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Comparison of the decomposition and N and P mineralization of canola, pea and wheat residues

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Abstract Insight into nutrient cycling is gained by understanding the dynamics and quantifying nutrient mineralization from decomposing crop residues. Since wheat (*Triticum aestivum* L.), canola (*Brassica napus* L.) and pulse crops such as pea (*Pisum sativum* L.) are commonly grown in rotation, our objectives were to: (1) compare, using the mesh bag technique, the dry matter (DM) loss and release of N and P of straw and root residues of those crops in the 10–11 months following harvest, and (2) determine the influence of N fertilizer on residue decomposition and nutrient release. The no-tillage study started in autumn 1997 when straw residues were placed on the soil surface and root residues were buried in the soil, and sampled periodically through the 1998 growing season. Wheat was grown in 1998 and received 0 or 60 kg N ha^{-1}. The study was repeated in 1998/1999. Wheat straw decomposed more slowly than canola or pea straw (losing an average of 12%, 24% and 25%, respectively, of initial DM in 10–11 months), however, the converse was noted for root residues (42%, 26% and 19% of initial DM). Average net N mineralization from wheat, canola and pea straw was essentially 0, 0.7 and 5.6 kg N ha^{-1}, respectively. Phosphorus released from straw ranged from 0.5 kg ha^{-1} for pea to 0.75 kg ha^{-1} for canola. Net N and P mineralization from root varied little between crop species: 0.9–1.6 kg N ha^{-1} and 0.1–0.3 kg P ha^{-1}. Nitrogen fertilization increased DM loss, and N and P release from straw residues.

Keywords Decomposition · Mineralization · Nitrogen · Phosphorus · Root and straw residues

Introduction

In recent years there has been a reduction in mixed farming and an increase in farms without livestock and practicing continuous grain production in North America and Europe. As a result, crop rotation with cash crops such as oilseed and pulse crops rather than legume forage crops has become quite common in farming systems. In such crop production systems, crop residues are the main source of organic materials that provide energy for heterotrophic soil microorganisms and maintain soil organic matter levels. Plant nutrients are recycled as microbes decompose the plant residues. The decomposition and nutrient loss of cereal straw residues have been studied extensively (Brown and Dickey 1970; Douglas et al. 1980; Christensen 1986). However, despite the importance of roots as a source of soil organic matter, their decomposition and mineralization have received relatively little attention. Field studies of prairie grassland suggest that roots decay more rapidly than foliage (Seastedt 1988; Seastedt et al. 1992). Seyni and Salema (1995) found in a greenhouse study that cowpea (*Vigna unguiculata* L.) root contributed 7–22% of the N uptake of the following millet crop compared to 4% for millet root.

Pulse crop and canola (or oilseed rape; *Brassica napus* L.) residues usually contain higher concentrations of N and P, and therefore return more of those nutrients to the soil, than cereal residues (Strong et al. 1986; Armstrong et al. 1994). Armstrong et al. (1994) reported that pea (*Pisum sativum* L.) straw in Australia contained 19–50 kg N ha^{-1}. However, in northwestern Alberta, Canada, pea straw returned an average of 22 kg N ha^{-1} compared to 16 kg N ha^{-1} for wheat straw and 50 kg N ha^{-1} for canola straw (Soon and Clayton 2002). Moreover, Bremer and van Kessel (1992) estimated that only 7% of N in lentil (*Lens culinaris* L.) straw was mineralized in the following growing season, similar to wheat (*Triticum aestivum* L.), and concluded that lentil straw was not a significant source of N. Few studies have compared mass and nutrient loss in the field of residues of crops such as canola and pea with those of cereal crops. Such data are required to better understand the role of various crop residues in nutrient cycling in agro-ecosystems. Also few studies have been conducted in cold agricultural soils (e.g. Cochran 1991; Koenig and Cochran 1994). Therefore, we initiated

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a study to evaluate the significance of canola and pea residues as sources of N and P.

The objective of this study was to estimate and compare the dry matter (DM), and N and P release from above-ground and root residues of wheat, canola and pea in a no-till agricultural field in a northern environment characterized by cool, short summers and cold, long winters, and a sub-humid climate. A second objective was to determine if decomposition and nutrient loss of residues was affected by N fertilizer application.

Materials and methods

The experimental site, located at the Agriculture and Agri-Food Canada research farm near Beaverlodge, Alberta (55°12′N 119°23′W), has a mean annual temperature of 2.0°C and total precipitation of 445 mm. The soil is an Albright silt loam, a Dark Grey Luvisol in the Canadian classification (Canada Soil Survey Committee 1978), and a fine montmorillonitic, frigid, Mollic Cryoboralf in the soil taxonomy (Soil Survey Staff 1994). Its Ap horizon had 37 g kg^{-1} organic C, 3.1 g kg^{-1} total N, and a pH (1:2 soil:water suspension) of 5.3.

The decomposition study was conducted using three crop rotations from an existing no-till experiment: (1) continuous wheat, (2) canola-wheat-wheat, and (3) pea-wheat-wheat. Each treatment was replicated four times in a randomized complete block design, and each plot was 7.5×30 m. For the decomposition study each plot was split into two subplots, with one half receiving no fertilizer N [other than what was applied as 11–51–0 (monoammonium phosphate) to supply P], and the other half 60 kg N ha^{-1}. Pea did not receive N other than that applied in 11–51–0, and the seed was inoculated with a granular inoculant. Phosphate fertilizer (11–51–0) was applied at rates varying from 15–20 kg P ha^{-1}, depending on the crop. Canola also received 6–10 kg S ha^{-1} as potassium sulfate. Sulfate and phosphate fertilizers were drilled with the seed, and the remaining N was banded (as urea) 3 cm beside and below the seed row. Seed rows were 23 cm apart. Weeds were controlled with herbicides.

Decomposition of residues, as measured by DM loss, from the first-course crop of the rotations was followed for approximately 11 months after the 1997 crop harvest. The decomposition study was repeated in 1998/1999. At crop maturity, plant shoots from two 1-m^2 areas of subplots were cut at ground level and threshed. Straw (cut to 5 cm lengths, if necessary), leaves and chaff (including podshells of canola and pea) were combined to constitute the above-ground samples which, for the sake of brevity, will be subsequently referred to as "straw". Crop roots were obtained by excavating six 25×23-cm areas centered along decapitated crop rows to a depth of approximately 12.5 cm. Loose soil was allowed to drop off by gentle shaking. In the laboratory, soil was washed from roots after soaking in a bucket of water for 10–15 min. Soil aggregates adhering to roots were washed off in a jet of water, supplemented by gentle brushing if necessary, and broken roots were caught on 0.5-mm sieves. Roots were dried between paper towels and kept in a refrigerator until ready for placement in plots. Subsamples of roots and straws were dried in a forced-convection oven at 65°C for 48 h to determine the moisture content. The mean percentage DM for each crop tissue type was used to convert weight of residues on placement in the field to a dry weight basis.

Ten grams straw residues were put in each nylon mesh bag (16.5×15.5-cm size), corresponding to a residue rate of 390 g DM m^{-2} . Root samples from two plants of pea or canola, or five plants of wheat were placed in each nylon bag (11 cm wide and 16 cm long). The mass of roots in individual bags were recorded and converted to a moisture-free (65°C) basis. Seven bags of each residue type were returned, as soon as possible, to the subplots they originated from after the plots had been combine-harvested. Straw bags were placed on the soil surface and held in place against wind-blow by a metal wire pushed into the ground at both ends. Root samples were buried vertically in the soil with the bottom edge of sample bags about 15 cm below the soil surface. A slit was made in the soil with a spade to bury the bags, thus minimizing soil disturbance. Each bag was randomly given a number to denote its position in the sampling sequence and marked with an orange-colored tag to facilitate its subsequent retrieval. One bag of each residue type was retrieved per subplot on each sampling date. The mesh size of the bags was 1 mm in 1997/1998, and 1.5 mm in 1998/1999.

A cool and relatively moist growing season in 1997 lengthened the growth period for the crops. Crops were harvested 2–4 weeks later than usual: on 7 September for pea, and on 3 October for canola and wheat. Mesh bags for peas were returned to plots on 10 September, and on 16 October for canola and wheat. Pea residues were first retrieved on 15 October. Canola and wheat residue retrievals started on 4 November. On the first retrieval date of 1997, pea roots were seen to have been damaged by wildlife, resulting in a loss of samples from two subplots. Thereafter, to prevent loss or disturbance by wildlife, bagged residues were covered with chicken wire mesh stretched across a wooden frame which was pegged to the ground. Sampling continued in 1998 on 14 April, 29 April, 5 June and 9 July. In spring 1998, the residue bags were removed prior to, and returned to the subplots after, seeding operations.

In the 1998/1999 repetition of the study, mature crop residues were taken from plots on 19 August, and processed samples returned in mesh bags on 26 August. We increased sample size of roots by using three roots of pea or canola instead of two per bag. Wheat root sample size remained at five roots per bag. Sample retrieval dates were: 17 September, 1 October, 15 October, and 5 November in 1998, and 27 April and 13 July in 1999.

Upon retrieval, samples in mesh bags were soaked in 1-l beakers filled with de-ionized water for 5–10 min and gently shaken to disperse and remove adhering soil particles. The waste water was passed through a 0.5-mm sieve to retrieve fine particulate material. The residue samples were dried at 65°C in a forced-convection oven and weighed. Weight loss was calculated by subtracting recovered residue dry weight from the original dry weight. Nutrient recovery in crop residues was calculated in units of mg g^{-1} of initial residue DM to facilitate conversion to mass per unit area basis.

Mature plant and residue samples were ground to pass through a 0.5-mm sieve, digested by a modified Kjeldahl procedure using K_2SO_4 + Se as catalyst, and the digests analyzed for N (using the indophenol method) and P (using the molybdivanadate method) by automated colorimetry (Soon and Kalra 1995). Organic C in tissue samples was determined by hot chromic acid digestion and spectrophotometry (Soon and Abboud 1991). Lignin in composite mature plant samples was determined by digestion of acid detergent fiber in 12 M sulfuric acid (Central Testing Laboratory, Winnipeg, MB).

Statistical analyses were run using SAS programs (SAS Institute 1990). Because residue samples of different crops were not exposed to the environment for similar periods of time due to their differing maturity dates in 1997 and to missing data, only the means and standard errors were calculated for each sampling date of the 1997/1998 residue data. Data for each residue sampling date for the 1998/1999 study and for 1997/1998 and 1998/1999 mature crop samples were analyzed by ANOVA (PROC GLM) using a split-plot design with N rates as subplot treatments. Also, 1998/1999 data across all sampling dates were analyzed by repeated measures ANOVA using a profile transformation which generated contrasts between adjacent sampling times. Effects and interactions were considered significant at $P \leq 0.05$.

Results

The mean monthly rainfall and air temperature for the study period (May 1997 to August 1999) are shown in Fig. 1. The long term (30-year) average rainfall for the growth period (May–August) is 244 mm. The actual

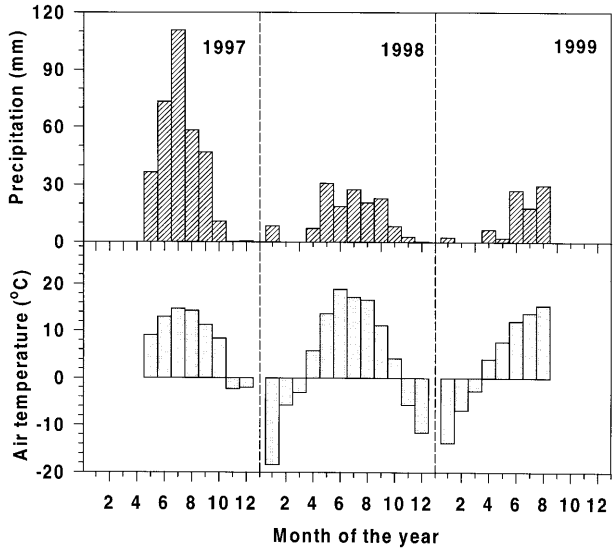

Fig. 1 Mean monthly air temperature and rainfall from May 1997 to August 1999

rainfall from May to August was 279 mm in 1997, 98 mm in 1998, and 96 mm in 1999. May to July of 1999 was also well below average in temperature, and this probably mitigated the effects of the drought on crop production. Mean daily temperature was mostly below 0°C between 7 November 1997 and 18 March 1998, and between 7 November 1998 and 5 April 1999.

Crop biomass and chemical composition of straw and root at maturity

At harvest the moisture content of straw ranged from 7% to 8.5% (1997 and 1998) and of root from 76% to 89% in 1997 and 58% to 73% in 1998. Wheat root consistently had a lower moisture content than pea or canola root. The means for canola and wheat straw DM in 1997 were significantly different between N-fertilized and unfertilized subplots (4.16 vs 2.87 Mg ha^{-1}, SE =0.265). However, in 1998, neither crop species nor N fertilizer had significant effects on straw production. Therefore, all data presented (except Table 2) are averages across N rates. In 1997, pea and wheat straw DM were not significantly different, however, both were significantly higher than that of canola straw DM (Table 1). Root DM production followed the trend: pea < canola < wheat (Table 1). The lower root DM production in 1997 was probably due to a cooler and moister soil than in 1998. The N concentrations of roots were significantly higher for pea as compared to canola or wheat, while the P concentration of canola straw was significantly higher than that of wheat straw. Pea straw P concentration was intermediate. Wheat straw and root consistently had the lowest N and P concentrations of the crops studied.

Carbon concentrations of the residues showed little variation: the range was 380–440 mg g^{-1} for straw, and 340–440 mg g^{-1} for root. The C/N ratios were higher in straw than root (Table 1). Pea root had the lowest C/N ratio, and wheat straw the highest. Roots had higher lignin content than straws, and canola straw had a higher lignin content than pea or wheat straw.

Nutrients returned to soil in residues were estimated from the product of residue DM and nutrient concentration. Nitrogen returned in pea straw residues varied from 31–41 kg ha^{-1} compared to 17–24 kg ha^{-1} for wheat and 16–20 kg ha^{-1} for canola. Nitrogen returned in root residues ranged from 2–3 kg ha^{-1} for pea to 2–6 kg ha^{-1} for wheat or canola. Phosphorus returned in crop residues was approximately one order of magnitude lower than N.

Dry matter loss from decomposing residues

In 1997, canola and wheat straws lost approximately 5% of their initial DM by the onset of winter in early November, while pea straw lost 10% (Fig. 2a). This can be attributed to the difference in the decomposition period, 55 days for pea compared to 20 days for canola and

Table 1 Dry matter (*DM*) and chemical composition of field pea, canola and wheat straw and root at maturity in 1997 and 1998 (*ND* not determined)

Crop/Year	Straw					Root				
	DM	N	P	C/N	Lignin	DM	N	P	C/N	Lignin
	Mg ha^{-1}	mg g^{-1}			g g^{-1}	Mg ha^{-1}	mg g^{-1}			g g^{-1}
1997										
Canola	2.28	7.04	1.29	71	0.15	0.24 (0.031)[a]	8.84	1.44	58	0.17
Pea	5.83	7.09	0.91	66	0.13	0.14 (0.007)	18.38	1.54	23	0.16
Wheat	4.75	5.06	0.81	97	0.11	0.45 (0.056)	7.59	0.92	59	0.18
SE (9 *df*)	0.63	0.56	0.09	ND	ND	ND	1.29	0.15	ND	ND
1998										
Canola	3.49	5.86	0.81	89	0.12	0.69 (0.073)	8.57	1.22	56	0.16
Pea	4.34	7.19	0.47	54	0.10	0.16 (0.010)	22.25	1.48	18	0.15
Wheat	4.23	4.00	0.29	105	0.095	0.70 (0.091)	7.43	0.52	48	0.14
SE (9 *df*)	0.25	0.75	0.12	ND	ND	ND	1.34	0.32	ND	ND

[a] SEs are shown separately for each crop because of the lack of homogeneity of the variance. Data are for the 12.5-cm depth

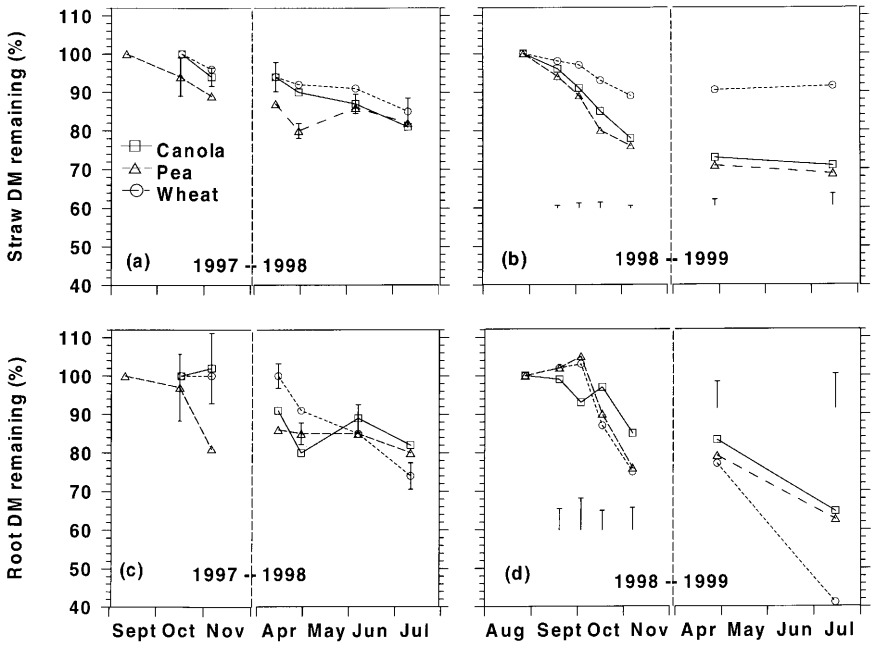

Fig. 2 Straw dry matter (*DM*) recovery during decomposition in **a** 1997/1998 and **b** 1998/1999, and root DM recovery during decomposition in **c** 1997/1998 and **d** 1998/1999. Typical standard errors (±1 SE) are shown for crop species in 1997/1998. Standard errors (1 SE) for 1998/1999 are pooled across crop species.

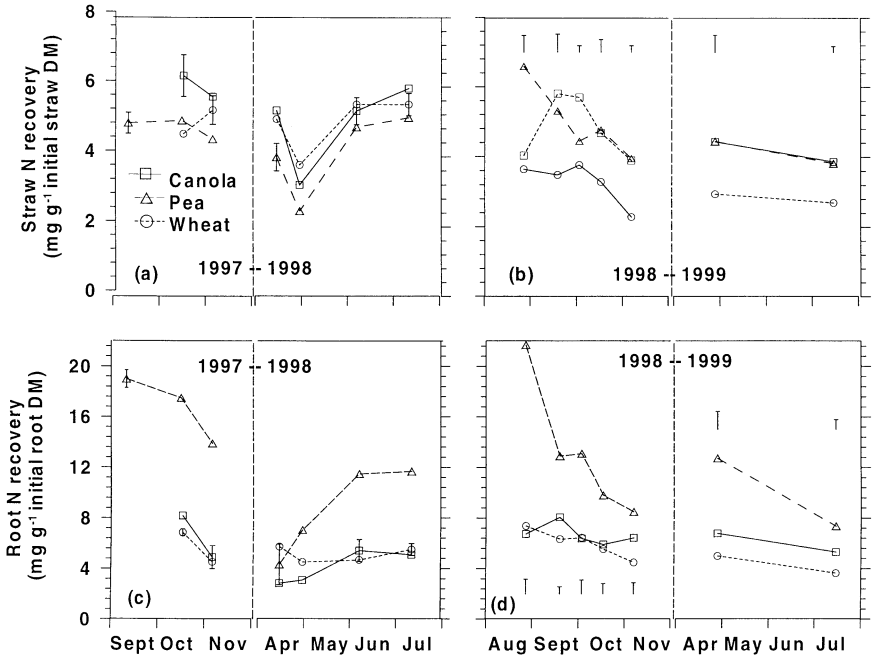

Fig. 3 Straw N recovery during decomposition in **a** 1997/1998 and **b** 1998/1999, and root N recovery during decomposition in **c** 1997/1998 and **d** 1998/1999. Typical standard errors (±1 SE) are shown for crop species in 1997/1998. Standard errors (1 SE) for 1998/1999 are pooled across crop species

wheat, as well as to the quality of the residues. In the period between April and July, canola straw lost another 13% of its DM, compared to 9% for wheat and 5% for pea. Pea root lost 19% of its dry mass in the autumn of 1997 compared to no measurable loss for canola or wheat root (Fig. 2c). Total root DM loss through July, however, was 26% for wheat, 20% for pea and 18% for canola.

Repeated measures ANOVA of 1998/1999 straw and root data indicated that there was a significant crop × time-of-sampling interaction (P =0.01), in addition to significant effects of time of sampling. Also, straw DM loss was higher in N-fertilized than unfertilized subplots until July (Table 2). Pea and canola straws lost DM at a significantly higher rate (24% and 22%, respectively) than wheat straw (11% loss) during autumn in 1998 (Fig. 2b). The greater mass loss for 1998 compared to 1997 is most likely due to the earlier harvest in 1998, hence more time for residues to decay before cold weather arrived. By July of the following growth period, DM loss increased to 32% for pea and 30% for canola, while it remained at 11% for wheat. The low rate of DM loss from straw in 1999 was probably due to a combination of low ambient temperature and moisture (Fig. 1). In autumn 1998, pea and wheat roots lost 25% of their DM

Table 2 Effect of N fertilizer application on mass and N and P recovery of straw in 1998/1999[a] (*DM* dry matter)

N fertilizer treatment	Date of sampling					
	17/9/98	1/10/98	15/10/98	5/11/98	27/4/99	13/7/99
Proportion of initial straw DM recovered						
–N	0.97	0.93	0.89	0.83	0.79	0.76
+N	0.95	0.91	0.85	0.80	0.75	0.76
Pr > F	0.02	0.01	0.05	0.01	0.02	0.99
N recovered in straw (mg g^{-1} of initial DM)[b]						
–N	5.34	5.04	4.58	3.77	4.57	3.89
+N	4.38	4.22	3.90	2.98	3.30	3.02
Pr > F	0.04	0.15	0.10	0.01	0.04	0.02
P recovered in straw (mg g^{-1} of initial DM)[c]						
–N	0.61	0.55	0.51	0.40	0.48	0.40
+N	0.42	0.43	0.40	0.29	0.30	0.30
Pr > F	0.01	0.11	0.10	0.05	0.05	0.06

[a] Data apply to canola and wheat straws only because pea plots received no N fertilizer
[b] N concentration at burial: –N, 4.96; +N, 4.65 mg g^{-1}. SE =0.298, 7 *df*
[c] P concentration at burial: –N, 0.43; +N, 0.40 mg g^{-1}. SE = 0.016, 7 *df*

compared to 15% for canola root. However, crop species effect on root DM loss was only significant at the July 1999 sampling (Fig. 2d) when accumulated DM loss was in the order: wheat (59%) > pea (38%) = canola (36%). In contrast to straw residues which were placed on the soil surface, root residues (buried) lost considerable DM (16–35%) between April and July.

After approximately 10–11 months, straw residues lost 15–20% of their initial dry weight in 1997/1998 compared to 10–32% in 1998/1999. Roots lost 18–26% of initial DM in 1997/1998 compared to 36–59% in 1998/1999. Root residues decayed faster than straw residues mainly because conditions within the soil were more favorable to decomposition: moisture and temperature varied less, and residues, biota and soil N were in close proximity. It is noteworthy that wheat straw exhibited the least DM loss (10–15%) while wheat root incurred the highest DM loss (26–59%).

Nitrogen release and retention

The portion of nutrients not recovered in crop residues at sampling was assumed to be mineralized and released into the soil where they may remain in mineral form or be immobilized or denitrified (in the case of N). The possibility of leaching loss is low during the growing season in the subhumid environment of the study area. There was little net N mineralization from straw residues from autumn 1997 to early spring 1998 (Fig. 3a). Straw N was rapidly released from all crop species during April 1998. However, there was a substantial increase in the N recovered in the residues in the summer of that year, indicating N immobilization. In contrast, release of N before the winter in 1998/1999 was evident for pea and wheat straws (Fig. 3b). Nitrogen was immobilized in canola straw in early autumn in 1998 and subsequently released before winter. Nitrogen mineralization from straw, as indicated by N recovery in residues, was greater on most sampling occasions in N-fertilized than unfertilized subplots (Table 2). Nitrogen released from straw from fertilized subplots over 11 months averaged 5.6 kg ha^{-1} compared to 3.8 kg ha^{-1} from unfertilized subplots.

In contrast to straw, N loss from decomposing roots was evident in autumn 1997, especially pea root (Fig. 3c). Pea root lost almost 10 mg N g^{-1} of initial DM between November and April. Subsequently, roots of canola and pea accumulated N (with little apparent DM loss) through July. Nitrogen loss per unit of root in 1997/1998 was least for wheat. During autumn 1998, approximately 13 mg N g^{-1} net was mineralized from pea root compared to 3 mg N g^{-1} from wheat and nil from canola (Fig. 3d). The April sampling indicated immobilization of N by pea root but this was followed by more mineralization. Release of N from wheat and canola roots during 1999 was slight.

Estimates of crop residues as a source of N after 10–11 months of decomposition ranged from 1 kg ha^{-1} or less of N mineralized from canola straw or root, and immobilization of 0.9 and 4 kg N ha^{-1} by pea and wheat straws in 1997/1998, to net mineralization of 4 and 12 kg N ha^{-1} by wheat and pea straws in 1998/1999 (Table 3). Roots exhibited less tendency to immobilize soil N, and due to their smaller mass, mineralized smaller amounts of N than straw. However, a higher percentage of the N contained in roots was mineralized compared to that in straws.

Phosphorus release and retention

Phosphorus was mineralized in significant amounts from pea straw only in autumn 1997, with no measurable amount released in summer 1998 (Fig. 4a). Canola and wheat straws lost significant amounts of P only during April in 1998. Straw P concentration of the 1998 crop was low (Table 1), consequently, there was little net mineralization of P in 1998/1999 (Fig. 4b). Straw residue P recovery was consistently lower in fertilized than unfertilized subplots, although the differences were significant on only three sampling occasions (Table 2). The higher recovery of P in straw residues from unfertilized as com-

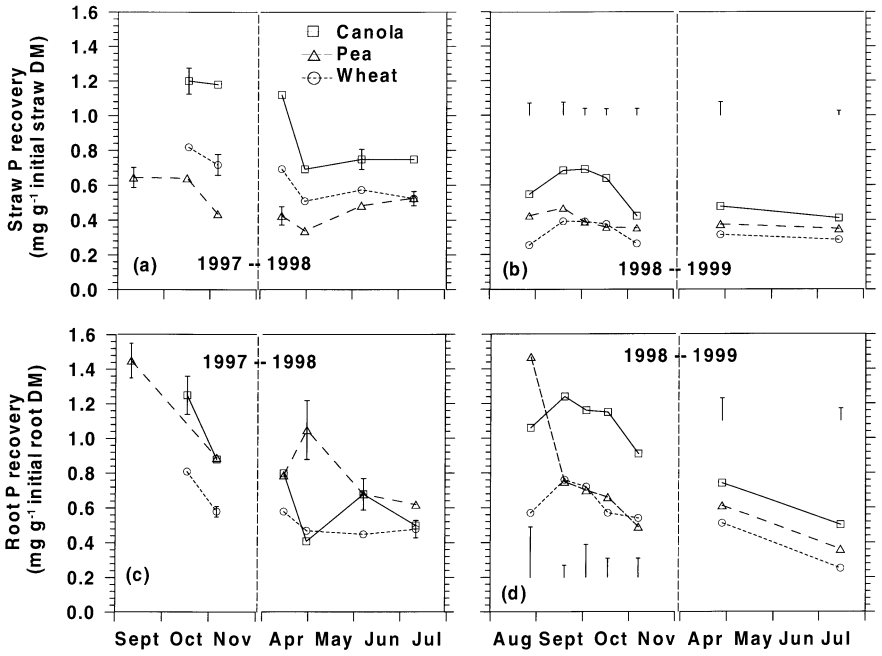

Fig. 4 Straw P recovery during decomposition in **a** 1997/1998 and **b** 1998/1999, and root P recovery during decomposition in **c** 1997/1998 and **d** 1998/1999. Typical standard errors (±1 SE) are shown for crop species in 1997/1998. Standard errors (1 SE) for 1998/1999 are pooled across crop species

Table 3 Estimates of N and P mineralized (+ *values*) from or immobilized (– *values*) by various straw and root residues after 10–11 months (*ND* not determined)

Year/Crop species	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})	
	Straw	Root	Straw	Root
1997/1998				
Canola	0.8 (5.9)[a]	0.74 (38)	1.03 (38)	0.18 (60)
Pea	–0.9	0.87 (38)	0.68 (18)	0.10 (57)
Wheat	–4.0	0.60 (20)	1.39 (36)	0.15 (41)
SE (9 *df*)	0.32	ND	0.05	ND
1998/1999				
Canola	0.6 (4.2)	1.00 (22)	0.48 (25)	0.39 (53)
Pea	12.1 (42)	1.86 (64)	0.33 (18)	0.15 (76)
Wheat	4.0 (26)	2.62 (51)	–0.13	0.22 (56)
SE (9 *df*)	0.13	ND	0.02	ND

[a] Values within parentheses are percentages of initial amount

pared to fertilized subplots at the first sampling after field placement is attributed to P immobilization. There was no initial difference in crop straw P concentration due to fertilization regime. Phosphorus released from autumn 1998 to summer 1999 was 0.37 kg P ha^{-1} from N-fertilized subplots compared to 0.17 kg P ha^{-1} from unfertilized subplots. Phosphorus mineralized from roots (in mg g^{-1}of root DM) decreased in the order: pea > canola > wheat (Fig. 4c, d), however, pea produced the least amount of root DM. Root residues exhibited no tendency to immobilize P. Phosphorus mineralized from straw ranged from 0.6–1.4 kg ha^{-1} in 1997/1998 to 0–0.5 kg ha^{-1} in 1998/1999, and root residues consistently released no more than 0.4 kg P ha^{-1} (Table 3).

Discussion and conclusions

Parker (1962) reported that the decomposition rate of corn stalk residues was higher in N-fertilized than unfertilized plots on three of ten sampling occasions. Our 1998/1999 data also showed that N fertilization increased mass loss, and N and P mineralization of straw but not root residues. Since N fertilization did not increase straw N and P concentrations (Table 2), i.e. residue quality, the observed effects are attributed to greater N availability with fertilization.

The decomposition of straw among the three test crops after approximately 10–11 months followed the order: pea ≥ canola > wheat. Root decomposition data showed more variability than straw decomposition, partly because an average %DM for each crop type was used to convert fresh weight to dry weight, and moisture content of root samples varied considerably. The decomposition rate of straw among the crop types was directly related to residue N concentration and/or C:N ratio, as found by Janzen and Kucey (1988), and lignin content played only a secondary role, if any. The decomposition of roots was not controlled by N concentration or the C:N ratio. Pea root with more than twice the N concentrations of canola and wheat roots (Table 1) lost DM at similar rates as wheat and canola roots for much of the study period (Fig. 2c, d).

Canola straw production was below average for the study area in 1997 (Table 1), therefore, estimates of nutrients mineralized would likely be below normal levels. Nitrogen uptake in canola straw of 50 kg ha^{-1} has been observed in another study (Soon and Clayton 2002) compared to 16–20 kg ha^{-1} in the present experiment. Our estimate for pea root mass could be low also. The dry matter of roots of peas grown in different environments

was found by Jensen (1989; by excavation to an unspecified depth) to be 200 kg ha^{-1}, by Biederbeck et al. (1993) to range from 100 to 303 kg ha^{-1} (to 30 cm depth), and by Armstrong et al. (1994) to vary from 450 to 550 kg ha^{-1} (to 20 cm depth). Our possible under-estimation due to incomplete recovery of fine roots should not exceed 10–20%. Brief washing of residues should result in negligible loss of nutrients since N lost from residues due to washing was reported to be less than 0.02% (Douglas et al. 1980). Our data on nutrient release from roots should be considered minimum estimates also because we recovered plant roots to only a 12.5-cm depth (where most organic matter turnover in soil should be confined to).

Canola straw had a consistently low net N mineralization of 1 kg N ha^{-1}or less, and approximately similar contribution from the root. Pea straw immobilized 1 kg N ha^{-1} one year and net mineralized 12 kg N ha^{-1} in another. Wheat straw showed a net N mineralization of 4 kg N ha^{-1} one year and immobilized as much N another year. When immobilization did not occur, decomposing pea and wheat straws contributed more available nutrients to the soil than roots. Nutrients were not immobilized by roots in our study as was found by Seastedt and co-workers (Seastedt 1988; Seastedt et al. 1992). However, a greater proportion of N and P turned over in roots than in straws during the 10–11 months of residue decomposition: 20–64% of root N and 41–76% of root P compared to a maximum of 42% of straw N and 38% of straw P (Table 3).

Net N mineralization from wheat residues have been reported in the range of 2.0 to 2.6 kg N ha^{-1} for inputs of straw N ranging from 17 to 30 kg N ha^{-1} (Wagger et al. 1985; Bremer and van Kessel 1992). Using ^{15}N-labeled residues, Stevenson et al. (1998) estimated that aboveground pea residues contributed 10 kg N ha^{-1} to the subsequent wheat crop, whereas wheat residues contributed only 3 kg N ha^{-1}. Muller and Sundman (1988) reported that approximately twice as much mineralized N (34–46%) from legume residues was found in the soil as was recovered by the subsequent barley crop (17–24%). Ladd et al. (1981) found only 5–10% of legume residue N in the following wheat crop as compared to 72–78% remaining in soil organic matter, and concluded that the main value of legume residues as a source of N is long term, i.e. maintaining soil N concentrations at adequate levels.

An assessment of the contribution of crop-derived nutrients to nutrient cycling has to also consider rhizodeposition during crop growth. Rhizodeposition of N into the soil by the crop plant has been estimated to range from 22% to 46% of total below-ground, plant-derived N for pea (Sawatsky and Roper 1991), and from 18% to 33% of assimilated N for wheat (Janzen 1990). Those data suggest that rhizodeposition can release significant amounts of N.

In conclusion, pea and canola straws decomposed more rapidly over 10–11 months than wheat straw, while the converse was true for root residues. Substantially more N was net mineralized from pea straw than root, and nearly equal amounts from canola straw and root. Decomposing wheat root was a more consistent source of N than wheat straw. More P was released from decomposing crop straw than root. However, a higher percentage of N and P was turned over in root than straw. The percentage of nutrients mineralized from straw varied more from year to year than those from root. Average N mineralized from straw and root combined were: pea (7.0 kg ha^{-1}) > canola (1.6) = wheat (1.6). Average P mineralized varied from 0.6 kg ha^{-1} for pea to 1.0 kg ha^{-1} for canola. Fertilizer N resulted in greater DM loss and N and P release from straw and no significant differences in root DM loss or nutrient release.

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