
GIN2	20 N +PKS	$499	5.0	$114
GIN2	40 N + PKS	$682	5.8	$269
GIN2	60 N + PKS	$767	4.8	$325
THE2	0 N + PKS	$772		
THE2	20 N +PKS	$854	2.9	$54
THE2	40 N + PKS	$898	2.2	$70
THE2	60 N + PKS	$893	1.4	$36
JAM2	0 N + PKS	$627		
JAM2	20 N +PKS	$579	-1.7	-$77
JAM2	40 N + PKS	$626	0.0	-$58
JAM2	60 N + PKS	$630	0.0	-$83

§§ For a definition of profit refer to "Profitability" section on p. 24.

Table 3.6. Phase 2 N fertiliser treatment gross margins, N fertiliser return on investment (ROI) and overall N fertiliser profit for each '+ PKS' treatment within rotations at all sites.

Trial ID	Treatments	C/W			W/W		
		Gross margin ($/ha)	ROI	Profit [§§] ($/ha)	Gross margin ($/ha)	ROI	Profit [§§] ($/ha)
CLE1	0 N + PKS	$745			$643		
CLE1	20 N +PKS	$889	5.1	$116	$733	3.2	$63
CLE1	40 N + PKS	$836	1.6	$34	$780	2.4	$81
CLE1	60 N + PKS	$921	2.1	$90	$783	1.7	$56
GIN1	0 N + PKS	$405			$349		
GIN1	20 N +PKS	$522	4.1	$89	$482	4.7	$104
GIN1	40 N + PKS	$623	3.9	$162	$646	5.3	$240
GIN1	60 N + PKS	$712	3.6	$223	$743	4.6	$309
THE1	0 N + PKS	$764			$455		
THE1	20 N +PKS	$852	3.1	$60	$647	6.8	$164
THE1	40 N + PKS	$818	1.0	-$3	$649	3.4	$138
THE1	60 N + PKS	$923	1.9	$75	$836	4.5	$296
JAM1	0 N + PKS	$871			$883		
JAM1	20 N +PKS	$949	2.8	$50	$862	-0.7	-$49
JAM1	40 N + PKS	$899	0.5	-$28	$864	-0.3	-$75
JAM1	60 N + PKS	$886	0.2	-$69	$803	-1	-$165
CLE2	0 N + PKS	$443			$384		
CLE2	20 N +PKS	$454	0.4	-$17	$439	1.9	$27
CLE2	40 N + PKS	$435	-0.1	-$64	$393	0.2	-$48
CLE2	60 N + PKS	$299	-1.7	-$229	$356	-0.3	-$113
GIN2	0 N + PKS	$570			$475		
GIN2	20 N +PKS	$601	1.1	$3	$578	3.6	$75
GIN2	40 N + PKS	$569	0.0	-$58	$570	1.7	$39
GIN2	60 N + PKS	$531	-0.5	-$124	$502	0.3	-$58
THE2	0 N + PKS	$719			$698		
THE2	20 N +PKS	$813	3.3	$66	$701	0.1	-$25
THE2	40 N + PKS	$822	1.8	$46	$688	-0.2	-$67
THE2	60 N + PKS	$703	-0.2	-$0	$594	-1.2	-$189
JAM2	0 N + PKS	$959			$715		
JAM2	20 N +PKS	$1,017	2.1	$31	$799	3	$56
JAM2	40 N + PKS	$926	-0.6	-$89	$648	-1.2	-$123
JAM2	60 N + PKS	$869	-1.1	-$74	$594	-1.4	-$205

[§§] For a definition of profit refer to "Profitability" section on p. 24.

4.0 Macronutrient fertiliser trials (Nutrition priority 2014-15)

Objective

To compare and contrast the effectiveness of bag fertiliser management practices in CQ dryland grain cropping that reflect either current farmer practice or strategic targeting of soil nutrient deficiencies in the profile based on appropriate diagnostics and application methodology

Research questions

- For a given paddock/soil type, what is the crop-specific, maximum (nutrient-unlimited) yield for available water and how far below it are current yields?
- How much does application of non-limiting rates of N fertiliser only (using current application practice) contribute to achieving maximum yield?
- How much does increasing starter fertiliser rate (using current farmer application practice) contribute to achieving maximum yield?
- How much does using a different starter fertiliser product (using current farmer application practice) contribute to achieving maximum yield?
- How much does using a different fertiliser strategy (with nutrients and application rate determined by soil test and recent research) and alternative application practice (based on recent research) contribute to achieving maximum yield?

Methodology

Ten sites with suspected nutrient deficiencies were selected across CQ on commonly cropped soil types based on soil nutrient characterization data for each site (Table 4.0.1). Comprehensive soil characterisation information for each site can be found in Appendix 5.6.

Table 4.0.1. Metadata for 2014 fertiliser trial sites in CQ.

Trial ID	Location	Property	Co-operator	Soil Type	Nutrient# deficiency
NMT-1405-CLE3	Mt McLaren	Undarra West	Merv Bourne	Open Downs	S
NMT-1405-CLE4	Clermont	Blair Athol Station	John Jago	Open Downs	P
-	Capella	The Glen	Don Sampson	Open Downs	P & S
NMT-1404-GIN3	Gindie	Glenora Downs	Dion Sampson	Open Downs	S
-	Gindie	Kilmeen	Ken Sullivan	Flooded Coolabah	P & K
NMT-1405-ORI1	Orion	Cambridge Downs	Luke Tincknell	Open Downs	S
NMT-1404-ROL1	Rolleston	Broken Plains	Kurt Mayne	Brigalow Scrub	P
NMT-1404-DUA1	Duaringa	Sorrell Hills	Collin Dunne	Flooded Coolabah	N
-	Jambin	Bongers Farms	Tony & Peter Bongers	Callide Alluvial	N
NMT-1405-THE3	Theodore	Silverton	Peter Durkin	Brigalow Scrub	P

Inferred subsoil nutrient deficiency based on interpretation of soil test(s)

Table 4.0.2. Treatment list and nutrient rates (kg/ha) applied in fertiliser response trial sites in CQ (2014).

Treatment	Shallow applied fertiliser rates (0 - 10 cm) – all sites						Deep applied fertiliser (P:K:S) rates (15 - 20 cm) at sites				
	Cereal N	Legume N	P	K	S	Zn	GIN4	CLE4 ROL1 THE3	CAP1	CLE3 GIN3 ORI1	All sites
Control											
100 N	100	100									
Starter Z	2.5	2.5	5		0.9	0.23					
100 N + Starter Z	100	2.5	5		0.9	0.23					
100 N + Starter PKS	100	4.5	5	4.2	2.2	0.28					
50 N + Deep	50	4.5	5	4.2	2.2	0.28	25:50:0	25:0:0	25:0:18	0:0:18	
100 N + Deep	100	4.5	5	4.2	2.2	0.28	25:50:0	25:0:0	25:0:18	0:0:18	
Nonlimiting	100	4.5	5	4.2	2.2	0.28					35:100:28
Deep rip only											

Trial design

The field layout was based on a randomised block design with nine treatments (Table 4.0.2) and three replicates. Treatment plots were 4 m wide; plots were laid out at an angle of 90º to the direction of traffic in the paddock. For this reason plot length was dependent on the planter width of farmer co-operators (18 m, 24 m, 30 m, 35 m, or 36 m). Wheat, mungbean and chickpea were planted on 50 cm rows; sorghum on 1m rows. Trials were planted when the farmer was going to plant the field.

Treatments

Nine treatments were selected to address the research questions and trial aims (Table 4.0.2). These treatments included two different types of starter fertiliser, high and moderate rates of N, a nutrient nonlimiting treatment, high rates of P, K, S or a specific combination of these applied at depth in response to sub-surface deficiencies indicated by a soil test, and a deep rip only without any fertiliser applied to gauge the effects of water loss from the deep fertiliser treatments. Nutrient rates applied in each treatment are listed in Table 4.0.2.

Fertiliser treatments

All fertiliser products were granular, with the exception of the technical grade Zinc sulphate added to the NPKSZn starter blend.

Deep P, K, S and deep rip treatments were applied in the first week of December 2013 before any crops were planned, to provide time for the soil surface to flatten out and recharge any lost soil moisture after the deep application process. Deep fertiliser and the deep rip treatment were applied to a depth of 15-20 cm at 50 cm spacing. Summer crops had N fertiliser (urea) applied at planting in side rows whilst winter crops generally had their N applied pre-plant to maximise the opportunity for rain to mobilise N into the soil profile (GIN3 being the exception). Starter was applied with the seed at planting. All fertiliser was applied using a 2 m wide fixed bar tyned planter. Narrow point Yeoman tines were used for the deep application. The nutrient composition of products used in the trials is listed in Table 4.0.3.

Table 4.0.3. Nutrient composition of products used in fertiliser response trials in CQ (2014).

fertiliser type	N %	P %	K %	S %	Zn %
Granulock Z	11.0	21.8		4.0	1.0
CK55 (S)	12.8	14.2	11.9	6.4	
Triple Super		20.1		1.0	
SuPerfect		8.8		11.0	
Muriate of Potash			50.0		
Sulphate of Potash			41.0	18.0	
Zinc sulfate monohydrate				17.2	35.0
Gran-Am	20.2			24.0	
Urea	46.0				

Sampling Protocols

Soil Sampling

Soils were sampled for site characterisation, N and water. Soil samples were collected using a hydraulic soil corer. Sample increments were 0-10 cm, 10-30 cm, 30-60 cm, 60-90 cm. Four soil cores were collected from each plot, bulked together and split in two for water and N analysis. N sampling included six additional 10 cm deep foot-stomps for each plot, bulked with the 0-10 cm increment from hydraulic cores. Soil water sampling was done at planting and harvest. N sampling was done at planting and harvest. Site characterisations were undertaken before the start of the first crop at each trial site. Soil cores for PAW assessment were oven dried at 105^oC for at least three days for dry weights. Soil cores for N assessment were oven dried at 40^oC for at least 3 days before being ground finer than 2 mm and sent to ASPAC accredited laboratories for nitrate and ammonium analysis.

Plant Counts

Two samples were taken from each plot and averaged to provide a plot plant count. Each sample was 1 m long by two rows (1 m^2). Plant density was assessed by early tillering (prior GS20) for wheat and sorghum and around V2-V5 for chickpeas and mungbean.

Biomass

Two samples were taken from each plot and averaged to provide a plot dry matter estimate. Each sample consisted of 2 crop rows by 1 m long (0.5 m^2 for wheat, mungbean and chickpea and 1 m^2 for sorghum). Biomass sampling was done post flowering. Samples were cut off at ground level with dagging shears for wheat and secateurs for chickpeas, mungbean and sorghum. Samples were dried in drying ovens at 40^oC for at least 3 days and then weighed. Bag weights were subtracted from final biomass weights; individual bag weights were collected for each hessian bag used for sorghum while 50 bag averages (brown paper bags) were used for other crops. The dried samples were ground to finer than 2 mm and sent to ASPAC accredited laboratories for ICT and nitrogen analysis.

Grain Yield

The plots were harvested when the farmer harvested the crop surrounding the trial site. The central 2 m from each plot was harvested with a small plot combine harvester. Length of harvested plot was measured to within 10 cm. Grain samples were collected for each plot. Grain moisture was either analysed using a PFEUFFER HOH-EXPRESS HE50 grain moisture meter or calculated by over drying at 40^oC and using wet and dry grain weights. Grain moisture was used to adjust all yield values to maximum receival standards at CQ depots (12.5% for wheat and chickpea, 13% for sorghum and 12 % for mungbeans).Grain protein level were determined for all treatments.

Statistical analysis

Data from individual trials were analysed using the General Analysis of Variance procedure in GENSTAT 16th Edition (VSN International 2013). Fisher's Protected Least Significant Difference test was used to test for differences between means at P=0.05. Where normality of the data distribution was in doubt, an appropriate transformation (arcsine, angular or log) was used prior to analysis. Treatment means and the statistical significance of multiple comparisons among means shown in each graph in the following section are given in Appendices 5.7.

Profitability

Approximate grain prices ($/t) for delivery at the local depot of each trial were calculated for the month of harvest. Mt McLaren is the local depot for CLE3 and CLE4. Capella is the local depot for CAP1. Gindie is the local depot for GIN3, GIN4, ORI1 and ROL1. Moura is the local Depot for THE3, Dingo is the local depot for DUA1 and Koorngoo is the local depot for JAM3.

Port prices were sourced from historical Pentag Nidera daily bid sheets and freight costs were sourced from figures quoted from 'Grain Traders Australia' 2011. Full details local depot grain prices for each trial can be found in Appendix 5.8.

Fertiliser prices (Table 4.0.4) used to calculate the profitability of treatments were sourced from resellers in Emerald QLD in early September 2014 and have been used for all trials.

Table 4.0.4. Fertiliser costs ($/t) for Emerald QLD, September 2014 (GST inclusive).

Fertiliser product	Fertiliser price ($/t)
Urea	$650
Supreme Z Extra	$950
Crop King 55 S	$1000
Zinc Sulphate monohydrate	$58,700
Gran-Am	$650
Triple Super	$925
SuPerfect	$605
Muriate of Potash	$710
Sulphate of Potash	$1230

Results

4.1 NMT-1405-CLE3

- Previous crop was sorghum in summer 2012/13
- Deep fertiliser applied on 4/12/2013
- Pre-plant N applied on 17/03/2014
- Wheat was planted on 1/05/2014
- Fallow rainfall = 237 mm
- In-crop rainfall = 33 mm – insufficient for secondary root development

Soil N

Soil NO_3 at planting averaged 51 kg/ha. At harvest soil NO_3 averaged 48 kg/ha for 0 N treatments and 111 kg/ha for 100 N treatments.

Soil Water

Plant available soil water averaged 34 mm for deep rip treatments and 38 mm for untilled treatments. At harvest plant available soil water averaged 34 mm for deep rip treatments and 38 mm for untilled treatments.

Plant population

Plant population density within the experimental plots was assessed on 26/05/2014. There was no significant difference (P>0.05) in plant population at this site, populations ranged from 570,833 to 759,167 with an average of 671,358 plants/ha.

Biomass

Biomass samples were collected on 28/07/2014 at soft dough. There was no significant difference (P>0.05) in crop biomass among treatments at this site; above ground dry matter ranged from 445 kg/ha to 701 kg/ha with an average of 531 kg/ha.

Yield

The trial was harvested on 2/10/2014. There was no significant difference in yields for this site with very low drought impacted yields (P>0.05). Yields ranged from 68 kg/ha to 163 kg/ha with an average of 108 kg/ha.

Grain Protein

There was no significant difference in grain proteins for this site (P>0.05). Proteins ranged from 13.0% to 14.5%, averaging 14% (APH).

4.2 NMT-1409-CLE4

- Previous crop was sorghum in summer 2012/13
- Deep fertiliser applied on 4/12/2013
- Pre-plant N applied on 17/03/2014
- Wheat was planted on 9/05/2014
- Fallow rainfall = 348 mm
- In-crop rainfall = 154 mm

Soil N

Soil NO_3 at planting averaged 56 kg/ha. At harvest soil NO_3 averaged 33 kg/ha for 0 N treatments and 32 kg/ha for 100 N treatments.

Soil Water

Plant available soil water averaged 171 mm for deep rip treatments and 171 mm for untilled treatments. At harvest plant available soil water averaged 77 mm for deep rip treatments and 88 mm for non-ripped treatments.

Plant population

Plant population density within the experimental plots was assessed on 26/05/2014. There were significant differences ($P<0.001$) in plant populations for this site (Table 4.2). Plant population was reduced in 100 N treatments which had not received a deep P fertiliser application in December 2013. Other treatments had similar plant populations.

Table 4.2. Wheat population density in the Clermont (CLE4) trial (2014).

Treatment	Population (plants/ha)
Control	950,833 a
100 N	578,333 c
Starter PSZn	932,500 a
100 N + Starter PSZn	764,167 b
100 N + Starter PKSZn	607,500 c
50 N + Deep P	943,333 a
100 N + Deep P	935,833 a
Nutrient nonlimiting	965,833 a
Deep rip	989,167 a

Biomass

Biomass samples were collected on 30/09/2014, at grain fill. There was a significant difference ($P<0.001$) in crop biomass among treatments (Fig. 4.2.1). Treatments with N fertiliser and P either as starter of deep applied generally had higher biomass than those with only N or P.

Yield

The trial was harvested on 23/10/2014. There were significant yield differences ($P<0.001$) among treatments at this site. There was a yield response to N but only in the presence of P; deep fertiliser treatments with high amounts of P out-yielded those with starter (less P). There was no yield penalty from the 'deep rip' treatment. The nutrient nonlimiting treatment was not significantly different in yield to the deep P only treatments ($P>0.05$).

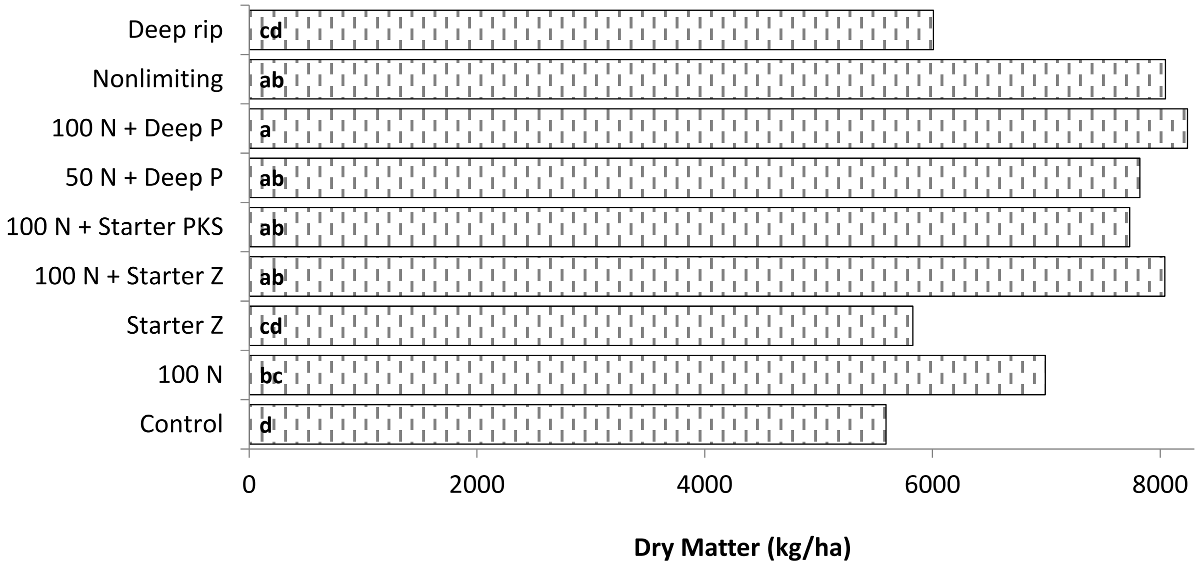

Fig. 4.2.1. Mean dry matter (biomass) accumulated by wheat test crops in response to fertiliser and deep rip combinations at Clermont (CLE4) in 2014. Means (bars) sharing the same alphabet are not significantly different (P>0.05).

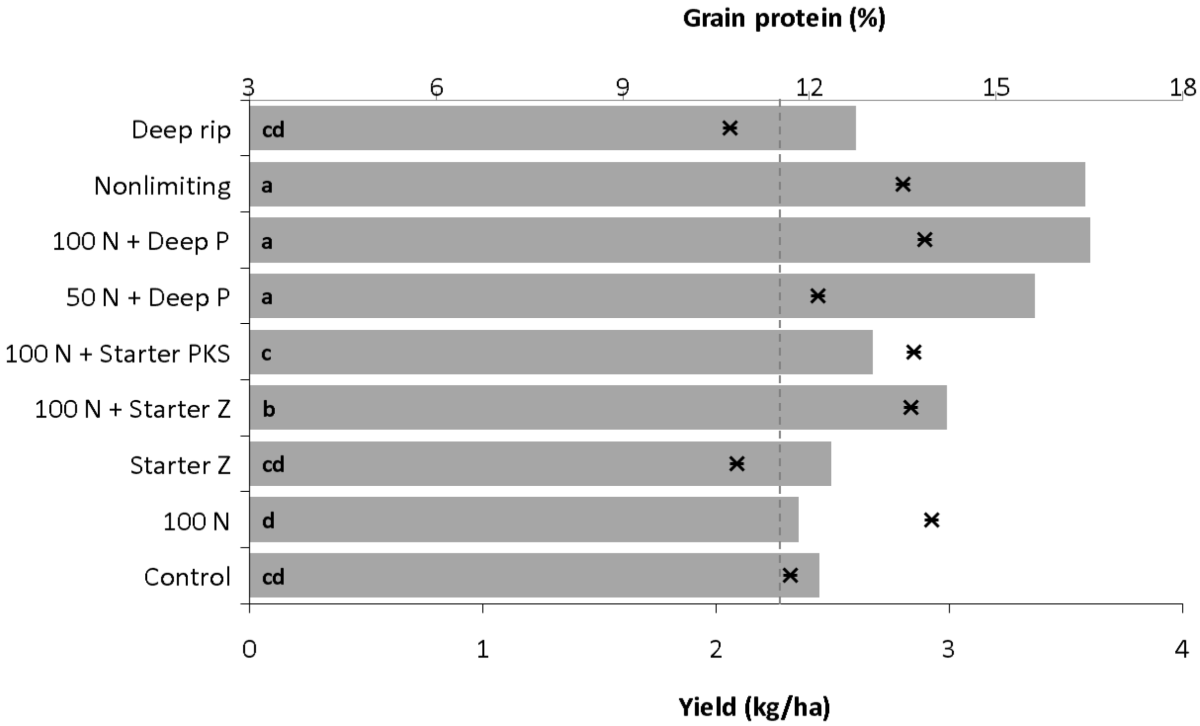

Fig. 4.2.2. Mean yield of wheat test crops in response to fertiliser and deep rip combinations at Clermont (CLE4) in 2014. Means (bars) sharing the same alphabet are not significantly different (P>0.05). The symbols represent wheat grain protein; the dotted grey line indicates 11.5 % grain protein (see text for details).

Grain Protein

Grain proteins increased with N fertiliser use from 10.7, 10.8 (APW) and 11.7 (AH) for 0 N treatments to prime hard (APH) for all 100 N treatments. 50 N produced 12.1 (AH), a protein roughly between the nil N and 100 N treatments (Fig. 4.2.2).

4.3 NMT-1404-GIN3

- Previous crop was sorghum in summer 2012/13
- Deep fertiliser applied on 3/12/2013
- Wheat was planted on 11/04/2014
- Fallow rainfall = 219 mm
- In-crop rainfall = 130 mm (89 mm ineffective late rain prior harvest)

Soil N

Soil NO_3 at planting averaged 9 kg/ha. At harvest soil NO_3 averaged 29 kg/ha for 0 N treatments and 34 kg/ha for 100 N treatments. At this site N fertiliser was applied at planting; there was insufficient follow-up rain to wash the fertiliser into the root zone.

Soil Water

Plant available soil water averaged 112 mm for deep rip treatments and 124 mm for non-ripped treatments, a potential soil water loss of 12 mm from the deep rip operation. At harvest plant available soil water averaged 84 mm for deep rip treatments and 86 mm for non-ripped treatments.

Plant population

Plant population density within the experimental plots was assessed on 30/04/2014. There was a significant difference (P<0.001) in plant population due to loose dirt being 'thrown' over the planting row of all N fertiliser treatments (Table 4.3). Plant population averaged 934,584 plants/ha for treatments with no loose dirt and 475,278 plants/ha for treatments with loose dirt.

Table 4.3: plant population with significance indicated for Gindie (GIN3) 2014 wheat.

Treatment	Population (plants/ha)	
Control	934,167	ab
100 N	583,333	c
Starter PSZn	1,030,000	a
100 N + Starter PSZn	531,667	c
100 N + Starter PKSZn	611,667	c
50 N + Deep S	347,500	d
100 N + Deep S	401,667	d
Nutrient nonlimiting	375,833	d
Deep rip	839,167	b

Biomass

Biomass samples were collected on 24/07/2014 during grain fill. There were significant differences (P<0.001) in crop biomass among treatments (Fig. 4.3.1). Treatments without N fertiliser tended to have smaller biomass (average of 1,176 kg/ha) while treatments with N fertiliser (average 1,691 kg/ha) had greater biomass.

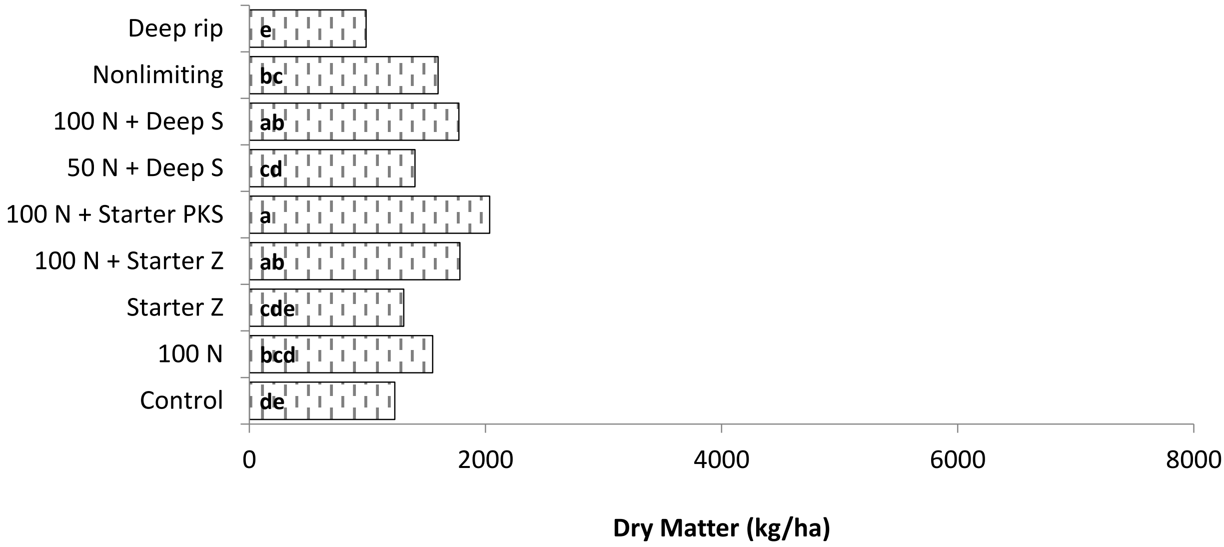

Fig. 4.3.1. Mean dry matter (biomass) accumulated by wheat test crops in response to fertiliser and deep rip combinations at Gindie (GIN3) in 2014. Means (bars) sharing the same alphabet are not significantly different (P>0.05).

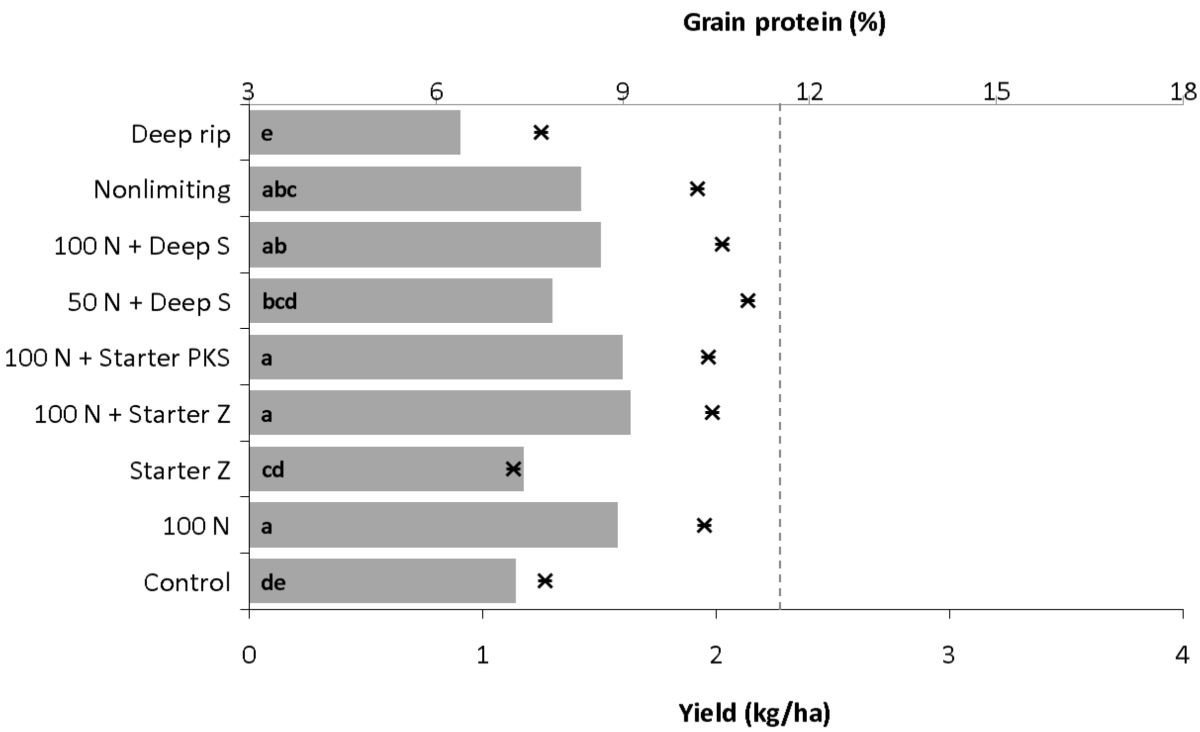

Fig. 4.3.2. Mean yield of wheat test crops in response to fertiliser and deep rip combinations at Gindie (GIN3) in 2014. Means (bars) sharing the same alphabet are not significantly different (P>0.05). The symbols represent wheat grain protein; the dotted grey line indicates 11.5 % grain protein (see text for details).

Yield

The trial was harvested on 1/10/2014. There were significant yield differences (P<0.001) with 100 N treatments (average 1,506 kg/ha) out-yielding 0 N treatments (average 1,075 kg/ha; Fig. 4.3.2). The three 100 N treatments without any deep rip affect were the highest yielding (average 1,603 kg/ha).There was no significant yield penalty from the 'deep rip' treatment.

Grain Protein

Grain protein increased from an average 7.6% (FED1) for 0 N treatments to an average of 10.5% (APW) for N containing treatments (Fig. 4.3.2).

4.4 NMT-1405-ORI1

- Previous crop was sorghum in summer 2012/13
- Deep fertiliser applied on 5/12/2013
- Chickpea was planted on 6/05/2014
- Fallow rainfall = 269 mm
- In-crop rainfall = 132 mm (98 mm late rain)

Soil N

Soil NO_3 at planting averaged 19 kg/ha. At harvest soil NO_3 averaged 20 kg/ha for 0 N treatments and 12 kg/ha for 100 N treatment.

Soil Water

Plant available soil water averaged 96 mm for deep rip treatments and 105 mm for non-ripped treatments. At harvest plant available soil water averaged 47 mm for deep rip treatments and 54 mm for non-ripped treatments.

Plant population

Plant population density within the experimental plots was assessed on 2/06/2014. There was no significant difference among treatments in plant population (P>0.05) which averaged 154,722 plants/ha.

Biomass

Biomass samples were collected on 1/09/2014 during grain fill. There appeared to be a S response as evidenced by larger plants and earlier canopy closure during the vegetative stages of the crop but this visual difference was no longer apparent during the reproductive stages. There was no significant difference in biomass among treatments (P>0.05), which averaged 2,561 kg/ha.

Yield

The trial was harvested on 8/10/2014. There was no significant (P>0.05) difference in chickpea yields which averaged 1,589 kg/ha.

4.5 NMT-1404-ROL1

- Previous crop was mungbean in summer 2012/13
- Deep fertiliser applied on 5/12/2013
- Pre-plant N applied on 18/03/2014
- Wheat was planted on 27/04/2014
- Fallow rainfall = 221 mm; In-crop rainfall = 28 mm

Soil N

Soil NO_3 at planting averaged 271 kg/ha. At harvest soil NO_3 averaged 223 kg/ha for 0 N treatments and 307 kg/ha for 100 N treatment. The high residual soil N may be due to this paddock being converted from leucaena to cropping 2-3 years prior to this trial.

Soil Water

Plant available soil water averaged 104 mm in the deep rip treatments and 116 mm in the non-ripped treatments, a potential soil water loss of 12 mm from the deep rip operation. At harvest plant available soil water averaged 117 mm for deep rip treatments and 118 mm for non-ripped treatments, mostly at depth.

Plant population

Plant population density within the experimental plots was assessed on 19/05/2014. There was a significant difference (P<0.05) in density among treatments and deep rip treatments tended to have lower populations (Table 4.5)

Table 4.5. Mean population density of wheat in the Rolleston (ROL1) 2014 trial.

Treatment	Population (plants/ha)	
Control	1,032,500	a
100 N	963,333	ab
Starter PSZn	948,333	abc
100 N + Starter PSZn	932,500	abc
100 N + Starter PKSZn	1,044,167	a
50 N + Deep P	882,500	bc
100 N + Deep P	811,667	c
Nutrient nonlimiting	826,667	bc
Deep rip	805,833	c

Biomass

Biomass samples were collected on 29/07/2014 during grain fill. There were significant differences (P<0.01) in crop biomass among treatments. Deep ripped treatments had 52% more biomass than non-ripped treatments (941 kg/ha versus 449 kg/ha).

Yield

The trial was harvested on 11/09/2014. Yield was significantly (P<0.001) reduced by 487 kg/ha (65%) from an average 746 kg/ha for non-deep tilled treatments to an average of 259 kg/ha for deep tilled treatments. The lack of rain in the early stages of the crop inhibited secondary root development due to which the crop could not access moisture at depth.

Grain Protein

All grain proteins achieved Prime Hard (APH) ranging from 14.7% to 15.8%, averaging 15.3%.

4.6 NMT-1404-DUA1

- Previous crop was chickpea in 2013
- Deep fertiliser applied on 5/12/2013
- Pre-plant N applied on 17/03/2014
- Wheat was planted on 8/04/2014
- Fallow rainfall = 229 mm
- In-crop rainfall = 188 mm (108 mm ineffective rainfall in September 2013)

Soil N

Soil NO_3 at planting averaged 118 kg/ha. At harvest soil NO_3 averaged 15 kg/ha for 0 N treatments and 86 kg/ha for 100 N treatment.

Soil Water

Plant available soil water averaged 84 mm for deep rip treatments and 84 mm for non-ripped treatments. At harvest plant available soil water averaged 24 mm for deep rip treatments and 38 mm for non-ripped treatments.

Plant population

Plant population density within the experimental plots was assessed on 23/04/2014. There was no significant difference (P>0.05) in plant population density among treatments which ranged from 623,333 plants/ha to 819,167 plant/ha, averaging 718,117 plants/ha.

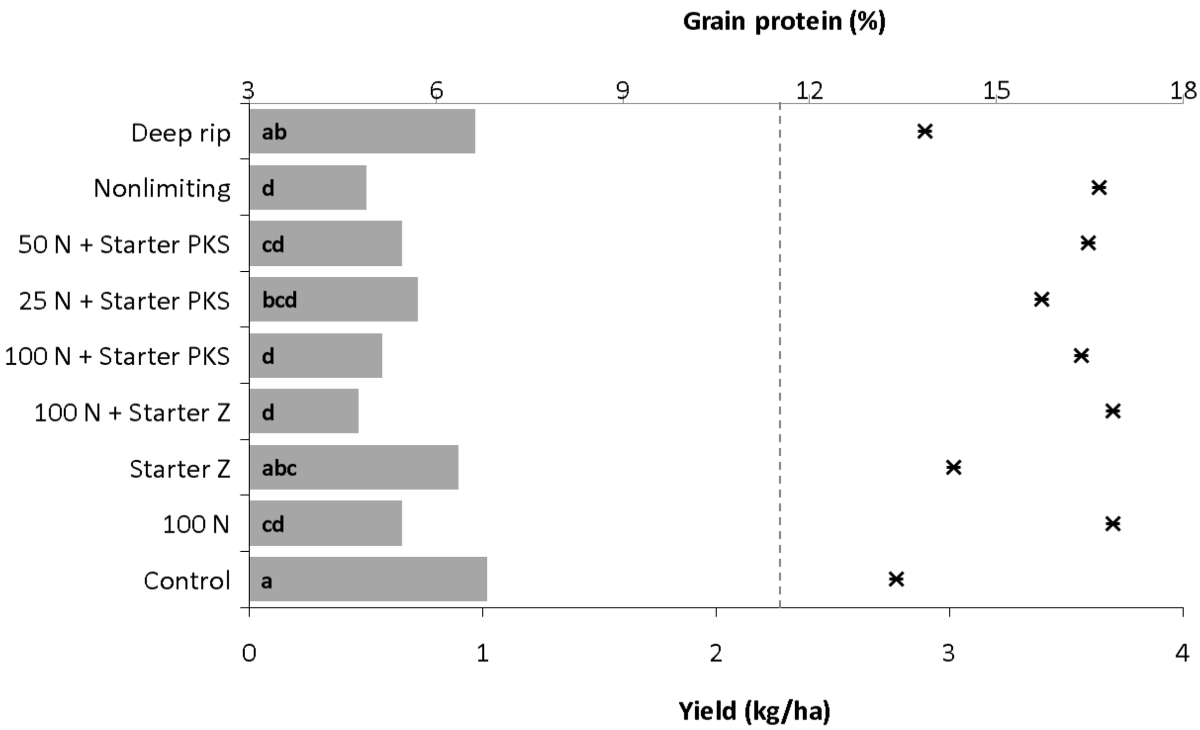

Fig. 4.6. Mean yield of wheat test crops in response to fertiliser and deep rip combinations at Duaringa (DUA1) in 2014. Means (bars) sharing the same alphabet are not significantly different (P>0.05). The symbols represent wheat grain protein; the dotted grey line indicates 11.5 % grain protein (see text for details).

Biomass

Biomass samples were collected on 21/08/2014 during grain fill. There were no significant differences (P>0.05) among treatments in biomass which ranged from 1,649 kg/ha to 2,157 kg/ha, averaging 1,920 kg/ha.

Yield

The trial was harvested on 15/10/2014. There was a significant (P<0.01) yield decline for treatments containing high rates of N fertiliser (Fig. 4.6). There was no significant yield penalty from deep rip. There was frost injury and army worm (*Leucania convecta*) damage was apparent in this trial.

Grain Protein

All grain proteins achieved Prime Hard (APH) ranging from 13.4% to 16.9%, averaging 15.6%.

4.7 NMT-1405-THE3

- Previous crop was wheat in 2013
- Deep fertiliser applied on 6/12/2013
- Pre-plant N applied on 18/03/2014
- Wheat was planted on 14/05/2014
- Fallow rainfall = 249 mm
- In-crop rainfall = 166 mm

Soil N

Soil NO_3 at planting averaged 120 kg/ha. At harvest soil NO_3 averaged 207 kg/ha for 0 N treatments and 104 kg/ha for 100 N treatment.

Soil Water

Plant available soil water averaged 102 mm for deep rip treatments and 104 mm for non-ripped treatments. At harvest plant available soil water averaged 40 mm for deep rip treatments and 37 mm for non-ripped treatments.

Plant population

Plant population density within the experimental plots was assessed on 2/06/2014. There was no significant difference among treatments (P>0.05) in density which ranged from 785,833 plants/ha to 958,333 plant/ha, averaging 889,259 plants/ha.

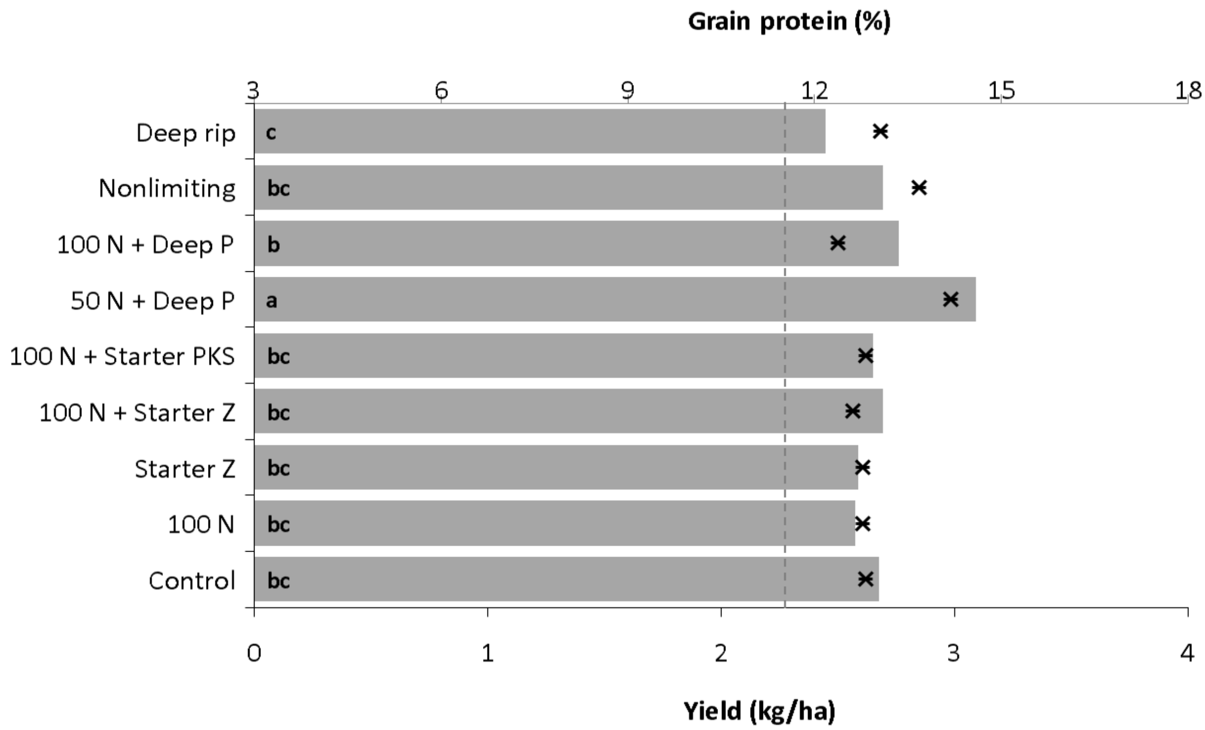

Fig. 4.7. Mean yield of wheat test crops in response to fertiliser and deep rip combinations at Theodore (THE3) in 2014. Means (bars) sharing the same alphabet are not significantly different (P>0.05). The symbols represent wheat grain protein; the dotted grey line indicates 11.5 % grain protein (see text for details).

Biomass

Biomass samples were collected on 10/09/2014. There were no significant differences among treatments (P>0.05) in biomass which ranged from 2,392 kg/ha to 3,043 kg/ha, averaging 2,578 kg/ha.

Yield

The trial was harvested on 22/10/2014. There was a significant (P<0.01) yield difference among treatments with ‘50 N + deep P’ (3,092 kg/ha) out yielding all other treatments (Fig. 4.7). ‘100 N + deep P’ (2,759 kg/ha) also yielded better than deep rip (2,445 kg/ha). There was no significant yield penalty from deep rip.

Grain Protein

Grain proteins ranged from 12.4% (AH) to 14.2% (APH) averaging 13.0% (APH).

4.8 In-progress trials (2015)

NMT 1410-JAM3

NMT 1412-ROL1

NMT 1501-THE3

NMT-1501-CAP1

NMT-1501-GIN3

NMT 1501-DUA1

NMT 1502-ORI1

NMT-1502-CLE4

The trials listed above were in progress when this report was compiled and are not included here.

General Discussion

These trials were able to demonstrate that significant yield increases are possible by correctly identifying and remediating P deficiency with application of P fertiliser into the sub-soil (15-20 cm) under optimal growing conditions, ie. when water and other nutrients, particularly N, are not limiting. This result can be extrapolated to K on the basis of findings from other nutrient response research currently underway in CQ.

These trials were conducted during drier than average conditions with the majority of 2014 sites either water limited at the end or impacted by drought, which may explain why sites expected to provide a fertiliser response to N, P, K or S failed to do so.

The deep P response at CLE4 wheat gave a return of 2.1:1 on the cost of deep fertiliser. The commercially more relevant 50 N rate gave a return on N fertiliser of 2.2:1. Accounting for the cost of N, starter and deep P; a return of 0.95:1 was achieved. This appears to be a commercially viable outcome; recovering the cost of N and starter fertiliser and breaking even for deep P in the first year of a five year investment.

The rates of P, K and S applied at depth were chosen on the assumption that the amount applied would be sufficient to meet the demands of cropping for 3-5 years/crops. Monitoring of these trial sites and treatment plots over successive crops will be necessary to determine the long-term impacts of deep fertiliser application on productivity and profitability.

What is the nutrient nonlimiting yield potential of a paddock?

The ‘Nonlimiting’ treatment had starter, high rates of N, P, K and S fertiliser such that yield should not be constrained by nutrient deficiencies, thereby allowing the crop to produce to its maximum water limited yield potential. This treatment was designed primarily to test the accuracy of soil test interpretation. If the interpretation is correct there should be no yield difference between ‘Nonlimiting’ and ‘100 N + Deep.’

At no site did the ‘Nonlimiting’ treatment yield significantly better than 50 N or 100 N + deep treatments; suggesting that for the seasons the test crops were grown in, the interpretation of the soil test did not miss a yield limiting deficiency.

Starter fertiliser benefits

Only one site (CLE4 wheat) was there a significant yield benefit from the use of starter (Starter Z or Starter PKS) fertiliser. A significant yield response (22%) was achieved to 100 N but only in the presence of starter fertiliser. This is evident by the lack of yield response for ‘100 N’ treatment compared to significantly greater yields for other 100 N rates where either of the starter fertilisers was used.

Possible reasons for the lack of yield responses to starter fertilisers at other sites may include sufficient nutrients in the top soil, average to below average yielding crops, other nutrient limitations (including sub-soil deficiencies) and the low volume of nutrients in starter unable to meet the needs of severe nutrient deficiencies. Some trial sites were impacted by drought and frost injury was evident at one site.

Changing from the simpler NPZn starter to the more nutrient complete NPKSZn starter did not give any significant benefit.

As demonstrated at CLE4, starter fertiliser is important during the early stages of the crop to set grain number and maximum yield potential; especially when the young crops root system is too small to explore a large soil volume or intercept other fertiliser bands to meet its nutrition needs.

Deep fertiliser benefits

There were significant yield increases to deep fertiliser application at CLE4 wheat and THE3 wheat, the highest yielding sites with the greatest potential to respond the deep fertiliser. CLE4 wheat had a 24% (689 kg/ha) yield increase to deep P, on top of the 22% yield increase to starter and N fertiliser combination. The significant yield response in the '50 N + Deep' treatment at THE3 cannot be easily explained, given low variability for the trial (s.e.d. of 127 kg) and the failure of the other two deep P treatments to respond. There was a vegetative stage visual S response at ORI1 chickpeas which was not observed in biomass or yield.

N fertiliser benefits

At CLE4 wheat yields were increased by 22% (548 kg/ha) with N fertiliser (conditional on the presence of starter) which grew an additional $142.82/ha of grain, giving a 100 N fertiliser ROI of 0.89:1. At GIN3 wheat yields were significantly increased by an average of 38% (443 kg/ha) which grew an average additional $129.26/ha of grain, giving a 100 N fertiliser ROI of 0.85:1. Given GIN3 treatments almost broke even for 100 N in a drought year with limited mobilisation of applied N fertiliser, low plant populations and grain proteins below 11.5%; it is reasonable to expect this site could have given a profitable N fertiliser response under more favourable conditions.

The '50 N + Deep' treatment was designed to reflect potential commercial deep fertiliser practice, using a relatively common N fertiliser rate of 50 N (108 kg urea/ha). If there were any additional benefits to be gained from adding more N than was required to meet the yield potential of the crop, those benefits would become apparent from the response to the '100 N + Deep.' There was no difference in wheat yields between the 50 N and 100 N + Deep P treatments at CLE4. This is because the crop's N requirements - 70 kg N/ha to grow 3.37 t/ha at 12.14% protein - were met by starting soil N (17 N), 50 N as fertiliser and in-crop mineralisation. This is apparent from the grain protein of 12.14% (AH) which is accepted as indicating N sufficiency. However, the 100 N treatments did generate a higher grain protein or 13.85% (APH) which indicates that in some high yielding situations additional N fertiliser may provide some additional benefit but the cost-effectiveness of such practices needs to be considered.

Is yield being lost from under-fertilising?

Several trials grew additional yield with fertiliser use, including CLE4 wheat, GIN3 wheat and THE3 wheat. Under drier conditions and with yield limitations (including frost) fertiliser gave no yield advantage at CLE3 wheat, ORI1 chickpea, ROL1 wheat or DUA1 wheat. As demonstrated at CLE4, yield can be forgone if sub-soil deficiencies of P are not identified and corrected. Responsiveness to S application could not be adequately tested in this series of trials due to prevailing water limited growing conditions.

Can the application of fertiliser at depth reduce soil moisture?

The results of these trials clearly demonstrate that when there is insufficient fallow rain to replenish any lost soil moisture due to deep fertiliser application (ripping effect); the following crop can be significantly impacted. At ROL1 yield was reduced by an average 487 kg/ha (65%) by deep fertiliser application which also significantly reduced biomass production. Soil water averaged 12 mm less following deep rip compared to no tillage. Rainfall was a major factor in this situation; fallow rain post deep fertiliser application totalled 221 mm but only 28 mm in-crop rain resulted in poor secondary root development. Soil water averaged 104 mm where the soil was not ripped and 116 mm where it had been ripped for deep fertiliser application.

There was still an observable soil water reduction at ROL1 at planting of the subsequent sorghum crop, with an average 21 mm less plant available soil water in the tilled treatments compared to the non-ripped treatments.

At the majority of sites, there was no yield penalty or soil moisture difference between disturbed and undisturbed treatments. Application of deep fertiliser as early in fallow as possible, ideally on the first shower after harvest will maximise fallow length to help replace any soil moisture that is lost. Using equipment which minimises soil disturbance may also assist.

Deep fertiliser application process

It was mechanically relatively easy to place fertiliser bands 50 cm apart and 15 – 20 cm deep. These trials found driving along existing tram lines in zero-till systems and avoiding tilling on wheel tracks was the easiest technique. Narrow pointed tines assisted (assuming narrow discs would also) and it was easier and resulted in less soil surface disturbance when the top soil was slightly damp following a light shower (see photo A).

(A) Minimal soil disturbance when deep fertiliser is applied in the direction of traffic; (B) Major disturbance across direction of traffic.

Deep application became difficult with considerable soil surface disturbance when the direction of application was perpendicular (across) the usual farmers direction of traffic (see photo B). This was slower, required additional power and brought large soil clods (exceeding 30 cm across) to the soil surface.

Using current guidelines can a soil test be successfully interpreted to identify P, K or S deficiency, including sub-soil deficiency?

P deficiency was successfully identified at CLE4 wheat and corrected by application of P at depth. Yield was increased from 2,830 kg/ha to 3,518 kg/ha (24%). Nutrient 'Nonlimiting' was no better than deep P, suggesting soil test interpretation was correct in not missing any K or S deficiencies for this site.

P deficiency may also have been identified at THE3 wheat where '50 N + Deep P' yielded 418 kg/ha (14%) significantly better than no deep P. However the other two deep P treatments failed to give yield response; casting doubt over weather this yield increase is real or due to other factors.

A possible S response may have been observed for the ORI1 chickpea crop. There was a visible crop height and canopy closure advantage between deep S and non-S treatments during the vegetative stage of this crop. Visual differences became less apparent during flowering and early grain fill; and were not observable in biomass or reflected in yield. If yields had been higher, nutrient demand would have been greater and this may have enabled this possible S response to eventuate.

Case Study: CLE4 wheat – response and profitability of deep P

A comparison of '100 N + Deep P' to '100 N + Starter PKS' (only difference being deep P) allows the deep P yield contribution to be determined and its value estimated (Table 4.9). Provided sufficient N fertiliser and a suitable starter fertiliser were used, deep P increased yields by 35%, which generated an additional income of $230.44/ha. Subtracting $137.68/ha for deep P fertiliser cost gives a profit of $92.76/ha. This gives a ROI of 1.7:1 for deep applied P in the first year. Future deep P yield responses are expected and will further increase profitability as fertiliser cost have already been recovered in the first year and responses are conceivably expected for another 4-5years.

Table 4.9. Profitability of deep P fertiliser application to wheat in the CLE4 trial.

<table>
<tr><th>Treatment</th><th>Yield (t/ha)</th><th>Yield difference (t/ha)</th><th>Yield difference (%)</th><th>Treatment Value ($/ha)</th><th>Difference ($/ha)</th><th>Deep P cost ($/ha)</th><th>Deep P GM ($/ha)</th><th>ROI</th></tr>
<tr><td>100 N + Starter PKS</td><td>2.67 c</td><td rowspan="2">0.932</td><td rowspan="2">35%</td><td>$660.16</td><td rowspan="2">$230.44</td><td></td><td></td><td></td></tr>
<tr><td>100 N + Deep P</td><td>3.60 a</td><td>$890.59</td><td>$137.68</td><td>$92.76</td><td>1.7:1</td></tr>
</table>

Summary

- Existing farm machinery should be able to apply fertiliser at depth (10-20 cm). When applying, keep to tram-lines and avoiding tilling wheel tracks to make it easier.
- The deep fertiliser application process can reduce soil water for the following crop. Minimise the risk of yield penalties by strategically applying deep fertiliser early in the fallow, ideally following the first rain after harvest.
- Use a crop N budget to determine if and how much N fertiliser to apply, especially if grain proteins have been low (<11.5% for wheat or <9.5% for sorghum) and a yield increase after correcting P, K or S deficiency is anticipated.
- Soil tests are getting more reliable at identifying P deficiencies where an economic response to deep P fertiliser can be expected.
- Responses to deep applied fertiliser are more likely in better than average yielding crops.
- S does not have to be applied at depth as it will move through the soil profile similarly as N whereas P and K are immobile in the soil and must be placed at depth if trying to correct a sub-soil deficiency.
- Starter fertiliser is still important even if deep fertiliser is applied; starter sets yield potential by setting grain number. Starter also supplies Zn, some P and other nutrients during the early stages of a crop before its root system can grow to explore a large volume of the soil or come into contact with other fertiliser bands to meet its nutrition needs.
- The cost of large applications of deep fertiliser and expected resulting profits should be budgeted over several crops/years.

5.0 Appendices

5.1 Soil characterisation information for 2011 initiated trial sites.

Indicator	Depth	CLE1	GIN1	THE1	JAM1
pH	0-10	8.9	7	8.2	7.7
	10_30	9	7.4	8.3	8.3
	30-60	9.2	-	8.5	8.4
	60-90	9.2	8.3	8.8	8.4
	60-120	8.9	-	8.2	8.2
	120-150	8.8	-	7.3	8.1
OC%	0-10	0.55	0.65	0.89	1.03
	10_30	0.53	0.53	0.79	0.89
	30-60	0.46	0.59	0.81	0.9
	60-90	0.57	0.28	-	0.71
	60-120	0.47	-	0.61	0.9
	120-150	0.39	-	0.42	0.85
Colwell P (mg/ha)	0-10	14	39	8	28
	10 30	8	23	4	10
	30-60	8	20	3	6
	60-90	10	14	<5	6
	60-120	12	-	4	8
	120-150	13	-	19	9
PBI	0-10	172	105	128	94
	10 30	155	121	147	142
	30-60	137	132	149	134
	60-90	120	122	-	142
	60-120	112	-	129	113
	120-150	114	-	99	119

Indicator	Depth (cm)	CLE1	GIN1	THE1	JAM1
BSES P mg/ha	0-10	439	466	18	44
	10_30	514	486	12	21
	30-60	482	483	13	20
	60-90	446	1240	7.2	19
	60-120	506	-	16	24
	120-150	446	-	53	22
N kg/ha	0-90	51	38	21	76
	0-10	5.8	5	5.8	9.2
	10_30	7	10.2	7.1	18.6
	30-60	17.5	missing	7.8	25.2
	60-90	21	12	5.1	22.5
	60-120	31.5	0	0	31.7
	120-150	52.4	0	0	31.7
S mg/kg	0-10	3	4	4	3
	10 30	3	3	5	4
	30-60	6	9	5	7
	60-90	69	3	-	15
	60-120	162	-	64	29
	120-150	201	-	110	31
Cl mg/kg	0-10	<20	<20	21	<20
	10_30	<20	<20	21	<20
	30-60	25	-	22	20
	60-90	294	<20	100	44
	60-120	1190	-	490	151
	120-150	2050	-	947	271

5.2 Soil characterisation information for 2012 initiated trial sites.

Indicator	Depth	CLE2	GIN2	THE2	JAM2
pH	0-10	8.5	7.5	8.5	7.9
	10_30	8.5	7.6	8.7	8.8
	30-60	8.5	8.5	8.8	8.8
	60-90	8.5	8.0	8.8	8.7
	60-120	8.6	8.6		8.7
	120-150	8.7			8.7
OC%	0-10	0.91	0.67	0.87	1.29
	10_30	0.39	0.60	0.73	0.99
	30-60	0.81	0.57	0.63	1.01
	60-90	0.51	0.40	0.55	0.33
	60-120	0.24	0.24		0.33
	120-150				0.33
Colwell P (mg/ha)	0-10	16	26	29	46
	10_30	13	13	9	13
	30-60	4	10	6	10
	60-90	5	10	8	7
	60-120	10	8		9
	120-150				9
PBI	0-10	224	108	140	71
	10_30	173	139	164	125
	30-60	198	149	158	128
	60-90	172	15	143	99
	60-120	167	127		105
	120-150				105

Indicator	Depth (cm)	CLE2	GIN2	THE2	JAM2
BSES P mg/ha	0-10	278	114	49	80
	10_30	1110	78	30	23
	30-60	147	139	20	18
	60-90	31	971	19	20
	60-120	119	1050		44
	120-150				44
N kg/ha	0-90	32.9	19.7	57.6	106.3
	0-10	15.5	1.3	5.8	17.3
	10_30	6.6	2.6	16.5	23.9
	30-60	3.4	7.8	23.4	33.6
	60-90	7.4	8.0	11.9	31.5
S mg/kg	0-10	<1	2	3	4
	10_30	2	2	6	5
	30-60	2	1	9	17
	60-90	2	2	37	46
	60-120	2	1		79
	120-150				79
Cl mg/kg	0-10	<20	<20	<20	<20
	10_30	<20	<20	<20	36
	30-60	<20	<20	<20	135
	60-90	<20	<20	97	385
	60-120	<20	<20		792
	120-150				792

5.3 Prices used in analyses

Pentag Nidera Port Prices in October

Grain	2011		2012		2013	
	Mackay	Gladstone	Mackay	Gladstone	Mackay	Gladstone
Chickpea	$500	$500	$560	$550	-	-
APH	$300	$300	$317	$317	$283	$283
AH	$254	$254	$304	$304	$275	$275
APW	$227	$227	$299	$299	$265	$265
ASP	$194	$194	$275	$275	$255	$255
AGP	$187	$187	-	$269	$250	$250
FED	$180	$180	-	-	-	-

2011 Grain Trade Australia Location Differentials

Trial	Depot	Wheat	Chickpea
CLE1 & CLE2	Mt. McLaren	$28.32	$25.75
GIN1 & GIN2	Gindie	$43.37	$38.50
THE1 & THE2	Moura	$24.74	$22.00
JAM1 & JAM2	Koorngoo	$21.14	$18.50

Calculated Depot Delivery Prices

Grade	CLE1 & CLE2			GIN1 & GIN2			THE1 & THE2			JAM1 & JAM2			Grade
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013	
Chickpea	$474	$534	-	$462	$512	-	$478	$528	-	$482	$542	-	Chickpea
APH	$272	$289	$255	$257	$274	$240	$275	$292	$258	$279	$296	$262	APH
AH	$226	$276	$247	$211	$261	$232	$229	$279	$250	$233	$283	$254	AH
APW	$199	$271	$237	$184	$256	$222	$202	$274	$240	$206	$278	$244	APW
ASP	$166	$247	$227	$151	$232	$212	$169	$250	$230	$173	$254	$234	ASP
AGP	$159	-	$222	$144	$226	$207	$162	$244	$225	$166	$248	$229	AGP
FED	$152	-	-	$137	-	-	$155	-	-	$159	-	-	FED

5.4 Fertiliser treatment means for rotation trials initiated in 2011

5.4.1 ROT-1105-CLE1

Table 5.4.1a: Phase 1 means

Fert. Treatment (kg/ha)	Plant Counts (plants/ha)		Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	ns		ns		ns	
0 N - PKS	191,250	a	3,712	a	2,736	a
0 N + PKS	189,375	a	4,034	a	2,648	a
lsd(5%)	31,297		621		253	
Wheat	ns		***		*	
0 N - PKS	1,166,250	a	2636	c	1669	b
0 N +PKS	1,383,750	a	2900	c	1620	b
20 N +PKS	1,193,750	a	3709	b	2086	ab
40 N +PKS	1,197,500	a	4209	ab	2397	a
60 N +PKS	1,403,750	a	4434	a	2373	a
Lsd (5%)	471,427		708		554	

Table 5.4.1b: Phase 2 means

Treatment	Plant Counts (plants/ha)	Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	n.s.	**		n.s.	
0 N - PKS	678,333	5,534	b	2,810	
0 N +PKS	680,833	5,304	b	2,754	
20 N +PKS	712,500	6,495	a	3,178	
40 N +PKS	643,333	6,356	a	3,237	
60 N +PKS	629,167	6,952	a	3,482	
Lsd (5%)	174,806	785		607	
Wheat	n.s.	**		*	
0 N - PKS	585000	4,947	c	2,518	b
0 N +PKS	681667	5,234	bc	2,374	b
20 N +PKS	605000	5,997	ab	2,763	ab
40 N +PKS	606667	6,314	a	3,034	a
60 N +PKS	685833	6,658	a	3,007	a
Lsd (5%)	156,817	779		417	

5.4.2 ROT-1105-GIN1

Table 5.4.2a: Phase 1 means

Fert. Treatment (kg/ha)	Plant Counts (plants/ha)		Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	ns		ns		ns	
0 N - PKS	162,500	a	4,805	a	1,332	a
0 N + PKS	169,375	a	4,748	a	1,416	a
Lsd (5%)	18,456		663		221	
Wheat	ns		*		n.s.	
0 N - PKS	1,180,000	a	3,255	c	1,163	a
0 N +PKS	1,112,500	a	3,555	bc	1,267	a
20 N +PKS	1,026,250	a	3,702	bc	1,466	a
40 N +PKS	1,036,250	a	4,136	ab	1,496	a
60 N +PKS	990,000	a	4,556	a	1,389	a
Lsd (5%)	362,333		799		325	

Table 5.4.2b: Phase 2 means

Treatment	Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	***		***	
0 N - PKS	4,336	d	1,527	d
0 N +PKS	4,608	d	1,584	d
20 N +PKS	5,312	c	2,152	c
40 N +PKS	5,817	b	2,659	b
60 N +PKS	6,859	a	3,117	a
Lsd (5%)	322		273	
Wheat	***		***	
0 N - PKS	4,194	c	1,539	d
0 N +PKS	4,383	c	1,367	d
20 N +PKS	5,333	b	1,994	c
40 N +PKS	6,314	a	3,034	a
60 N +PKS	6,658	a	3,007	a
Lsd (5%)	779		417	

5.4.3 ROT-1105-THE1

Table 5.4.3a: Phase 1 means

Fert. Treatment (kg/ha)	Plant Counts (plants/ha)		Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	**		*		**	
0 N - PKS	185,000	a	1,964	b	1,880	b
0 N + PKS	160,625	b	2,573	a	2,463	a
lsd(5%)	14,878		469		351	
Wheat	ns		***		***	
0 N - PKS	855,000	a	1,102	c	854	c
0 N +PKS	893,750	a	1,195	c	1,098	c
20 N +PKS	926,250	a	2,262	b	1,629	b
40 N +PKS	733,750	a	2,403	ab	1,631	b
60 N +PKS	916,250	a	2,747	a	2,248	a
Lsd (5%)	205,383		346		352	

Table 5.4.3b: Phase 2 means

Treatment	Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	***		**	
0 N - PKS	6,235	c	2,689	b
0 N +PKS	7,580	b	2,757	b
20 N +PKS	8,434	ab	3,178	ab
40 N +PKS	9,258	a	3,155	ab
60 N +PKS	8,085	b	3,639	a
Lsd (5%)	1,112		492	
Wheat	**		***	
0 N - PKS	5,171	d	1,565	c
0 N +PKS	5,560	cd	1,799	c
20 N +PKS	6,728	bc	2,439	b
40 N +PKS	7,271	ab	2,548	b
60 N +PKS	8,324	a	3,265	a
Lsd (5%)	1,412		424	

5.4.4 ROT-1105-JAM1

Table 5.4.4a: Phase 1 means

Fert. Treatment (kg/ha)	Plant Counts (plants/ha)	Dry Matter (kg/ha)	Yield (kg/ha)
Chickpea	n.s.	**	n.s.
0 N - PKS	198,000 a	3,250 b	3,416 a
0 N + PKS	186,250 a	4,066 a	3,525 a
lsd(5%)	35,762	523	212
Wheat	ns	ns	**
0 N - PKS	437,000 a	3,453	3,340 b
0 N +PKS	541,000 a	3,695	3,653 b
20 N +PKS	501,000 a	3,989	4,571 a
40 N +PKS	499,000 a	3,578	3,658 b
60 N +PKS	493,000 a	3,914	3,944 b
Lsd (5%)	196,110	575	608

Table 5.4.4b: Phase 2 means

Treatment	Plant Counts (plants/ha)	Dry Matter (kg/ha)	Yield (kg/ha)
Chickpea	n.s.	P=0.088	n.s.
0 N - PKS	280,000 a	5,738	3,077 a
0 N +PKS	225,000 a	6,427	2,917 a
20 N +PKS	286,000 a	6,681	3,274 a
40 N +PKS	236,000 a	6,143	3,200 a
60 N +PKS	225,000 a	7,013	3,253 a
Lsd (5%)	62,307	938	385
Wheat	n.s.	n.s.	n.s.
0 N - PKS	261,000 a	5,986 a	2,949 a
0 N +PKS	294,000 a	6,647 a	2,958 a
20 N +PKS	256,000 a	6,512 a	2,983 a
40 N +PKS	229,000 a	5,641 a	3,084 a
60 N +PKS	202,000 a	6,465 a	2,972 a
Lsd (5%)	87,280	1,047	226

5.4.5 ROT-1205-CLE2

Table 5.4.5a: Phase 1 means

Fert. Treatment (kg/ha)	Plant Counts (plants/ha)		Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	n.s.		***		***	
0 N - PKS	254,583	a	2,635	b	1,145	b
0 N + PKS	249,583	a	3,252	a	1,544	a
lsd(5%)	28,605		335		204	
Wheat	n.s.		***		*	
0 N - PKS	586,667	a	3,402	b	1,187	b
0 N +PKS	704,167	a	3,014	b	1,006	b
20 N +PKS	522,500	a	4,867	a	1,407	ab
40 N +PKS	676,667	a	4,679	a	1,400	ab
60 N +PKS	633,333	a	5,728	a	1,776	a
60 N - PKS	635,000	a	5,087	a	1,856	a
lsd(5%)	135,025		1,106		486	

Table 5.4.5b: Phase 2 means – wheat following either chickpea (C/W) or wheat (W/W)

Treatment	Plant Counts (plants/ha)	Dry Matter (kg/ha)		Grain Protein (%)		Yield (kg/ha)
C/W	n.s.	n.s.		***		n.s.
0 N - PKS	796,250	4,481		10.8	c	1,662
0 N +PKS	818,750	4,173		11.0	c	1,871
20 N +PKS	836,250	4,411		13.6	b	1,892
40 N +PKS	850,000	5,149		14.1	b	1,929
60 N +PKS	845,000	4,991		15.5	a	1,506
60 N - PKS	761,250	4,465		13.9	b	1,723
lsd(5%)	181,724	1,007		1.1		365
W/W	n.s.	***		***		n.s.
0 N - PKS	643,750	3,356	b	9.4	d	1,607
0 N +PKS	665,000	3,514	b	9.4	d	1,694
20 N +PKS	677,500	4,377	a	11.0	c	1,973
40 N +PKS	673,750	5,093	a	13.0	b	1,764
60 N +PKS	630,000	4,984	a	14.8	a	1,730
60 N - PKS	690,000	5,035	a	14.5	a	1,858
lsd(5%)	222,602	850		0.9		299

5.4.6 ROT-1205-GIN2

Table 5.4.6a: Phase 1 means

Fert. Treatment (kg/ha)	Plant Counts (plants/ha)		Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	n.s.		n.s.		n.s.	
0 N - PKS	270,833	a	4,789	a	2,092	a
0 N + PKS	262,500	a	4,744	a	2,091	a
lsd(5%)	29,538		503		91	
Wheat	n.s.		***		***	
0 N - PKS	525,000	a	4,212	c	1,659	d
0 N +PKS	583,333	a	4,321	c	1,581	d
20 N +PKS	530,000	a	5,915	b	2,155	c
40 N +PKS	475,833	a	5,781	b	2,667	b
60 N +PKS	556,667	a	6,724	a	2,942	a
60 N - PKS	565,833	a	6,192	ab	2,765	ab
lsd(5%)	123,350		808		265	

Table 5.4.6b: Phase 2 means – wheat following either chickpea (C/W) or wheat (W/W)

Treatment	Plant Counts (plants/ha)	Dry Matter (kg/ha)		Grain Protein (%)		Yield (kg/ha)	
C/W	n.s.	*		***		n.s.	
0 N - PKS	576,250	5,799	c	11.0	d	2,480	
0 N +PKS	628,750	5,975	bc	11.1	d	2,572	
20 N +PKS	536,250	6,612	ab	13.0	c	2,627	
40 N +PKS	660,000	6,857	a	14.1	b	2,609	
60 N +PKS	557,500	6,788	a	15.1	a	2,567	
60 N - PKS	617,500	6,007	bc	13.3	c	2,453	
lsd(5%)	162,165	663		0.6		167	
W/W	n.s.	***		***		***	
0 N - PKS	633,750	5,414	c	8.9	d	2,293	b
0 N +PKS	636,250	5,305	c	8.5	d	2,299	b
20 N +PKS	593,750	6,312	ab	11.8	c	2,617	a
40 N +PKS	615,000	6,244	ab	13.3	b	2,614	a
60 N +PKS	661,250	6,651	a	15.0	a	2,446	b
60 N - PKS	668,750	5,735	bc	12.3	c	2,351	b
lsd(5%)	128,128	581		0.5		161	

5.4.7 ROT-1205-THE2

Table 5.4.7a: Phase 1 means

Fert. Treatment (kg/ha)	Plant Counts (plants/ha)		Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	n.s.		n.s.		n.s.	
0 N - PKS	69,583	a	3,710	a	2,241	a
0 N + PKS	64,479	a	4,086	a	2,441	a
lsd(5%)	10,981		624		429	
Wheat	n.s.		n.s.		P=0.09	
0 N - PKS	190,000	a	5,375	a	2,523	b
0 N +PKS	200,000	a	5,956	a	2,787	ab
20 N +PKS	175,833	a	6,346	a	3,083	a
40 N +PKS	209,167	a	5,943	a	3,185	a
60 N +PKS	210,833	a	6,431	a	3,026	a
60 N - PKS	205,000	a	6,093	a	2,933	ab
lsd(5%)	51,236		828		472	

Table 5.4.7b: Phase 2 means – wheat following either chickpea (C/W) or wheat (W/W)

Treatment	Dry Matter (kg/ha)	Grain Protein (%)		Yield (kg/ha)
C/W	n.s.	n.s.		n.s.
0 N - PKS	6,554	12.2		2,846
0 N +PKS	6,979	12.0		2,842
20 N +PKS	6,443	12.9		3,325
40 N +PKS	6,608	14.1		3,364
60 N +PKS	6,832	13.6		3,019
60 N - PKS	7,250	13.9		3,225
lsd(5%)	1,978	1.8		606
W/W	n.s.	***		n.s.
0 N - PKS	6,259	10.6	c	2,739
0 N +PKS	6,001	10.6	c	2,872
20 N +PKS	7,323	11.9	b	2,884
40 N +PKS	6,977	14.0	a	2,851
60 N +PKS	6,205	15.0	a	2,599
60 N - PKS	6,119	14.8	a	2,623
lsd(5%)	1,283	1.0		403

5.4.8 ROT-1205 JAM

Table 5.4.8a: Phase 1 means

Fert. Treatment (kg/ha)	Plant Counts (plants/ha)		Dry Matter (kg/ha)		Yield (kg/ha)	
Chickpea	n.s.		n.s.		n.s.	
0 N - PKS	165,000	a	4,516	a	2,156	a
0 N + PKS	170,257	a	4,444	a	2,207	a
lsd(5%)	39,428		845		214	
Wheat	n.s.		n.s.		n.s.	
0 N - PKS	386,250	a	5,152	a	2,082	a
0 N +PKS	329,440	a	5,663	a	2,102	a
20 N +PKS	320,757	a	5,455	a	1,939	a
40 N +PKS	367,500	a	5,822	a	2,097	a
60 N +PKS	417,500	a	5,634	a	2,109	a
60 N - PKS	410,000	a	5,443	a	2,151	a
lsd(5%)	124,918		1,315		439	

Table 5.4.8b: Phase 2 means – wheat following either chickpea (C/W) or wheat (W/W)

Treatment	Plant Counts (plants/ha)	Dry Matter (kg/ha)	Grain Protein (%)		Yield (kg/ha)
C/W	n.s.	n.s.	n.s.		n.s.
0 N - PKS	427,500	9,600	13.4		3,372
0 N +PKS	419,167	9,609	13.7		3,624
20 N +PKS	450,833	9,465	13.8		3,953
40 N +PKS	416,667	9,725	14.1		3,716
60 N +PKS	415,000	9,707	14.2		3,605
60 N - PKS	407,500	8,949	14.5		3,506
lsd(5%)	63,649	694	0.9		557
W/W	n.s.	n.s.	**		n.s.
0 N - PKS	357500	6,694	13.6	b	2,489
0 N +PKS	377500	7,283	13.6	b	2,703
20 N +PKS	390000	6,938	13.6	b	3,129
40 N +PKS	373333	7,335	14.2	ab	2,664
60 N +PKS	394167	6,590	14.9	a	2,566
60 N - PKS	385000	6,759	14.4	a	2,673
lsd(5%)	63,138	1,317	0.7		670

5.5 Profitability of each N fertiliser treatment in the rotation trials

Table 5.5a. Profitability of N fertiliser use in ROT-1105 trials.

Trial ID	Treatment	Cost ($/ha)	2011 Wheat			Wheat following Chickpea			Wheat following Wheat		
			Yield difference# ($/ha)	Profit ($/ha)	ROI	Yield difference# ($/ha)	Profit ($/ha)	ROI	Yield difference# ($/ha)	Profit ($/ha)	ROI
1105-CLE1	20 N +PKS	28	149	121	4.3	172	23	0.2	119	91	3.2
	40 N + PKS	56	219	163	2.9	147	-72	-0.3	194	137	2.4
	60 N + PKS	85	214	129	1.5	260	46	0.2	225	141	1.7
1105-GIN1	20 N +PKS	28	79	50	1.8	145	67	0.8	160	132	4.7
	40 N + PKS	56	124	68	1.2	275	150	1.2	353	297	5.3
	60 N + PKS	85	166	81	1.0	392	226	1.4	478	393	4.6
1105-THE1	20 N +PKS	28	109	81	2.9	117	8	0.1	220	192	6.8
	40 N + PKS	56	109	53	0.9	110	1	0.0	251	194	3.4
	60 N + PKS	85	296	212	2.5	244	-52	-0.2	466	381	4.5
1105-JAM1	20 N +PKS	28	216	188	6.7	107	-110	-0.5	7	-21	-0.7
	40 N + PKS	56	169	113	2.0	84	-85	-0.5	38	-19	-0.3
	60 N + PKS	85	250	165	2.0	100	-150	-0.6	4	-80	-1.0

Total value of N treatment grain subtracted from total value of control grain

Table 5.5b. Profitability of N fertiliser use in ROT-1205 trials.

Trial ID	Treatment	Cost ($/ha)	2012 Wheat			Wheat following Chickpea			Wheat following Wheat		
			Yield difference# ($/ha)	Profit ($/ha)	ROI	Yield difference# ($/ha)	Profit ($/ha)	ROI	Yield difference# ($/ha)	Profit ($/ha)	ROI
1205-CLE1	20 N +PKS	28	133	105	3.7	39	11	0.4	83	55	1.9
	40 N + PKS	56	138	82	1.4	48	-8	-0.1	65	9	0.2
	60 N + PKS		265	180	2.1	-59	-144	-1.7	57	-28	-0.3
	60 N - PKS	85	215	130	1.5	45	-39	-0.5	109	24	0.3
1205-GIN1	20 N +PKS	28	125	96	3.4	59	31	1.1	131	103	3.6
	40 N + PKS	56	146	89	1.6	55	-1	0.0	151	95	1.7
	60 N + PKS		111	26	0.3	45	-40	-0.5	111	26	0.3
	60 N - PKS	85	-67	-151	-1.8	38	-46	-0.5	71	-14	-0.2
1205-THE1	20 N +PKS	28	82	54	1.9	122	94	3.3	32	4	0.1
	40 N + PKS	56	126	70	1.2	159	103	1.8	46	-10	-0.2
	60 N + PKS		121	36	0.4	69	-16	-0.2	-20	-104	-1.2
	60 N - PKS	85	166	82	1.0	122	37	0.4	19	-66	-0.8
1205-JAM1	20 N +PKS	28	-31	-59	-2.1	87	59	2.1	113	84	3.0
	40 N + PKS	56	-4	-61	-1.1	24	-32	-0.6	-10	-67	-1.2
	60 N + PKS		-1	-85	-1.0	-5	-90	-1.1	-36	-121	-1.4
	60 N - PKS	85	21	-64	-0.8	35	-49	-0.6	49	-36	-0.4

Total value of N treatment grain subtracted from total value of control grain

5.6 Macronutrient Fertiliser Trials

Appendix 5.6.1. Detailed soil characterisation for CLE3 and CLE4.

Characteristic	GPS	S22º 22.831 E147º 43.858			GPS	S22º 39.769 E147º 33.708		
	CLE3				CLE4			
Depth (cm)	0-10	10-30	30-60	60-90	0-10	10-30	30-60	60-90
Colour	BR	BR	LTBR		DKGR	GR	GR	
Gravel(%)	0	0	0		0	0	0	
Texture	3	3	2.5		3	3	3	
Organic Carbon(%)	1.06	0.88	0.64		0.92	0.72	0.65	
Ammonium Nitrogen(mg/kg)	2	1	<1	1	1	<1	<1	2
Nitrate Nitrogen (mg/kg)	<1	1	2	1	1	1	1	<1
Phosphorus Colwell (mg/kg)	12	6	4		8	2	<2	
BSES Phosphorus (mg/kg)	278	266	522		41	20	19	
PBI	161	168	164		160	187	190	
Exc. Potassium (meq/100g)	0.65	0.34	0.23		0.77	0.41	0.34	
Exc. Potassium (mg/kg)	254	133	90		300	160	133	
Potassium Colwell (mg/kg)	254	131	88		300	163	133	
Sulphur (mg/kg)	2.2	2.5	2.0	2.4	2.8	3.1	3.7	5.9
MCP Sulfur (mg/kg)	2	2.8	2.2	<1.0	3	4	5	5
Conductivity (dS/m)	0.120	0.148	0.152	0.113	0.095	0.067	0.091	0.153
pH Level ($CaCl_2$)	7	7.6	7.7	7.9	7	7	8	8
pH Level (H2O)	8.4	8.3	8.6	8.8	8.1	8.4	8.5	8.5
DTPA Copper (mg/kg)	2	1.86	1.36		2	2	2	
DTPA Iron (mg/kg)	17.23	15.21	15.88		23.47	24.48	24.89	
DTPA Manganese (mg/kg)	9	4.82	2.78		16	6	6	
DTPA Zinc (mg/kg)	1.03	0.57	0.43		1.01	0.53	0.52	
Exc. Aluminium (meq/100g)	0	0.043	0.038		0	0	0	
Exc. Calcium (meq/100g)	55.16	50.53	45.41		38.75	38.95	37.68	
Exc. Magnesium (meq/100g)	14	13.52	12.36		24	25	27	
Exc. Sodium (meq/100g)	0	0.22	0.26		0	1	1	
Boron Hot $CaCl_2$ (mg/kg)	0.44	0.47	0.47		0.41	0.58	0.87	
Chloride (mg/kg)	3	2.6	2.3	<1.0	4	<1.0	4	5

Appendix 5.6.2. Detailed soil characterisation for CAP1 and GIN3.

Characteristic	GPS	S23º 14.029 E148º 06.735			GPS	S23º 47.692 E148º 14.556		
	CAP1				GIN3			
Depth (cm)	0-10	10-30	30-60	60-90	0-10	10-30	30-60	60-90
Colour	GR	GR	GR		BR	BR	LTBR	
Gravel(%)	0	0	0		0	0	0	
Texture	3	3	2.5		3	3	3	
Organic Carbon(%)	0.84	0.62	0.95		0.85	0.74	0.59	
Ammonium Nitrogen(mg/kg)	2	<1	<1	1	<1	<1	<1	<1
Nitrate Nitrogen (mg/kg)	2	<1	<1	<1	1	<1	<1	<1
Phosphorus Colwell (mg/kg)	13	4	2		13	4	3	
BSES Phosphorus (mg/kg)	86	60	102		104	96	313	
PBI	107	119	122		147	167	181	
Exc. Potassium (meq/100g)	0.56	0.29	0.22		0.77	0.35	0.28	
Exc. Potassium (mg/kg)	218	113	86	0	300	137	109	
Potassium Colwell (mg/kg)	217	113	87		323	141	109	
Sulphur (mg/kg)	3.2	2.6	2.6	4.6	2.4	1.8	1.9	2.2
MCP Sulfur (mg/kg)	2	2	3	2.6	2.9	2.3	2.1	<1.0
Conductivity (dS/m)	0.075	0.064	0.107	0.145	0.061	0.136	0.127	0.148
pH Level ($CaCl_2$)	7	7	7.5	7.9	6.9	7.3	7.5	8
pH Level (H2O)	7.9	8.2	8.5	8.9	7.9	8.1	8.5	8.7
DTPA Copper (mg/kg)	2	2	1.5		2.14	1.88	1.6	
DTPA Iron (mg/kg)	20.13	22.32	17.83		23.25	24.56	22.39	
DTPA Manganese (mg/kg)	16	7	4.44		14.53	6.16	4	
DTPA Zinc (mg/kg)	0.61	0.51	0.40		0.84	0.52	0.58	
Exc. Aluminium (meq/100g)	0	0	0.061		0.062	0.059	0.036	
Exc. Calcium (meq/100g)	29.42	29.24	26.76		41.04	43.84	43.64	
Exc. Magnesium (meq/100g)	28	30	30.45		17.48	17	17.34	
Exc. Sodium (meq/100g)	1	1	1.77		0.14	0.19	0.28	
Boron Hot $CaCl_2$ (mg/kg)	0.48	0.66	0.88		0.41	0.49	0.44	
Chloride (mg/kg)	4	3	3.4	3.5	3.3	1.8	1.4	2

Appendix 5.6.3. Detailed soil characterisation for GIN4 and ORI1.

Characteristic	GPS	S23º 51.542 E148º 17.624			GPS	S24º 16.427 E148º 26.495		
	GIN4				ORI1			
Depth (cm)	0-10	10-30	30-60	60-90	0-10	10-30	30-60	60-90
Colour	DKGR	DKGR	DKGR		GR	GR	GR	
Gravel(%)	0	0	0		0	0	0	
Texture	3	3	3		3	3	3	
Organic Carbon(%)	0.99	0.76	0.80		0.91	0.92	0.87	
Ammonium Nitrogen(mg/kg)	3	<1	<1	1	<1	<1	<1	<1
Nitrate Nitrogen (mg/kg)	2	<1	<1	<1	2	<1	<1	<1
Phosphorus Colwell (mg/kg)	15	3	2		20	12	12	
BSES Phosphorus (mg/kg)	57	14	35		1211	1060	1100	
PBI	46	64	65		185	196	197	
Exc. Potassium (meq/100g)	0.34	0.14	0.13		1.45	1.01	0.88	
Exc. Potassium (mg/kg)	133	55	51		566	394	343	
Potassium Colwell (mg/kg)	131	56	51		576	394	341	
Sulphur (mg/kg)	3.4	2.5	3.8	24.8	2	1.8	1.6	1.9
MCP Sulfur (mg/kg)	3	2.4	4	27.6	2.4	1.7	1.7	<1.0
Conductivity (dS/m)	0.080	0.061	0.143	0.194	0.08	0.144	0.167	0.226
pH Level ($CaCl_2$)	7	7.4	7.8	8.1	7.2	7.4	7.5	8
pH Level (H2O)	8.0	8.4	8.8	9.1	8.2	8.4	8.5	8.6
DTPA Copper (mg/kg)	1	0.88	0.76		2.59	2.37	2.38	
DTPA Iron (mg/kg)	10.62	13.18	11.86		30.57	30.46	27.68	
DTPA Manganese (mg/kg)	16	4.9	2.56		10.88	5.53	4.51	
DTPA Zinc (mg/kg)	0.94	0.58	0.62		0.87	0.77	0.57	
Exc. Aluminium (meq/100g)	0	0.04	0.049		0.053	0.071	0.071	
Exc. Calcium (meq/100g)	19.82	20.08	20.83		41.21 0	41.98	40.64	
Exc. Magnesium (meq/100g)	9	11.7	15.64		24.12	25.52	27.18	
Exc. Sodium (meq/100g)	0	0.76	2.4		0.36	0.71	1.27	
Boron Hot $CaCl_2$ (mg/kg)	0.52	0.66	0.91		0.55	0.81	1.02	
Chloride (mg/kg)	5	2.4	6.9	11.5	<1.0	<1.0	<1.0	1

Appendix 5.6.4. Detailed soil characterisation for GROL1 and DUA1.

Characteristic	GPS	S24º 32.052 E148º 42.756			GPS	S23º 33.358 E149º 41.315		
	ROL1				DUA1			
Depth (cm)	0-10	10-30	30-60	60-90	0-10	10-30	30-60	60-90
Colour	GR	GR	GR		GR	GR	LTGR	
Gravel(%)	0	0	0		0	0	0	
Texture	3	3	2.5		3	3	3	
Organic Carbon(%)	1.69	1.08	0.86		1.01	0.80	0.70	
Ammonium Nitrogen(mg/kg)	2	2	1	2	3	3	2	3
Nitrate Nitrogen (mg/kg)	11	8	9	6	10	1	<1	<1
Phosphorus Colwell (mg/kg)	5	2	<2		72	40	35	
BSES Phosphorus (mg/kg)	51	37	31		340	279	331	
PBI	173	150	137		142	159	147	
Exc. Potassium (meq/100g)	1.18	0.67	0.51		1.04	0.65	0.64	
Exc. Potassium (mg/kg)	460	261	199		406	254	250	
Potassium Colwell (mg/kg)	469	237	198		393	254	242	
Sulphur (mg/kg)	7.2	8.4	52.0	891.8	3.8	2.3	3.3	9.4
MCP Sulfur (mg/kg)	9	11	64.1	1101.6	4	3	5	10
Conductivity (dS/m)	0.182	0.263	0.377	1.151	0.099	0.116	0.148	0.279
pH Level ($CaCl_2$)	8	8	8	7.8	8	7.8	8	8
pH Level (H2O)	8.6	8.8	9.0	8.5	8.4	8.6	9.1	9.2
DTPA Copper (mg/kg)	2	2	2.17		2	2.56	3	
DTPA Iron (mg/kg)	17.56	18.91	18.33		30.99	33.61	34.31	
DTPA Manganese (mg/kg)	7	5	4.59		13	4.48	4	
DTPA Zinc (mg/kg)	0.70	0.88	0.53		1.03	0.64	0.40	
Exc. Aluminium (meq/100g)	0	0	0.069		0	0.059	0	
Exc. Calcium (meq/100g)	39.25	39.46	30.49		30.57	30.47	29.28	
Exc. Magnesium (meq/100g)	13	18	18.77		11	12.51	16	
Exc. Sodium (meq/100g)	2	5	8.94		0	1.15	3	
Boron Hot $CaCl_2$ (mg/kg)	1.06	1.86	4.16		0.72	0.87	1.27	
Chloride (mg/kg)	19	17	75.1	350.9	10	1.9	1	3

Appendix 5.6.5. Detailed soil characterisation for JAM3 and THE3.

Characteristic	GPS	S24º 13.933 E150º 24.126			GPS	S24.765449 E150.144136		
	JAM3				THE3			
Depth (cm)	0-10	10-30	30-60	60-90	0-10	10-30	30-60	60-90
Colour	GR	GR	GR		Grey	Grey		
Gravel(%)	0	0	0					
Texture	3	3	3		Clay	Clay		
Organic Carbon(%)	1.68	1.25	1.24		1.70	0.77		
Ammonium Nitrogen(mg/kg)	4	2	2	2			1.8	1.8
Nitrate Nitrogen (mg/kg)	6	2	2	2	10.0	5.2	2.8	2.8
Phosphorus Colwell (mg/kg)	36	10	9		10	<5		
BSES Phosphorus (mg/kg)	98	59	64					
PBI	103	114	116		95	135		
Exc. Potassium (meq/100g)	0.77	0.43	0.41		0.77			
Exc. Potassium (mg/kg)	300	168	160					
Potassium Colwell (mg/kg)	300	168	160		300	190		
Sulphur (mg/kg)	3.9	6.6	6.3	28.7				
MCP Sulfur (mg/kg)	6	9	8	30	6.8	10.0		
Conductivity (dS/m)	0.067	0.097	0.096	0.350	0.18	0.25		
pH Level ($CaCl_2$)	6	8	7	8	7.80	8.00		
pH Level (H2O)	7.4	8.5	8.3	8.6	8.50	8.80		
DTPA Copper (mg/kg)	4	4	5		0.94	1.10		
DTPA Iron (mg/kg)	47.64	41.60	45.70		9.7	17.0		
DTPA Manganese (mg/kg)	24	7	8		4.20	3.60		
DTPA Zinc (mg/kg)	1.88	0.56	0.60		0.42	0.24		
Exc. Aluminium (meq/100g)	0	0	0					
Exc. Calcium (meq/100g)	22.28	21.60	21.46		27.00	30.00		
Exc. Magnesium (meq/100g)	15	17	17		6.30	9.10		
Exc. Sodium (meq/100g)	1	5	5		0.70	2.0		
Boron Hot $CaCl_2$ (mg/kg)	0.78	1.23	1.29					
Chloride (mg/kg)	26	75	68	303	10.0	18.0	27	27

Appendix 5.7. Macronutrient Fertiliser Trials - Treatment Means

Table 5.7.1. CLE3 Wheat treatment means.

CLE3 Wheat	Population (plants/ha)		Dry matter (kg/ha)		Yield[a] (kg/ha)
	n.s.		n.s.		n.s.
Control	785,833		701		164
100N	615,000		605		91
StarterZ	759,167		619		139
100N+StarterZ	673,333		579		134
100N+StarterPKS	689,167		554		101
25N+StarterPKS	655,000		573		137
50N+StarterPKS	570,833		445		119
Unlimiting	672,500		603		91
DeepTillage	621,389		534		68
s.e.d.	71,137		97		42
l.s.d.					

[a] 12.5% grain moisture

Table 5.7.2. CLE4 Wheat treatment means.

CLE4 Wheat	Population (plants/ha)		Dry matter (kg/ha)		Yield[a] (kg/ha)	
	***		***		***	
Control	950,833	a	5592	d	2441	cd
100N	578,333	c	6990	bc	2352	d
StarterZ	932,500	a	5827	cd	2495	cd
100N+StarterZ	764,167	b	8041	ab	2989	b
100N+StarterPKS	607,500	c	7731	ab	2670	c
25N+StarterPKS	943,333	a	7821	ab	3368	a
50N+StarterPKS	935,833	a	8240	a	3602	a
Unlimiting	965,833	a	8045	ab	3584	a
DeepTillage	989,167	a	6008	cd	2598	cd
s.e.d.	67,113		577		124	
l.s.d.	142,273		1223		262	

[a] 12.5% grain moisture

Table 5.7.3. GIN3 Wheat treatment means.

GIN3 Wheat	Population (plants/ha)		Dry matter (kg/ha)		Yield[a] (kg/ha)	
	***		***		***	
Control	934,167	ab	1232	de	1143	de
100N	583,333	c	1553	bcd	1579	a
StarterZ	1,030,000	a	1308	cde	1177	cd
100N+StarterZ	531,667	c	1784	ab	1632	a
100N+StarterPKS	611,667	c	2035	a	1599	a
25N+StarterPKS	347,500	d	1402	cd	1297	bcd
50N+StarterPKS	401,667	d	1774	ab	1506	ab
Unlimiting	375,833	d	1598	bc	1422	abc
DeepTillage	839,167	b	988	e	906	e
s.e.d.	60,850		171		122	
l.s.d.	128,996		363		259	

[a] 12.5% grain moisture

Table 5.7.4. ORI1 (chickpea) treatment means.

ORI1 Chickpea	Population (plants/ha)		Dry matter (kg/ha)		Yield[a] (kg/ha)	
	n.s.		n.s.		n.s.	
Control	164,167		2397		1606	
100N	151,667		2547		1506	
StarterZ	165,000		2409		1642	
100N+StarterZ	159,167		2311		1584	
100N+StarterPKS	141,667		3005		1789	
25N+StarterPKS	137,500		2617		1435	
50N+StarterPKS	165,000		2905		1826	
Unlimiting	165,833		2550		1627	
DeepTillage	142,500		2306		1371	
s.e.d.	18,137		260		223	
l.s.d.						

[a] 12.5% grain moisture

Table 5.7.5. ROL1 Wheat treatment means.

ROL1 Wheat	Population (plants/ha)		Dry matter (kg/ha)		Yield[a] (kg/ha)	
	*		**		***	
Control	1,032,500	a	890	a	716	a
100N	963,333	ab	956	a	726	a
StarterZ	948,333	abc	932	a	755	a
100N+StarterZ	932,500	abc	1080	a	813	a
100N+StarterPKS	1,044,167	a	853	a	720	a
25N+StarterPKS	882,500	bc	401	b	245	b
50N+StarterPKS	811,667	c	500	b	258	b
Unlimiting	826,667	bc	430	b	280	b
DeepTillage	805,833	c	463	b	253	b
s.e.d.	67,676		160		56	
l.s.d.	143,466		339		120	

[a] 12.5% grain moisture

Table 5.7.6. DUA1 Wheat treatment means.

DUA1 Wheat	Population (plants/ha)		Dry matter (kg/ha)		Yield[a] (kg/ha)	
	n.s.		n.s.		**	
Control	685,000		2048		1021	a
100N	819,167		2157		656	cd
StarterZ	691,667		1878		895	abc
100N+StarterZ	704,167		1844		470	d
100N+StarterPKS	750,833		2085		571	d
25N+StarterPKS	739,167		1802		722	bcd
50N+StarterPKS	742,500		1861		656	cd
Unlimiting	707,222		1649		502	d
DeepTillage	623,333		1960		969	ab
s.e.d.	65,806		200		140	
l.s.d.					297	

[a] 12.5% grain moisture

Table 5.7.7. THE3 Wheat treatment means.

THE3 Wheat	Population (plants/ha)		Dry matter (kg/ha)		Yield[a] (kg/ha)	
	n.s.		n.s.		**	
Control	956,667		2821		2676	bc
100N	878,333		2392		2572	bc
StarterZ	933,333		2715		2585	bc
100N+StarterZ	958,333		2755		2692	bc
100N+StarterPKS	785,833		2727		2652	bc
25N+StarterPKS	879,167		3192		3092	a
50N+StarterPKS	902,500		2745		2759	b
Unlimiting	797,500		3043		2693	bc
DeepTillage	911,667		2430		2445	c
s.e.d.	99,342		325		127	
l.s.d.					269	

[a] 12.5% grain moisture

Appendix 5.8. Local depot prices for relevant grain grades for each trial for the month of harvest.

Trial	Grades and prices								
2014	APH	AH	APW	ASW	AGP	FED1	Chickpea	SOR1	Mungbean Processing
CLE3	240	237	232	224					
CLE4	247	244	239	231					
GIN3	233	230	225	217	214	203			
ORI1							377		
ROL1	249	246	241	233					
DUA1	253	250	238	230					
THE3	258	255	253	245					
2015									
CLE4								…	
CAP1								242	
GIN3								229	
ORI1								…	
ROL1								235	
DUA1									1200
THE3								275	