Project UMU00041- Report 6: Assessing the nutritional benefits of clay amendment and cultivation of sands

Badgingarra Research Station

Two field experiments were assessed at Badgingarra Research Station (360310.95 mE, 6641856.02 mS), a clay rate experiment and a replicated tillage, liming and claying experiment. These experiments were established in 2009 by DAFWA. The clay rate (demonstration) experiment consisted of 5 subsoil clay rates (0, 50, 100, 360 and 450 t/ha), with 3 control (0 t/ha) or nil treatment plots distributed between single replicates of the other subsoil clay treatments. The second experiment consisted of 7 incorporation treatments: nil, offset discs, rotary hoe, deep ripping, spader, mouldboard plough dry and mouldboard wet. All incorporation treatments were replicated in conjunction with the addition of 0 or 150 t/ha of sub-soil clay and the addition of 0 or 3 t/ha of lime sand.

Both experiments at Badgingarra were assessed in the present project in 2013 and 2014 however, only a selection of treatments from the second (replicated) trial were monitored, focussing on deep tillage: measured treatments including no till and spading in combination with nil, claying and lime treatments. Chemical characteristics of subsoil clay applied to these experiments are given in Table 1. These samples were taken from different depths (2 – 5 m) within a clay pit in close vicinity to the experiments.

For both 2013 and 2014, fertiliser was applied at seeding which consisted of (kg/ha): 10.4 N, 14.0 P, 9.1 K and 5.1 S. During the growing season 75 kg/ha of N was applied in a split application of urea.

Sampling methods

Crop biomass and grain yields

In 2013, biomass hand cuts consisted of 5 (double row) 1 m length cuts per treatment replicate collected at anthesis. These were dried at 60 – 70 ^{o}C to constant dry weight and dry weight values were then applied to estimate biomass yield on a per hectare basis. Grain yields for 2013 were provided by Steve Davies (DAFWA). In 2014, biomass and harvest (grain) estimates were based on hand cuts consisting of 10 (double row) 1 m cuts per treatment replicate.

Crop nutrition

Leaf samples for nutrient analysis were collected from all treatments at flag leaf stage, consisting of 50 – 60 leaves which were oven dried at 40 ^{o}C and submitted to CSBP laboratories for nutrient analysis. Nutrient analysis was performed to determine nitrogen, phosphorus, potassium, sulphur, copper, zinc, manganese, calcium, magnesium, sodium, iron, boron, nitrate, chloride and molybdenum.

Soil sampling

Soil samples at 0-10, 10-20 and 20-30 cm depths were collected at sowing with a purpose built sampling apparatus in 2013. This soil sampler had a nominal internal diameter of 72 mm and enabled volumetric sampling to 30 cm depth with the extraction of intact cores at the required depth intervals. Soil samples were air dried at 40 ^{0}C before sieving through a 2 mm laboratory grade sieve in preparation for analysis. For 0 – 10 cm depth, a comprehensive suite of analysis was performed beginning with the standard analysis: Colwell phosphorous, Colwell potassium, sulphur (KCl 40), organic carbon (Walkley-Black), nitrate nitrogen, ammonium nitrogen, electrical conductivity, pH (water), pH ($CaCl_2$), boron and including trace elements (DTPA: copper, zinc, manganese, Iron) and exchangeable cations (calcium, magnesium, sodium, potassium, aluminium).

Clay rate experiment

2013

The clay rate experiment was located on a duplex profile, with 25 – 30 cm of pale sand over gravel. Molarity of Ethanol Droplet tests (MED) conducted on dry sieved soil samples indicated no water repellence (Table 1) with MED values ranging from 0 to 0.2. However, earlier MED values (2009) for the site were high enough (2.25) for water repellence to be a constraint to crop establishment (S. Davies, personal communication).

The subsoil clays added contained very low mineral N and Colwell P, and low Colwell K, organic C and micronutrients apart from B (Table 2). There were low levels of exchangeable Na, but high exchangeable Mg and extractable S. The pH of subsoil was non-limiting (5.5-6.1).

Table 1. Molarity of Ethanol Droplet tests (MED) for subsoil clay treatments of the clay rate experiment at Badgingarra (2013).

Sub-soil clay treatment (t/ha)	Molarity of Ethanol Droplet test (MED)
control	0
50	0.0
100	0.0
control	0.0
360	0.1
450	0.2
control	0.0

Soil analysis after application of treatments (Table 3) indicated Colwell phosphorus levels were varied with levels either below or within the critical range (13 – 16 mg/kg) for grey sands (Anderson et al. 2015) for both control and clay treatments. Colwell potassium levels were above the critical range (39 – 45 mg/kg: Anderson et al. 2015) with an increase in potassium levels for some clayed treatments. Sulphur levels were adequate for both control and clay treatments.

All three subsoil samples from the clay pit were dominated by quartz and kaolinite mineralogy (Table 4). Only the deepest sample from the pit contained traces of illite, but that was not reflected in changes in the Colwell K values.

Nutrient analysis of wheat at flag leaf stage (Table 5) indicate adequate levels of nitrogen exceeding critical levels (1.8 – 3.5 %: Reuter et al. 1997) for both treatments: phosphorus levels were also above the critical range (0.3 – 0.35 %) . Potassium levels were within the adequate range (1.5 – 3.6%), for all treatments (Reuter et al. 1997). Sulphur levels are above the critical range (0.15 – 0.3 %). Tissue levels exceed the critical range (0.18 – 0.21 %) for calcium and magnesium (0.12 – 0.15 %) for control and clayed treatments. Flag leaf Cu, Mn and Zn concentrations were adequate (Reuter et al. 1997).

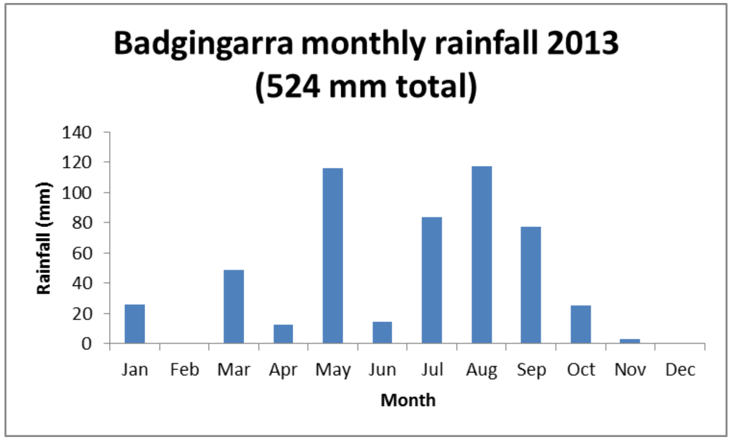
Biomass and grain yield was high (Fig 2 and 3) reflecting favourable rainfall (Fig. 1) with rains early in the season (March) and good finishing rains through to October. Biomass trends were not reflected in grain yields with a varied effect of claying being evident. Wheat yield ranged from 3.8 – 4.4 t/ha with the highest yield from the 360 t/ha clay rate. Considering the variation in yields of the control plots, there was no clear evidence of an effect of clay addition on yield of wheat in 2013.

Table 4. Mineralogy of subsoil from the pit used to excavate clay for the field experiments. A, B, C represent samples from increasing depth in the pit.

Sample	Mineral identified, in order of decreasing abundance		
A	quartz	kaolinite	
B	quartz	kaolinite	
C	quartz	kaolinite	Illite (trace)

Table 2. Chemical analysis of subsoil clay at different depths within a clay pit applied for clay amendment of sands on Badgingarra Research Station.

Depth (m)	Ammonium Nitrogen (mg/kg)	Nitrate Nitrogen (mg/kg)	Phosphorus Colwell (mg/kg)	Potassium Colwell (mg/kg)	Sulphur (mg/kg)	Organic Carbon (%)	Conductivity (dS/m)	pH Level ($CaCl_2$)	pH Level (H_2O)	DTPA Copper (mg/kg)	DTPA Iron (mg/kg)	DTPA Manganese (mg/kg)	DTPA Zinc (mg/kg)	Exc. Aluminium (meq/100g)	Exc. Calcium (meq/100g)	Exc. Magnesium (meq/100g)	Exc. Potassium (meq/100g)	Exc. Sodium (meq/100g)	Boron Hot ($CaCl_2$) (mg/kg)
2 - 3	< 1	< 1	< 2	26	46.1	< 0.05	0.02	5.9	6.4	0.41	1.2	0.12	0.14	0.14	0.64	0.65	0.07	0.03	0.54
3 - 4	4	2	< 2	36	44.2	< 0.05	0.02	6.1	6.8	0.31	< 1.0	0.12	0.18	0.12	0.54	0.74	0.09	0.1	0.4
4 - 5	1	< 1	< 2	33	32.6	0.1	0.02	5.5	6.5	0.2	2.2	0.1	0.1	0.20	0.33	0.96	0.09	0.18	0.43



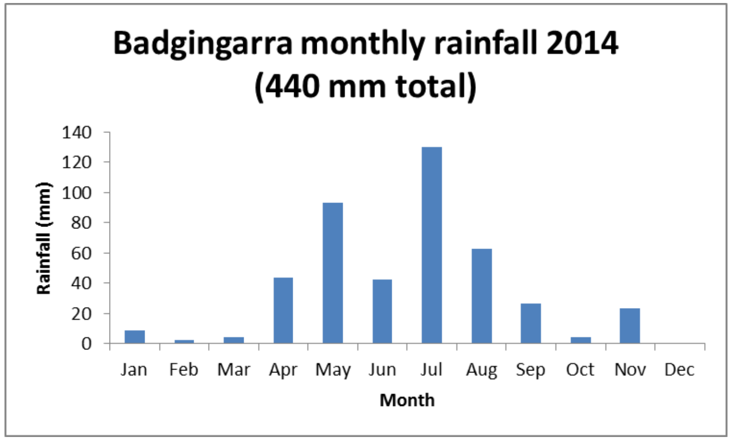


Fig. 1. Monthly rainfall for Badgingarra Research Station for 2013 and 2014

Table 3. Soil analysis for treatments of the clay rate experiment at Badgingarra Research Station for 0 – 10 cm depth after treatments were applied, 2013.

Treatment (t of subsoil/ha)	Ammonium Nitrogen (mg/kg)	Nitrate Nitrogen (mg/kg)	Phosphorus Colwell (mg/kg)	Potassium Colwell (mg/kg)	Sulphur (mg/kg)	Exc. Calcium (meq/100g)	Exc. Magnesium (meq/100g)	Exc. Potassium (meq/100g)	Exc. Sodium (meq/100g)
Control	3	27	14	71	7.7	2.71	0.32	0.16	0.04
50	2	23	13	98	8.2	2.64	0.35	0.19	0.03
100	3	26	15	106	8.3	2.81	0.37	0.24	0.03
Control	2	21	12	58	8.2	2.73	0.31	0.14	0.03
360	3	25	13	69	8.6	2.38	0.31	0.16	0.03
450	2	20	12	63	8.3	2.37	0.29	0.16	0.04
Control	2	20	10	62	5	1.69	0.21	0.14	0.03

Treatment (t of subsoil/ha)	DTPA Copper (mg/kg)	DTPA Iron (mg/kg)	DTPA Manganese (mg/kg)	DTPA Zinc (mg/kg)	Exc. Aluminium (meq/100g)	Boron Hot $CaCl_2$ (mg/kg)
Control	0.37	10.8	2.14	1.04	0.08	0.26
50	0.39	21.4	2.89	1.1	0.10	0.35
100	0.41	12.9	2.57	0.95	0.09	0.38
Control	0.29	6.3	1.95	0.97	0.13	0.3
360	0.34	11.8	2.67	0.95	0.15	0.25
450	0.35	7.2	2.14	0.82	0.11	0.23
Control	0.33	10.7	2.92	0.92	0.07	0.19

Table 5. Foliar analysis for wheat (flag leaf stage) for the clay rate experiment at Badgingarra Research Station, 2013.

Treatment (t of subsoil/ha)	Boron (mg/kg)	Copper (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Molybdenum µg/Kg	Zinc (mg/kg)
Control	7.9	5.1	76	106	745	27.7
50	8.3	5.9	79	125	622	37.6
100	8.7	5.0	79	97	523	30.3
Control	8.4	4.6	76	107	696	29.9
360	7.1	4.9	75	104	614	30.8
450	7.3	4.7	71	120	598	32.9
Control	8.2	5.0	74	133	585	31.7

Treatment (t of subsoil/ha)	Calcium (%)	Chloride (%)	Magnesium (%)	Nitrate (mg/kg)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulfur (%)	Total Nitrogen (%)
Control	0.82	0.73	0.26	<40	0.37	2.06	0.03	0.34	4.3
50	0.74	0.72	0.27	<40	0.37	2.06	0.03	0.33	4.19
100	0.68	0.68	0.26	<40	0.38	2.3	0.03	0.33	4.12
Control	0.77	0.76	0.27	<40	0.37	1.97	0.03	0.33	3.92
360	0.7	0.71	0.24	<40	0.38	2.06	0.03	0.31	4
450	0.77	0.75	0.25	<40	0.37	1.86	0.03	0.3	3.86
Control	0.87	0.72	0.28	<40	0.37	1.7	0.03	0.3	3.87

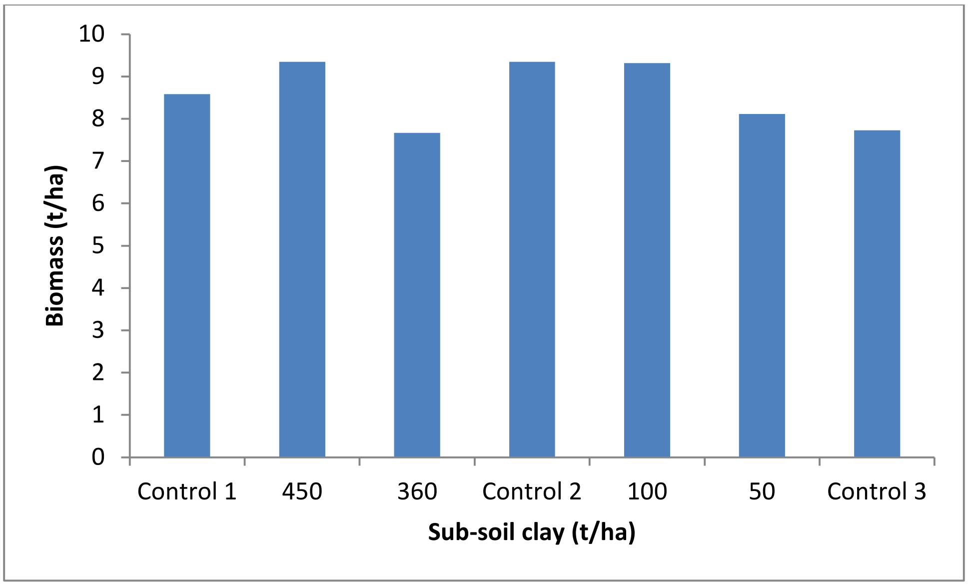


Fig. 2. Wheat above-ground biomass (t/ha) for the clay rate experiment at Badgingarra in 2013. Note the control was replicated in this experiment, but not the remaining treatments.

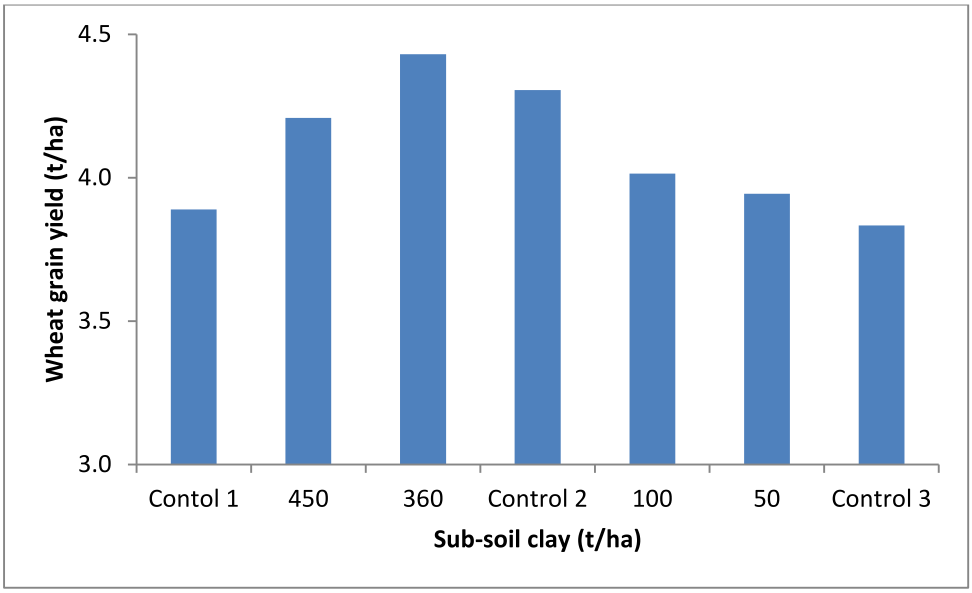


Fig.3. Wheat grain yield for the clay rate trial at Badgingarra in 2013. Note the control was replicated in this experiment, but not the remaining treatments.

2014

In the 2014 season, treatments were sown to barley and monitoring was primarily on crop yield. No further soil analysis or plant analysis was performed. The annual rainfall (Fig. 1) for 2014 was approximately 85 mm less than 2013. Despite a lower annual rainfall, overall barley yields were quite high (3.7-4.2 t/ha). The addition of subsoil clay had minimal effects on barley grain yields at this site in 2014 (Fig. 4). The addition of clay may have reduced water repellence of surface sands however yield benefits of claying are not evident, possibly due to a more fertile subsoil gravel layer in the profile at 25 – 30 cm depth.

Mean grain yield from 2009 to 2014 showed no effect of claying on grain yield (Fig. 5).

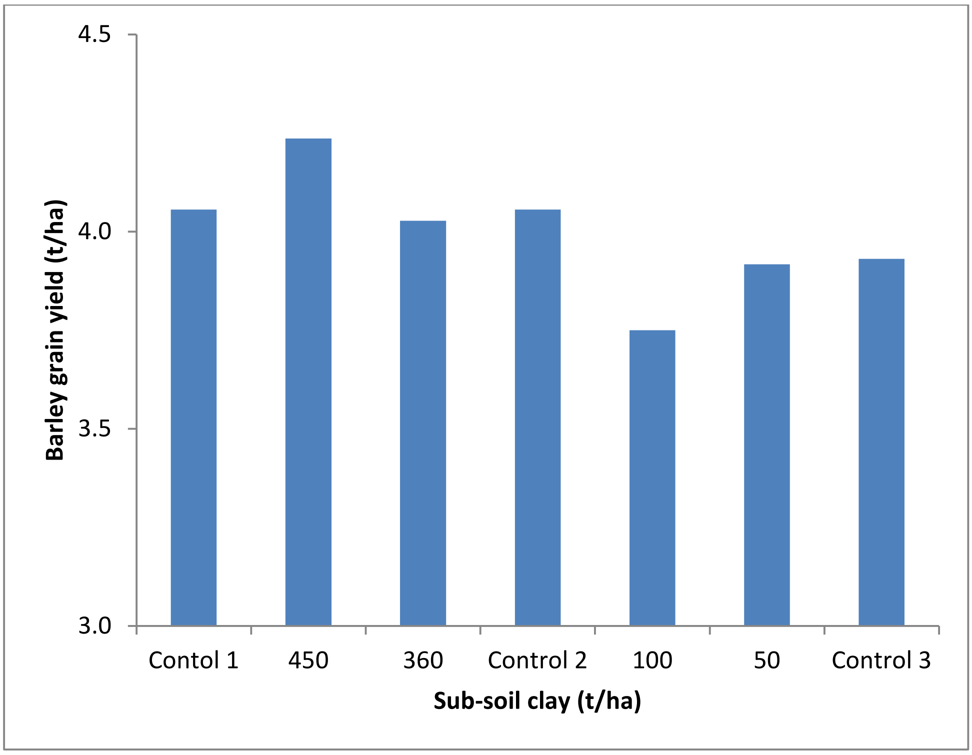


Fig. 4. Grain yield (barley) for the clay rate experiment at Badgingarra (2014). Note the control was replicated in this experiment, but not the remaining treatments.

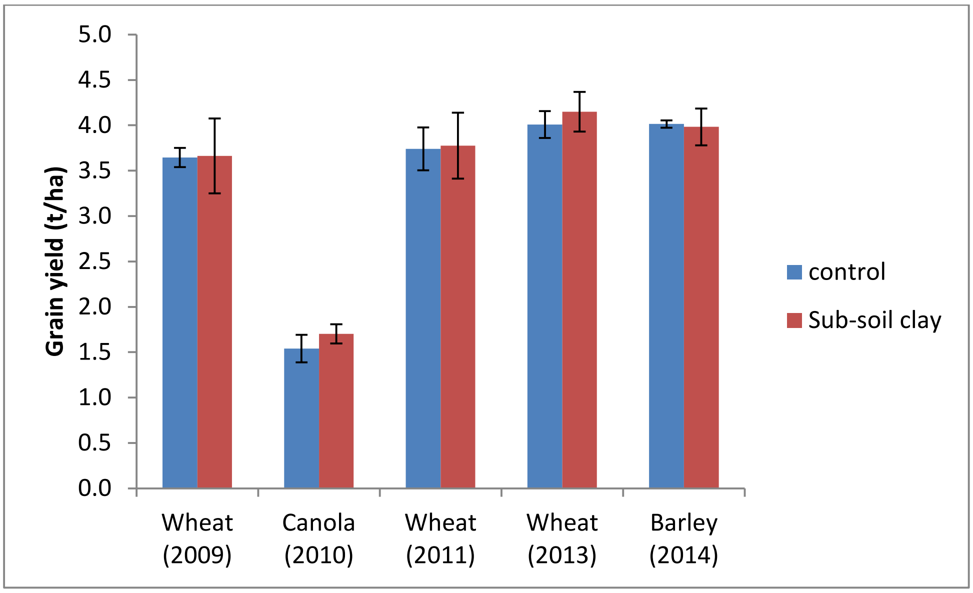


Fig. 5. Mean grain yield for the clay rate experiment at Badgingarra from 2009 to 2014. No crop yields were collected in 2012 due to hail damage.

Incorporation, claying and lime experiment

2013

In 2013, the treatments were sown to wheat. Molarity of Ethanol Droplet tests conducted on dry sieved soil samples indicated a small degree of water repellence with MED values ranging from 0 to 0.4 (Table 6). Results of soil analysis (Table 7) indicate levels of phosphorus below critical levels for the unincorporated control and clay treatments and within the critical range (13 – 16 mg/kg: Anderson et al. 2015) for the remaining treatments for grey sands. Potassium levels were at the lower end of the critical range (39 – 45 mg/kg) for both control treatments (no till and spading) and for the no-till lime treatment: the remaining treatments were marginally above the critical range (Anderson et al. 2015). Sulphur levels were adequate for all treatments for wheat but tend to be less for all spaded treatments indicating a dilution effect from this incorporation method.

Mean values for flag leaf nutrient analysis (Table 8) indicate adequate levels of nitrogen exceeding critical levels (1.8 – 3.5 %: Reuter et al. 1997) for all treatments. Similarly, phosphorus levels were above the critical range (0.22 – 0.35 %) for all treatments despite the low soil Colwell P concentrations. Potassium levels are below the adequate range (1.5 – 3.6 %), for all treatments (Reuter et al. 1997). All treatments were at the upper end of the critical range (0.15 – 0.3 %) for sulphur and exceed the critical range (0.18 – 0.21 %) for calcium and magnesium (0.12 – 0.15 %) for all treatments. Flag leaf Cu, Mn and Zn concentrations were adequate (Reuter et al. 1997).

Clay additions increased soil and plant potassium levels and part of the yield response to clay may be attributed to increased potassium availability to crops. Spading decreased flag leaf potassium. Leaf nitrogen was adequate and unaffected by clay or tillage. Leaf phosphorus, magnesium, zinc and copper concentrations also declined at this site with higher yield but levels were more than adequate for wheat yield.

Biomass yield at anthesis indicate trends of increased biomass production for liming and clay treatments, however the grain yield increase was restricted to clayed treatments regardless of incorporation (Fig. 6)

Table 6. Molarity of Ethanol Droplet tests (MED) for control, clay and lime of the incorporation treatments at Badgingarra (2013).

Treatment	Incorporation	Molarity of Ethanol Droplet test (MED)
Control	no till	0.4
	spader	0.3
Lime	no till	0.1
	spader	0.2
Clay	no till	0.0
	spader	0.0

Table 7. Mean values for soil analysis for treatments of the claying and liming trial at Badgingarra Research Station for 0 – 10 cm depth 2013.

Treatment	Incorporation	Ammonium Nitrogen (mg/kg)	Nitrate Nitrogen (mg/kg)	Phosphorus Colwell (mg/kg)	Potassium Colwell (mg/kg)	Sulphur (mg/kg)	Exc. Calcium (meq/100g)	Exc. Magnesium (meq/100g)	Exc. Potassium (meq/100g)
Control	no till	2.3	11.5	9.8	38.8	6.05	1.72	0.14	0.09
	spader	2.5	11.3	11.0	39.8	5.43	1.85	0.16	0.09
Lime	no till	2.0	11.7	15.0	38.0	6.23	3.41	0.25	0.10
	spader	1.5	10.8	13.3	47.5	5.85	3.05	0.22	0.12
Clay	no till	3.0	18.5	9.8	52.3	6.33	2.11	0.22	0.13
	spader	3.8	13.8	13.3	54.0	5.63	1.94	0.20	0.12

Treatment	Incorporation	DTPA Copper (mg/kg)	DTPA Iron (mg/kg)	DTPA Manganese (mg/kg)	DTPA Zinc (mg/kg)	Exc. Aluminium (meq/100g)	Exc. Sodium (meq/100g)	Boron Hot $CaCl_2$ (mg/kg)
Control	no till	0.36	9.1	3.47	1.56	0.07	0.03	0.20
	spader	0.41	9.6	3.62	1.58	0.08	0.03	0.14
Lime	no till	0.35	8.1	2.56	1.36	0.07	0.02	0.18
	spader	0.28	5.5	2.61	1.13	0.05	0.03	0.19
Clay	no till	0.45	16.1	4.66	1.47	0.13	0.03	0.20
	spader	0.45	18.3	4.43	1.67	0.14	0.03	0.18

Table 8. Mean values of foliar analysis for the claying and liming trial for wheat (flag leaf stage) sampled at Badgingarra Research Station, 2013.

Treatment	Incorporation	Calcium (%)	Chloride (%)	Magnesium (%)	Nitrate (mg/kg)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulfur (%)	Total Nitrogen (%)
Control	no till	1.08	0.81	0.30	<40	0.43	1.27	0.05	0.29	3.67
	spader	1.15	0.86	0.32	<40	0.46	1.15	0.05	0.30	3.65
Lime	no till	1.12	0.80	0.34	<40	0.38	1.33	0.04	0.29	3.64
	spader	1.27	0.83	0.36	42	0.41	1.20	0.05	0.29	3.67
Clay	no till	0.91	0.74	0.28	<40	0.39	1.53	0.05	0.29	3.70
	spader	0.91	0.76	0.27	<40	0.39	1.58	0.05	0.29	3.71

Treatment	Incorporation	Boron (mg/kg)	Copper (mg/kg)	Iron (mg/kg)	Manganese (mg/kg)	Molybdenum (µg/kg)	Zinc (mg/kg)
Control	no till	9.9	5.75	74	176	434	29.4
	spader	10.0	6.14	71	214	445	30.4
Lime	no till	10.0	5.28	73	87	1015	27.1
	spader	10.6	5.51	71	102	1090	27.0
Clay	no till	8.9	5.44	71	159	391	28.8
	spader	8.2	6.01	72	190	383	30.2

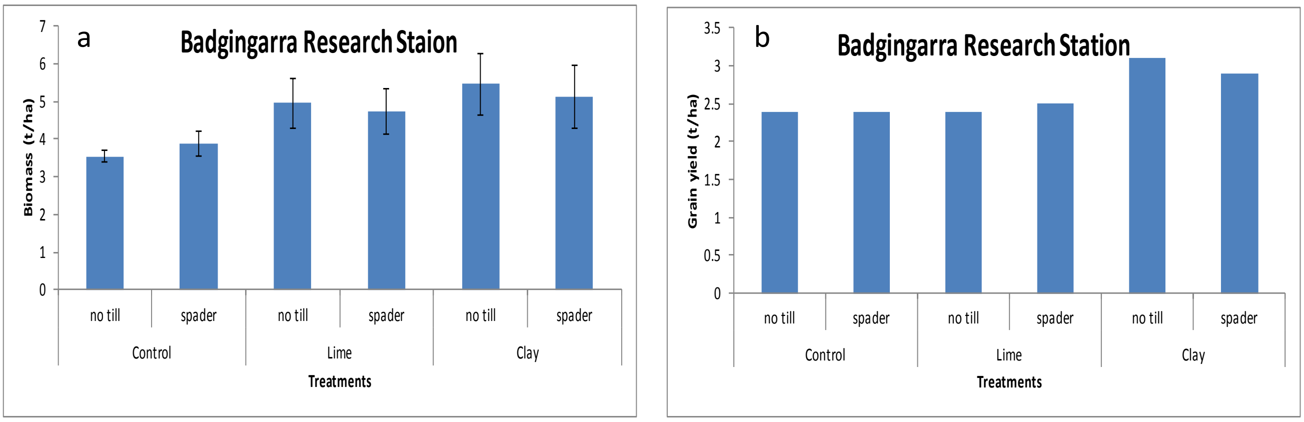
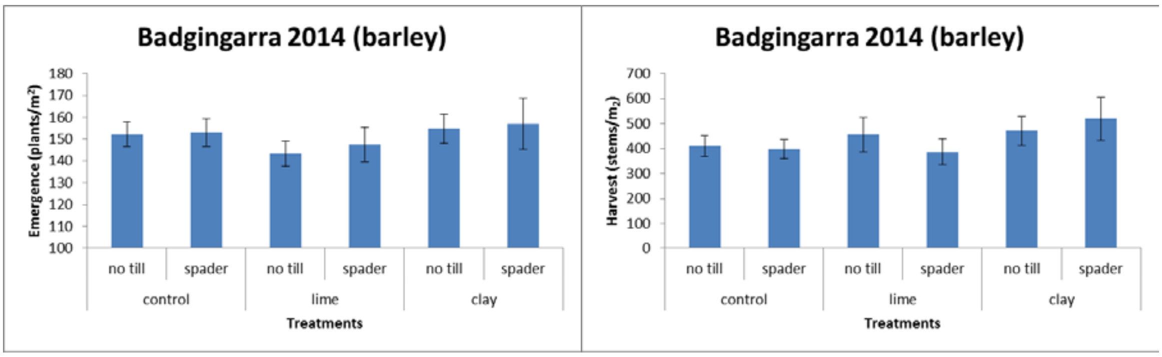


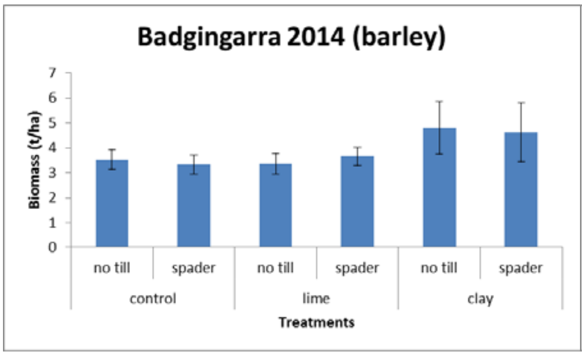
Fig. 6. a) Biomass yield at anthesis and b) grain yield (Steve Davies, DAFWA) for; control, lime and clay treatments for no till and spading at Badgingarra Research Station, 2013.

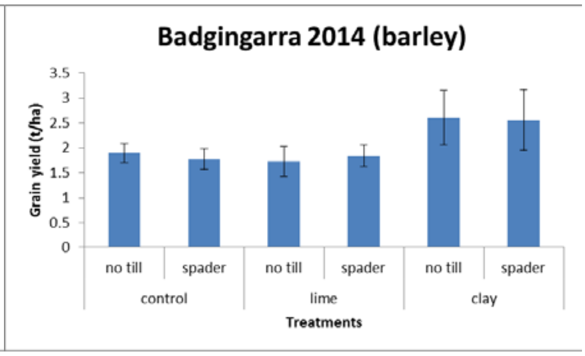
2014

In 2014 treatments were sown to barley and was assessed primarily for crop yield with no further soil or plant analysis. Grain yield responses were observed for clayed treatments but not liming or tillage, with both biomass and grain yield having similar trends (Fig. 7). Clay treatment increased grain yield by over 0.5 t/ha from 1.7 to 2.5 t/ha. Emergence and harvest stem density followed similar trends with the exception of the no till limed treatment where tillering increased to a greater extent than other treatments.



a) b)





c) d)

Fig. 7. Growth and yield parameters; a) emergence, b) stem density at harvest, c) biomass at harvest and d) grain yield for control, lime and clay treatments for no till and spading at Badgingarra in 2014

Discussion and conclusions

Neither of the Badgingarra sites had significant water repellence when assessed in 2013, hence responses to clay addition during the present study were probably not related to the alleviation of water repellence. Earlier assessments had shown MED values of 2.25, which may have imposed a constraint for crop establishment during the earlier years of the experiments (S. Davies, personal communication). The low MED values in 2013 may be attributable to the time of sampling. Soil samples were collected at seeding and the presence of soil moisture following seasonal rains may have reduced soil water repellency.

The range in wheat yields between control plots of the clay rates experiment from 3.8 to 4.3 t/ha in 2013 suggests variability across the site, which may be related to varied depths to subsoil gravel/ clay layer in the profile. The variation in barley yields across control plots in 2014 was less, from 3.9 to 4.1 t/ha. In five crops harvested since the clay rates experiment started in 2009, clay addition had no significant effect on crop yields.

The subsoil used at Badgingarra was low in K (26-36 mg Colwell K/kg) and also in extractable P, Mn and Zn. However, the sand to which clay was added in the clay rates experiment had more than adequate extractable K. Hence, in that experiment there was likely little impact of clay addition on crop K nutrition. Flag leaf analysis confirmed that wheat K status was adequate in 2013. While the sand on this site had Colwell P levels in the marginal range of grey sands (Anderson et al. 2013), there was no consistent effect of clay addition or rate on Colwell P values in the 0-10 cm layer.

At the lime, clay and incorporation experiment, clay had positive effects on yield in 2013 and 2014. Even though the same subsoil material was used, the soil test values at the incorporation experiment were lower in Colwell P and K than the clay rates experiment. Colwell P was deficient in the control no-till sands. Addition of clay had no effect on Colwell P, but Colwell K was increased from 39 mg/kg, which is considered deficient for crops, to 52 mg/kg which is adequate (Anderson et al. 2013). Hence the alleviation of K deficiency may explain the increase in crop yields with clay addition, but soil P levels remained deficient. The increase in yield with clay addition was consistent with an increase in wheat flag leaf K in 2013 from 1.3 % K which is deficient to 1.5 % K which is borderline adequate.

Clay addition may also have increased soil water storage, but no data was collected on water availability.

References

Anderson, G., Chen, W., Bell, R.W. and Brennan, R.F. (2015). Making better fertiliser decisions for cropping systems in Western Australia. Soil test - crop response relationships and critical soil test values and ranges. Department of Agriculture and Food, West Australia. Bulletin 4865. **DOI:** 10.13140/R.2.1.4641.9283