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Phosphorus and potassium release during decomposition of roots and shoots of green manure crops

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Decomposition rates of above- and underground biomass and the dynamics of the remaining phosphorus (P) and potassium (K) were studied in trials at the Estonian University of Life Sciences (58°23′N, 26°44′E) in Nordic conditions. The research focused on the decomposition of roots and leaves/shoots of green manure plants. In shoot residues of bird's-foot trefoil and white melilot, after 6 months 19% and 20%, respectively, of P remained. Red clover shoots decomposed the slowest, remaining 44% of P in the residue. In a year, legumes remained 20–22% of initial organic P and 11% in 2 years. Rapid release of K from legume shoot residue occurred in 6 months. The roots released K in a period lasting from 6 to 12 months. The roots retained 15–32% K over a year. White clover roots were the slowest in K release. Residue decomposition and P, K release were all influenced by weather conditions.

Keywords: decomposition; green manure; phosphorus; potassium

Introduction

Crop productivity depends to a large extent on the use of organic fertilizers, especially in organic farming; as a consequence, green manure crops have an increasingly important role in crop husbandry. Decomposition of green manure residues plays a key role in the nutrient circulation of ecosystems. Decomposition of crop residues increases soil organic matter (Boehm & Anderson 1997) and drives the nutrient return from plant litter to soil (Soon & Arshad 2002; Lupwayi et al. 2005), which directly determines the availability of nutrients for plant uptake.

Organic material decomposition is a complex process determined by three main interacting groups of factors: chemical (composition of the litter), physical (climate and environment surrounding the litter), and biotic (microorganisms and invertebrates that take part in litter decomposition) (Berg & Laskowski 2006). Incorporation of plant material into the soil generally stimulates microbial growth and activity. After decomposition, the organic phosphorus (P) and potassium (K) bound in the green manure crop may provide an easily accessible form of P and K to succeeding crops (Askegaard & Eriksen 2008; Eichler-Löbermann et al. 2009). In organic farming without possibility to use animal manure, the most important way to improve the nutrient supply for succeeding crops are the green manures.

Numerous studies of net nitrogen (N) mineralization from decomposing legume material have been made on whole-plant materials of different species (Marstorp &

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Kirchmann 1991; Haynes 1997). P and K release from shoot organic matter decomposition has been studied by Canadian scientists (Soon & Arshad 2002; Lupwayi et al. 2006a, 2006b, 2007). Information on the contribution of individual plant parts and different stages of maturity is available for red clover and yellow melilot (Wivstad 1997, 1999). However, roots are important source of soil organic matter and their decomposition have received little attention.

Red clover and white melilot are the most popular green manure crops in Estonia, but studies show that lucerne and large-leaved lupin can also be successfully used for this purpose (Talgre et al. 2012; Lauringson et al. 2013). Species theoretically cultivatable as green manure were selected for the present study which focuses on nutritional content in roots and leaves/stems, and their release to soil, depending on plant matter decomposition rate. Such studies are also important because in many cases not all plant parts are returned to soil. It is important to evaluate the effects of changes in the distribution of green manure plant components on subsequent net P and K mineralization. The objectives of the study were (1) to assess the decomposition rate of the above- and underground biomass in Nordic conditions and (2) to determine the content of P and K in decomposing material over time that further allowed quantification of the decomposition rate and P and K release to soil.

Materials and methods

The trials were carried out during 2007–2010 in the Department of Field Crop and Grassland Husbandry at the Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences (58°23′N, 26°44′E). Trials were carried out in 2007–2009 (Experiment 1) and in 2008–2010 (Experiment 2). Plant species used in the study of Experiment 1 were: red clover (*Trifolium pratense* L.), lucerne (*Medicago sativa* L.), bird's-foot trefoil (*Lotus corniculatus* L.) and white melilot (*Melilotus albus* Med). In Experiment 2, they were red clover, white melilot and large-leaved lupin (*Lupinus polyphyllus* Lind.).

The soil type of the experiment area is sandy loam Stagnic Luvisol according to the WRB 2006 classification (FAO 2006). The mean characteristics of the humus horizon were: C_{org} 1.1–1.2%, N_{tot} 0.10–0.12%, P 110–120 mg kg^{-1}, K 253–260 mg kg^{-1}, pH_{KCl} 5.9 and soil bulk density 1.45–1.50 g cm^{-3}. The humus horizon was 27–29 cm. Soil organic carbon (C) was determined by the Tjurin method, P and K by the Mehlich III method and the total N content by the Kjeldahl method.

The experimental area belongs to the South-Estonian upland agro-climatic region where the average annual sum of active air temperatures (sum > 5°C) is 1750–1800°C (mean annual temperature 4.4°C) and total precipitation is 550–650 mm. The period of active plant growth (mean diurnal temperature continuously above 10°C) ranges usually from 115 to 135 days (Tarand 2003). During the experimental period, rainfall and air temperature were recorded daily at a meteorological station located within the experimental area using a Metos Model MCR300 weather station (Pessl Instruments GmbH, Weiz, Austria) (Table 1).

Green manure pure crops were sown at the beginning of May (2007 and 2008). The length of growing season of green manure crops was on average 6 months. Four replicates of roots and shoots were collected from field-grown plants of each species before green manure incorporation at the end of October. Roots were sampled from a 0.25 m^2 frame, 0–30 cm depth, and soil was washed from the roots. Samples of aboveground biomass were taken from 0.25 m^{-2}. The roots and shoots were cut into 5 cm pieces. It is equivalent

Table 1. Monthly precipitation and average air temperature during both experimental periods.

	Air temperature (°C)				Precipitation (mm)			
Month	2007	2008	2009	2010	2007	2008	2009	2010
January	−7.1	−1.3	−3.4	−12.7	29	22	10	3
February	−6.6	0.6	−4.9	−7.9	23	34	7	5
March	−2.4	0.4	−1.5	−2.1	26	8	22	30
April	4.2	7.1	5.3	6.1	33	27	14	26
May	11.6	10.6	11.5	12.6	55	27	13	61
June	15.1	14.4	13.8	14.6	66	110	137	73
July	16.7	16.1	16.9	22.2	72	54	55	36
August	15.6	17.7	15.4	18.2	79	118	89	107
September	10.4	9.8	12.8	11.1	66	46	49	93
October	5.7	8.2	4.1	4.2	52	68	116	49
November	0.3	2.3	2.3	0.8	48	49	36	53
December	−4.2	−1.1	−3.8	−7.7	40	24	41	17

to the effect of the machinery used for green manure crushing before incorporation. Fresh plant residues (25 g) were placed in 20 cm × 20 cm nylon bags with a 1 mm mesh. The bags were placed at 22 cm depth with 0.3 m spacing between them. The bags were buried at the end of October, before ploughing to a depth of 18–20 cm.

After 6, 12 and 24 months of decomposition, four replicate bags for each species were selected to measure dry matter (DM) and nutrient content.

Plant materials remaining in the nylon bags at each sampling time were manually separated from soil and organic debris. After that, these were oven-dried to a constant weight at 65°C. The oven-dried samples were separately weighed to determine DM losses. Then, the samples were ground to pass a 0.5 mm sieve for chemical analysis. The chemical analysis was done separately for each replicate. Digestion with sulphuric acid solution was used to determine P, K content in plant material (Methods of soil and plant analysis 1986). Total N and C contents of oven-dried samples were determined by dry combustion method on a varioMAX CNS elemental analyzer (Elementar, Hanau, Germany).

The software STATISTICA 7.0 (Statsoft, Inc. 2005) was used for statistical data analysis. Analysis of variance Tukey test were used to assess the statistical significance of the difference between means at $p < 0.05$. A correlation analysis using Pearsońs correlation coefficient was conducted to quantify relationships between residue chemical composition and P and K mineralization.

Results and discussion

DM and nutrient content of legumes before decomposition is shown in Table 2. In general, the P content in roots was higher (except in large-leaved lupin roots), and C/N ratio was lower than in aboveground biomass ($p < 0.05$). K content in aboveground biomass was higher than in roots ($p < 0.05$). Talgre et al. (2012) found that in Nordic conditions pure green manure crops fixed up to 144 kg K and up to 24 kg P ha^{-1}.

Plant-accessible nutrients are released from organic matter to soil as the result of various decomposition and mineralization processes. Much information exists on the effects of residue quality on rates of decomposition, and N mineralization but fewer studies have evaluated the relationship between residue quality and P and K release during decomposition. The decomposition of the green manure material and the P release from

Table 2. DM and nutritional content of legumes before set for decomposition.

	DM (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	C/N	C/P	C/K
Red clover						
Shoots	271.2	2.6	24.1	18.9	167.3	18.1
Roots	300.6	3.2	12.7	18.3	121.0	32.8
White melilot						
Shoots	346.4	2.7	19.0	23.2	166.8	24.5
Roots	294.2	3.2	12.7	15.8	119.3	36.8
Bird's-foot trefoil						
Shoots	315.7	2.3	20.6	22.6	200.3	22.4
Roots	402.1	3.0	11.2	15.1	133.9	35.9
Lucerne						
Shoots	433.7	2.0	17.8	21.6	228.4	25.7
Roots	459.8	4.0	9.4	17.1	110.2	46.9
Large-leaved lupin						
Shoots	188.5	3.1	22.0	19.2	132.4	17.0
Roots	264.5	2.5	10.4	18.5	159.7	28.6

Note: Data for red clover and white melilot are the mean of two trials.

plant tissue is a complex process depending on N/P ratio of the green material, P content in soil and P cycling (Dorado et al. 2003).

From the green manure shoot biomass that was buried into soil, up to 51% decomposed in half a year; the roots decomposed up to 46%. By contrast, Berg et al. (1987) found that organic matter loss was fast during the first 13 days and almost ceased after 30 days when about 29% of the organic material remained.

As the result of shoot biomass mineralization in Experiment 1, after 6 months 19–44% of initial P remained, depending on culture (Table 3). Bird's-foot trefoil and white melilot shoot biomass decomposed the fastest. After 6 months, P retained by shoots of these cultures was only 19% and 20% of the initial P content bird's-foot trefoil and white melilot. Red clover shoots decomposed the slowest; after 6 months, the plant residue still contained 44% of the initial P amount. Lupwayi et al. (2004) found that under conventional tillage clover released up to 70% of the residue P after 12 months but with most of the P returned to the soil within 5 weeks of application. In the present study, 78–80% of initial P content was released in 12 months and 89% in 24 months. In Experiment 1 in 6 months, 50–57% of P in roots became available to the plants

Table 3. Phosphorus remaining (%) in biomass after 6, 12 and 24 months.

	Shoots			Roots		
Green manure species	6	12	24	6	12	24
Experiment 1						
Red clover	44b	18c	17a	50a	21c	6c
White melilot	19c	19b	11c	45c	41a	7c
Bird's-foot trefoil	20c	19b	15b	43d	22c	8bc
Lucerne	25c	20a	17a	49b	27b	15a
Experiment 2						
Red clover	55a	23a	16a	86b	43a	19a
White melilot	28b	23a	11b	92a	36b	12b
Large-leaved lupin	23b	17b	11b	73c	31c	18a

Note: Different letters indicate statistically significant difference ($p < 0.05$) between means within each sampling time/experiment combination.

(Table 3). White melilot roots and lucerne roots decomposed the slowest. This may be due to the fact that roots contain more as cellulose and lignin that are slow decomposing compounds.

P immobilization has been noted in earlier studies (Lupwayi et al. 2007; Rodríguez-Lizana et al. 2010). Field pea root residues exhibited no tendency to immobilize P (Soon & Arshad 2002). The release of P and K depends on the nutrient concentration of the organic matter and the C-to-nutrient ratio (Nygaard Sorensen & Thorup-Kristensen 2011). Lupwayi et al. (2007) found that the percentages of residue P released were positively correlated with P concentration. The present experiment could not confirm these results ($r = -0.85$, $p < 0.05$ for roots, for aboveground biomass not significant). P release was negatively correlated with C/P ratios, which is in accordance with the present results.

In Experiment 2, similar results for P release from shoot residue biomass were obtained although decomposition was slower than in Experiment 1. In Experiment 2, of the initial shoot residue P, 23–55% remained after 6 months. Comparatively, 73–92% of root residue P remained after 6 months. The difference may have been caused by the fact that in winter 2008–2009, the soil was frozen for much longer and decomposition was very slow. The effect of weather on biomass decomposition has also been described by Soon and Arshad (2002) and Kauer et al. (2012). In Experiment 2, P release after 6 months was greatest from lupin roots and shoots.

In Experiment 1, 24 months since the beginning of decomposition, 17% of the initial P content remained in the shoots of red clover and lucerne and 15% in roots of lucerne. In Experiment 2, where decomposition rate was lower, significantly more P remained in red clover residue compared with white melilot and large-leaved lupin shoots. At the end of the experiment, there was still 16% of the initial P content remained in the shoots and 19% of initial P left in the roots.

In Estonia in recent years, more P and K has been removed than added to soil. According to research data from Estonia (Kõlli 2012), adding balanced and optimal amounts of P and K to soil will result in leaching of $< 0.5\%$ of P and $< 10\%$ of K in sandy soils with $< 1\%$ of K in clay soil. Because leaching is very low P and K released from legumes can be used by succeeding crops. According to Lupwayi et al. (2007), P released from leguminous green manure residues would meet up to 62% of succeeding wheat P requirements.

K is not associated with structural components of plants (Marschner 1995), its release from crop residues will depend less on microbiological decomposition of the residues than N or P release. Thus, the extent and rate of K release from crop residues is usually greater than residue DM decomposition and N or P release (Lupwayi et al. 2006a). Both experiments showed that a large percentage of K release from legume aboveground biomass occurs in 6 months. After 6 months decomposition K content was 11% in bird's-foot trefoil and up to 18% in red clover (Table 4). The dynamics of green manure decomposition can be enhanced by proper timing of incorporation (Lahti & Kuikman 2003). It is important for green manure crop incorporation to occur in late autumn, when low temperatures delay mineralization, or in spring.

K release from roots was slower. It mainly occurred in the period of 6–12 months. After 12 months (Experiments 1 and 2), depending on plant species, the roots retained 16–32% K. Slowest K release was from white melilot roots. In 24 months, 93–95% of aboveground biomass K was released, similar to the study of Lupwayi et al. (2006a), where 92–99% of the K in green manure and 65–95% of the K in the other residues was released. K release was negatively correlated with K concentration in roots ($r = 0.72$, $p < 0.1$), and aboveground biomass was not significant. Additionally, we found that K

Table 4. Potassium remaining (%) in biomass during after 6, 12 and 24 months.

	Shoots			Roots		
Green manure species	6	12	24	6	12	24
Experiment 1						
Red clover	18a	6c	7a	61b	18c	8bc
White melilot	17b	14a	7a	79a	32a	6c
Bird's-foot trefoil	11c	9b	7a	48c	16c	10b
Lucerne	11c	6c	5b	72a	24b	16a
Experiment 2						
Red clover	15a	6b	3b	79b	16c	7b
White melilot	15a	10a	4b	95a	26b	3c
Large-leaved lupin	15a	9a	5ab	73c	31a	18a

Note: Different letters indicate statistically significant difference ($p < 0.05$) between means within each sampling time/experiment combination.

release was negatively correlated ($r = -0.63$, $p < 0.1$) with residue C/N ratio and positively correlated ($r = 0.70$, $p < 0.1$) with C/K ratio of residue. Lupwayi et al. (2006a) also found that K release was positively correlated with lignin content and reasoned that because K is not a structural component of plant tissue, K release, unlike N, may occur independently of microbial decomposition. We confirmed the findings that the K was never immobilized in any crop residue (Lupwayi et al. 2006a).

K release rate is highly conditioned by the precipitation during the decomposition period (Lupwayi et al. 2004; Rodríguez-Lizana et al. 2010). In the present study, this tendency can be noted by the K release from root decomposition. Intensive root decomposition and K release occurred from June to August with much rain received during these months. This effect is less prominent in aboveground mass decomposition.

Depending on biomass, green manure crops can bind up to 144 kg K and up to 24 kg P ha^{-1} (Talgre et al. 2012). The K content in roots was lower than in aboveground biomass (Table 2). K is mostly contained in crop residues (Whitbread et al. 2000). These can be an important source of soil K. Therefore, it is important to plough all the green manure into soil. Lupwayi et al. (2006b) found that all crop residues recycled agronomically contain significant amounts of K, i.e. recycled green manure residues provided 52–100% of succeeding wheat K requirements.

Conclusion

The most intensive P and K release happened in 6 months. In that period, 80% P and 89% K was released from legume shoot residue. Legume roots decomposed more slowly than aboveground residue.

Weather had an effect on biomass decomposition as well as nutrient release rate. In winter, when the soil was frozen for an extended period, biomass decomposition and nutrient release were hindered. Periods of abundant rainfall favoured P release. Aboveground biomass of bird's-foot trefoil and white melilot were the fastest in decomposition. We suggest that shoot residue decomposes rapidly and serves as a source of P and K for the subsequent crop. The root residue decomposes more slowly, and their P and K will be available in second year. Also, green manure should be ploughed into the soil in late autumn or early spring, thus decreasing the leaching of nutrients and increasing the effect on the yield of succeeding crops.

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References

Askegaard M, Eriksen J. 2008. Residual effect and leaching of N and K in cropping systems with clover and ryegrass catch crops on a coarse sand. Agric Ecosyst Environ. 123:99–108.

Berg B, Laskowski R. 2006. Litter decomposition: a guide to carbon and nutrient turnover. Adv Ecol Res. 38:19–71.

Berg B, Müller M, Wessen B. 1987. Decomposition of red clover (*Trifolium pratense*) roots. Soil Biol Biochem. 19:589–593.

Boehm MM, Anderson DW. 1997. A landscape-scale study of soil quality in three prairie farming systems. Soil Sci Soc Am. 61:1147–1159.

Dorado J, Zancada M, Almendros G, López-Fando C. 2003. Changes in soil properties and humic substances after long-term amendments with manure and crop residues in dryland farming systems. J Plant Nutr Soil Sci. 166:31–38.

Eichler-Löbermann B, Gaj R, Schnug E. 2009. Improvement of soil phosphorus availability by green fertilization with catch crops. Comm Soil Sci Plant Anal. 40:70–81.

Food and Agriculture Organization (FAO). 2006. World reference base for soil resources. 2nd ed. World Soil Resources Report 103. Rome: FAO.

Haynes RJ. 1997. Fate and recovery of 15N derived from grass/clover residues when incorporated into a soil and cropped with spring or winter wheat for two succeeding seasons. Biol Fert Soil. 191:77–87.

Kauer K, Raave H, Köster T, Viiralt R, Noormets M, Keres I, Laidna T, Parol A, Selge A. 2012. The decomposition of turfgrass clippings is fast at high air humidity and moderate temperature. Acta Agric Scand Sect B – Plant Soil Sci. 62:224–234.

Kõlli R. 2012. Mullateke ja mullaprofiil [Soli formation and profile]. In: Astover A, editor. Mullateadus [Soil science]. Tartu: Estonian University of Life Sciences; p. 221–247 (in Estonian).

Lahti T, Kuikman PJ. 2003. The effect of delaying autumn incorporation of green manure crop on N mineralization and spring wheat (*Triticum aestivum* L.) performance. Nutr Cycl Agroecosyst. 65:265–280.

Lauringson E, Talgre L, Makke A. 2013. Large-leaved lupin (*Lupinus polyphyllus* Lind.) and early red clover (*Trifolium pratense* L.) as green manure crops. Proc Latvian Acad Sci B: Nat Exact Appl Sci. 67:242–246.

Lupwayi NZ, Clayton GW, Harker KN, Turkington TK, Johnston AM. 2005. Impact of crop residue type on potassium release. Better Crops. 89:14–15.

Lupwayi NZ, Clayton GW, O’Donovan JT, Harker KN, Turkington TK, Rice WA. 2004. Decomposition of crop residues under conventional and zero tillage. Can J Soil Sci. 84:403–410.

Lupwayi NZ, Clayton GW, O’Donovan JT, Harker KN, Turkington TK, Soon YK. 2006a. Potassium release during decomposition of crop residues under conventional and zero tillage. Can J Soil Sci. 86:473–481.

Lupwayi NZ, Clayton GW, O’Donovan JT, Harker KN, Turkington TK, Soon YK. 2006b. Soil nutrient stratification and uptake by wheat after seven years of conventional and zero tillage in the Northern Grain belt of Canada. Can J Soil Sci. 86:767–778.

Lupwayi NZ, Clayton GW, O’Donovan JT, Harker KN, Turkington TK, Soon YK. 2007. Phosphorus release during decomposition of crop residues under conventional and zero tillage. Soil Till Res. 95:231–239.

Marschner H. 1995. Mineral nutrition of higher plants. London: Academic Press.

Marstorp H, Kirchmann H. 1991. Carbon and nitrogen mineralization and crop uptake of nitrogen from six green manure legumes decomposing in soil. Acta Agric Scand. 41:243–252.

Methods of soil and plant analysis. 1986. Jokioinen: Department of Soil Science, Agricultural Research Centre.

Nygaard Sorensen J, Thorup-Kristensen K. 2011. Plant-based fertilizers for organic vegetable production. J Plant Nutr Soil Sci. 174:321–332.
Rodríguez-Lizana A, Carbonell P, González R, Ordóñez R. 2010. N, P and K released by the field decomposition of residues of a pea–wheat–sunflower rotation. Nutr Cycl Agroecosyst. 87:199–208.
Soon YK, Arshad MA. 2002. Comparison of the decomposition and N and P mineralization of canola, pea and wheat residues. Biol Fert Soil. 36:10–17.
Statsoft, Inc. 2005. Statistica 7.0. Tulka (OK): Statsoft, Inc.
Talgre L, Lauringson E, Roostalu H, Astover A, Makke A. 2012. Green manure as a nutrient source for succeeding crops. Plant Soil Environ. 58:275–281.
Tarand A. 2003. Time series of observed air temperature in Tallinn. Tartu: Publications Instituti Geographici Universitatis Tartuensis.
Whitbread AM, Blair GJ, Lefroy RD. 2000. Managing legume leys, residues and fertilizers to enhance the sustainability of wheat cropping systems in Australia. Soil Till Res. 54:63–75.
Wivstad M. 1997. Plant morphology and content of nitrogen, cell wall and lignin at different phonological stages of red clover and yellow sweet clover. Swed J Agric Res. 27:3–14.
Wivstad M. 1999. Nitrogen mineralization and crop uptake of N from decomposing 15N labelled red clover and yellow sweet clover plant fractions of different age. Plant Soil. 208:21–31.