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Review

An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada

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Abstract

The current interest in characterizing, predicting and managing soil C dynamics has focused attention on making estimates of C inputs to soil more accurate and precise. Net primary productivity (NPP) provides the inputs of carbon (C) in ecosystems and determines the amount of photosynthetically fixed C that can potentially be sequestered in soil organic matter. We present a method for estimating NPP and annual C inputs to soil for some common Canadian agroecosystems, using a series of plant C allocation coefficients for each crop type across the country. The root-derived C in these coefficients was estimated by reviewing studies reporting information on plant shoot-to-root (S:R) ratios ($n = 168$). Mean S:R ratios for annual crops were highest for small-grain cereals (7.4), followed by corn (5.6) and soybeans (5.2), and lowest for forages (1.6). The review also showed considerable uncertainty (coefficient of variation for S:R ratios of ~50% for annual crops and ~75% for perennial forages) in estimating below-ground NPP (BNPP) in agroecosystems; uncertainty was similar to that for Canadian boreal forests. The BNPP (including extra-root C) was lower for annual crops (~20% of NPP) than for perennial forages (~50%). The latter was similar to estimates for relative below-ground C allocation in other Canadian natural ecosystems such as mixed grasslands and forests. The proposed method is easy to use, specific for particular crops, management practices, and driven by agronomic yields. It can be readily up-dated with new experimental results and measurements of parameters used to quantify the accumulation and distribution of photosynthetically fixed C in different types of crops.

Keywords: Roots; C inputs; C allocation; Uncertainty; Agroecosystems; Natural ecosystems

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1. Introduction

Increases in the concentration of CO_2 in the atmosphere have prompted renewed interest in increasing the stocks of carbon (C) in the world's croplands to mitigate climate change and also improve soil quality (IPCC, 2000; Lal, 2004a,b). To better characterize, predict and manage soil C dynamics, we need more precise and accurate estimates of C inputs to soil. The C fixed in plants by photosynthesis and added to soil as above- and below-ground litter, is the primary source of C in ecosystems (Warembourg and Paul, 1977). Predicting the changes in C stocks (notably in soils), therefore, depends on reliable estimates of net primary productivity (NPP) and the proportion of the NPP returned to the soil (Paustian et al., 1997; Grogan and Matthews, 2002; Bolinder et al., 2006; Campbell et al., 2000; Izaurralde et al., 2001). The concept and definition of NPP varies in the literature. Scurlock and Olson (2002) defined NPP as the increase in plant mass plus losses (such as mortality, herbivory, etc.), summed for both above- and below-ground compartments per unit area of ground per unit of time.

The annual NPP in agroecosystems, and the distribution of C in plant parts, is usually calculated from agricultural yield, the plant component most often measured. In cereal crops, for example, C inputs from post-harvest above-ground residue (i.e., straw) is estimated from grain yields using 'harvest index' values or related regression relationships, and below-ground C inputs are calculated from shoot-to-root (S:R) ratios (Bolinder, 2004; Campbell et al., 2000). While such approaches have been useful, better estimates of crop NPP are needed to adequately assess regional and national contributions of agriculture to the global C budget (Prince et al., 2001).

The largest uncertainty in deriving NPP may originate in estimates of below-ground NPP (BNPP), including inputs from roots, exudates, and other root-derived organic material from root-turnover (root hairs and fine roots that are sloughed during the growing season). Though a large proportion of NPP is allocated to below-ground plant parts (Li et al., 2003; Stanton, 1988), the amount of BNPP is one of the most poorly understood attributes of terrestrial ecosystems (Laurenroth, 2000). Quantifying these below-ground C inputs, notably from exudates and other ephemeral root-derived materials, is difficult and remains a research priority (Balesdent and Balabane, 1996; Gill et al., 2002; Grogan and Matthews, 2002; Kurz et al., 1996; Kuzyakov and Domanski, 2000).

Our objective was to develop a set of coefficients for estimating total annual NPP, C allocation patterns, and annual C inputs to soil for common agricultural crops in Canada. To do this, we outline a broadly applicable approach for expressing NPP and C allocation in plants, with an emphasis on BNPP, and provide estimates of coefficients, based on a review of the literature, largely from Canadian studies. This approach, using values easily updated, can then be used in modelling efforts to estimate soil C changes in agricultural soils of Canada.

2. Estimates of root biomass in Canadian agroecosystems

We reviewed data from studies with field measurements of shoot and root biomass at or near plant maturity (i.e., harvest), considering only studies published after 1970. Most of the studies were conducted in Canada, though some U.S. studies were included when Canadian data were insufficient and the climate was similar to that in Canada (Tables 1 and 2).

2.1. Description of experiments

The crops in all studies were usually fertilized according to local recommendations, except where the experiment involved fertilizer treatments. Most of the data we used were from studies with conventional experimental designs (i.e., randomized-block, split–plot, split–split–plot and criss–cross) with two to five replicates. Only a few studies involved a field (Soon, 1988; Allmaras et al., 1975), or unreplicated field-plots (Buyanovsky and Wagner, 1986; Kisselle et al., 2001) sub-divided to provide pseudo-replicated experimental units. The number of sub-samples taken for root biomass measurements from each experimental unit (which were subsequently averaged) varied from one to six, but usually one to two sub-samples were taken.

Where possible, we reported or calculated S:R ratios at the treatment level. The data reported for the study by Bowren et al. (1969) on forages (Table 2) were averaged across fertilized and unfertilized treatments (effects were not