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Analyzing the impact of different dryland cropping histories in Southern NSW Australia on mycorrhizal colonization and biomass of upland cereal and legume crops in glasshouse

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Abstract. This study aimed to examine the impacts of different cropping sequences of dryland crops in southern NSW Australia on root colonization levels by the native arbuscular mycorrhizal fungi (AMF) of the soil and biomass weight of some upland cereal and legume crops (sorghum, oats, soybean, and sub-clover) grown on the soil samples in the glasshouse of the University of Western Sydney. The field soil samples were taken from southern NSW areas having different histories of dryland cropping, namely pasture only (PO), pasture-canola-wheat (PCW), and pasture-wheat (PW). For each category of cropping history, there were two sites sampled, each with two bulk field replicates. Each replicate of field soil sample was also analyzed for its content of nutrients and AMF spores and colonization levels of the field crop roots. The results indicated that there were no significant different in soil properties between categories of cropping history, except for Mg and Na contents, which were highest in PO than in PCW and PW soil. There were positive significant correlation between field root colonization and sub-clover colonization and soybean biomass, between total spores and colonization of sorghum and sub-clover, between available P and biomass of sorghum, sub-clover and oats, between Mg or Na and sorghum colonization, between Ca and oats biomass, and negative correlation between Mg and sorghum biomass. However, there were significant interaction between cropping history and several soil properties, indicating significant impacts of cropping history on the relationship between soil properties or AMF colonization and biomass of the glasshouse crops.

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1. INTRODUCTION

Many researchers have reported that types of previous crops have significant effects on growth and yield of the subsequent crops. Arihara and Karasawa (2000) reported that grain yield of succeeding maize was much higher when following mycorrhizal crops (such as sunflower, maize, soybean, potato or wheat) than following non-mycorrhizal crops (such as rape and cabbage), especially after two years of the cropping sequences. However, when following rape or cabbage, grain yield of the succeeding maize can be significantly improved by increasing dose of P fertilizer. Further research results reported by Karasawa et al. (2001) indicated that growth of succeeding maize plants was more determined by levels of roots colonization by arbuscular mycorrhizal fungi (AMF) on the preceding sunflower plants instead of by soil properties. In addition, Grant et al. (2009) also reported that flax growth, P accumulation, and seed yield were significantly greater when flax was seeded following wheat, a mycorrhizal crop, than following canola, a non-mycorrhizal crop. These all indicate the positive effects of good development of arbuscular mycorrhiza in the preceding mycorrhizal crops on growth and yield of the succeeding mycorrhizal crops, such as soybean and sorghum, which can have percentage length of roots colonized by AMF more than 60% (Thompson, 1991). With certain species of AMF such as *Glomus intraradices*, soybean can have root colonization up to 87% with mycorrhizal dependency up to 94%, while maize can have mycorrhizal dependency up to 81% (Tawaraya, 2003).

Types of previous land uses can also have significant impacts on growth and yield of the succeeding crops especially for mycorrhizal crop, such as those reported by Thompson (1987), who found that total root length colonized by AMF and plant dry weight were significantly lower in various crops, such as sorghum, sunflower, soybean, wheat and maize, grown on the soil after long fallow (>12 months) than after short fallow in Queensland, Australia. Plant P content (%) also significantly lower in those crops grown after long fallow than after short fallow although there were no significant differences in available P of between two types of the soil. In addition, sunflower plants showed P-deficiency symptom when grown on long fallow soil, but this symptom was not found in sunflower plants grown in long fallow soil inoculated with 20% cropped soil or fertilized with P-fertilizer (Thompson, 1987). Pre-cropping with winter wheat and a perennial weed dandelion before growing maize was found to significantly increase AMF inoculum potential and increased levels of AMF colonization of maize roots, P content and dry weight of maize shoots compared with maize plants grown following fallow without pre-cropping with winter wheat or dandelion. However, root colonization level, plant P content and dry weight of maize were significantly higher when grown following dandelion than following winter wheat (Kabir & Koide, 2000).

Ellis (1998) reported that post flood syndrome had the same detrimental effect on plant growth as long fallow disorder reported by Thompson (1987), with the main problem of P deficiency symptom of plants growing on soil following flooded condition. According to Ellis (1998), this post flood syndrome, resulted in P-deficiency in plants grown after flooded condition, was associated with depletion of AMF population by flooding, and starter P fertilization with 80 lb P per acre resulted in plants with no P-deficiency symptom. Ilag et al. (1987) also reported significantly lower population of AMF infecting propagules following flooded rice-rice cropping pattern than following rice-corn-mungbean pattern. Wangiyana et al. (2006) also reported that AMF colonization was very poor in flooded rice but it was much higher in upland rice or in non-rice crops at the same sampling period of the same soil type. AMF colonization in “Gora” rice (upland growing condition during vegetative growth stages) was also much higher than in flooded rice (Wangiyana et al., 2016). In contrast, no AMF colonization was found flooded rice roots in Riverina areas (Australia), but when the soil samples were used to grow upland crops in the glasshouse, high AMF colonization was found, especially in soybean roots (Wangiyana, 2004).

Yield of soybean was also significantly lower when direct seeded following flooded rice than following rice grown under aerobic irrigation system (Maemunah & Wangiyana, 2019), and intercropping red rice with peanut on raised beds under aerobic irrigation system resulted in the highest grain yield of soybean direct-seeded following rice-peanut intercropping compared with following aerobic rice and following conventional rice (Dulur et al., 2020). Yield of soybean on vertisol rice-land was also significantly higher when direct seeded following "SRI" rice (intermittent flooded and dry condition during vegetative growth stages), either with or without application of mycorrhiza bio-fertilizer in the nursery compared with following flooded rice, and application of mycorrhiza bio-fertilizer to the soybean plants at seeding was found to significantly increase grain yield of the soybean plants (Wangiyana et al., 2019). Application of mycorrhiza bio-fertilizer during the dry season also significantly increased grain yield of soybean direct-seeded following rice crop (Wangiyana & Farida, 2019). Other mycorrhizal crop, such as maize, was reported to produce significantly higher biomass weight and grain yield when it was grown following mycorrhizal crops such potato, soybean, maize and sunflower compared with following fallow or rape (Arihara & Karasawa, 2000). Higo et al. (2010) also reported that AMF inoculation or rotation with mycorrhizal crops will improve mycorrhizal condition and grain yield of succeeding maize. These all indicate the types of preceding crops and how they were managed on growth and yield of the succeeding mycorrhizal crops, such as soybean and maize.

This study aimed to examine the impacts of different cropping sequences of dryland crops in southern NSW Australia on root colonization levels by the native arbuscular mycorrhizal fungi (AMF) of the soil and biomass weight of some upland cereal and legume crops (sorghum, oats, soybean, and sub-clover) grown on the soil samples in the glasshouse.

2. MATERIALS AND METHODS

Research results reported here are parts of a series of research projects reported in a Ph.D. thesis (Wangiyana, 2004), but reanalyzed in a different way. A larger objective of the study was to quantify AMF population dynamics in different categories of cropping history in different types of land use in the southern areas of New South Wales (NSW), Australia, and its impacts on growth and biomass production of various crops in the glasshouse of the University of Western Sydney, Hawkesbury Campus. The field soil sampling was done in March 2001.

2.1. Field sampling design and sample handling

For this study, there were six sites sampled, which can be categorized into three categories of cropping histories, i.e. Pasture only (PO), Pasture-Canola-Wheat (PCW), and Pasture-Wheat (PW). In each category of cropping history, there were two sites (or paddocks) sampled, by taking samples of rhizosphere of crop available in the field, from four points on the diagonals of a selected paddock (90 - 120 ha each). These four samples, each of which consisted of soil (2 x 20 cm x 20 cm x 15 cm volume) and roots of the field crops functioned as field replicates, which were bulked into two replicates of glasshouse soil, which were used to grow upland cereal and legume crops in the glasshouse of the University of Western Sydney, Hawkesbury Campus.

Before analyzing and using them for growing several crops in the glasshouse, those field soil samples were air-dried and sieved using test sieve having 2 mm opening size. Soil analyses were performed for each of the field replicates, by sending the air-dried field soil samples for analysis by Incitec Ltd, Queensland, Australia. For growing several crops (sorghum, oats, soybean and sub-clover) in the glasshouse, two field replicates were bulked into one glasshouse replicate.

2.2. Glasshouse experiment

For growing two cereals (sorghum and oats) and two legume crops (soybean and sub-clover) in the glasshouse, growing media were taken from the field soil samples as sources of AMF propagules and soil taken from pasture around the University of Western Sydney, Richmond campus, but this soil was autoclave sterilized before applied as the base layer of the growing media in pot. The entire procedures followed in growing those upland crops in the glasshouse are as explained in detail in Wangiyana (2004).

2.3. Observation variables and data analysis

The observation variables measured in this study were results of soil analysis of field soil samples and shoot oven dry weight and levels of AMF colonization in roots of the glasshouse crops. Field soil analysis included soil pH in CaCl2 (1:5 w/v); organic Carbon, using the Walkley-Black method; available P using the Colwell method; K, Na, Ca, Mg, number of AMF spores per 10 g air dried soil, and AMF colonization levels of field crop roots in the field soil samples, as described in Wangiyana (2004). After clearing and staining roots using modified staining method (Wangiyana, 2004), the percentage of root colonization was measured using gridline intersect method (Giovannetti and Mosse, 1980), under a stereo microscope having a magnification of up to 300x. AMF spores were extracted using a wet sieving and decanting technique based on Brundrett et al. (1996).

Data were reanalyzed with Analysis of Variance (ANOVA) using CoStat for Windows ver. 6.303, and correlation and multiple regression analysis using Minitab for Windows Rel. 13. To find the impact of categories of cropping history on the relationship between variables, data analysis was done using mixed categorical and continuous independent variables based on algorithms presented by Pedhazur (1997) and Kleinbaum et al. (1998), as shown in Wangiyana (2009) and explained in details in Wangiyana (2004), and based on those principles, the three categories of cropping history were assigned two dummy variables with dummy coefficients as listed in Table 1, and the general regression equation is Y = a + b1.Pcw + b2.Pw + b3.X.Pcw + b4.X.Pw + b5.X for the regression between Y and X variable and interaction between X variable and Pcw (X.Pcw) or between X variable and Pw (X.Pw).

Table 1. Dummy variables assigned to each category of cropping history

Dummy variables	Dummy coefficient for each category of cropping history		
	PO (pasture only)	PCW (pasture-canola-wheat)	PW (pasture-wheat)
Pcw	0	1	0
Pw	0	0	1

3. RESULTS AND DISCUSSION

The ANOVA results and comparison of means using 5% LSD, summarized in Table 2, showed that there were some significant differences between categories of cropping history but only in terms of Mg and Na contents of the field soil samples. The mean values of both Mg and Na contents were not significantly different between PCW and PW soil samples but these all significantly lower than that in PO soil sample. This could mean that changing the land use from pasture only to cropping with canola and wheat or with wheat significantly reduced Mg and Na contents of the soil. Other variables of soil properties also tended to be lower in PCW or in PW compared with in PO soil, such as total field AMF spores, levels of AMF colonization in sorghum roots, dry weight (biomass) of soybean, organic C, and Ca contents. In contrast, some soil properties tended to be higher in PCW or in PW compared with in PO soil samples, such as soil pH, available P and K contents, and sub-clover and oats dry weight.

Table 2. Mean values of each observation variable and ANOVA results for comparison between categories of cropping history

Observation variables	**Mean values for each cropping history**			**LSD[1)]**
	Pasture only (PO)	**Pasture-canola-wheat (PCW)**	**Pasture-wheat (PW)**	
Field root colonization (ArcFcol)	13.89 a	13.75 a	12.99 a	ns
Total field AMF spores (TotSp)	196.00 a	168.38 a	185.13 a	ns
Soybean colonization (ArcSB)	54.32 a	50.35 a	54.93 a	ns
Sorghum colonization (ArcSG)	37.21 a	27.29 a	25.80 a	ns
Subclover colonization (ArcSC)	19.16 a	14.96 a	24.75 a	ns
Oats colonization (ArcOT)	22.62 a	26.42 a	27.48 a	ns
Soybean shoot biomass (SB-dw, g)	7.33 a	7.30 a	6.79 a	ns
Sorghum shoot biomass (SG-dw, g)	13.95 a	19.05 a	18.85 a	ns
Subclover shoot biomass (SC-dw, g)	16.81 a	21.40 a	17.70 a	ns
Oats shoot biomass (OT-dw, g)	15.91 a	16.67 a	16.99 a	ns
Soil pH (in CaCl2)	5.09 a	5.16 a	5.39 a	ns
Available (Av_P, Colwell- P, mg/kg)	33.88 a	46.13 a	46.13 a	ns
Organic C (%)	2.11 a	1.78 a	1.95 a	ns
K (meq/100 g)	1.33 a	1.75 a	1.46 a	ns
Ca (meq/100 g)	8.40 a	7.68 a	7.16 a	ns
Mg (meq/100 g)	5.39 a	2.92 b	2.62 b	2.10
Na (meq/100 g)	0.59 a	0.23 b	0.11 b	0.34

[1)] ns = non-significant for the ANOVA results; Arc = ArcSin transformation of percent data, such as in ArcFcol, ArcSB, ArcSG, ArcSC, and ArcOT

Although most soil properties did not significantly different between categories of cropping history, when correlation analysis among the observation variables was done, the results showed that some variables had a significant positive or negative correlation coefficient with other variables (Table 3). Some of them showed a high correlation coefficient with the highest R^2 = 60.2% in correlation between available P of the field soil and biomass of sorghum, with a p-value <0.01. Available P of the soil also had a significant positive correlation coefficient with sub-clover and oats dry weight. In contrast, AMF colonization levels in roots of sorghum in the glasshouse (ArcSG) had a negative correlation coefficient (r = -0.515) with p-value = 0.087, while ArcSG had a significant positive correlation with total AMF spore in the field soil samples. Due to the significant correlation with available P of the soil, it means that biomass production or dry weight of sorghum in the glasshouse was more determine by the high levels of available P content in the soil than by a high level of AMF colonization in its roots, which could also mean that dry weight of sorghum in the glasshouse was more dependent on available P content of the soil than on its root AMF colonization levels. This could be due to the relatively high content of available P in the soil samples taken from

PO, PCW and PW. However, under more categories of cropping history previously reported, based on results of a more complex regression analysis, it was found that the correlation between these variables was significantly negative in PO & PW, but it was significantly positive in soil with long rice cropping history (Wangiyana, 2004, 2009).

Table 3. Correlation coefficients and its p-value for the strength of relationship between variables

Variables	Coefficients of correlation and its p-value between variables									
	ArcFcol	**TotSp**	**ArcSB**	**ArcSG**	**ArcSC**	**ArcOT**	**SB-dw**	**SG-dw**	**SC-dw**	**OT-dw**
TotalSp	0.504									
p-value	0.095									
ArcSB	0.229	0.445								
p-value	0.473	0.148								
ArcSG	0.385	0.653	0.558							
p-value	0.217	**0.021**	0.059							
ArcSC	0.594	0.590	0.146	0.043						
p-value	**0.042**	**0.043**	0.650	0.895						
ArcOT	0.156	0.262	-0.504	-0.249	0.548					
p-value	0.629	0.410	0.095	0.435	0.065					
SB-dw	0.700	0.295	0.267	0.024	0.423	-0.190				
p-value	**0.011**	0.352	0.402	0.942	0.170	0.555				
SG-dw	0.161	-0.210	0.002	**-0.515**	0.235	0.258	0.140			
p-value	0.617	0.512	0.996	**0.087**	0.463	0.418	0.665			
SC-dw	0.442	0.013	0.022	-0.191	0.244	0.106	0.476	0.713		
p-value	0.150	0.968	0.945	0.553	0.444	0.742	0.118	0.009		
OT-dw	0.289	-0.022	0.203	-0.137	0.212	0.166	0.014	0.799	0.565	
p-value	0.362	0.945	0.528	0.670	0.508	0.606	0.966	0.002	0.055	
pH	-0.016	0.273	0.553	0.157	0.250	0.039	-0.203	0.512	0.367	0.669
p-value	0.960	0.391	0.062	0.626	0.433	0.904	0.527	0.089	0.241	**0.017**
Av_P	0.123	0.048	0.382	-0.096	0.165	-0.045	0.123	0.776	0.656	0.694
p-value	0.704	0.881	0.221	0.766	0.608	0.891	0.704	**0.003**	**0.021**	**0.012**
Ca	0.433	0.132	0.171	0.007	0.274	0.012	0.353	0.457	0.482	0.745
p-value	0.159	0.682	0.595	0.983	0.389	0.969	0.260	0.135	0.113	**0.005**
Mg	-0.091	0.388	0.253	0.771	-0.189	-0.166	-0.321	-0.747	-0.492	-0.345
p-value	0.778	0.213	0.428	**0.003**	0.557	0.605	0.308	**0.005**	0.104	0.272
Na	-0.267	0.166	0.377	0.591	-0.355	-0.426	-0.278	-0.495	-0.298	-0.132
p-value	0.402	0.607	0.228	**0.043**	0.257	0.168	0.381	0.102	0.347	0.682

In the case of the other cereal crop, i.e. oats, it can be seen from Table 3 that its dry weight (OT-dw) had a significant positive correlation with soil pH and available P (Av_P) but has no correlation with AMF colonization level in its roots (ArcOT) nor in the roots of field samples. In contrast, soybean dry weight (SB-dw) had a significant positive correlation with AMF colonization of field samples (ArcFcol) although both ArcFcol and SB-dw did not show a significant correlation with colonization level of soybean roots (ArcSB). However, the other legume crop, i.e. sub-clover, although its dry weight (SC-dw) did not show a significant correlation with its root colonization (ArcSC) or field root colonization (ArcFcol), ArcSC had a significant positive correlation with ArcFcol and total AMF spore (TotSp) of the field soil samples. In addition, AMF colonization levels in sorghum roots (ArcSG) had a significant positive correlation with Mg or Na content of the soil, while its shoot dry weight (SG-dw) had a significant negative correlation, which was similar to the relationship between ArcSG and SG-dw (Table 3).

The common findings, which have been accepted as the most common theory of the contribution of AMF to their host plants, are that higher AMF colonization levels in the roots generally result in higher crop growth, nutrient uptake and dry weight (Smith et al., 2003). The results reported by Treseder (2013) also showed that response ratio of plant biomass increased significantly as the difference in percent root length colonized by AMF increased. Astiko et al. (2019) also reported that higher percentage of AMF colonization of roots was highly associated with higher N and P uptake, and shoot biomass of maize in dryland areas.

However, since there were no significant differences in observation variables between categories of cropping history, except for Mg and Na contents of the soil, but some of the correlation coefficients between variables were significant, then to find out a meaningful pattern or relationship, multiple regression was done based on Pedhazur (1997) and Kleinbaum et al. (1998) using the dummy variables listed in Table 1, to find out if the relationships between variables are influenced by categories of cropping history. The results of the multiple regression analysis showing interaction effects between an observation variable and the categories of cropping history, i.e. showing a significant coefficient of Pcw.X or Pw.X, are listed in Table 4.

Table 4. Coefficients of a multiple regression Y= a+b1.Pcw+b2.Pw+b3.Pcw.X+b4.Pw.X+b5.X between X and Y variables that have a significant interaction term

X-variable	The coefficients of a, b1, b2, b3, b4 and b5 of the regression equation Y= a+b1.Pcw+b2.Pw+b3.Pcw.X+b4.Pw.X+b5.X						Y-variable
	a	Pcw	Pw	Pcw.X	Pw.X	X	
Av_P	15.4 ***	1.98 ns	-10.7 *	0.045 ns	0.239 *	0.042 ns	SC-dw
ArcFcol	5.66 **	-4.69 ns	-5.83 *	0.34 ns	0.416 *	0.12 ns	SB-dw
ArcFcol	15.6 **	1.79 ns	-13.7 *	0.204 ns	1.13 *	0.084 ns	SC-dw
pH	346 ns	-3386 *	-1012 ns	651 *	187 ns	-29.5 ns	TotSp
pH	95 ns	-156 ns	-273 *	29.7 ns	52.6 *	-14.9 ns	ArcSC
TotSp	-18.7 ns	29 *	27.2 *	-0.146 *	-0.142 *	0.166 *	ArcFcol
TotSp	-29.8 ns	44.2 *	15.3 ns	-0.246 *	-0.038 ns	0.25 *	ArcSC
Ca	-11.8 ns	90.4 *	24.7 ns	-12.5 *	-4.04 ns	5.84 ns	ArcSG
Ca	10.6 *	-5.27 ns	-16.6 *	0.646 ns	2.18 *	-0.387 ns	SB-dw
Ca	2.03 ns	6.4 *	10 *	-0.58 ns	-0.962 *	1.65 **	OT-dw
Mg	-0.59 ns	20.3 *	18.3 *	-4.11 *	-3.35 *	3.06 *	OT-dw
Na	34 ***	-1.94 ns	-16.8 **	-5.3 ns	111 **	-19.3 *	ArcOT
Na	9.82 *	14.1 **	10.2 *	-28.4 *	-17.2 ns	7.03 ns	SG-dw
Na	12.9 **	6.09 *	4.48 ns	-15.3 *	-8.5 ns	5.13 ns	OT-dw
ArcSB	19.933 *	-17.05 *	-39.28 **	0.32 *	0.71 **	-0.23 ns	SB-dw

Remarks: ns = non-significant; *, **, and *** = significant at p<0.05, p<0.01 and p<0.001 respectively

By running a multiple regression analysis with mixed categorical and continuous variables as the X-variable in relation to a Y-variable, it can be seen from Table 4 that several variables had a significant interaction with categories of cropping history in relation to a response variable. A significant interaction between an X variable and categories of cropping history means that those categories of cropping history had significant effect on the magnitude and/or direction of the relationships between the X and Y variables. In other words, the regression equation of the relationships could be different between categories of cropping history, and by running linear regression in each category of cropping history, the results are as listed in Table 5.

Table 5. Coefficients of simple regression of Y= a+b.X developed from the multiple regression in Table 4 between X and Y variables in each category of cropping history

X-variable	Regression coeffcients of a & b of Y=a+bX in each cropping history						Y-variable
	PO (Pcw=0; Pw=0)		PCW (Pcw=1; Pw=0)		PW (Pcw=0; Pw=1)		
	a	b	a	b	a	b	
Av_P	15.40	0.04	17.38	0.09	4.70	0.28	SC-dw
ArcFcol	5.66	0.12	0.97	0.46	-0.17	0.54	SB-dw
ArcFcol	15.60	0.08	17.39	0.29	1.90	1.21	SC-dw
pH	346.00	-29.50	-3040.00	621.50	-666.00	157.50	TotSp
pH	95.00	-14.90	-61.00	14.80	-178.00	37.70	ArcSC
TotSp	-18.70	0.17	10.30	0.02	8.50	0.02	ArcFcol
TotSp	-29.80	0.25	14.40	0.00	-14.50	0.21	ArcSC
Ca	-11.80	5.84	78.60	-6.66	12.90	1.80	ArcSG
Ca	10.60	-0.39	5.33	0.26	-6.00	1.79	SB-dw
Ca	2.03	1.65	8.43	1.07	12.03	0.69	OT-dw
Mg	-0.59	3.06	19.71	-1.05	17.71	-0.29	OT-dw
Na	34.00	-19.30	32.06	-24.60	17.20	91.70	ArcOT
Na	9.82	7.03	23.92	-21.37	20.02	-10.17	SG-dw
Na	12.90	5.13	18.99	-10.17	17.38	-3.37	OT-dw
ArcSB	19.93	-0.23	2.88	0.09	-19.34	0.48	SB-dw

From the results of correlation analysis (Table 3), for example, there were no significant correlation coefficients between percentage of root colonization and dry weight of the glasshouse crops, except a negative correlation between colonization and dry weight of sorghum. In contrast, sorghum dry weight was positively correlated with available P of the soil. So did the dry weight of sub-clover (SC-dw) and oats (OT-dw), as listed in Table 3. However, based on the results of multiple regression analysis in Table 4, soil available P showed significant interaction with categories of cropping history only on sub-clover dry weight, in which the slope coefficient between available P and sub-clover dry weight was highest and significant only in sub-clover grown on soil from PW cropping history (Table 6). Similarly, although dry weight of oats shows significant correlation with available P of the soil, the regression between available P and oats dry weight (OT-dw) was significant only in oats grown on soil samples taken from PW cropping history (Table 6).

Table 6. Coefficients of simple regression of Y= a+b.X between X and Y (dry weight) variables in each category of cropping history

Crops	X-var	Y-var	Regression eq.	Sig.	Regression eq.	Sig.	Regression eq.	Sig.
Sub-clover	Av-P	SC-dw	Y= 15.40+0.042X	ns	Y= 17.38+0.087X	ns	Y= 4.74+0.281X	*
Oats	Av_P	OT-dw	Y=13.60+0.068X	ns	Y= 11.68+0.108X	ns	Y= 14.21+0.060X	**
Sorghum	Av_P	SG-dw	Y= 9.29+0.138X	ns	Y= 11.32+0.168X	ns	Y= 13.36+0.119X	ns
Sorghum	ArcSG	SG-dw	Y= 9.25+0.126X	ns	Y= 24.35-0.194X	ns	Y= 6.32+0.486X	ns

In contrast, soybean did not show significant correlation between AMF colonization (ArcSB) in the roots and dry weight of soybean (SB-dw), although there was a significant correlation between AMF colonization of crop roots (ArcFcol) in the field samples and soybean dry weight (Table 3). However, multiple regression analysis revealed that AMF colonization in soybean had a significant interaction with categories of cropping history in relation to soybean dry weight (Table 4). This means that the relationship between the two variables was affected by categories of cropping history, which resulted in different regression equation between categories of cropping history (Table 5). This effect is visually presented in Fig. 1, which shows the differences in the degrees of relationship between those variables among the categories of cropping history.

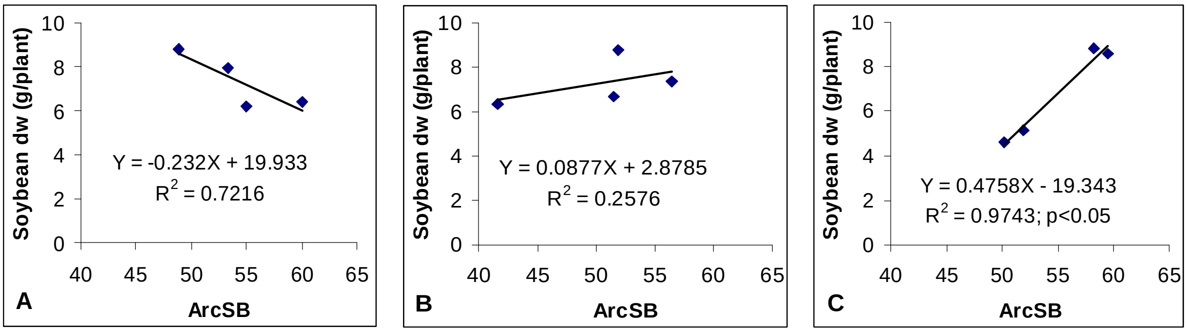

Fig. 1. Regression between AMF colonization (ArcSB) and dry weight of soybean grown on soil from PO (A), PCW (B), and PW (C) cropping history

This kind of analysis in fact could reveal a significant relationship within a non-significant overall relationship by taking into account some categorical variables in the analysis. From Fig. 1 it can be seen that although the overall relationship between ArcSB and SB-dw was not significant, in fact it was actually significant and positive in soybean plants grown on the soil samples taken from the PW cropping history (Fig. 1.C), while it was not significant in PO (Fig. 1.A) and PCW (Fig. 1.B). In fact, the relationship tended to be negative in soybean plants grown on the soil samples from PO cropping history. This indicates that the effects of AMF colonization in the roots of a host plant are affected by other environmental factors. The relationship could be visually positive (mutualistic), could be neutral or could be negative or parasitic (Johnson et al. (1997), as it also happened in the case of tobacco stunt disease caused by high population of the AMF species *Glomus macrocarpum* due to certain cropping history (An et al., 1993). Johnson (1993) also reported that fertilization can select less mutualistic species of AMF. In fact, based on an experiment using isotopic P-fertilizers, it was revealed that AMF still capable of transferring P from the growing medium to their host plants although there was no significant differences in growth effect and total P-uptake between mycorrhizal and non-mycorrhizal plants (Smith et al., 2004; Li et al., 2006). Therefore, non-significant differences of crop dry weight between the main treatments do not necessary mean that there was no effect. Application of relevant multiple regression analysis can be used to reveal if there is something significant within a non-significant difference.

4. CONCLUSION

Although almost all observation variables were not significantly different between categories of cropping history, application of multiple regression analysis involving mixed categorical and continuous X-variables could reveal significant effects of cropping history on relationship between soil properties or AMF colonization and dry weight of crops grown on the soil samples taken from different sites having different categories of cropping history. This data analysis technique could reveal some significant interaction effects within non-significant effects of cropping history or non-significant correlation between AMF colonization and crop dry weight.

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AUTHORS' CONTRIBUTIONS

Author1 conducted the field sampling, laboratory work and pot culture experiment in the glasshouse under supervision of Author2. Author2 was the main Supervisor of Author1 during the Ph.D. study of Author1 in the Hawkesbury Campus of the University of Western Sydney. Author2 also provided continuous help and additional assistants during field sampling and handling the samples from the field and the glasshouse experiments.

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