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Soil respiration within riparian buffers and adjacent crop fields

A. Tufekcioglu*, J.W. Raich, T.M. Isenhardt, and R.C. Schultz

A.Tufekcioglu; Dep. of Forestry, 253 Bessey Hall, Iowa State Univ., Ames, IA 50011,
Phone: (515) 294 3289, *Corresponding author (*atufekcl@iastate.edu*)

J.W. Raich; Dep. of Botany, 353 Bessey Hall, Iowa State Univ., Ames, IA 50011

T.M. Isenhardt; Dep. of Forestry, 253 Bessey Hall, Iowa State Univ., Ames, IA 50011

R.C. Schultz; Dep. of Forestry, 253 Bessey Hall, Iowa State Univ., Ames, IA 50011

This manuscript has 24 pages of text, 2 figures and 2 tables

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Key words: agroecology, soil-CO₂ emissions, soil moisture, soil temperature

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Abstract

We quantified rates of soil respiration among sites within an agricultural landscape in central Iowa, USA. The study was conducted in riparian cool-season grass buffers, in re-established multispecies (switchgrass + poplar) riparian buffers and in adjacent crop (maize and soybean) fields. The objectives were to determine the variability in soil respiration among buffer types and crop fields within a riparian landscape, and to identify those factors correlating with the observed differences. Soil respiration was measured approximately monthly over a two-year period using the soda-lime technique. Mean daily soil respiration across all treatments ranged from 0.14-8.3 g C m⁻² d⁻¹. There were no significant differences between cool-season grass buffers and re-established forest buffers, but respiration rates beneath switchgrass were significantly lower than those beneath cool-season grass. Soil respiration was significantly greater in both buffer systems than in the cropped fields. Seasonal changes in soil respiration were strongly related to temperature changes. Over all sites, soil temperature and soil moisture together accounted for 69 % of the seasonal variability in soil respiration. Annual soil respiration rates correlated strongly with soil organic carbon (R =0.75, P<0.001) and fine root (<2 mm) biomass (R=0.85, P<0.001). Annual soil respiration rates averaged 1140 g C m⁻² for poplar, 1185 g C m⁻² for cool-season grass, 1020 g C m⁻² for switchgrass, 750 g C m⁻² for soybean and 740 g C m⁻² for corn. Overall, vegetated buffers had significantly higher soil respiration rates than did adjacent crop fields, indicating greater soil biological activity within the buffers.

1 **Introduction**

2 Natural and re-established riparian buffers reduce nonpoint source pollutants
3 derived from upland agricultural lands, and enhance terrestrial and aquatic habitat (Hill,
4 1996; Isenhardt et al., 1997; Jordan et al., 1993; Peterjohn and Correll, 1983; Schultz et al.,
5 1995). The quality of soils in riparian buffers plays an important role in facilitating these
6 functions. To a large extent, the rates at which organic matter is provided to and cycles
7 through riparian soils mediate their effectiveness as living filters between agricultural
8 fields and surface waters. Soil respiration is an excellent indicator of total soil biological
9 activity, and therefore of overall soil quality (Karlen et al., 1997; Parkin et al., 1996).

10 Riparian areas differ from uplands in soil and hydrologic characteristics, but few
11 studies of soil respiration have been conducted in riparian zones (Griffiths et al., 1997;
12 Tufekcioglu et al., 1998). Their location between crop fields and streams places riparian
13 buffers in a unique position to serve as sinks for sediments, nutrients, and pesticides; to
14 protect stream banks from erosion; and to reduce excessive runoff into stream channels
15 (National Research Council, 1993). To fulfill these functions, riparian buffer soils should
16 have high biological activity and conditions that foster water infiltration and gas
17 diffusion.

18 The rate of soil respiration is controlled primarily by the rate of CO₂ production
19 by biota within the soil, but is modified by factors influencing the CO₂ movement out of
20 the soil (Raich and Schlesinger, 1992; Schlesinger, 1977). Environmental factors such as
21 soil moisture and temperature influence soil biological activity and CO₂ diffusion, and
22 therefore have pronounced influences on the seasonal dynamics of soil respiration
23 (Davidson et al., 1998; Kowalenko et al., 1978; Singh and Gupta, 1977). Factors such as

1 the availability of soil organic matter and density of plant roots, which provide the
2 substrates for soil biological activity, may control the overall magnitudes of soil
3 respiration (Bowden et al., 1993; Franzluebbers et al. 1995; Kelting et al., 1998).

4 The objective of this study was to compare rates of soil respiration among two
5 riparian buffer systems and their adjacent crop fields, and to identify the underlying
6 environmental variables most likely causing differences in soil respiration among sites,
7 and among seasons within sites. We hypothesized that riparian buffers have higher rates
8 of soil biological activity, and therefore have higher rates of soil respiration than do
9 adjacent croplands

11 **Materials and methods**

12 This study was conducted on a private farm along Bear Creek, in Story County,
13 Iowa, USA (42° 11' N, 93° 30' W). The study was done on two types of riparian buffers
14 (multi-species riparian buffer and cool-season grass buffer), and in adjacent crop fields.
15 Multi-species riparian buffers were established along Bear Creek in 1990 on soil that had
16 been cultivated or grazed for more than 75 years. The basic design of the multi-species
17 buffer consists of five rows, at 1.2 x 1.8 m spacing, of hybrid poplar (*Populus X*
18 *euroamericana* 'Eugenei') planted closest to and parallel to the creek. Upslope from the
19 trees are a row of red osier dogwood (*Cornus sericea* L.) and a row of ninebark
20 (*Physocarpus opulifolius* L.). A 7.3 m-wide strip of switchgrass (*Panicum virgatum* L.),
21 a native warm-season grass, is planted upslope from the shrubs at the interface with the
22 cropped fields (Schultz et al., 1995). Cool-season grass buffers were directly adjacent to
23 the multi-species riparian buffers and were formerly grazed riparian meadows, dominated

1 by cool-season grasses, that form the traditional streamside management system in this
2 intensively cropped region.

3 Six transects, three each bisecting cool-season and multispecies buffers, were
4 established in either side of a 0.8 km stretch of Bear Creek, perpendicular to the stream.
5 In multispecies buffers soil respiration was measured in poplar (streamside), switchgrass
6 (cropside) and in the cropfield plots. In cool-season buffers soil respiration was
7 measured in streamside plots, cropside plots and in the adjacent cropfield plots. The
8 cool-season grass sites were divided into a streamside and cropside plots to control for
9 the potential effect of distance from stream on soil respiration. Plot sizes varied from 7 X
10 10 m to 10 X 15 m. The crop fields were under an annual maize-soybean rotation.
11 Maize (*Zea mays* L.) usually was planted in the early May and harvested at the end of
12 October. Soybean (*Glycine max* (L.) Merr.) usually was planted in mid-May and
13 harvested in mid-September. The cool-season grass sites were part of a grazed riparian
14 pasture prior to 1989 when grazing was stopped. Dominant grass species in the cool-
15 season grass sites were smooth brome (*Bromus inermis* Leysser.), timothy (*Phleum*
16 *pratense* L.), and Kentucky bluegrass (*Poa pratensis* L.). These same species were also
17 found in the poplar understory.

18 The study sites were on Coland soil (fine-loamy, mixed, mesic Cumulic
19 Haplaquoll) which is well drained to poorly drained and formed from till or local
20 alluvium and colluvium derived from till (DeWitt, 1984). The soils graded into Clarion
21 soils (fine-loamy, mixed, mesic Typic Hapludolls) in the croplands distant from the
22 stream (DeWitt, 1984). Our sampling was conducted mainly in Coland soils, but two
23 crop and two switchgrass plots were in Coland-Clarion transitional soils. Average slope

1 of the study area was 2 %. Organic carbon contents of the soils (0-35 cm depth) were
2 obtained from Marquez et al. (1999) who examined organic matter fractions of the same
3 plots (Table 1). The biomass of fine (0-2 mm) roots was assessed by sequentially
4 collecting five 35-cm deep, 5.4-cm diameter cores per plot each month from April
5 through November in 1996. Roots were sorted into live and dead fractions based on the
6 elasticity of their tissues and the color of the cortex (Tufekcioglu et al., 1999).

7 Soil respiration rates were measured approximately monthly in three randomly
8 selected locations in each of the three plots (i.e. vegetation types) per transect from July
9 1996 to August 1998 using the soda-lime method (Cropper et al., 1985; Edwards, 1982;
10 Raich et al., 1990). The soda-lime method may underestimate actual soil respiration rates
11 at high flux rates (e.g. Ewel et al., 1987; Haynes and Gower, 1995). However, the
12 method does distinguish between higher and lower flux rates and, therefore, it is an
13 appropriate method for comparing sites.

14 Buckets 20 cm tall and 27.5 cm in diameter were used as measurement chambers.
15 One day prior to measurements, plastic rings with the same diameter were placed over
16 the soil and carefully pushed about 1 cm into the soil. All live plants inside the plastic
17 rings were cut to prevent aboveground plant respiration. Carbon dioxide was absorbed
18 with 60 g of soda-lime contained in 7.8 cm diameter by 5.1 cm tall cylindrical tins. In the
19 field, the plastic rings were removed, measurement chambers were placed over the tins of
20 soda-lime, and the chambers were held tightly against the soil with rocks. After 24 h the
21 tins were removed, oven dried at 105° C for 24 h, and weighed. Blanks were used to
22 account for carbon dioxide absorption during handling and drying (Raich et al. 1990).
23 Soda-lime weight gain was multiplied by 1.69 to account for water loss (Grogan, 1998).

1 Soil temperature was measured at 5 cm soil depth adjacent to each chamber in early
2 morning. Gravimetric soil moisture was determined by taking soil samples at 0-5 cm
3 depth and drying them at 105 C for 24 h on the day that the soda-lime tins were removed
4 from the plots. Soil moisture was not measured in winter, when the soil was frozen.

5 Statistical comparisons were made using the general linear models procedure of SAS (SAS
6 Institute 1985). We used ANOVA to compare soil respiration rates, soil temperatures, and soil moisture
7 contents among buffer types, position from stream (streamside, cropland and cropland), and sampling
8 dates using a repeated measures design. Paired comparisons among vegetation covers, plot positions and
9 sampling dates were determined with Least Significant Difference test (SAS Institute, 1985) at $\alpha=0.05$.
10 Step-wise multiple regression analysis was performed to evaluate the importance of soil temperature and
11 soil moisture on seasonal soil respiration rates. The possible effects of soil organic carbon content and fine
12 root biomass on annual soil respiration rates were evaluated among vegetation types with correlation
13 analysis.

14 **Results**

15 Among all treatments, mean daily soil respiration ranged from 0.14 to 6.7 g C m⁻²
16 d⁻¹ (Fig. 1A). Highest rates were observed in late July when soil temperatures were high,
17 while lowest rates were observed in January when soil temperatures were minimal (Fig.
18 1B). Soil respiration varied significantly among sampling dates and landscape positions
19 ($P<0.0001$). The cropped fields had significantly lower soil respiration than did all plots
20 in riparian buffers. Soil respiration in multi-species riparian buffers was not significantly
21 different than in cool-season grass buffers. Within the riparian buffers, the poplar and
22 cool-season grass sites had significantly greater soil respiration rates than did the
23 switchgrass plots ($P<0.05$).

1 Soil temperature and soil moisture varied among landscape positions and
2 sampling dates ($P<0.01$) (Fig. 1B & 1C). Soil temperatures in the crop fields were
3 significantly ($P<0.05$) different from those in switchgrass, being higher in the spring and
4 the summer; and lower in the winter, but no other temperature differences among
5 different vegetation components of buffers and crops were found. Soil moisture contents
6 under the poplar, cropland cool-season grass and switchgrass sites were significantly
7 greater than in the corn, soybean and streamside cool-season grass sites ($P<0.05$).

8 Within sites, seasonal changes in soil respiration were correlated most highly with
9 soil temperature. When all sites were considered together, mean daily soil respiration
10 varied with soil temperature and moisture ($r^2 = 0.69$, $P<0.0001$):

$$\ln(\text{SR}) = 0.0865 T + 0.0246 M - 0.264$$

12 where SR is the soil respiration rate ($\text{g C m}^{-2} \text{ d}^{-1}$), T is morning surface-soil (0-5 cm
13 depth) temperature ($^{\circ}\text{C}$) and M is surface-soil (0-5 cm depth) gravimetric moisture
14 content (% H_2O). All three parameters were significant ($P<0.01$).

15 Among sites, mean annual soil respiration rate correlated positively with mean
16 soil organic carbon content, dead fine root biomass, live fine root biomass, total fine root
17 biomass (dead + live) and soil moisture content (Table 2, Fig. 2). Despite the pronounced
18 influence of soil temperatures on seasonal variations in soil respiration (Fig. 1), mean
19 annual soil respiration rates among vegetation types did not correlate with mean annual
20 soil temperatures (Table 2). Soil temperature and soil moisture were negatively
21 correlated, suggesting that high (mean annual) soil temperatures were associated with
22 drier soils. Live, dead and total fine root biomass were positively correlated at $P<0.005$,
23 so we discuss total fine root biomass only, which had the highest correlations with soil

1 respiration rates. Soil moisture, total fine root biomass, and soil organic carbon content
2 were all positively correlated with one another (Table 2), making the clear identification
3 of cause and effect impossible.

4 For summary comparisons, annual soil respiration rates were estimated by
5 calculating the average soil respiration rate per month over the duration of the study and
6 assuming February respiration equaled the average of the January and March rates.
7 Annual soil respiration totaled 1220 g C m⁻² for streamside cool-season grass, 1150 g C
8 m⁻² for cropland cool-season grass, 1140 g C m⁻² for poplar, 1030 g C m⁻² for switchgrass,
9 750 g C m⁻² for soybean and 740 g C m⁻² for the corn sites.

11 Discussion

12 The mean daily soil respiration rates measured in this study (0.14 to 6.7 g C m⁻² d⁻¹)
13 were similar to those observed by others (Coleman, 1973; Jurik et al., 1991; Kucera &
14 Kirkham, 1971; Lessard et al., 1994). Soil respiration increased from winter to summer
15 and decreased from summer to fall, as is typical in temperate latitudes (e.g., Hudgens and
16 Yavitt, 1997; Kowalenko et al., 1978). Kowalenko et al. (1978) reported that temperature
17 was limiting during the winter and spring (cold and moist) and moisture was limiting
18 during the summer or fall. A similar effect of temperature on soil respiration was
19 observed in this study; but temperature was also a limiting factor during late fall.
20 Although soil moisture was higher or similar in November than in August; soil
21 respiration was higher in August than in November (Fig 1). This indicates the limiting
22 effect of temperature during fall. Significant soil temperature differences were only
23 observed between the switchgrass and cropped plots. Soil temperature in the switchgrass

1 sites was higher in fall and lower in spring than in adjacent crop fields. Switchgrass
2 produces aboveground biomass up to 16300 kg ha⁻¹ (Huang et al., 1996). The surface
3 litter in the switchgrass sites probably delayed soil warming in early spring and cooling in
4 late fall.

5 While temperature was the most important factor driving seasonal variation in soil
6 respiration (Fig. 1), it was not significant in terms of explaining variation among
7 vegetation types (Table 2). The crop fields had the highest average soil temperature but
8 the lowest overall soil respiration rates. This is probably due to lowest root biomass, soil
9 organic carbon and water contents in the crop fields (Table 1).

10 Soil respiration rates in the buffer sites were significantly higher than in the crop
11 fields (Fig. 1). Previous comparisons between perennial and adjacent cropped systems by
12 other researchers have given inconsistent results. Higher soil respiration rates in a forest
13 than a nearby corn field were reported by Lessard et al. (1994), whereas Beyer (1991)
14 found both higher and lower soil respiration rates in forests compared to cropped fields.
15 Grasslands had higher rates of soil respiration than did cropped fields in studies by de
16 Jong (1981) and Wagai et al. (1998), but Buyanovsky et al. (1987) found lower overall
17 soil respiration rates in a prairie than in a winter wheat system. In our case, the higher
18 soil respiration rates in the buffers were correlated with more soil organic carbon
19 contents, greater fine root biomass, and higher soil moisture contents, all of which
20 correlated significantly with one another (Table 2).

21 Respiration by roots and their associated microbial components represent a
22 significant part of soil respiration in most ecosystems (Bowden et al., 1993; Kelting et al.,
23 1998). While live roots directly contribute to soil respiration, dead roots and root

exudates provide carbon as an energy source and nutrients for microbial biomass. Grayston et al. (1996) reported that root exudates stimulate microbial growth and activity because they are readily assimilated, and they may act as primers for the degradation of existing soil organic matter. In a native prairie, belowground litter contributed 20-25 %, root respiration contributed 25-30 %, and decay of organic matter contributed 30-35 % of the total soil respiration (Buyanovsky et al., 1987). Root respiration accounted for 33-50 % of total soil respiration in broad-leaved forests, 17-40 % in grasslands, and 12-38 % in crop fields in temperate regions (Raich and Tufekcioglu, 1999). Higher annual soil respiration in poplar, switchgrass and cool season grass sites compared to crop sites might be driven mainly by root biomass, and soil organic matter content differences among sites.

Switchgrass had the highest live fine root biomass, but soil respiration was lower in switchgrass sites than in poplar and cool-season grass sites. This might be due to either relatively low root turnover, low root respiration of switchgrass, or low C:N ratio of switchgrass detritus. Hartnett (1989) reported that switchgrass produced long-lived rhizomes and maintained intact rhizome interconnections among stems up to 10 y. Substrate quality and root respiration differences between the switchgrass and cool-season grasses might also result in different soil respiration rates. For example, Wedin (1995) reported that low-quality litter from the prairie grass *Schizachyrium scoparium* (Michx.) Nash., a C₄ species, decomposed slowly and immobilized large amounts of N, whereas litter from the C₃ grass *Agropyron repens* (L.) Beauv. decomposed faster and showed no net N immobilization. We hypothesize that physiological or substrate-quality

1 differences between switchgrass and the cool-season grass species may lead to lower
2 rates of C cycling in the soils beneath switchgrass.

3 Soil organic matter is an important determinant of soil respiration and soil
4 moisture. Franzluebbers et al. (1995) found a significant relationship between soil
5 organic carbon and soil respiration in crop fields planted with soybean, sorghum and
6 wheat under no-tillage regimes. Management practices also influence soil respiration
7 rates through their influence on soil organic matter (Franzluebbers et al., 1995). In
8 general, cultivation decreases the soil organic matter content of agricultural soils except
9 in intensively manured fields. Decreases from 20 to 68 % in soil organic carbon were
10 reported depending on years under cultivation (Collins et al., 1999; Ellert and Gregorich,
11 1996, Mann, 1986). Lower soil organic matter under crops are likely the result of the
12 combined effect of annual vegetation and management practices.

13 Soil moisture differences among sites were probably also driven by soil organic
14 matter differences. Water holding capacity of soil increases with an increase in soil
15 organic matter (Kern, 1995). More soil organic matter in the poplar and grass plots may
16 have enhanced soil respiration by providing carbon as an energy source to
17 microorganisms and by increasing the water-holding capacity of the soil. Increased water
18 holding capacity provides better conditions for root growth and for microorganisms,
19 which may lead to higher soil respiration. Rochette et al. (1997) found that soil
20 respiration in moist soil was two to three times greater than in drier soils. Soil moisture
21 contents under crop fields were significantly lower than under other vegetation types
22 except the streamside cool-season grass. The relatively low soil moisture content of the

1 streamside cool-season grass plots (Fig. 1C) was due to sandy sediment deposited on the
2 soil surface by flooding events.

3 Annual carbon release values found in this study ($740\text{--}1220\text{ g C m}^{-2}\text{ y}^{-1}$) are
4 within the ranges reported by others. Soil respiration rates in our grass sites ($1030\text{--}1220$
5 $\text{g C m}^{-2}\text{ y}^{-1}$) were higher than those observed in tallgrass prairie by Risser et al. (1981)
6 ($660\text{ g C m}^{-2}\text{ y}^{-1}$), and Buyanovsky et al. (1987) ($490\text{ g C m}^{-2}\text{ y}^{-1}$), who also used static,
7 closed chamber techniques. Rates in prairie ecosystems measured with dynamic IRGA-
8 based systems include $450\text{ g C m}^{-2}\text{ y}^{-1}$ in Missouri (Kucera and Kirkham, 1971), 720 g C
9 $\text{m}^{-2}\text{ y}^{-1}$ in Wisconsin (Wagai et al., 1998), and $1100\text{--}2100\text{ g C m}^{-2}\text{ y}^{-1}$ in Kansas (Bremer
10 et al., 1998; Knapp et al., 1998). Our crop field values ($740\text{--}750\text{ g C m}^{-2}\text{ y}^{-1}$) are slightly
11 higher than those found in a winter wheat ecosystem in Missouri ($640\text{ g C m}^{-2}\text{ y}^{-1}$)
12 (Buyanovsky et al., 1987), and from tilled and no-till corn in Wisconsin ($508\text{--}534\text{ g C m}^{-2}$
13 y^{-1}) (Wagai et al., 1998); and are close to those found in a soybean field in Missouri (760
14 $\text{g C m}^{-2}\text{ y}^{-1}$) (Buyanovsky and Wagner, 1995).

15 The buffers had significantly higher rates of soil respiration than did the crop
16 fields, but were also closer to the stream. Therefore, a position effect might be expected.
17 However, switchgrass and cropland cool-season grass sites were in the same positions,
18 yet they had significantly different soil respiration rates. There was no significant
19 difference between streamside and cropland grass sites, suggesting that stream- and
20 cropland cool-season grass sites were similar or no position effect existed under the same
21 vegetation type. Overall, the perennial vegetation present in the buffers supported higher
22 rates of C cycling through the soil than did annual crops. These higher rates of soil
23 respiration are evidence of high rates of the biological activity that promote the

effectiveness of riparian buffers as living filters between agricultural fields and surface waters.

Acknowledgments

Journal Paper No. J-17839 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project No. 3332, and supported by Hatch Act and State of Iowa funds. The research has also been funded in part by the Iowa Department of Natural Resources through a grant from the U.S. Environmental Protection Agency under the Federal Non-point Source Management Program (Section 319 of the Clean Water Act), by the Leopold Center for Sustainable Agriculture, a State of Iowa Institution located at Iowa State University, and by the U.S. Department of Agriculture National Research Initiative Competitive Grants Program award number 95-37192-2213.

This material was prepared with the support of a grant from the Agriculture in Concert with the Environment (ACE) program, which is jointly funded by the U.S. Department of Agriculture, Cooperative State Research, Education and Extension Service, and the Environmental Protection Agency under Cooperative Agreement No. 94-COOP-1-0809.

Any opinions, findings, conclusions, or recommendations expressed here in are those of the authors and do not necessarily reflect the views of the U.S. Department of Agriculture or the Environmental Protection Agency.

We would like to thank to Akif Karsli, Kathie Taylor, Michelle Ludwig, Seyrani Goncagul and Zeki Gokalp for their assistance with this study in the field and laboratory.

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1 **Figure Legend**

2 Figure 1: Mean monthly (± 1 SE) soil respiration rates (A), soil temperature (B), and soil
3 moisture content (0-5 cm depth) (C) in poplar, cool-season grasses (CSG-S:
4 streamside, CSG-C: cropland), soybean and maize sites in central Iowa, averaged
5 over the two year period, 1996-1998.

6 Figure 2: Mean annual soil respiration in relation to soil organic carbon (A) and root
7 biomass content (0-35 cm depth) (B) in Bear Creek Watershed, Iowa (n=18).

8

1 Table 1: Mean soil respiration, soil temperature, soil moisture, soil organic carbon and
2 root biomass in the six vegetation types investigated in this study (n=3 plots per
3 vegetation). Root data are from Tufekcioglu et al. (1999) and soil organic carbon
4 data are from Marquez et al. (1999); both refer to the surface 35 cm of soil.

	Poplar	Switch-	Streamside	Cropside	Soybean	Corn
Vegetation types		grass	Cool-season grass	Cool-season grass		
Mean soil respiration (g C m ⁻² d ⁻¹)	3.34	2.99	3.55	3.33	2.16	2.15
Mean soil organic carbon content (g kg ⁻¹)	41.7	28.3	34.0	29.5	14.8	21.1
Mean dead fine root biomass (<2 mm) (g m ⁻²)	174	146	256	365	53	39
Mean live fine root biomass(<2 mm) (g m ⁻²)	646	896	673	704	91	111
Mean soil temperature(C)	4.67	4.40	4.73	4.57	4.94	4.58
Mean soil moisture (g g ⁻¹)	0.32	0.28	0.21	0.29	0.17	0.17

5

1 Table 2: Pearson correlation coefficients among measured variables in the study area
2 (n=18). Asterisks refer the level of significance; *, P<.05; **, P<.01; ***, P<.001

Variables	SOC	DFRB	LFRB	TFRB	M	T
SR ¹	.751***	.809***	.796***	.857***	.672***	-.288
SOC	1.0	.506*	.579**	.600**	.649**	-.287
DFRB ²		1.0	.658**	.803***	.529*	-.164
LFRB ²			1.0	.977***	.662**	-.410
TFRB ²				1.0	.673**	-0.371
M					1.0	-.730***

3

4 1 SR: soil respiration ($\text{g C M}^{-2} \text{ d}^{-1}$); SOC: Mean soil organic carbon content (g kg^{-1}).

5 2

6 3 DFRB, LFRB & TFRB: Mean dead, live and total fine root biomass (g m^{-2}),
7 respectively.

8 M: Mean soil moisture (%).

9 T: Mean soil temperature (C)

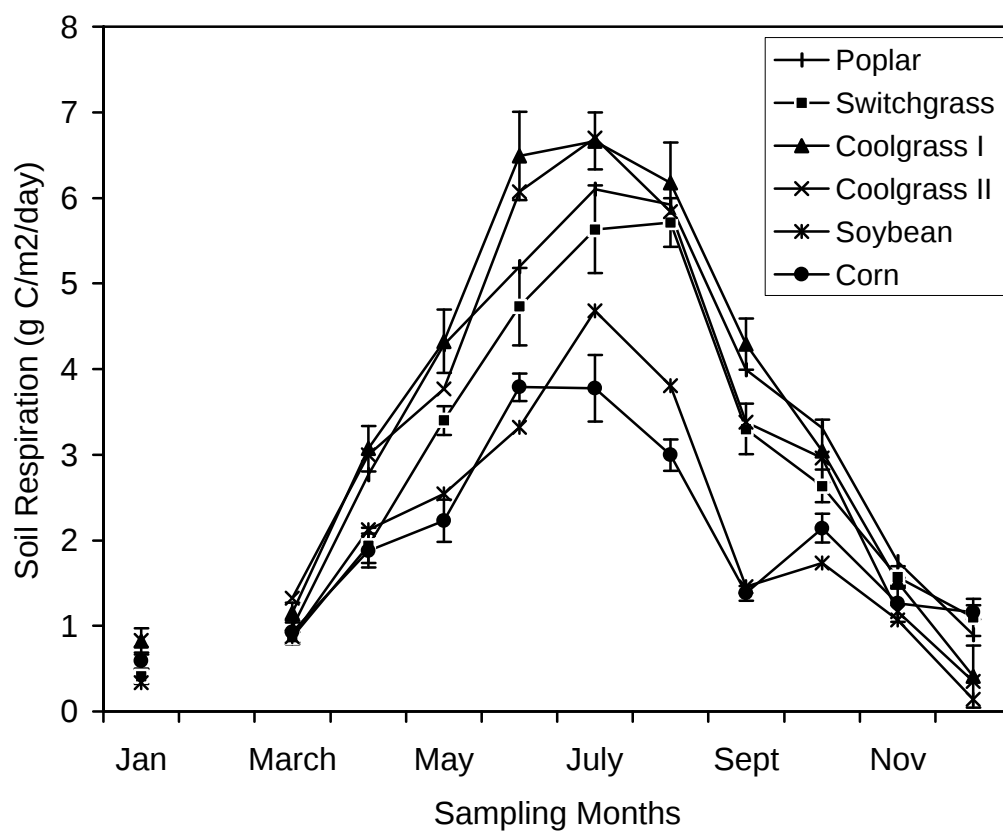
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1 **Figure Legend**

2 Figure 1: Mean monthly ($\pm$ 1 SE) soil respiration rates (A), soil temperature (0-5 cm
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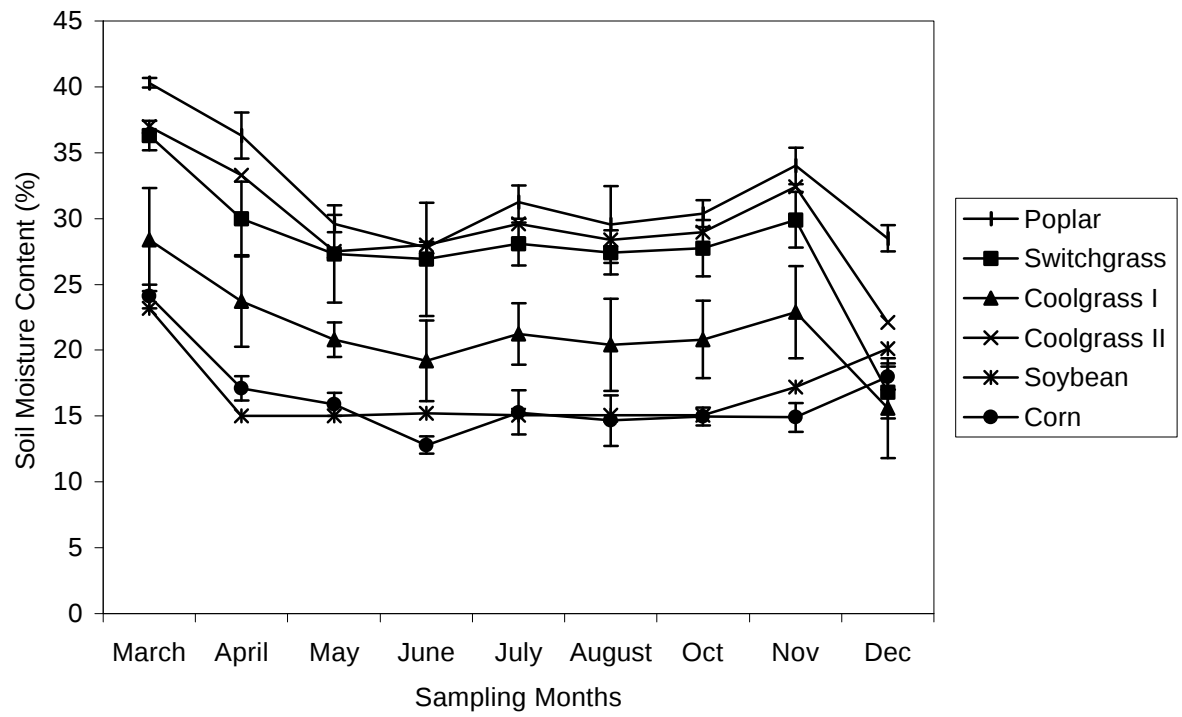
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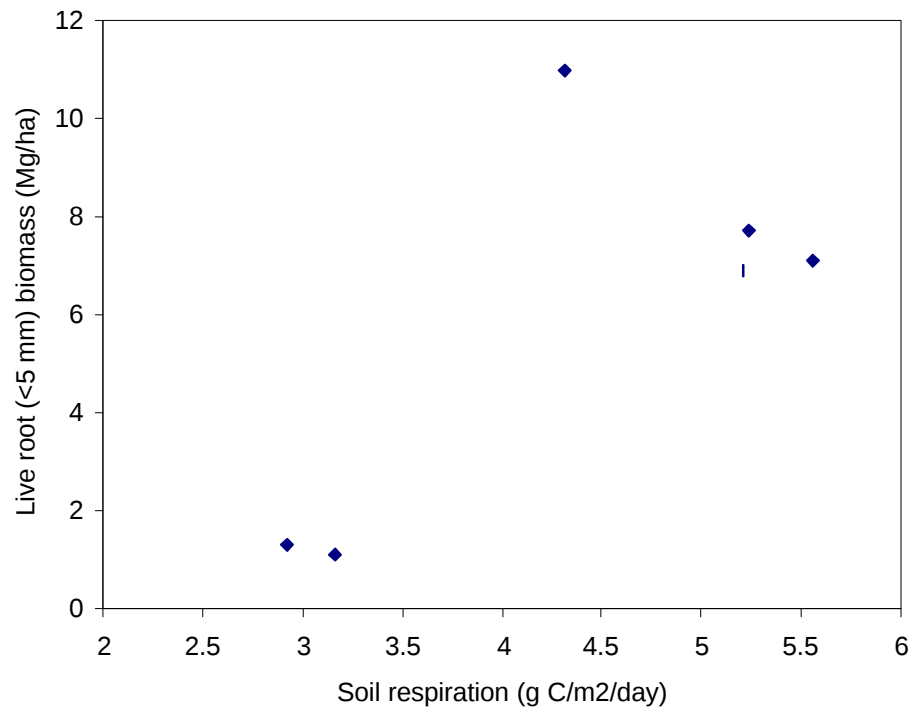
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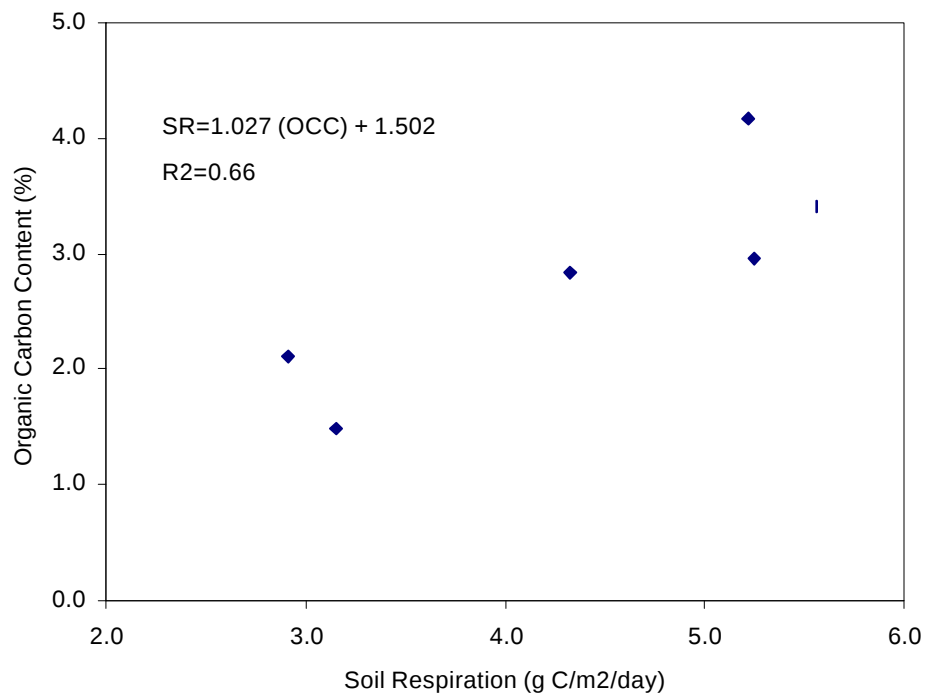
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