Nutrient status of rhizosphere and bulk soil in coleus as influenced by agronomic management practices

ARUNJITH P[1], SHEEBA REBECCA ISAAC[1] and KC MANORAMA THAMPATTI[2]

[1]Department of Agronomy, [2]Department of Soil Science and Agricultural Chemistry
College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India
Email for correspondence: arunjithp0077@gmail.com

Received: 08.06.2021/Accepted: 20.06.2021

ABSTRACT

A study was conducted at instructional farm of the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala during October 2019 to February 2020 to assess the variations in soil nutrient status with the agronomic management practices adopted in coleus cultivation. The experiment was laid out in split plot design replicated four times with methods of planting as main plots and combinations of nutrient management practice and growth promoter as sub-plot treatments. Results revealed the higher available NPK content in rhizosphere soil compared to bulk soil. Bulk soil nutrient status was significantly higher under the wider spacing of 30 cm x 30 cm (319.35 kg N/ha, 36.90 kg P/ha and 423.49 kg K/ha). Irrespective of the growth promoters used, the integrated nutrient package, 60:30:120 kg NPK/ha + PGPR Mix 1 recorded higher contents of N, P and K in the rhizosphere and bulk region. Interaction effects were also significant except for available N in the bulk soil. The management practice of bed, ridge and mound method of planting with a spacing of 30 cm x 30 cm and integrated nutrient management 60:30:120 kg NPK/ha + PGPR Mix 1 was found to record higher available N, P and K status in the rhizosphere soil.

Keywords: Bulk soil; coleus, growth promoters; method of planting; nutrients; rhizosphere

INTRODUCTION

The availability of plant nutrients can be a major constraint to plant growth in crop production. Nitrogen (N), phosphorus (P) and potassium (K) are primary nutrients used in biological processes in plants and have to be provided on crop basis for which soil acts as a major contributor (Li et al 2019). The rhizosphere in close proximity with the plant roots forms the nexus between root system and soil environment and its properties tend to differ from that in the bulk soil. According to Zhao et al (2015), rhizosphere soil is nutrient-rich and a hot-spot of microbial interactions and is contemplated to play an important role in the soil ecosystem influencing plant growth much greater than the bulk soil.

Tropical tuber crops form an important staple or subsidiary food for about 500 million of the global population (Suja and Sreekumar 2014). Coleus [*Plectranthus rotundifolius* (Poir) JK Morton], also known as Chinese potato is a minor tropical tuber crop grown in many parts of the world for its edible and delicious tubers. There exists a wide gap between the potential yield and actual yield in coleus and higher proportion of smaller tubers in the harvested produce reduces the marketability of tubers (Enyiukwu et al 2014). Agronomic management practices have significant influence on growth and yield of coleus and soil fertility (Suja et al 2021). The variations in available NPK status with planting geometry and nutrient management practices in the post-harvest bulk soil are reported (Mastiholi 2008). However the influence of the management practices on soil rhizosphere properties has been less explored.

In this background, the paper attempted to compare the available NPK contents in the rhizosphere and bulk soil in coleus raised under different agronomic management practices in the southern laterites of Kerala, India.

MATERIAL and METHODS

The field experiment was conducted at the instructional farm of the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala located at 8.5°N latitude and 76.9°E longitude and 29 m amsl during October 2019 to February 2020. The soil of the experimental site was sandy clay loam with an acidic pH (6.05), medium available N (301.06 kg/ha), high available P (27.24 kg/ha) and available K (327.04 kg/ha). The photo-insensitive coleus variety Suphala released from Kerala Agricultural University was used for the study. Field experiment was laid out in split plot design with five methods of planting as main plots and six combinations of nutrient management practices (2) and growth promoters (3) as sub-plot treatments in four replications. The main plot treatment, methods of planting included m_1: Bed method (30 cm x 15 cm), m_2: Bed method (30 cm x 30 cm), m_3: Ridge method (30 cm x 15 cm), m_4: Ridge method (30 cm x 30 cm) and m_5: Mound method (30 cm x 30 cm). Nutrient management practices (n_1: 60:30:120 kg NPK/ha + PGPR Mix 1, n_2: 60:30:120 kg NPK/ha) and growth promoters (g_1: Humic acid @ 5 g/l, g_2: Benzyl adenine @ 50 mg/l and g_3: Water spray) in combination comprised the sub-plot treatments.

The land was ploughed thoroughly, limed @ 100 kg/ha based on the soil test results and laid out into main (14.4 m x 1.5 m) and sub-plots (2.4 x 1.5 m) as per experimental design. Beds, ridges and mounds were prepared in the respective plots. Farmyard manure (FYM) was incorporated @ 10 tonnes/ha and healthy vine cuttings of 10-15 cm size were planted in the spacings fixed as per treatments. Half the dose of N and K and full dose of phosphorus (P) were applied basally and remaining quantity of N and K was given at 45 days after planting (DAP) along with earthing up. The chemical sources used were urea (46% N), rock phosphate (20% P_2O_5) and muriate of potash (60% K_2O). Consortium biofertilizer, PGPR Mix 1 (N fixers, *Azospirillum lipoferum*, *Azotobactor chroococcum*, P solubiliser, *Bacillus megaterium* and K solubiliser, *B sporothermodurans*) developed in the Department of Agricultural Microbiology, College of Agriculture, Vellayani, Kerala was mixed with FYM @ 2 per cent and 5 g of the mixture was applied per plant thrice at the time of planting, 30 DAP and 60 DAP in n_1. Humic acid @ 5 g/l, benzyl adenine 50 mg/l and water were used as g_1, g_2 and g_3 treatments respectively at a spray volume of 500 l/ha. All cultural operations were done as per the package of practices recommendation (Anon 2016) and the crop was harvested when the top portion started yellowing (140 DAP).

Rhizosphere soil samples were collected after uprooting the tubers. The soil on the tubers was shaken and the adhering soil was taken as rhizosphere soil sample. Composite samples collected from each treatment plots formed the bulk soil samples. The samples were cleaned of debris, gravels etc, shade-dried and sieved through 2 mm sieve for estimating soil available NPK contents. The standard procedure of alkaline permanganate method was used for the estimation of available N (Subbiah and Asija 1956), Dickman and Bray's molybdenum blue spectrophotometry method for available P (Jackson 1973) and neutral normal ammonium acetate extraction and flame photometry for available K (Jackson 1973). NPK contents estimated were expressed in kg/ha.

The data were analysed statistically and the significance was tested by F-test (Cochran and Cox 1965). Critical differences were calculated for treatment comparison wherever F-test was found significant.

RESULTS and DISCUSSION

The effect of methods of planting, nutrient management and growth promoter combination on the available NPK in the rhizosphere and bulk soil is presented in Tables 1a and 1b. There was remarkable improvement in soil nutrient status compared to the initial soil test value due to the agronomic management practices adopted in coleus.

Effect of methods of planting (m) on available N, P and K

Perusal of the data (Table 1a) reveals the significant variations in the available nutrient status with the methods of planting and ridges with planting at a spacing of 30 cm x 30 cm (m_4) recorded higher available N (461.45 kg/ha) in the rhizosphere soil which was on par with bed planting, at a spacing of 30 cm x 30 cm (m_2) and mound method of planting (m_5). In the bulk soil, mounds at the wider spacing of 30 cm x 30 cm (m_5) recorded higher available N (319.35 kg/ha) which was on par with m_2 and m_4. Available P and K in the rhizosphere were 39.58 and 524.96 kg/ha respectively and that in bulk soil 36.90 and 423.49 kg/ha respectively, both being higher in the planting on mounds at 30 cm x 30 cm (m_5) which were on par with m_2 and m_4.

Methods of planting have distinctive effects on the soil micro-ecological environment as well as

Table 1a. Effect of methods of planting and combination of nutrient management and growth promoter on available N, P and K (kg/ha) of rhizosphere and bulk soil

Treatment	N		P		K	
	Rhizosphere	Bulk	Rhizosphere	Bulk	Rhizosphere	Bulk
Method of planting (m)						
m_1	397.70	309.73	31.90	29.91	465.53	374.28
m_2	455.18	317.37	39.10	35.13	522.34	408.89
m_3	393.49	310.99	33.08	31.60	447.09	376.84
m_4	461.45	318.10	38.16	36.00	518.74	422.26
m_5	454.72	319.35	39.58	36.90	524.96	423.49
SEm	2.84	1.93	0.63	0.60	6.55	4.86
$CD_{0.05}$	8.76	5.94	1.94	1.85	20.18	14.98
Nutrient management (n) x growth promoter (g)						
n_1g_1	447.79	322.39	40.28	38.14	517.77	413.47
n_1g_2	450.32	319.37	40.24	37.06	513.98	409.24
n_1g_3	444.67	319.74	41.68	38.15	521.23	414.18
n_2g_1	415.83	310.09	32.14	30.19	472.59	388.50
n_2g_2	418.46	308.58	32.16	29.70	477.05	387.80
n_2g_3	417.97	310.46	31.69	30.22	471.77	393.72
SEm	3.46	3.08	0.60	0.46	7.22	5.04
$CD_{0.05}$	9.76	8.68	1.68	1.28	20.36	14.18

Method of planting= m_1: Bed method (30 x 15 cm), m_2: Bed method (30 x 30 cm), m_3: Ridge method (30 x 15 cm), m_4: Ridge method (30 x 30 cm), m_5: Mound method (30 x 30 cm); Nutrient management practices= n_1: 60:30:120 kg NPK/ha + PGPR Mix 1, n_2: 60:30:120 kg NPK/ha; Growth promoters= g_1: Humic acid @ 5 g/l, g_2: Benzyl adenine @ 50 mg/l, g_3: Water spray

soil quality (Qin et al 2016). The plots with lower plant population (1,11,111 per ha; m_2, m_4 and m_5) recorded higher available nutrients. This might be due to the reduced nutrient uptake in these plots compared to plots with higher plant population (2,22,222 per ha; m_1 and m_3). The findings are in close conformity with the findings of Kalaichelvi (2008) and Shukla et al (2014) who reported higher available P under wider spacing of plants. Higher soil NPK in lesser plant population due to wider spacing was reported by Srikanth et al (2009) in maize.

In general higher available N, P and K were recorded in the rhizosphere soil compared to bulk soil and the trend is in agreement with the reports of Marschner et al (1987). Plants take up most of the mineral nutrients from the rhizosphere where microorganisms interact with root exudates. The root exudates which consist of a complex mixture of organic acid anions, phytosiderophores, sugars, vitamins, amino acids, purines, nucleosides, inorganic ions (eg HCO_3^-, OH^-, H^+), gaseous molecules (CO_2, H_2), enzymes and root border cells have major direct or indirect effects on the acquisition of mineral nutrients for plant growth (Dakora and Phillips 2002). The root exudates also serve as substrates for microbial proliferation. Microorganisms have a pivotal role in solubilising and mobilising nutrients in soil for plant uptake. The increased microbial activity would have favoured the mineralization of organic matter and solubilisation of the unavailable nutrients. These peculiarities of rhizosphere soil might have contributed to higher nutrient status compared to bulk soil.

Effect of nutrient management and growth promoters (N x G) on available NPK

The combination of nutrient management and growth promoters exerted significant effect on available nutrient status. Irrespective of the growth promoters, all the plots which received integrated nutrient package, 60:30:120 kg NPK/ha + PGPR Mix 1 recorded an increased status of N, P and K in the rhizosphere and bulk soil; 2.49-49.57 per cent in N, 9.03-53.01 per cent in P and 18.57-59.37 per cent in K. Higher available N (450.32 kg/ha) was registered in integrated nutrient management (INM) with benzyl adenine 50 mg/l (n_1g_2), on par with combinations of INM + humic acid @ 5 g/l (n_1g_1), and INM + water spray (n_1g_3) in rhizosphere soil. In the bulk soil, INM + humic acid @ 5 g/l recorded higher available N (322.39 kg/ha) but was on par with

Table 1b. Interaction effect of methods of planting and combination of nutrient management and growth promoter on available N, P and K (kg/ha) of rhizosphere and bulk soil

Treatment	N		P		K	
	Rhizosphere	Bulk	Rhizosphere	Bulk	Rhizosphere	Bulk
$m_1n_1g_1$	401.41	314.87	34.02	31.61	470.12	401.13
$m_1n_1g_2$	407.68	312.33	35.65	32.13	474.70	396.74
$m_1n_1g_3$	407.68	309.19	35.28	31.77	481.76	403.03
$m_1n_2g_1$	385.73	307.33	28.65	27.86	454.27	349.93
$m_1n_2g_2$	393.30	304.19	28.87	27.33	459.20	342.38
$m_1n_2g_3$	390.40	310.47	28.93	28.74	453.15	352.47
$m_2n_1g_1$	482.94	324.28	41.33	39.66	549.88	410.20
$m_2n_1g_2$	476.62	321.14	42.19	38.20	565.82	398.41
$m_2n_1g_3$	470.35	324.28	43.43	40.69	555.30	404.40
$m_2n_2g_1$	439.04	313.60	36.42	30.23	482.83	409.17
$m_2n_2g_2$	426.25	313.60	36.23	30.40	495.04	425.14
$m_2n_2g_3$	435.90	307.33	35.02	31.63	485.18	406.02
$m_3n_1g_1$	398.27	313.60	36.66	34.64	444.18	383.10
$m_3n_1g_2$	398.27	310.46	37.78	34.14	442.58	380.36
$m_3n_1g_3$	401.41	313.60	36.79	35.90	436.66	374.19
$m_3n_2g_1$	385.73	310.46	28.87	28.87	451.58	371.53
$m_3n_2g_2$	388.63	307.33	30.29	28.74	459.20	366.04
$m_3n_2g_3$	388.63	310.46	28.12	27.33	448.34	385.81
$m_4n_1g_1$	479.64	329.92	43.96	40.54	562.35	432.78
$m_4n_1g_2$	486.08	326.78	41.17	40.04	521.19	434.04
$m_4n_1g_3$	470.40	333.05	45.69	40.53	561.12	447.40
$m_4n_2g_1$	435.90	307.33	33.64	32.13	492.80	401.76
$m_4n_2g_2$	457.65	304.19	31.76	31.00	486.64	399.34
$m_4n_2g_3$	439.04	307.33	32.76	31.76	488.32	418.23
$m_5n_1g_1$	476.67	329.28	45.44	44.25	562.32	440.16
$m_5n_1g_2$	482.94	326.14	44.43	40.80	565.60	436.66
$m_5n_1g_3$	473.54	318.60	47.19	41.85	571.31	441.87
$m_5n_2g_1$	432.77	311.74	33.12	31.88	481.49	410.09
$m_5n_2g_2$	426.50	313.60	33.68	31.00	485.18	406.08
$m_5n_2g_3$	435.90	316.74	33.64	31.63	483.84	406.08
SEm±	7.74	6.89	1.33	1.02	16.16	11.26
$CD_{0.05}$	21.81	NS	3.75	2.87	45.52	31.73

M= Method of planting, n= Nutrient management, g= Growth promoter; Method of planting= m_1: Bed method (30 x 15 cm), m_2: Bed method (30 x 30 cm), m_3: Ridge method (30 x 15 cm), m_4: Ridge method (30 x 30 cm), m_5: Mound method (30 x 30 cm); Nutrient management practices= n_1: 60:30:120 kg NPK/ha + PGPR Mix 1, n_2: 60:30:120 kg NPK/ha; Growth promoters= g_1: Humic acid @ 5 g/l, g_2: Benzyl adenine @ 50 mg/l, g_3: Water spray

n_1g_2 and n_1g_3. The combination, INM + water spray (n_1g_3) was recorded in higher available P (41.68 and 38.15 kg/ha) and K (521.23 and 414.18 kg/ha) in rhizosphere and bulk soil respectively.

Application of biofertilizer consortium, PGPR Mix 1 augments the rhizosphere microbiome and increases nutrient availability. The microorganisms present in the PGPR Mix 1 include N fixers, P and K solubilisers and these help in the mineralisation of organic fraction and solubilisation of nutrients in the soil through release of organic acids into the rhizosphere. The end result would be a modification of soil reaction and enhanced nutrient availability (Babu 2020). The increase in N status might be due to the fixation of atmospheric nitrogen by N fixers present in the PGPR Mix 1. High efficiency of P solubilisers in releasing the soil P from insoluble sources is reported by Meenakumari et al (2008). The enhancement in P availability could be due to the production of enzymes (phosphatases), organic acids, protons etc by the P solubilisers present in the biofertilizer consortium (Miransari 2013). Availability of K is affected by biological activities in the soil. Application of PGPR enhances the K availability by different mechanisms including acidolysis, chelation and oxidoreduction and thereby solubilising K from minerals (Uroz et al 2009).

Interaction effect of methods of planting, nutrient management and growth promoters (M x N x G) on available NPK

The interaction effect of methods of planting (main plots) and combination of nutrient management and growth promoters (sub-plots) on the available nutrients under study was found to be significant except for available N in the bulk soil (Table 1b).

Available N status in the rhizosphere soil was higher (486.08 kg/ha) in the treatment combination, ridge planting (30 x 30 cm) + 60:30:120 kg NPK/ha + PGPR Mix 1 with benzyl adenine spray ($m_4n_1g_2$), on par with the treatment combinations involving ridge, bed or mound method of planting at 30 x 30 cm and INM package. Nitrogen fixation and mineralisation processes in soil enhance the soil status. Nevertheless lower plant density in the plots with wider spacing might have resulted in lower nutrient uptake of plants resulting in the higher N status in the post-harvest soil. Increase in N content has often been observed following inoculation of *Azospirillum* by Okon (1994).

Mound method of planting with INM + water spray ($m_5n_1g_3$) registered higher available P (47.19 kg/ha) in rhizosphere which was on par with $m_5n_1g_1$, $m_5n_1g_2$, $m_4n_1g_1$ and $m_4n_1g_3$ and in bulk soil it was the maximum in $m_5n_1g_1$ (44.25 kg/ha) but on par with $m_5n_1g_3$. PGPR Mix 1 encompasses P soulbiliser *B megaterium* which helps in the solubilisation of complex structured phosphate such as tricalcium phosphate and rock phosphate (Kaushal 2019). In the present study, high initial P status in the soil along with the applied chemical fertilizers and solubilsation by *B megaterium* in the PGPR mix 1 would have led to the positive balance in soil even after coleus uptake as reported by Babu (2020) in cassava. The higher P content in rhizosphere soil compared to the bulk soil agree to the reports of Li et al (2016) who had earlier recorded a nearly 10-fold higher soil available P in the rhizosphere compared to the non-rhizosphere soil. Root exudates which play a major role in P bioavailability, can enhance the activity of phosphate-solubilising bacteria thus increasing the P supply (Hinsinger 2001, Vance et al 2003).

Higher available K (571.31 kg/ha) status was found in mound method of planting with nutrient management option of 60:30:120 kg NPK/ha + PGPR Mix 1 and water spray but on par with $m_2n_1g_1$, $m_2n_1g_2$, $m_2n_1g_3$, $m_4n_1g_1$, $m_4n_1g_3$, $m_5n_1g_1$ and $m_5n_1g_2$ the combinations involving wider spacing and INM package. Among the soil samples of bulk soil, treatment combination $m_4n_1g_3$ recorded the highest available K (447.40 kg/ha) and was on par with $m_4n_1g_1$, $m_4n_1g_2$, $m_4n_2g_3$, $m_5n_1g_1$, $m_5n_1g_2$. $m_5n_1g_3$ and $m_2n_2g_2$. The inherent ability of the K solubiliser, *B sporothermodurans* to release organic acids for the solubilisation that could be the persuasive reason for higher available K in soil. Improved status of available P and K in coleus with the application of PGPR mix 1 was also documented by Jayapal (2012).

CONCLUSION

The study revealed that the agronomic management practices, methods of planting, nutrient management and growth promoters adopted in coleus enhanced available N, P and K, the increase being higher in the rhizosphere soil compared to bulk soil. The maximum available N, P and K were recorded in the combination of modified method of planting (mound) with wider spacing and INM of 60:30:120 kg NPK/ha + PGPR Mix 1.

REFERENCES

Anonymous 2016. Package of practices recommendations: crops. 15th edn, Kerala Agricultural University, Thrissur, Kerala, India, 392p.

Babu CSA 2020. Economising nutrient use in cassava (*Manihot esculenta* Crantz) with liquid consortium biofertilizer. MSc Thesis, Kerala Agricultural University, Thrissur, Kerala, India.

Cochran WG and Cox GM 1965. Experimental designs. Asia Publishing House, Bombay, Maharashtra, India.

Dakora FD and Phillips DA 2002. Root exudates as mediators of mineral acquisition in low-nutrient environments. Plant and Soil **245:** 35-47.

Enyiukwu DN, Awurum AN and Nwaneri JA 2014. Potentials of Hausa potato [*Solenostemon rotundifolius* (Poir) JK Morton] and management of its tuber rot in Nigeria. Greener Journal of Agronomy Forestry and Horticulture **2(2):** 27-37.

Hinsinger P 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant and Soil **237:** 173-195.

Jackson ML 1973. Soil chemical analysis. Prentice Hall of India Pvt Ltd, New Delhi, India.

Jayapal A 2012. Production technology for organic coleus. MSc Thesis, Kerala Agricultural University, Thrissur, Kerala, India.

Kalaichelvi K 2008. Effect of *Bt* hybrids, plant geometry and fertilizer levels on soil nutrient availability. Agricultural Science Digest **28(4):** 250-253.

Kaushal M 2019. Climatic resilient agriculture for root, tuber and banana crops using plant growth-promoting microbes. In: Climate change and agricultural ecosystems: current challenges and adaptation (KK Choudhary, A Kumar, and AK Singh, eds), Woodhead Publishing, Sawston, United Kingdom, pp 307-329.

Li J, Zhou L and Lin W 2019. Calla lily intercropping in rubber tree plantations changes the nutrient content, microbial abundance and enzyme activity of both rhizosphere and non-rhizosphere soil and calla lily growth. Industrial Crops and Products **132:** 344-351.

Li Z, Zu C, Wang C, Yang J, Yu H and Wu H 2016. Different responses of rhizosphere and non-rhizosphere soil microbial communities to consecutive *Piper nigrum* L monoculture. Scientific Reports **6(1):** 35825; doi: 10.1038/srep35825.

Marschner H, Romheld V and Cakmak I 1987. Root-induced changes of nutrient availability in the rhizosphere. Journal of Plant Nutrition **10(9):** 1175-1184.

Mastiholi AB 2008. Effect of spacing, time of harvest and NPK levels on growth, yield and quality of medicinal coleus (*Coleus forskohlii* Briq) under irrigated condition. PhD Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India.

Meenakumari KS, Sivaprasad P and Geegi MT 2008. Role of phosphate-solubilizing microorganisms in P dynamics of soil system. In: Microbial inoculant technology for sustainable farming (P Sivaprasad and KS Meenakumari, eds), Kalyani Publishers, Ludhiana, Punjab, India, pp 129-135.

Miransari M 2013. Soil microbes and the availability of soil nutrients. Acta Physiologiae Plantarum **35(11):** 3075-3084.

Okon Y 1994. Azospirillum-plant root associations. CRC Press, Boca Raton, Florida.

Qin S, Yeboah S, Wang D and Zhang J 2016. Effects of ridge-furrow and plastic mulching planting patterns on microflora and potato tuber yield in continuous cropping soil. Soil Use and Management **32(3):** 465-473.

Shukla UN, Khakare MS, Singh S and Verma SK 2014. Effect of crop geometries and fertility levels on growth, yield and residual nutrients of cotton (*Gossypium hirsutum*) hybrids under rainfed condition. Indian Journal of Agricultural Sciences **84(6):** 780-783.

Srikanth M, Mohamed AM, Muthukrihan P 2009. Influence of plant density and fertilizer on yield attributes, yield and grain quality of hybrid maize. Madras Agriculture Journal **96(1-6):** 139-143.

Subbiah DV and Asija GL 1956. Rapid procedure for estimation of available nitrogen in soil. Current Science **25(8):** 259-260.

Suja G and Sreekumar J 2014. Implications of organic management on yield, tuber quality and soil health in yams in the humid tropics. International Journal of Plant Production **8(3):** 291-310.

Suja G, Sreekumar J, Byju G, Veena SS, Sunitha SA, Ramesh V, Maria CL and Raj RK 2021. Organic management of Chinese potato: growth, yield, quality, soil health and economics. International Journal of Vegetable Science; doi: 10.1080/19315260.2021.1907829.

Uroz S, Calvaruso C, Turpault M-P, Frey-klett P 2009. Mineral weathering by bacteria: ecology, actors and mechanisms. Trends in Microbiology **17(8):** 378-387.

Vance CP, Uhde-Stone C and Allan DL 2003. Phosphorus acquisition and use: critical adaptations by plants for securing a non-renewable resource. New Phytologist **157(3):** 423-447.

Zhao Y, Wu L, Chu L, Yang Y, Li Z, Azeem S, Zhang Z, Fang C and Lin W 2015. Interaction of *Pseudostellaria heterophylla* with *Fusarium oxysporum* f sp *heterophylla* mediated by its root exudates in a consecutive monoculture system. Scientific Reports **5:** 8197; doi: 10.1038/srep08197.