PREDICTING PLANT-AVAILABLE NITROGEN RELEASE FROM COVER CROP RESIDUES

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ABSTRACT
Improved methods are needed to estimate the timing and amount of plant-available N (PAN) release from cover crops. The OSU Organic Fertilizer and Cover Crop Calculator, a downloadable spreadsheet tool, assists agricultural professionals in estimating N fertilizer replacement value of organic inputs. We conducted a series of laboratory incubations with cover crop biomass incorporated into soil to determine: (i) speed of PAN release, (ii) amount of PAN release, and (iii) robustness of the OSU Calculator predictions of cover crop PAN across a variety of cover crop types, crop maturities, and soils. Incubations were conducted in moist sandy loam and silt loam soils, and PAN was measured after 28 and 70d. In all three years of incubation studies, measured PAN from cover crops at 70d was equal or greater than that predicted by the literature regression equation implemented within the 2010 version of the Calculator. The general approach implemented in the Calculator, the prediction of PAN contribution from cover crops based on cover crop analytical data, is a step up from traditional static values for "cover crop N credits" traditionally used in university fertilizer or nutrient management guides. Adjustments for soil temperature and moisture conditions are the next steps in Calculator refinement. We welcome collaboration with others to extend the range and utility of our Calculator.

INTRODUCTION
Adoption of national rules for Certified Organic food production in the USA in 2002 stimulated greater interest in organic farming and meeting crop N needs using manures, cover crops and other organic materials. Typical guidance for manure use in organic crop production (Kuepper, 2003) provides only typical total nitrogen analyses for manures with no estimate of PAN. Many correlations between N analyses of organic materials and the amount and timing of available N release have been reported for animal manures, crop residues, and other organic materials (Vigil and Kissel, 1991; Trinsoutrot et al., 2000).

The Organic Fertilizer and Cover Crop Calculator, available at the Oregon State University Small Farms website, is a planning tool that estimates PAN release from organic inputs based on total N concentration. We have found that most organic inputs (except compost) have total C concentrations close to 40%, so input N concentration acts as a surrogate for input C:N ratio. The Calculator predicts PAN for 28d and 70d after spring or early summer incorporation of organic material, assuming typical field conditions for our summer irrigated vegetable crops (moist soil; 20 to 25 ^{o}C). Equations for organic fertilizers and compost were developed based on laboratory incubation and field research conducted from 2002 to 2005 in western Oregon and western Washington (Gale et al, 2006) and published in the intial 2007 version of the Calculator (Andrews and Foster, 2007). We released a new version of the Calculator in 2010 that added a prediction equation for PAN release from cover crops. The prediction equation implemented within the new version of the Calculator was originally developed by Vigil and Kissel (1991) to predict PAN release from crop residues in Kansas:

$$\text{PAN (\% of cover crop total N)} = -53.44 + 16.98\,(\text{cover crop \%N} \times 10)^{1/2} \quad [1]$$

We chose this equation (referred to hereafter as the "VK Equation") to predict PAN from our cover crops because it was based on a range of plant materials, and because it was developed based on both field and laboratory studies. We wanted to be conservative in our estimates of PAN release, in order to avoid under-predicting PAN release under field conditions for our growers. Because the VK Equation was based in part on studies with mature crop residues, we thought it likely to be a conservative predictor of PAN release for our cover crop residues which are typically much younger (less advanced crop growth stage) and therefore a more labile source of PAN. The VK Equation is a square root equation that is of the same general shape as a linear plateau model, but with a more gradual approach to the "plateau" at higher total N concentrations. It is of a similar shape to linear plateau models implemented in the OSU Organic Fertilizer and Cover Crop Calculator for prediction of PAN from manures and other organic fertilizers.

METHODS

Above-ground cover crop cover crop biomass samples were collected from Willamette Valley fields in April or early May. Cover crops harvested in April were vegetative (jointing growth stage for cereals) with typical biomass of 2 to 4 Mg dry matter/ha In May, cover crops were flowering with typical biomass of 4 to 8 Mg dry matter/ha.

Cover crop samples were collected by cutting 60 x 60 cm quadrats at ground level. Whole plant samples were mixed, then subsampled. The subsamples of fresh cover crop biomass were sliced into pieces about 15-cm long, and stored by freezing in 3.8-L (1 gal) Ziploc freezer bags prior to incubation. At the start of each incubation, frozen cover crop biomass was sliced into smaller pieces (10 to 15-mm length) with a serrated knife and mixed repeatedly. A cover crop subsample was dried at 60^{o}C to determine cover crop dry matter. Cover crop total N concentration was measured using a LECO-CNS combustion gas analyzer equipped with an infrared detector.

Soils used in the cover crop incubations (pH 5.5 to 6.5) were collected from vegetable farms in the Willamette Valley, OR. They were silt loam soils (Mollisols) derived from Missoula flood deposits or sandy loam soils (Inceptisols) derived from river-deposited alluvium. A few weeks prior to the start of an incubation experiment, moist soil was collected from the field and refrigerated. The soil was brought out of cold storage and allowed to reach room temperature prior to beginning the incubation trials. When necessary, additional moisture was added to achieve soil moisture of 230 to 270 g/kg for silt loam soils and 180 to 220 g/kg for sandy loam soils. To reach these moisture levels, soil was spread out and moistened by repeated misting and mixing. During a 70-d incubation, evaporation typically reduced soil moisture by 20-40 g/kg.

The defrosted, sliced cover crop biomass samples were mixed with approximately 650-g moist soil (equivalent to approx 500-g dry soil), then placed in an 0.9-L (1-quart) Ziploc freezer bags. The zipper at the top of each bag was closed except at one end, where a drinking straw was placed in the zipper. The inserted straw allowed air entry into bags during incubation. Cover crop addition rates were 5 to 10 g dry matter kg^{-1} soil (0.5 to 1.0%). We used large amounts of soil in the incubation bags so that we could add a representative sample of fresh, sliced cover crop biomass to the bags. Also, we wanted to have enough soil in bags so that sequential sampling of soil from the same bags did not change soil volume appreciably. The large incubation bags maintained uniform soil moisture for extended incubation times.

Plant-available N released from cover crop residues via mineralization in soil was determined using the difference method. Soil nitrate-N accumulation after 28d and 70d of incubation at 22^{o}C was measured in subsamples collected from the incubation bags. A composite sample of 10-g soil was removed from incubation bags and extracted with 50 mL of 2M KCl. The filtered KCl extract was analyzed for nitrate-N via an automated cadmium reduction method. Companion soil samples were dried at 104^{o}C for determination of moisture content. In preliminary trials, we confirmed that ammonium-N concentrations were very low for a variety of cover crop samples after 28-d, so we did not determine ammonium-N in these incubations. PAN released from cover crop residues was corrected for nitrate-N present in the soil-only control bags, and then expressed as a percentage of cover crop total N input:

$$\text{PAN (\%)} = \frac{\text{soil } NO_3\text{-N with cover crop (mg/kg)} - \text{soil-only control } NO_3\text{-N (mg/kg)}}{\text{Cover crop total N added to incubation bag (mg/kg)}} \times 100 \quad [2]$$

For the 2008 incubations, bulk cover crop samples were mixed in the lab to achieve mixtures of 0/100, 25/75, 50/50, 75/25, and 100/0% legume/non-legume (dry wt. basis). Legumes were crimson clover (Trifolium incarnatum) or common vetch (Vicia sativa); non-legumes were cereal rye (Secale cereale), oats (Avena sativa), or phacelia (Phacelia tanacetifolia). Total N concentration was determined for bulk single species cover crop samples only. The percentage of N present in cover crop mixtures was estimated using weighted averages of species total N concentrations. For 2008, each data point in Figure 1 represents the mean of 3 replications of the same cover crop mixture.

For the 2009 and 2010 incubations, cover crop samples were collected from on-farm field plots seeded to winter cover crops of cereal rye, cereal rye + common vetch, or phacelia + common vetch. These field samples contained variable amounts of each cover crop species in each sample (each data point in Figure 1 = one field sample). In 2010, weeds from winter fallow field plots were also collected for incubation.

RESULTS AND DISCUSSION

Speed and amount of PAN release. For cover crops having more than 3% total N, most of the PAN was released in 28d (Figure 1). Cover crop mixtures containing lower concentrations of N had less PAN at 28d, but PAN increased substantially between 28 and 70d. At 70d, PAN averaged 47% of total N for cover crops containing 3% total N, and PAN averaged 35% of total N for cover crop mixtures containing 2% total N (Table 1).

The PAN values determined for cover crops in this study are higher than those determined for manures and other organic amendments at similar total N concentrations in our previous research. This result is not unexpected, because fresh cover crop residues are a more labile substrate than manures than have undergone storage and some inorganic N loss prior to field application.

Calculator predictions using the VK regression model vs. measured PAN.

2008. Our choice of the VK regression model was based on incubation data from 2008. This data can be considered our "calibration data set" for the VK Equation, because we deliberately mixed legumes and cereal cover crop samples to attain a wide range of N concentrations. At 70d, the VK Equation fit the data tightly, except that it overpredicted PAN for solo cereal coveer crops with total N concentrations below 1.5%.

2009 and 2010. Cover crop PAN measured in 2009 and 2010 was used to test VK Equation predictions. These samples contained varying mixtures of cereals, vetch and weeds, so they were similar to real samples that would be collected by our Extension clientele. We attribute some of the increased variability in the PAN data observed in 2008 and 2009 to sampling error, the failure to collect a perfectly mixed cover crop subsample for incubation and for determination of cover crop total N. Another source of error arose from freeziing and thawing of cover crop samples, and consequent difficulty in accurately measuring the cover crop dry weight added to incubation bags. In spite of these added sources of variation, we think frozen samples are best for this kind of research in terms of accurately estimating PAN. We chose to use frozen samples for this study because a previous trial in our lab showed PAN from dried grass clippings samples was lower than PAN from from frozen or fresh samples (Sullivan et al., 2004).

Table 1. Plant-available N (PAN) measured in cover crop incubations vs. PAN predicted by the VK-Equation[a].

	PAN measured in cover crop incubation[a]				
Cover crop N concentration	2008	2009	2010	3-yr Avg,	PAN Predicted by VK Eqn
% dry wt.	.-----------------PAN (% of cover crop total N)-------				
		28-d incubation			
2.0	13	23	15	17	22
2.5	21	30	23	25	31
3.0	30	36	31	32	40
3.5	39	43	39	40	47
		70-d incubation			
2.0	27	37	41	35	22
2.5	33	43	48	41	31
3.0	38	49	54	47	40
3.5	44	55	61	53	47

[a]Values for "PAN measured" were calculated using the linear regression equations given in Figure 1.

All Years Combined

Table 1 shows measured vs. VK-Equation predicted PAN vs. measured PAN for all incubation years at 28d and 70d. Values for each incubation year in Table 1 were summarized using the linear regression equations in Figure 1.

At 28-d. the VK equation systematically over-predicted PAN. For example, at a cover crop total N concentration of 2%, VK-predicted PAN was 22%, while the 3-yr average measured PAN percentage was 17%. Similarly, when cover crop total N was 3.5%, VK-predicted PAN was 47% and 3-yr average measured PAN was 40%.

At 70-d, the VK equation systematically under-predicted PAN, especially at lower cover crop N concentrations. For example, at a cover crop total N concentration of 2%, VK-predicted PAN was 22%, while the 3-yr average measured PAN percentage was 35%. Similarly, when cover crop total N was 3.5%, VK-predicted PAN was 47% and 3-yr average measured PAN was 53%.

NEXT STEPS

The general approach implemented in the Calculator, the prediction of PAN contribution from cover crops based on cover crop analytical data, is a step up from traditional static values for "cover crop N credits" traditionally used in university fertilizer or nutrient management guides. Adjustments for soil temperature and moisture conditions are the next steps in Calculator refinement. We welcome collaboration with others to extend the range and utility of our Calculator.

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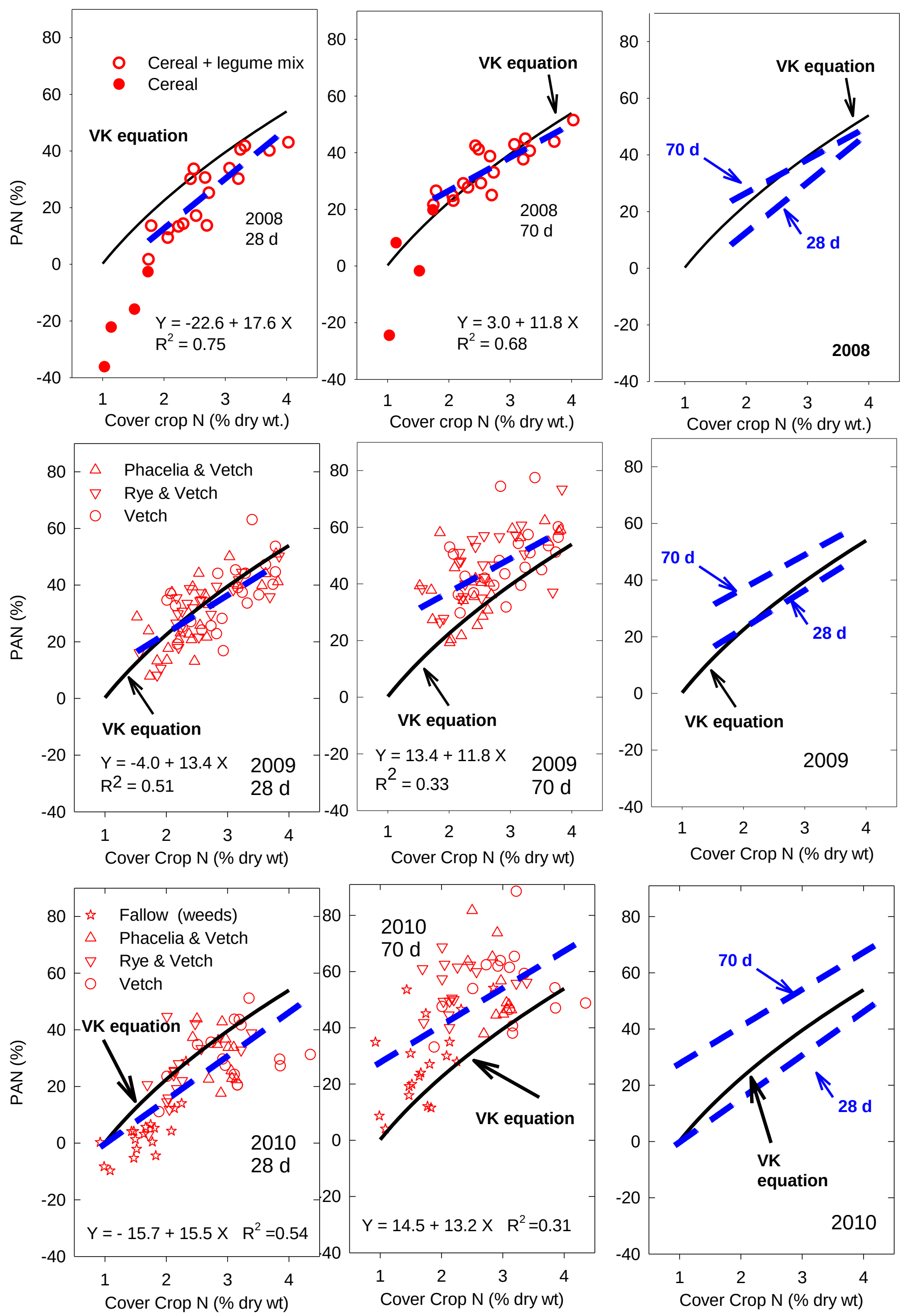

Figure 1. Relationships between cover crop residue total N concentration and plant-available N (PAN) determined in laboratory incubations in moist soil. Data from 2008 (top row), 2009 (middle row) and 2010 (bottom row). Within each year, PAN at 28d (left), PAN at 70d (middle), and linear regression PAN lines at 28d and 70d (right) are shown as compared with the "VK Equation" (Eq. 1; Vigil and Kissel, 1991). The VK Equation is currently implemented within the OSU Organic Fertilizer and Cover Crop Calculator. For 2008, only the data for cereal/legume mixes was fit to the listed linear regression equation (solo cereal crop data was omitted).