INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
19–1171/2020/23–5–889–898
DOI: 10.17957/IJAB/15.1366
http://www.fspublishers.org

Full Length Article

Soil Water and Residue Amendment Effects on Nutrient Availability and Wheat Growth in Silt Loam Soils of South Australia

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Received 20 July 2019; Accepted 01 January 2020; Published 03 March 2020

Abstract

A study was conducted for 45 days to examine the influence of soil residue amendments with different C:N ratios and soil wetting regimes on soil nutrient availability and plant growth. Four soil water treatments i.e. 20 days moist (20 M), 5 days moist followed by 15 days dry (15 D), 10 days moist followed 10 days dry (10 D) and 20 days dry (20 D) and three residue treatments i.e. control (CO), dry faba bean residue with C:N ratio of 60.2 (FB), dried kikuyu grass residue with C:N ratio of 20.1 (KK) were tested. The experimental soils were wetted and maintained at 50% of water holding capacity (WHC) for 10 days. 10,000 mg kg^{-1} of ground residues of KK and FB were added to pots containing 0.35 kg soil each, and the soils were subjected to water wetting treatments for 20 days. On day 20, all soil treatments were brought up to 50% of WHC and pre-germinated seeds of wheat were transplanted. No inorganic fertilizers were applied to wheat. Soil samples were collected at 5, 10, 15, 20 and 45 days after water treatment (DAWT) and were analysed for inorganic nitrogen (IN), percent ammonium nitrogen (% NH_4-N) of the inorganic N and the available phosphorus (AP). Water treatments' effects were significant with higher values found under 10D and 15 D water treatments. The KK treatment resulted in better plant growth, higher nutrient uptake and an increase in the soil IN and AP while the lowest in the FB soil. This study highlights the short-term detrimental effects of residues with relatively high C:N ratio and nutrient immobilization could present a real challenge to crop growth in the short term in such soils. © 2020 Friends Science Publishers

Keywords: C:N ratio; Nutrients release; Water holding capacity; Wet/dry cycles

Introduction

Soil water is essential in successful crop growth and production due to its role in maintaining cell turgidity, opening and closing of stomata, temperature regulation, thermal conductivity, nutrient cycling, mineralization, diffusion and availability of soil nutrients to crops. Australia has uneven rainfall distribution, mostly concentrated in winter with the occurrence of long spells of hot and dry weather, which is imposing stresses on plants (Livesley *et al.* 2004). In such conditions water availability for successful crops production becomes more important as many of the agricultural lands are located in arid to semi-arid region. The drying/wetting influence on the soil microbiology and nutrients release has been extensively studied. Drying and rewetting may result in significant lysis of microbial biomass and may affect microbial composition directly or indirectly. Alterations in bacterial community composition induced by drying-rewetting may be the reason of the variations in C mineralization rates (Fierer *et al.* 2003). Drying and wetting cycles affect the chemical properties of soil (Williams and Xia 2009), enhances rates of CO_2 production which may persist for more than 15 days after wetting (Beare *et al.* 2009) and this response of mineralization to wetting cycles varies greatly among various studies (Butterly *et al.* 2010). Soil organic matter contents and texture are important factors affecting biogenic gas production (CO_2 and N_2O) during dry wet cycles (Kirk *et al.* 2013). Dry/wet events change the equilibrium of soil C and N transformations relative to the unstressed soil. Soil water contents determine microbial activity that plays major role in nutrients mineralization (Paul *et al.* 2003).

Legumes are rich natural source of plant nutrients and play an important role in improving soil physical health (aggregation) and sustaining natural ecosystem by supplying nutrients like P (Kabir and Koide 2002). Plant residues induced modifications in soil phosphorus pools and concentration of soil P varies with time, but there is still need to verify either these changes are soil induced or applicable in different scenarios (Alamgir *et al.* 2012). Plant residues vary regarding their nutrients composition and decomposition rate and the decomposition can also be affected by environmental factors such as moisture and temperature. Much work has been done on nitrogen mineralization and residue quality but research efforts on P availability during decomposition process are few. Plant residue addition may start mobilization of P depending on C:N ratio of the added residues and most of the time, the dividing line between immobilization and mineralization is 20:1. P contents of organic residues affect decomposition and residues with high P contents decompose more rapidly (Achat *et al.* 2012) because higher P contents enhance microbial activities due to easy fulfilment of their nutrient requirements.

Legumes are much better in N and P uptake from the soil and are therefore rich sources of these nutrients due to which decomposition rates of these residues are higher compared to cereal residues (Nuruzzaman *et al.* 2005). Under existing water availability conditions, climate predictions are indicating very severe droughts in most arid and semi-arid parts of world (Iglesias *et al.* 2007). Water scarcity is expected to impose severe limitations on microbial processes, mineralization and C and N dynamics (Schimel *et al.* 2007). Drought was shown to cause higher microbial C:N ratio indicating a shift towards more fungal dominated microbial community capable of decomposing more complex compounds (Jensen *et al.* 2003). It is projected that future climate change will impose more pressure on poor nutrient ecosystems. An increase in seasonal variations and precipitation patterns may largely affect the microbial activity and nutrients immobilization (Buckeridge *et al.* 2013) and thus will affect the nutrients availability to plants (Michelsen *et al.* 1999). Under such a scenario, microbial nutrient mobilization becomes crucial in nutrient-deficient systems (Bargaz *et al.* 2018). The availability of phosphorus is much more complex and tricky as more than 80% of applied fertilizer is immediately fixed by iron and/or aluminium in acidic soils and by calcium in calcareous soils. Phosphatic fertilizers are manufactured using rock phosphate and its reserves are decreasing. Therefore, any management system that plays a role in mobilization of phosphorus and other nutrients in the soil after residue decomposition, will help towards sustainability in arid and semi-arid cropping systems. The objectives of this study were to:

i. determine the role of alternate wetting and drying in nutrients mobilization as a function of residue addition and soil water condition.

ii. evaluate the effect of residue addition on nutrients availability and wheat growth without addition of chemical fertilizers.

Materials and Methods

Soil preparation

Experimental soil was collected in Spring from 0–0.1 m depth from Urrbrae permanent pasture (longitude 138˚38'3.2" E Latitude 34˚58'02" S) South Australia. This site is situated in semi-arid region, with Mediterranean climate, wet and cold winter; and hot and dry summer with scattered rainfall. The soil used for this experiment was a silt loam (8% sand, 70% silt, and 22% clay) according to FAO classification (FAO 2001). The soil had maximum water holding capacity (WHC) of 0.34 kg kg^{-1}, pH (1:5) of 5.6; EC (1:5) of 0.1 dS m^{-1}; total organic carbon of 31 g kg^{-1}; total organic nitrogen of 1500 mg kg^{-1}; and a bulk density of 1.3 Mg m^{-3}.

Experiment set up

Soil was air dried and sieved by passing through a 2 mm sieve. In the first study phase, soil was pre-incubated for 10 days at 50% of water holding capacity (WHC) at room temperature for microbial activity activation. The soil water maintained by weighing the pots daily and adding back the corresponding amounts of water lost to evaporation. Residue hereafter referred to as amendment were air-dried, ground and passed through a 2 mm sieve to remove very fine fractions. Two amendment treatments applied were dried kikuyu grass (*Pennisetum clandestinum* L.*)* residue (C 38.1%, N 1.9%, P 0.42%, C:N 20.1 and C:P 90.7) and dried faba bean (*Vicia faba*) residue (C 40.9%, N 0.68%, P 0.074%, C:N 60.2 and C:P 552.7), and the third treatment was the control (CO), with no amendment applied. 0.35 kg soil was filled in each plastic pot having 0.5 kg capacity and amendments were uniformly mixed with the soil at a rate of 1% on weight basis (10 g amendment in 1 kg of soil).

Different soil water treatments applied were 20 days moist (20 M), 5 days moist followed by 15 days dry (15 D), 10 days moist followed by 10 days dry (10 D) and 20 days dry (20 D). All the water treatments were maintained at 50% of the WHC. The pots were maintained at target WHC by weighing and adding water daily. The unamended control was maintained at 50% of WHC throughout the study period. All pots were incubated for 20 days at mean room temperature of 20 degrees.

In the 2^{nd} phase of the study, which was 21 days after water and amendment treatments applications, all pots were again brought to 50% of WHC. Seeds of wheat (*Triticum aestivum* L.) were pre-soaked, and eight pre-germinated seeds were sown in each pot and thinned after establishment to maintain four plants per pot. No inorganic fertilizers were applied to wheat. Wheat plants were harvested 25 days after planting (DAP). During the whole wheat growth period, soil was kept at 50% of WHC. The timeline sequence for this experiment can be summarized as follows: i.) initial 10 days of wetting the soil and maintaining the soil water at 50% of

WHC in pots used for this experiment, ii) 20 days of application of water treatments in the pots, after soil amendment application and iii) 25 days of growing wheat as an index crop in the pots. This gave a total of 55 days for this experiment.

Plant measurements and analysis

Measurements taken from each pot during plant harvest at 25 DAP included the root and shoot biomass. The above ground biomass was carefully cut at the ground and weighed. After the shoot biomass was harvested, the soil inside of the pot was broken up to isolate the roots, and the roots were carefully washed under water and weighed. Harvested wheat biomass were dried and analysed for total N, P, N/pot and P/pot. Nitrogen was determined using Kjeldhal method for the tissue digestion, after which N was determined using a colorimetric procedure (Bradstreet, 1965). Phosphorus was determined by digesting the tissues samples with nitric acid and H_2O_2 (1:4), after which the quantitative amount of P was determined by colorimetric procedure (Hanson 1950).

Soil analysis

Soil samples were collected from pots using small cores at 5, 10, 15, 20 and 45 days after water treatment (DAWT) and were preserved in cold storage to minimize chemical changes. Soil samples were analysed for inorganic nitrogen (IN), % ammonium of inorganic nitrogen (%NH_4^+-N), available P (AP) at 5, 10, 15, 20 and 45 DAWT. It is worth noting that four of the samples taken at 5, 10, 15 and 20 DAWT were before the wheat plants were planted into the pots while the last measurement (45 DAWT) took place at the harvest of wheat plants. Soil NH_4-N were determined by using method described by Cavagnaro *et al.* (2006), modification of Miranda *et al.* (2001) and Willis *et al.* (1996). Soil P was determined from extract collected using anion-exchange resin membranes (Kouno *et al.* 1995) and P determination was done calorimetrically (Murphy and Riley 1962).

Statistical analysis

Statistical analysis was performed on the measurements using the ANOVA procedure in GenStat 15th edition (Payne 2008). Mean separation was performed using Turkey test ($P \leq 0.05$) after a significant F-ratio.

Results

Soil and water release characteristics

Soil used was a silt loam, with relatively high water holding capacity. As expected, the soil water was depleted as the soil dried down over 20 DAWT (Fig. 1). Generally, the water dropped from about 50% of WHC to under 15% of WHC over a period of 20 days. At 20 DAWT, the KK amendment (11.7% of WHC) and the control treatment (10.9% of WHC) had a slightly higher percentage of WHC than the FB residue amendment (8.5% of WHC) [Fig. 1].

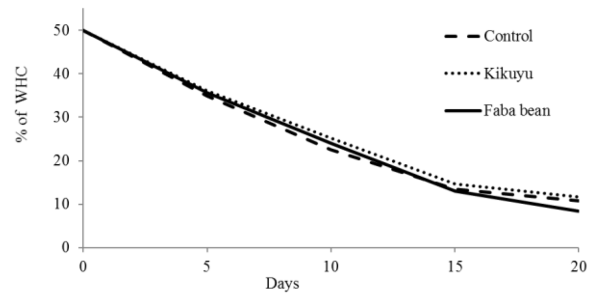

Fig. 1: Percentage of water holding capacity as a function of time in the control soil without amendment, soil amended with kikuyu grass residue and soil amended with faba bean residue

Soil inorganic nitrogen

Table 1 presents the average of the soil inorganic nitrogen (IN) across different moisture treatments. The soil IN decreased over time with maximum values observed at 5 DAWT and the minimum values at 45 DAWT (Table 1). At 5 and 10 DAWT, soil water effect was not significant, while its effect was significant at 15, 20 and 45 DAWT (Table 1). Highest IN was found in soil water treatment of 15D at 15 DAWT, while at 20 and 45 DAWT, highest IN was observed in 10D soil water treatment. IN was in sufficient range in 15 D at 15 DAWT while was deficient in 10 D at 20 and 45 DAWT. Amendments affected soil IN significantly throughout the incubation period, with the highest values found in KK amended soils, followed by CO, while the least values were observed in FB amended soils. Across all amendments, the highest value of IN was found at 5 DAWT, which generally decreased with time (Table 1). The interactive effects of soil water and amendments were also significant at 10, 15 and 20 DAWT, with the highest values found in KK × 15D at 15 DAWT, while lowest was found in FB × 10D at 20 DAWT (Fig. 2).

NH_4^+-N (% of inorganic nitrogen)

%NH_4^+-N was significantly affected by different amendments and soil water treatments throughout the period of crop growth (Table 2). %NH_4^+-N contents was highest at 15 DAWT across all soil water treatments, while 20 M had the lowest %NH_4^+-N contents during the incubation period compared to other soil water treatments (Table 2). Initially higher values of %NH_4^+-N contents were found in KK treatment, followed by FB, and the least in CO treatment (Table 2). For the KK treatment, there was a reduction from 5 to 45 DAWT in %NH_4^+-N contents while an increase in %NH_4^+-N contents for FB was observed with the highest at

Table 1: Inorganic Nitrogen (N) of soil in unamended soil (CO) and soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 10 days moist+10 days dry (10 D), 5 days moist+15 days dry (15 D), 20 days dry (10 D) (n=4)

	Inorganic N (mg kg^{-1})				
Water	5 DAWT*	10 DAWT	15 DAWT	20 DAWT	45 DAWT
20M	48.7	35.38	42.71 b	21.4 b	17.69 a
10D	45.2	32.83	39.54 c	26.65 a	17.89 a
15D	48.5	36.06	45.25 a	21.78 b	16.69 a
20D	44.4	33.91	38.76 c	22.34 b	13.94 b
Amendment					
CO	50.3 b	34.3 b	46.54 b	19.72 b	6.76 b
KK	84 a	64.52 a	72.04 a	46.9 a	38.86 a
FB	5.8 c	4.82 c	6.12 c	2.51 c	4.05 c
Water	ns	ns	**	**	**
Amendment	**	**	**	**	*
Water x Amendment	ns	**	**	**	ns

*DAWT – Days after water treatment

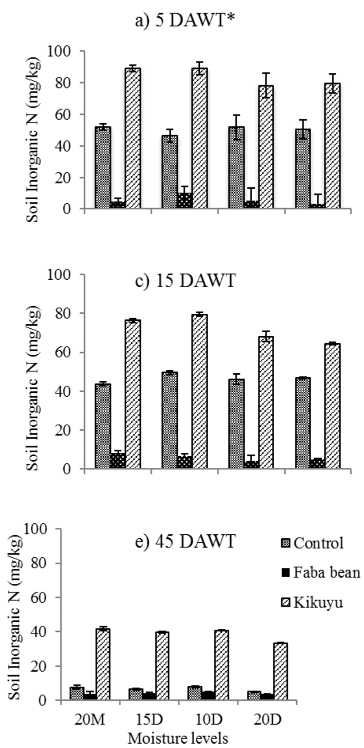

Fig. 2: Inorganic nitrogen of soil in the unamended soil (CO) and the soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 5 days moist + 15 days dry (15D), 10 days moist + 10 days dry (10 D), 20 days dry (20 D) (n=4). *DAWT – Days after water treatment

45 DAWT (Table 2). This may be indicative of less microbial activity that could oxidize NH_4-N to NO_3-N in FB treatment due to a higher C:N ratio. The interactive effects of soil water and amendments were significant, as the highest %NH_4^+-N contents were found in FB at 15 D x 45 DAWT and least in CO at 15 D x 20 DAWT (Fig. 3).

Soil available P (AP)

Overall highest AP was observed in 20 D treatment at 15 DAWT which was 35% higher than at the same level of moisture at 5 DAWT and 59% higher than at 45 DAWT (Table 3). Soil water effect on AP was significant at 5, 15, 20 and 45 DAWT. AP levels were higher at 15 D, 20 D, 10 D at 5, 10, 15, 20 and 45 DAWT respectively. On the other hand, lower AP levels were observed in 10 D and 20 M at 5, 10, 15, 20 and 45 DAWT (Table 3).

In amended soil the AP contents on 5, 15 and 20 DAWT were highest with KK residues, and lowest with FB residue. Addition of FB residue did not increase the soil AP

Table 2: Precent ammonium of inorganic N of soil in unamended soil (CO) and soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20M), 10 days moist + 10 days dry (10 D), 5 days moist + 15 days dry (15 D), 20 days dry (10 D) (n=4)

	NH_4-N (% of Inorganic N)				
Water	5 DAWT*	10 DAWT	15 DAWT	20 DAWT	45 DAWT
20M	33.2 b	29.69 c	41.18 c	15.1 b	42.9 b
10D	33.9 b	35.78 c	56.18 a	40.8 a	46.9 ab
15D	46.8 a	38.42 ab	47.97 b	23.3 b	45.5 b
20D	38.7 b	42.61 a	58.44 a	48.2 a	51.4 a
Amendment					
CO	6.7 c	5.34 c	27.7 c	8.1 c	40.2 b
KK	58.7 a	60.49 a	51.96 b	48.5 a	19.7 c
FB	49.1 b	44.04 b	73.17 a	39 b	80.2 a
Water	**	**	**	**	**
Amendment	**	**	**	**	*
Water x Amendment	*	**	**	*	*

*DAWT – Days after water treatment

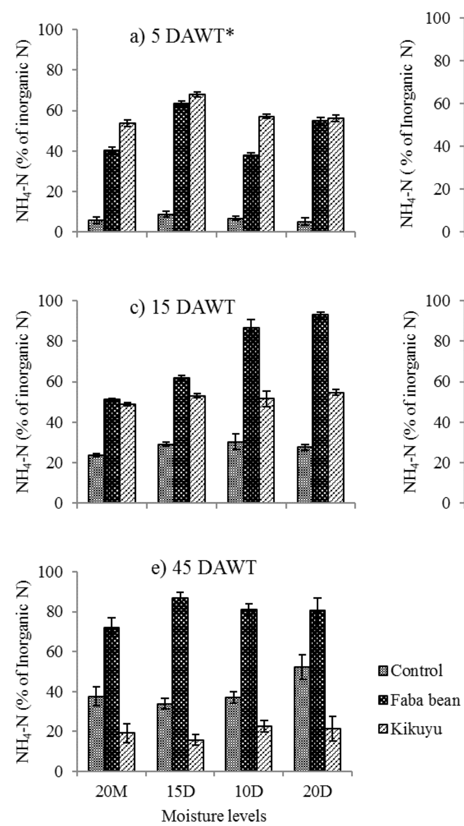

Fig. 3: Ammonium nitrogen in the unamended soil (CO) and the soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 5 days moist + 15 days dry (15 D), 10 days moist + 10 days dry (10 D), 20 days dry (20 D) (n=4). *DAWT – Days after water treatment

contents as compared to that of CO. Higher values of soil AP were found at 15 DAWT which gradually reduced up to 45 DAWT (Table 3). KK residue amendment increased soil AP contents from 5 to 20 DAWT, while there was reduction from 20 to 45 DAWT, which might be due to P uptake by wheat plants. Regarding interactive effects of soil water and amendments, the highest values of soil AP were found in KK15D and KK10D at 5, 10, 45 DAWT and 15, 20 DAWT respectively (Fig. 4). All the AP values observed for soil water, amendments and their interaction effects were in deficient range.

Wheat growth and development

There was no significant increase in shoot weight at different soil water levels, while residue amendment

Table 3: Soil available Phosphorus in unamended soil (CO) and soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 10 days moist+10 days dry (10 D), 5 days moist+15 days dry (15 D), 20 days dry (10 D) (n=4)

	Soil Available Phosphorus (mg kg^{-1})				
Water	5 DAWT*	10 DAWT	15 DAWT	20 DAWT	45 DAWT
20M	3.38 b	3.25	3.47 b	3.74 b	3.13 ab
10D	3.34 b	3.25	4.27 a	4.29 a	2.94 c
15D	3.65 b	3.24	3.67 b	3.83 b	3.27 a
20D	3.40 b	3.33	4.57 a	3.84 b	2.98 bc
Amendment					
CO	3.39 b	3.27b	3.83b	3.75 b	2.86 b
KK	5.28 a	5.12 a	6.08 a	6.13 a	4.58 a
FB	1.66 c	1.42 c	2.08 c	1.89 c	1.80 c
Water	*	ns	**	**	*
Amendment	**	**	**	**	**
Water x Amendment	*	ns	ns	ns	ns

*DAWT – Days after water treatment

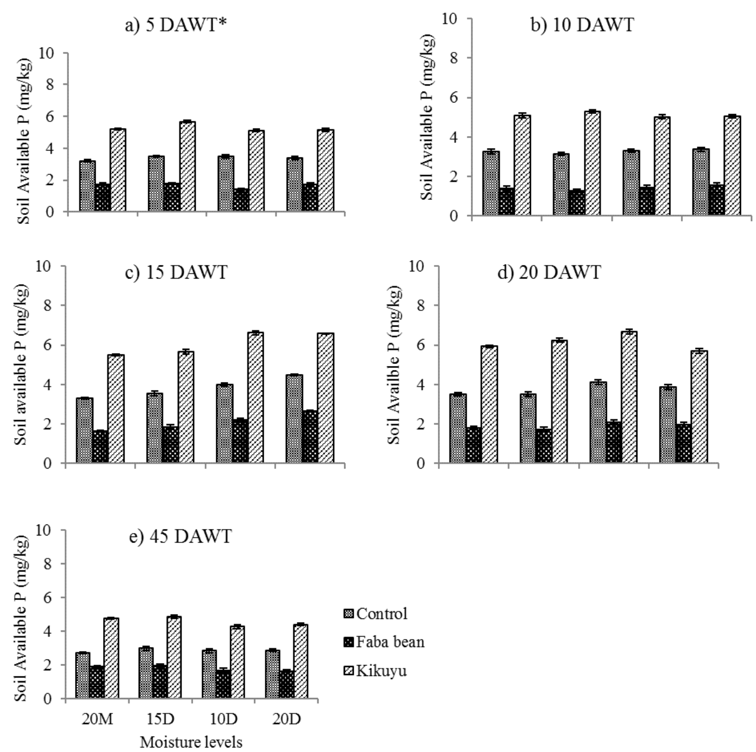

Fig. 4: Soil available phosphorus in the unamended soil (CO) and the soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 5 days moist + 15 days dry (15 D), 10 days moist + 10 days dry (10 D), 20 days dry (10 D) (n=4). *DAWT – Days after water treatment

resulted in significant differences in shoot weight (Table 4). Amendment with KK increased shoot weight by 23% compared to the control, while amendment with FB decreased shoot weight by 275% compared to CO. Higher root biomass was found in 20 D and least in 20 M, which may be reflecting a negative effect of moisture on root growth and development due to reduced soil oxygen. Soil amendment had significant effect on root weight, with the unamended soil having higher root weight than the amended soils (Fig. 5).

Plant total biomass was significantly affected by soil water levels with the total biomass of 20 D being the highest, while there was no significant difference between the total biomass at 15 D, 10 D and 20 M (Table 4). KK treatment increased biomass by about 4% compared to the CO and by 123% compared to the FB treatment, indicating a negative effect of FB residue addition on biomass yield.

Root/shoot ratio was the highest at 20 M and the lowest in 20 D, but effect was not statistically significant. Addition of residue amendment significantly increased the

Table 4: Shoot, root and total plant dry weight per pot and shoot/root ratio of wheat in unamended soil (CO) and soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 10 days moist+10 days dry (10 D), 5 days moist+15 days dry (15 D), 20 days dry (10 D) (n=4)

	Shoot	Root	Total Biomass	Shoot/Root
	(grams dry weight per pot)			
Water				
20M	0.25	0.12a	0.37a	2.07
10D	0.24	0.13ab	0.37a	1.85
15D	0.254	0.15ab	0.40ab	1.83
20D	0.26	0.16b	0.42b	1.71
Amendment				
CO	0.30b	0.16b	0.46b	1.93b
KK	0.37c	0.12a	0.49b	2.98c
FB	0.08a	0.13a	0.22a	0.68a
Water	ns	*	*	ns
Amendment	**	**	**	**
Water x Amendment	ns	ns	ns	ns

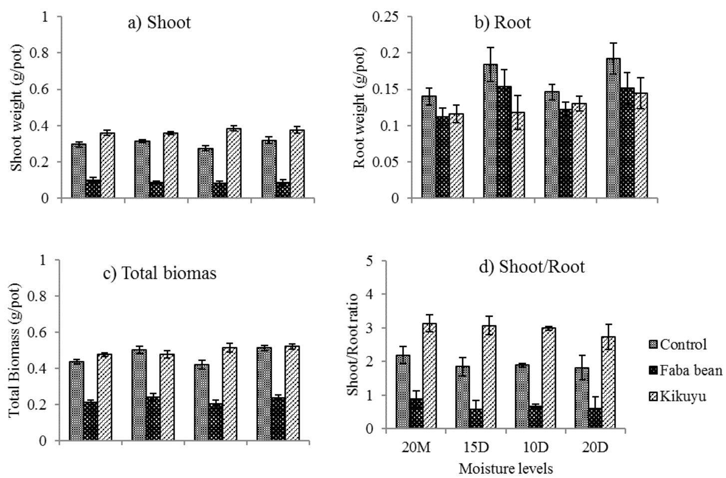

Fig. 5: Wheat shoot, root and total plant dry weight per pot and shoot/root ratio in the unamended soil (CO) and the soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 5 days moist + 15 days dry (15 D), 10 days moist + 10 days dry (10 D), 20 days dry (10 D) (n=4)

shoot/root ratio, with KK treatment having 53% higher ratio than the CO, while the FB treatment resulted in lowering of shoot/root ratio by 217% compared to the CO. The interaction effect between moisture levels and amendments was not statistically significant for the all plant growth parameters measured (Table 4).

Nutrient uptake by the crop

Soil water levels did not have significant effect on the N and P concentrations in the plant tissues, but the effect of the amendment was significant at 1% level. Interaction effects of soil water and amendment were not significant. Generally, the KK treatment had the highest tissue N and P followed by the CO, while the FB treatment had the lowest N and P concentrations (Table 5).

Discussion

This study showed that nutrient mineralization was influenced by the type of residue amendment and to some extent by the length of time that these amendments were in the soil and treated to different soil water levels. The response to amendment was well pronounced and dominant, while soil water level effects were less significant in comparison to the amendment effects.

Residues were amended under four soil water levels. At the very first day all the samples were at the same water level and after that, there was gradual reduction in moisture contents with time. The rate of reduction of the soil water appeared to be similar under all amendments up till day 5 before curve for each amendments started separating (Fig. 1).

Soil water levels at 45 DAWT affected soil IN significantly with the highest amount found in 15 D and lowest in 20 D. It is generally observed that after rewetting of soil N mineralization occurs in short-term and rate is often higher than that of the moist control (Borken and Matzner 2008). Plant growth can be affected not only by drying/wetting events but by the moist period also (Shi and

Table 4: Shoot, root and total plant dry weight per pot and shoot/root ratio of wheat in unamended soil (CO) and soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 10 days moist+10 days dry (10 D), 5 days moist+15 days dry (15 D), 20 days dry (10 D) (n=4)

	Shoot	Root	Total Biomass	Shoot/Root
		(grams dry weight per pot)		
Water				
20M	0.25	0.12a	0.37a	2.07
10D	0.24	0.13ab	0.37a	1.85
15D	0.254	0.15ab	0.40ab	1.83
20D	0.26	0.16b	0.42b	1.71
Amendment				
CO	0.30b	0.16b	0.46b	1.93b
KK	0.37c	0.12a	0.49b	2.98c
FB	0.08a	0.13a	0.22a	0.68a
Water	ns	*	*	ns
Amendment	**	**	**	**
Water x Amendment	ns	ns	ns	ns

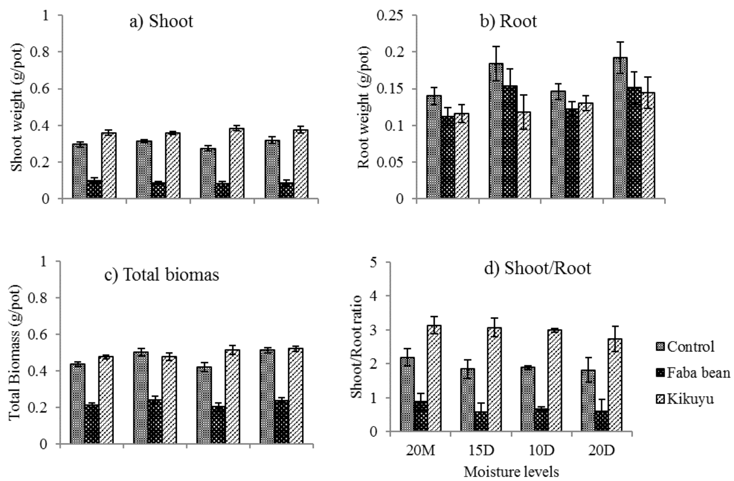

Fig. 5: Wheat shoot, root and total plant dry weight per pot and shoot/root ratio in the unamended soil (CO) and the soil amended with kikuyu (KK) or faba bean (FB) residues incubated at four soil water treatments before planting: 20 days moist (20 M), 5 days moist + 15 days dry (15 D), 10 days moist + 10 days dry (10 D), 20 days dry (10 D) (n=4)

Table 5: Tissue nitrogen and phosphorus contents in soil amended with kikuyu (KK) and faba bean (FB) residues compared with the control (CO) unamended soil

Treatments	N g/kg	P g/kg
Water*		
20M	30.42	4.18
10D	31.43	4.16
15D	28.77	3.94
20D	27.92	4.23
Amendment		
CO	30.17b	4.39b
KK	40.04c	5.10c
FB	18.7a	2.89a
Water	ns	ns
Amendment	**	**
Water x Amendment	ns	ns

*Soil incubated at four soil water treatments before planting: 20 days moist (20 M), 10 days moist+10 days dry (10 D), 5 days moist+15 days dry (15 D), 20 days dry (10 D)

Marschner 2014). In general, the highest IN value was found in 10D treatment at 5 DAWT. However, there was gradual reduction in IN content with time, possibly due to microbial activities utilizing the nitrogen for metabolism and also due to uptake by the wheat plants growing for almost for 25 days in the pots. The maximum uptake of IN was observed in treatments where the soil was kept dry for 20 days after initial wetting to field capacity. This repeated wetting/drying resulted in more availability and mobilization of IN and the highest level observed at 15 and 20 DAWT compared with all other intervals of moisture treatments.

Effect of amendments as a function of moisture level treatment was pronounced on IN, with the highest value observed in KK and lowest in FB at 5 and 45 DAWT. This might be due to more mineralization in the KK treatment with lower C:N ratio (20:1), which facilitated a more rapid microbial decomposition compared to FB treatment with medium C:N (60:1) ratio, with a more resistant residue to decomposition. Lower IN in FB treatment compared with the control may be due to the immobilization of the IN due to resistant insufficient nitrogen FB residue. In addition, poor wheat growth observed in FB treatment compared to the CO treatment may have been due to the immobilization of IN due to microbial decomposition of FB residue. Previous studies have indicated that residues having narrow C:N ratio decompose easily and can result in nutrient mineralization and with wide C:N ratio result in immobilization (Hadas *et al.* 2004). The gradual reduction of IN with time starting from 5 to 45 DAWT may be due to combined effect of microbial immobilization and crop uptake. Microbial immobilization would likely be stronger at the initial phase of crop growth while crop uptake would become more pronounced as the crop nutrient requirement increases with growth and development.

Opposite trend was almost observed regarding $\%NH_4^+$-N as lower values were found during initial days, and gradually increasing with time. In general, higher $\%NH_4^+$-N were found under 20D treatment with the highest value at 15 DAWT. Higher $\%NH_4^+$-N observed in FB treatment compared to KK at 45 DAWT might be due to the fact that the IN content under low C:N ratio decreased with time, as the N pool gradually became exhausted over time (Kamkar *et al.* 2014).

Soil AP significantly varied during all intervals except at 10 DAWT. Drying/wetting might have resulted in the shattering of aggregates due to increase in internal pressure upon rewetting (Borken and Matzner 2008) resulting in higher P availability (Blackwell *et al.* 2013). Soil AP contents increased with time, probably be due to P release from crop residues, and the highest values were observed at 20 DAWT in 10 D treatment. After crop establishment in the pots, there was significant reduction in soil AP contents, possibly due to crop uptake. Maximum soil AP contents were found in KK amended soil at 20 DAWT showing a good release of phosphorus due to low C:N ratio. Lowest soil AP contents were found in FB amended soils possibly due immobilization of phosphorus (Braschi *et al.* 2003).

Plant shoot growth was not significantly affected by soil water treatments. However, plant root growth was significantly affected by soil water treatments. With the root growth occurring in the order 20 D >15 D > 10 D > 20 M, there was an indication that root growth decreased with increasing number of moist days of incubation after amendment application, because exposure to drying resulted in increased nutrients release from residue and thus availability to crops. This might have led to root proliferation resulting in more aggressive root growth in 20 D treatment. Plant total biomass was significantly affected by soil water and soil amendments. Highest plant total biomass observed in 20 D and the least in 20 M, clearly indicated positive effects of wetting and drying cycles on nutrients mineralization and thus availability to crops resulting in higher total biomass (Ouyang and Li 2013). Enhanced P uptake by plant after drying and wetting cycles in a bioassay with different preceding moisture regimes during plant growth was reported by Bunemann *et al.* (2013).

Amendment application also affected total biomass significantly, with the highest total biomass found in KK amendment followed by CO and least biomass was under FB amendment. This might be due to the higher nutrient mineralization from KK as evident from soil IN and AP results.

Soil water treatments effect was not significant for shoot/root ratio, it was significant for the soil amendment effect. KK increased this ratio by about 4.4 times compared to FB and by about 1.5 times than that of the CO. This showed the higher nutrient mineralization due to low C:N ratio of KK amendment increased microbial activities, ultimately leading to a better crop growth. Similar to observations in this study, higher wheat yields were observed in soil amended with plant residue having low C:N ratio (Bunemann *et al.* 2013). Nitrogen mineralization depends upon C:N ratio of added residues and residues with narrow C:N ratio (high N content) enhance soil microbial activities leading to increased mineralization during decomposition (Singh and Kumar 2007; Mohanty *et al.* 2013).

Soil water levels effect was not significant on tissue N content while the amendment effect was significant, with the highest nitrogen uptake observed for KK treatment, followed by the CO, and the lowest tissue N was found in FB treatment. The results indicated that KK amendment was releasing more nitrogen into the soil through mineralization thus promoting a better crop growth and higher tissue N. Similar findings were observed by Soon and Arshad (2002). The addition of narrow C:N ratio residue results in mineralization and ultimately N release while wider C:N ratio results in immobilization and reduced nutrient release into the soil (Singh and Kumar 2007).

Similar to the tissue N, the tissue P was not significantly affected by soil water treatments, however, it was significantly affected by the amendments. Highest tissue P was found in KK treatment compared with the other treatments and lowest tissue P was found in FB treatment. The tissue P result showed that higher P mineralization probably occurred in the KK amended soil, resulting in a better P release into the soil and higher P uptake by the wheat plants (Venterink *et al.* 2002).

Conclusion

Organic amendments stimulated nutrients mobilization and uptake by the wheat crop and thus improved crop growth. KK residue addition significantly increased soil IN, $\%NH_4^+$-N, AP and wheat growth and FB caused immobilization due to wider C:N ratio resulted in poor crop growth. Microbes also add nutrients in the soil at their turnover. After 20 days, there was reduction in nutrients status in soil probably due to up taken by the crop. Incubation has shown positive effects of soil wetting/droning and residue amendments in enhancing the availability of nutrients to crops uptake, but its effect was non-significant in most of the cases.

Acknowledgements

Special thanks to the Australian Government for providing funds under the Endeavour Research Fellowship Award for this study. Support and facilities provided by the School of Agriculture, Food and Wine, The University of Adelaide, SA, Australia are highly appreciated.

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