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Modeling in situ N mineralization in conservation tillage fields: comparison of two versions of the CERES nitrogen submodel

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Abstract

Knowing the amount of N available from crop residues and soil is important for determining the amount of fertilizer N needed by a crop. Nitrogen availability in conservation tillage systems is often difficult to assess because of uncertain interactions of surface residues with N mineralization processes. Estimates of residual N availability in cotton systems are more critical because both over- and underfertilization can reduce lint yields. The CERES plant growth models use a moderately complex N submodel to simulate many interacting factors influencing net N mineralization and could be useful as a tool to estimate N needs. Simulations of in situ net N mineralization under two cotton (*Gossypium hirsutum* L.) cover crop systems were conducted with the original N submodel (CERES-N) and a version modified to allow user input of soluble carbohydrate, cellulose, and lignin pool sizes (CERES-NP) and were then compared to field data. Both model versions indicated greater in situ net N mineralization following crimson clover (*Trifolium incarnatum* L.) than following rye (*Secale cereale* L.) cover crops. This agreed with results measured in a field study during 1997 and 1998. Simulations of in situ N mineralization were better with CERES-NP than for CERES-N and were improved for both versions when using decomposition parameters determined from data of a previous field study. Simulations of residue biomass and N loss from bagged residues in 1998 indicate that the original model tends to overpredict in situ net N mineralization which is most likely related to the overestimation of soil organic matter N mineralization. Results with CERES-NP indicate that it can be a better tool for estimating N needs for cotton in conservation tillage cover crop systems than the original CERES-N.

Keywords: Nitrogen mineralization; Model; CERES; Conservation tillage; Cotton

1. Introduction

Nitrogen management in cotton is critical because both under- and overfertilization can nega-

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tively affect yields (Mullins and Burmester, 1990). Success of crop management decisions depends on predicting residual N availability because of the role of N in controlling vegetative growth and lint yield of cotton. However, predicting N availability in long-term no-till systems is difficult because cover crop residues remaining on the surface decompose and release N more slowly than residues incorporated into the soil with conventional tillage systems (Douglas et al., 1980; Wilson and Hargrove, 1986; Holland and Coleman, 1987; Varco et al., 1993; Schomberg et al., 1994). Additionally, soil organic matter becomes more stratified and microbial communities associated with the surface residues and near surface organic matter experience significant fluctuations of climatic conditions (Franzluebbers et al., 1994). These fluctuations near the soil surface can stress the microbial communities and cause greater immobilization of N than in non-stressed communities (Franzluebbers et al., 1994).

Since eradication of the boll weevil in the early 1990s, cotton has re-emerged as a significant component of the farm enterprise in the Southeast and especially in Georgia where production increased from 0.3 million acres in 1990 to 1.5 million acres in 1998 (CTIC, 1998). Adoption of conservation tillage for cotton production in the Southeast ranges from 5 to 30%, and is increasing (CTIC, 1998). Problems with cotton establishment and N management following legume and non-legume cover crops are often cited as the reason for slow adoption of conservation tillage in cotton (Touchton et al., 1984; Bauer and Busscher, 1996; Daniel et al., 1999a). In a 2-year study, Touchton et al. (1984) showed that organic matter, soil N, and soil bulk density were not affected by legume cover crops in cotton, but there was an increase in infiltration rates. Cotton response to the additional N was observed only in the second year following vetch. Bauer and Busscher (1996) concluded that winter legumes were not good cover crops in cotton due to limited biomass production while Thompson and Varco (1996) found that N fixed by legumes could eliminate the need for N application to the following cotton crop. Daniel et al. (1999a,b) observed little difference among cover crops for conservation-tillage cotton production in the Virginia Piedmont. Nitrogen assimilation in rye and crimson clover residues were nearly the same (65 and 60 kg ha^{-1}) but during the first 3 weeks of cotton flowering, rye conserved more soil moisture in the top 15 cm than other cover crop residues due to slower decomposition rates. Apparent immobilization of N by wheat residues reduced cotton yields, while a grass–legume mixture resulted in the greatest yields. Adoption of cover crops should grow with the development of more sustainable production systems. However, better estimates of net N mineralization are needed to improve N management.

Efficient N management depends on understanding complex interactions among soil and site properties, crop characteristics, climate, and biological processes influencing N dynamics. Models of N dynamics within soil–plant–atmospheric systems provide useful tools to assess the transfer of N among crop residues, soil organic matter, microbial biomass, and mineral N (McGill et al., 1981; Diekkrüger et al., 1995). Applicability of models to management decisions beyond the region of development is often restricted due to limited availability of data sets for validation at diverse locations. Comparison among simulation models tested against identical data-sets is rare (de Willigen, 1991; Diekkrüger et al., 1995). Diekkrüger et al. (1995) found that results differed significantly among 19 models when tested with the same data sets. However, several of the models produced reliable estimates of N availability using simple model structures. Confidence in simulation models for management decisions is improved with validation under various conditions.

The CERES models are a widely applicable group of related crop–soil system simulation models developed in an international research network and designed to require a minimum input data set (Tsuji et al., 1994). The models share a common N submodel (Godwin and Jones, 1991) that partitions crop residue inputs into three pools (soluble carbohydrate, cellulose, and lignin) for predicting decomposition and N mineralization-immobilization. Tests of the original N submodel (CERES-N) have shown the need to decrease decomposition rate constants because of the overestimation of mass loss and net N mineralization from crop residues (Vigil et al., 1991; Bowen et al., 1993; Quemada and Cabrera, 1995; Schaaf et al., 1995). Schaaf et al. (1995) modified the model to allow user input of C-to-N ratios and reduced the maximum decay rate for carbohydrates from 0.8 to 0.2. Quemada and Cabrera (1995) showed that allowing user input of carbohydrate, cellulose, and lignin pools sizes improved simulation of residue decomposition and net N mineralization in laboratory experiments. Input of pool sizes also produced significantly better results compared to the original model for simulation of N release from surface residues in a field study (Quemada et al., 1997) but simulated values tended to underestimate field data. No attempt was made to evaluate the influence of the proposed model changes on simulation of mineral N in the soil.

This paper evaluates the ability of the CERES-N submodel to simulate net N mineralization in two cotton-cover crop no-till production systems. Data from a field study of N mineralization using in situ soil cores were used to compare the original N submodel to a version that allows user input of residue pool sizes developed by Quemada and Cabrera (1995).

Table 1
Decomposition rates used to model the carbohydrate (CARB), cellulose (CELL), lignin (LIGN) and soil humus (HUM) pools of organic matter in the various versions of the CERES-N model

Version	Decomposition rate constants ($g\ g^{-1}\ day^{-1}$)			
	CARB	CELL	LIGN	HUM
CERES-N[a]	0.8	0.05	0.0095	0.0006
CERES-Nf	0.67	0.021	0.0095	0.0006
CERES-NP	0.14	0.0034	0.0095	0.0002
CERES-NPf	0.17	0.011	0.0095	0.0002

[a] CERES-N, the original version; CERES-Nf, original version with field data derived rate constants; CERES-NP, version modified to allow user input of residue pool sizes and uses laboratory derived rate constants; CERES-NPf, pool version with field data derived rate constants.

2. Materials and methods

2.1. Description of the original CERES-N submodel and modifications

The original CERES-N submodel simulates mineralization, immobilization, nitrification and denitrification and is presented in detail with Fortran code in Godwin and Jones (1991). The mineralization-immobilization subroutine simulates the decay of fresh organic matter (FOM) and humus (HUM). The FOM is divided among soluble carbohydrate (CARB), cellulose (CELL) and lignin (LIGN) pools as 20, 70, and 10%, respectively. The three pools decompose simultaneously using first-order kinetics and separate decay constants for each pool (Table 1). Three multiplicative factors based on residue C/N ratio, soil water, and soil temperature are used to modify the rate constants daily (see Quemada et al. (1997) for further discussion of these functions). Initial fresh residue N (FON) is estimated from the input values for dry weight and residue C/N ratio. The flows between the different pools are calculated in terms of carbon, the corresponding nitrogen flows depending on the C/N ratio of the receiving pool. The C/N ratios of the various pools are assumed to be constant through time. Twenty percent of the N mineralized daily is added to the soil organic fraction, the rest enters the soil inorganic pool and can be immobilized, leached, denitrified, or taken up by plants. Mineralization or immobilization of mineral-N is determined as the balance between the release of nitrogen during decomposition and immobilization during microbial synthesis and humification. Immobilization is based on microbial demand for N (0.2 mg of N per mg of dry matter) which is calculated by multiplying the fraction of C in FOM (0.4) by the microbial biosynthesis efficiency (0.4) and dividing by the microbial biomass C/N ratio (0.8). An inadequate supply of mineral-N to satisfy the immobilization demand results in a slowing of the decomposition. Both ammonium- and nitrate-N are available for immobilization, though ammonium-N is used preferentially.

The original CERES-N submodel was compared with one modified to allow user input of

Table 2
Initial soil organic matter (HUM), soil organic N (SON), fresh organic matter (FOM), C concentration, C/N ratio, and carbohydrate (CARB), cellulose (CELL), and lignin (LIGN) pool sizes for cover crop residues for 1997 and 1998 used to evaluate the models

Cover crop	HUM ($Mg\ ha^{-1}$)	SON ($Mg\ ha^{-1}$)	FOM ($Mg\ ha^{-1}$)	Total C ($kg\ kg^{-1}$)	C/N	CARB (%)	CELL (%)	LIGN (%)
1997								
Crimson clover	39.1	1.5	4.6	0.424	18.4	0.52	0.38	0.10
Rye	38.5	1.5	8.4	0.441	28.2	0.23	0.70	0.07
1998								
Crimson clover	39.1	1.5	4.5	0.420	15.7	0.62	0.28	0.10
Rye	38.5	1.5	5.7	0.428	31.5	0.32	0.61	0.07

FOM pool sizes (CERES-NP) (Quemada and Cabrera, 1995). The rate constants and pool sizes are given in Table 1. CERES-Nf and CERES-NPf use rate constants determined from field data (Quemada et al., 1997). In our evaluations of the models we used the same value of 0.45 for the fraction of C in FOM as used by Quemada et al. (1997) to aid in making consistent comparisons to their results.

The CARB, CELL, and LIGN pools were estimated for the cover crop residues from soluble and non-soluble carbohydrate pools determined using near infrared reflectance (NIR) (McLellan et al., 1991) (Table 2). Soluble carbohydrate from NIR was used to represent the CARB pool while the non-soluble NIR determination represented cellulose, hemicellulose, and lignin fractions. Average lignin values presented for crimson clover and rye in Quemada et al. (1997) were used for the LIGN component in the model, because the range of lignin concentrations for these crops is small (W.F. Barton, pers. commun., 2000) and the cover crops were grown under similar climatic and management conditions. CELL was calculated by subtracting LIGN from the NIR determined non-soluble carbohydrate value. The rate constant for HUM in CERES-NP and CERES-NPf was from a study by Johnson et al. (1999) for soil with similar organic matter and textural properties located within 300 m of the two watersheds used in this study.

2.2. Field study

In situ net N mineralization was measured during 1997 and 1998 in two 1.3 ha instrumented fields, at the J. Phil Campbell, Sr., Natural Resource Conservation Center in Watkinsville, GA (33°59′ N, 83°27′ W). The adjacent fields are used to study cropping system effects on sediment and nutrient loss on a slightly eroded Cecil sandy clay loam (fine, kaolinitic, thermic Typic Kanhapludults) soil (2–3% slope) and have been no-till cropped with cotton following a cover crop since 1994. Cereal rye was grown as the cover crop in one watershed and crimson clover was grown in the other. Soil C and N concentrations measured in May 1997 were 10.1 and 0.70 $g\ kg^{-1}$ in the cotton–crimson clover and 10.4 and 0.73 $g\ kg^{-1}$ in the cotton–rye soils, respectively. Cover crops were planted into cotton residues in late October using a no-till grain drill. Cotton was planted on 26 May in 1997 and 1998 directly into cover crop residues with a four row no-till planter. Nitrogen, as NH_4NO_3, was applied to cotton at 34 and 67 $kg\ ha^{-1}$ following crimson clover and rye, respectively, and 56 $kg\ N\ ha^{-1}$ to the rye each fall, using a drop spreader. In 1997, clover was near maturity at cotton planting and was not killed to allow for natural reseeding but clover was killed with glyphosate 2–3 weeks prior to planting cotton in 1998 as was the rye in both years.

Nitrogen mineralization during the cotton growing season was measured at nine locations

30–35 m apart, within each watershed. Distances between sample locations were considered far enough apart to constitute replications for determining N mineralization rates for each watershed. In situ soil cores (DiStefano and Gholz, 1986; Kolberg et al., 1997) were established 1 day following planting and fertilizer operations in 1997 (one per each of the nine locations). In 1998, cores were placed in the field following application of herbicide to the cover crops and prior to planting the cotton. At the beginning of each incubation period, an aluminum cylinder (110- by 50-mm, depth by diameter) was driven into the ground and then gently removed with the soil intact. Soil was removed from the lower 10 mm using a 19-mm wide chisel (a 60-mm length of square steel rod was attached to the chisel 10 mm from the end to ensure uniform depth). A nylon mesh bag containing approximately 15 g (25 ml) of a 50:50 mixture of anion and cation exchange resins (Sybron Ionac ASB-1 and C-249)[1] sufficient to fill the 10-mm excavated area was placed in the cavity. The resin mixture served to capture both NO_3^- and NH_4^+ leaching from the soil core (DiStefano and Gholz, 1986; Kolberg et al., 1997). The soil core with the resin bag was returned to the same hole. An additional soil core was collected at each location to determine initial soil mineral N content, i.e. ambient soil N. Cores were placed between crop rows in areas without growing plants and remained in the field for 2- to 5-week periods. Soil for ambient soil N was collected each time a set of in situ soil cores was established for subsequent incubation periods.

At the end of an incubation period, soil and resin bag were removed from the cylinder, placed in separate clean plastic bags and kept in a cooler in the field. Samples were refrigerated at 3 °C within 2–3 h, and analyzed within 3–5 days. Field moist soil was passed through a 6.35-mm screen, and thoroughly mixed before subsampling. Both NH_4^+ and NO_3^- were determined by shaking a 10-g subsample with 50 ml of 1 M KCl for 1 h and filtering the extract through pre-rinsed filter paper. Nitrogen was extracted from the resin bags by three successive 20-min shakings with 20 ml KCl which consistently recovered more than 85% of the N in the resin bags. An automated analysis system was used for determining NH_4^+ and NO_3^- (Technicon 1977a,b)[1]. Nitrogen mineralized ($Nmin_t$) during each period (t) was calculated as follows

$$Nmin_t = Ncore_t + Nresin_t - Nambient_t \tag{1}$$

where $Ncore_t$ is mineral N in the incubated soil core at the end of period t, $Nresin_t$ is mineral N in the resin bag at the end of period t, and $Nambient_t$ is mineral N in the non-incubated soil core collected at the beginning of period t. Estimates of net N mineralization were calculated on a dry weight basis and expressed in kg ha^{-1}. Soil water content (g g^{-1}) for each core was determined gravimetrically by drying a 10-g subsample for 72 h at 105 °C. Soil bulk density was determined from the volume and mass of the soil core.

In 1998, mass and N remaining in cover crop residues were determined by placing bags of residue in the field at the same nine locations used to measure in situ soil net N mineralization. Cover crop residues for the residue bags were collected the day before applying herbicide and dried in a forced draft oven at 35 °C for 24 h. Residues were weighed (13.75 g dry weight basis) and placed in bags (25 × 25 mm) having 1-mm mesh opening to give an effective loading rate of 2.2 Mg ha^{-1}. Residue bags were placed in the field on 21 April and collected after 2, 4, 8, 16, and 24 weeks. Residue remaining in each bag was dried at 60 °C (48–72 h), weighed, ground, and analyzed for total N using a LECO CNS 2000 analyzer (LECO, St Joseph, MI). Nitrogen remaining in the residue was calculated by multiplying the total N concentration by residue dry matter weight.

Rainfall, air temperature, and soil temperature at 5 cm under tall fescue sod were measured with an automated weather station less than 300 m from the watersheds. Volumetric soil water content θ_v was measured by time-domain reflectometry (TDR) using an ESI 920 and segmented TDR probes (six per watershed) two to three times each

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[1] The mention of trade or manufacture names is made for information only and does not imply an endorsement, recommendation, or exclusion by the United States Department of Agriculture, Agricultural Research Service.

week in 1997 and one to two times per week in 1998. For modeling N mineralization, daily values of θ_v were estimated by interpolating values between measurements using an exponential decay equation

$$\theta_v = a \times \exp(b \times days + c \times soil\ \ temperature) \qquad (2)$$

where a, b, and c were fit parameters and days is the number of days since a rainfall event greater than 6 mm. Measured θ_v from the study area and climatic data from the weather station were used to determine values for a, b, and c of 0.26, -0.033, and -0.01, respectively. Comparison of estimated θ_v values to measurements indicated an r of 0.86 for the 1987 data. The equation was used to interpolate values between measurement dates. The same equation and parameters were used to estimate θ_v between measurements in 1998.

2.3. Evaluation of model versions

We evaluated the CERES-N and CERES-NP models using in situ net N mineralization (0–10 cm) measurements from 1997 and 1998 and measurements of N remaining in the residues in 1998. Modeled net N mineralized from soil HUM plus net N mineralized from residue CARB, CELL, and LIGN pools was considered to represent the pool of mineral N measured by the in situ soil cores. Model performance was evaluated following the methodology proposed by Addiscott and Whitmore (1987) and Whitmore (1991). Statistics used included the correlation coefficient (r), mean difference between measured and simulated data (M) and its standard error (S.E.), root mean square error (RMSE), fraction of error, and lack of fit (LOFIT). The sum of squares of the LOFIT was obtained by subtraction of the error (SSE) from the residual sum of squares (RSS):

$$\mathrm{RSS} = \sum_{i=1}^{N} \sum_{j=1}^{n_i} (measured_{ij} - simulated_i)^2 \qquad (3)$$

$$\mathrm{SSE} = \sum_{i=1}^{N} \sum_{j=1}^{n_i} (measured_{ij} - \langle measured_i \rangle) \qquad (4)$$

$$\mathrm{LOFIT} = \mathrm{RSS} - \mathrm{SSE} \qquad (5)$$

where N is the number of sampling dates (for soil — seven in 1997 and six in 1998; for residues six in 1998), n_i is the number of replications for each date (9), $measured_{ij}$ is the measurement for each jth replicate at the ith sampling time, and $simulated_i$ is the simulated value for the ith sampling time, $\langle measured_i \rangle$ is the mean of the measurements at the ith sampling time. F_LOFIT was calculated from the mean square LOFIT (MSLOF) and mean square error (MSE) as follows:

$$F_\mathrm{LOFIT} = \frac{\mathrm{MSLOF}}{\mathrm{MSE}} = \frac{\mathrm{LOFIT}}{\mathrm{df}_\mathrm{LOFIT}} \div \frac{\mathrm{SSE}}{\mathrm{df}_\mathrm{SSE}} \qquad (6)$$

The degrees of freedom (df) were calculated as

$$\mathrm{df}_\mathrm{LOFIT} = N \ \text{ and } \ \mathrm{df}_\mathrm{SSE} = \sum_{i}^{N} (n_i - 1) \qquad (7)$$

The RMSE was calculated as

$$\mathrm{RMSE} = (\mathrm{RSS} + \mathrm{df}_\mathrm{RSS}) \qquad (8)$$

where df_RSS is the number of observations. In general, a statistically satisfactory simulation is characterized by a high r, low S.E., a low RMSE and a non-significant MSLOF. We also evaluated the regression between measured and simulated data for one-to-one correspondence of values as indicated by an intercept not different from 0 and a slope near 1. Data analyses were conducted using the Statistical Analysis System (SAS, 1989).

3. Results and discussion

Temperatures during summer of 1997 ranged from 0.3 to 2.6 °C below long-term monthly averages and were very low during the last week of May and first week of June (Fig. 1). Monthly rainfall during this period was more than 30 mm above average (Fig. 1). Spring of 1998 was very wet (data not shown) but after cotton planting it was dryer and hotter than long-term averages. Monthly temperatures during this period were 1–2 °C above long-term averages while monthly rain was below average with several long periods without rain (Fig. 1).

Significant net N mineralization occurred in both cropping systems with differences between years and cropping systems being visually apparent (Figs. 2 and 3). Cumulative net N mineralization during the first 35 days following cotton planting was 25–30 kg N ha^{-1} greater in 1998 than in 1997. Much of this difference is attributed to more favorable early season water availability (the spring period had above normal rainfall during 1998, data not shown), warmer soil temperatures, and killing the cover crops at an earlier stage of growth in 1998. Wilson and Hargrove (1986) found that 40–60% of the N in crimson clover could be mineralized after 4 weeks depending on the decomposition environment. Statistical comparison between the two watersheds is not possible due to the experimental layout, but as would be expected more N was mineralized following crimson clover than following rye, with a significant portion being mineralized prior to full bloom and maturation of the cotton crop (late July to September). Mineralization of N following rye was slower and the in situ soil cores indicated periods of net N immobilization early in the 1997 cotton growing season. Mineralization rates during May through August averaged 0.65 and 0.32 kg N ha^{-1} day^{-1} for the clover and rye systems, respectively (averaged for 1997 and 1998). The net

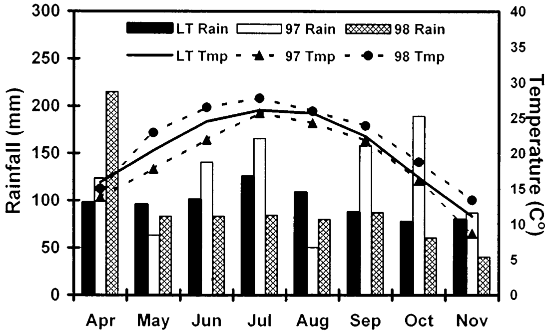

Fig. 1. Rainfall and air temperature for the 1997 and 1998 cotton growing seasons and the long term (30 years) averages for the research site near Watkinsville, GA.

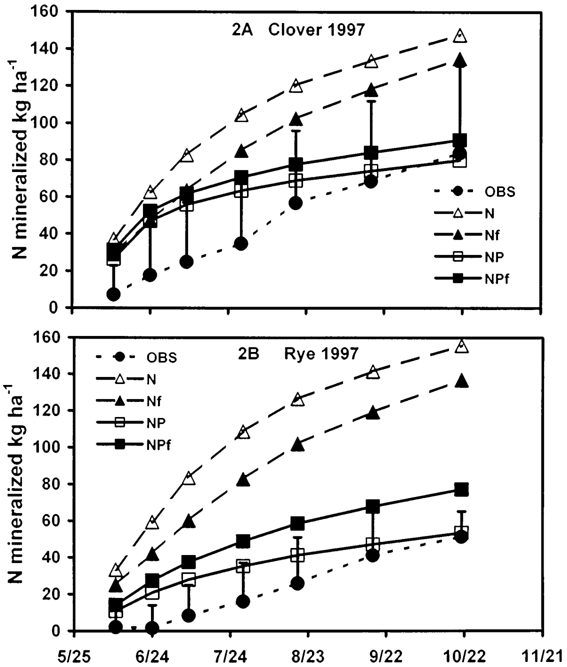

Fig. 2. Cumulative measured (OBS) and simulated (N, Nf, NP, NPf) in situ soil net N mineralized for the crimson clover (a) and rye (b) systems in 1997. Bars indicate the upper 95% confidence limit of measured values.

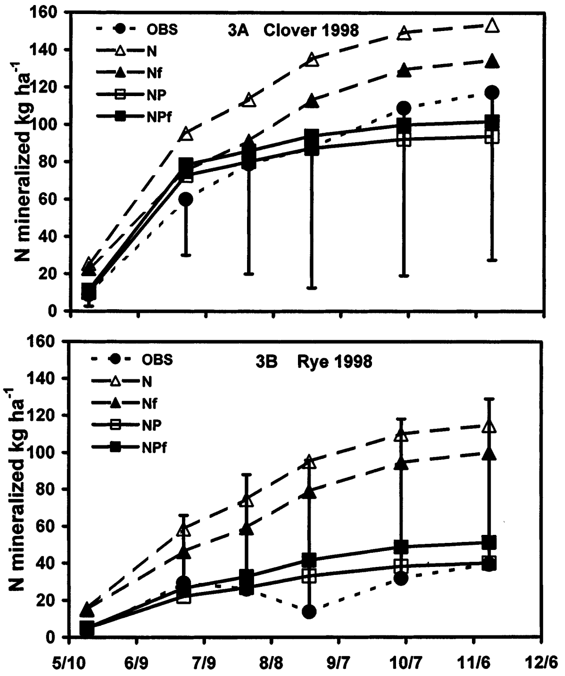

Fig. 3. Cumulative measured (OBS) and simulated (N, Nf, NP, NPf) in situ soil net N mineralized for the crimson clover (a) and rye (b) systems in 1998. Bars indicate the 95% confidence limit of measured values for rye (upper limit) and crimson clover (lower limits).

N mineralization rate in the rye system is similar to the 0.40 and 0.35 kg N ha^{-1} day^{-1} reported for a gramineous system of wheat–corn–fallow soil in Colorado (Kolberg et al., 1997). The rate for the clover system is in the range found for soil amended with low C-to-N ratio vegetable residues (De Neve et al., 1996).

The original CERES-N submodel overpredicted net N mineralization for the soil cores in both cover crop systems in 1997 (Fig. 2). Estimates were nearly two and six times greater than measured in situ for rye and crimson clover systems, respectively. Using the parameters fit by Quemada et al. (1997) to field data improved simulations with CERES-Nf but still resulted in significant overprediction of in situ net N mineralization following rye (Fig. 2b). The CERES-NP models overestimated net N mineralization for several dates but total cumulative amounts estimated at the end of the season were nearly the same as those measured. The best simulations of in situ net N mineralization were obtained with CERES-NP and CERES-NPf as indicated by the smaller RMSE, *M*, and S.E. (Table 3). The regressions of simulated versus measured indicate a poor fit to the measured data with the CERES-N models (Table 3). The LOFIT test indicated that improvements in the predictions could be expected for each of the model versions but the modified versions (CERES-NP and CERES-NPf) performed better than the original version.

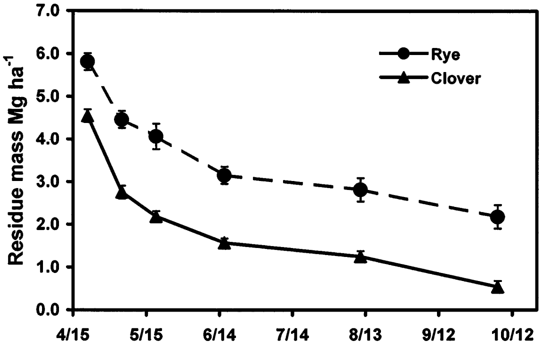

Fig. 4. Measured crimson clover and rye biomass remaining in residues placed on the soil surface in the fields during 1998. Bars indicate the upper and lower 95% confidence limits.

Simulations of in situ net N mineralization were better for 1998 than for 1997 (Figs. 2 and 3). Similar to the 1997 data, CERES-N overestimated in situ net N mineralization in the rye system while CERES-NP and CERES-NPf closely simulated measured values (Fig. 3). The RMSE, *M*, and S.E. indicated better simulations with CERES-NP and CERES-NPf (Table 3). Intercepts and slopes for CERES-NP and CERES-NPf also indicated good simulations of net N mineralization in the rye system. Simulations with CERES-N were improved for both years by using the decomposition rates determined from field data (CERES-Nf) thus supporting the need to alter decomposition rate constants as found in earlier studies (Bowen et al., 1993; Vigil et al., 1991; Quemada and Cabrera, 1995). Results for the four model versions indicate that additional changes are needed to better predict soil mineral N dynamics and N needs of the cotton crop (Table 3).

Biomass losses from residues in 1998 followed an exponential rate of decomposition which was greater for crimson clover than for rye (Fig. 4). Residue N loss followed a pattern similar to the biomass loss for crimson clover but not for rye residues (Fig. 5). Nitrogen remaining in crimson clover residues declined rapidly during the first 4 weeks which is similar to results reported by Wilson and Hargrove (1986) for another location in Georgia. At the last sampling date, very little crimson clover residue remained in the litter bags and the material was very fragile due to its advanced state of decomposition. This probably increased the errors for measurement of mass loss and N content and contributed to the large drop in biomass and N at this date. During the first 2 weeks following placement in the field, the rye residue lost nearly 50% of its mineral N. Much of this must have been due to loss of water soluble N because less than 25% of the mass was lost during this period. Subsequent declines in mass and N of rye residue were slower than those observed for crimson clover residue which agrees with work of Quemada et al. (1997) and Ranells and Wagger (1997).

Nitrogen remaining in crimson clover residue was simulated well for the first 4 weeks by

Table 3
Statistics[a] for comparing measured and simulated values of in situ net N mineralization for the cover crop–cotton systems. Simulated values obtained using CERES-N and CERES-NP with indicated rate constants (Table 1) and pool sizes (Table 2)

Cover crop	Version	Intercept[b] (kg ha^{-2})	Slope	r	M (kg ha^{-2})	S.E. (kg ha^{-2})	Error (%)	RMSE (kg ha^{-2})	MSLOF (kg ha^{-2})	F_{LOFIT}	Prob > F
1997											
Crimson	CERES-N	37.05[c]	1.43[c]	0.96	−55.5	15.91	−58.1	16.42	1894	28.53	0.0001
Crimson	CERES-Nf	22.40[c]	1.41[c]	0.98	−40.0	13.38	−52.5	13.14	1023	15.42	0.0001
Crimson	CERES-NP	32.57[c]	0.63[c]	0.92	−16.5	12.32	−23.6	13.63	1141	17.19	0.0001
Crimson	CERES-NPf	36.28[c]	0.72[c]	0.93	−22.8	10.38	−32.7	14.32	1316	19.82	0.0001
Rye	CERES-N	78.98[c]	2.10[c]	0.87	−90.6	29.91	−82.1	19.88	3037	46.71	0.0001
Rye	CERES-Nf	59.64[c]	2.04[c]	0.92	−70.6	25.04	−78.5	15.73	1706	26.24	0.0001
Rye	CERES-NP	26.28[c]	0.71	0.88	−23.3	8.77	−45.3	10.08	394	6.06	0.0001
Rye	CERES-NPf	35.85[c]	1.09	0.90	−36.8	10.03	−66.1	10.70	510	7.84	0.0001
1998											
Crimson	CERES-N	17.90[c]	1.15	0.99	−29.9	8.11	−44.2	26.01	1302	2.18	0.0615
Crimson	CERES-Nf	12.11	1.00	0.99	−12.1	4.81	−35.4	24.55	640	1.07	0.3931
Crimson	CERES-NP	12.26	0.73	0.96	9.6	14.15	−7.6	25.12	894	1.49	0.2002
Crimson	CERES-NPf	13.26	0.79	0.96	3.8	12.56	−14.4	25.40	1022	1.71	0.1392
Rye	CERES-N	13.48	1.82	0.87	−42.5	23.57	−87.8	25.40	2822	7.56	0.0001
Rye	CERES-Nf	11.03	1.53	0.85	−30.1	19.47	−85.6	23.91	2160	5.79	0.0001
Rye	CERES-NP	4.56	0.65	0.89	8.0	8.62	−64.1	21.13	1034	2.77	0.0215
Rye	CERES-NPf	4.23	0.85	0.88	1.3	8.46	−71.9	21.18	1053	2.82	0.0196

[a] r is the correlation coefficient; RMSE is the root mean square error for the difference between measured and simulated; M is the mean difference between measured and simulated; S.E. is the standard error of the mean difference; Error is mean percent error for August measurements; MSLOF is mean square due to lack of fit, and F_{LOFIT} is MSLOF divided by MSE.

[b] Intercept and slope fit for simulated = intercept + slope × measured.

[c] Significantly different from 0 for the intercept and from 1 for the slope ($\alpha = 0.05$).

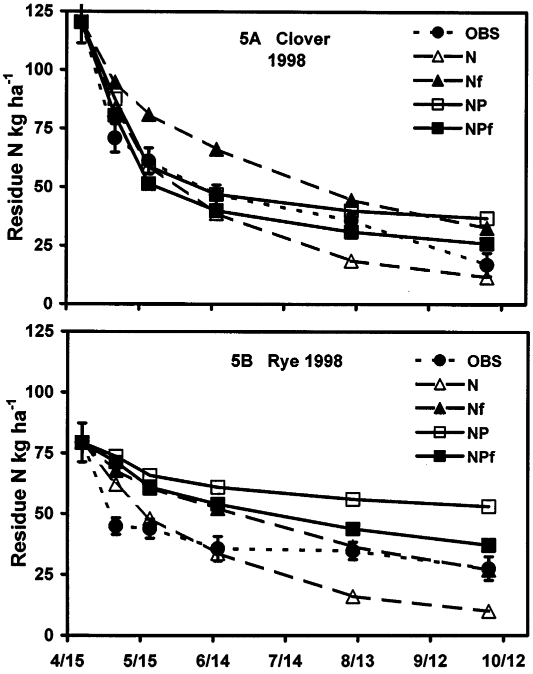

Fig. 5. Measured (OBS) and simulated (N, Nf, NP, NPf) N remaining in crimson clover (a) and rye (b) residues placed on the soil surface in the fields during 1998. Bars indicate the upper and lower 95% confidence limits of measured values.

CERES-NP, CERES-NPf, and CERES-N (Table 4 and Fig. 5). Simulations were better with CERES-NP and CERES-NPf than with CERES-N for later periods. The substantial drop in N remaining in the crimson clover residues at the final sampling date probably contributed to overprediction of N remaining by CERES-NP and CERES-NPf. Regression analysis of simulated versus measured data indicated good agreement for CERES-NP, CERES-NPf, and CERES-N. The best simulation of N remaining in clover residues was obtained with CERES-NPf (smallest RMSE, *M*, S.E. and LOFIT). Surprisingly, CERES-N and CERES-Nf simulated N remaining in rye residue better than did CERES-NP and CERES-NPf (Table 4 and Fig. 5). The large and unexplained loss of N from the rye residues during the first 2 weeks was not simulated by the four models although CERES-N produced values similar to measured values at 4 and 8 weeks. Nitrogen losses from rye residue after the first 2 weeks followed a pattern closely simulated by CERES-NP while final N remaining was simulated best by CERES-Nf (Table 4).

When evaluated across years and cover crops, simulations of in situ net N mineralization were improved with the user input of pool sizes (Table 5). Even though some over- and underprediction of net N mineralization occurs with the CERES-NP models, the disagreement with measured data is consistently less than for the original model. Simulation of N remaining in the residues and in situ net N mineralization are improved for the original model by changing the decomposition rates for the pools (compare CERES-N vs. CERES-Nf). Difference between CERES-Nf and CERES-NPf would be expected to be small if the user input of pool sizes did not affect the simulations but overall results favor use of the CERES-NP model.

Comparisons of other simulation models to field measured data indicate the difficulty of applying models across broad conditions (de Willigen, 1991; Diekkrüger et al., 1995). Otter-Nacke and Kuhlmann (1991) showed that estimates of soil N with three different models exceeded 20 kg N ha^{-1} for 18–38% of the measurements depending on the model and the year of simulation. The mean error for the three models was near 20 kg N ha^{-1} indicating that the models could not provide reliable simulations for evaluating regulatory compliance. The best model performance appeared to be with the simplest of the three models which considered only two pools of decomposable organic substrate and constant C/N ratio for each fraction.

Mueller et al. (1998) using the DAISY model that considered fast and slow pools of added organic matter (AOM), soil microbial biomass (SMB) and nonliving soil organic matter (SOM) found generally a close agreement between measured and observed soil mineral N for soils with and without added crop residues. The RMSEs for the four treatments were very similar (31–35%) and deviations from measured values were mostly less than 20 kg N ha^{-1}.

Schaaf et al. (1995) using a modified version of the CERES-N model also found good predictions for N content in arable soils. They simulated 15

Table 4

Statistics[a] for comparing measured and simulated values of N remaining in cover crop residues on the soil surface. Simulated values were obtained using CERES-N and CERES-NP with different rate constants (Table 1) and pool sizes (Table 2)

Cover crop	Model	Intercept (kg ha^{-2})	Slope	r	M (kg ha^{-2})	S.E. (kg ha^{-2})	Error (%)	RMSE (kg ha^{-2})	MSLOF (kg ha^{-2})	F_{LOFIT}	Prob > F
1998											
Crimson	CERES-N	−9.83	1.12	0.98	−15.1	8.8	93.8	12.15	833	16.76	0.0001
Crimson	CERES-Nf	22.64[b]	0.87	0.97	2.9	9.3	−19.6	18.12	2497	50.23	0.0001
Crimson	CERES-NP	14.24	0.87	0.97	−6.9	9.4	−11.6	12.85	1052	21.15	0.0001
Crimson	CERES-NPf	1.63	0.97	0.98	−0.0	7.9	16.1	10.54	512	10.30	0.0001
Rye	CERES-N	−13.73	1.27	0.88	−10.4	10.6	116.8	14.91	1468	27.58	0.0001
Rye	CERES-Nf	15.07	0.89	0.85	2.0	13.0	−11.3	15.50	1626	30.54	0.0001
Rye	CERES-NP	43.85[b]	0.48[b]	0.88	−21.3	10.8	−38.2	23.89	4599	86.36	0.0001
Rye	CERES-NPf	25.37	0.74	0.86	−14.2	9.5	−20.8	17.61	2254	42.34	0.0001

[a] Definitions as in Table 3.

[b] Significantly different from 0 for the intercept and from 1 for the slope ($\alpha = 0.05$).

Table 5

Statistics[a] for comparison of measured and simulated values of net N mineralized or remaining in residues estimated across cover crops (and years for soil cores) using the original and modified versions of the CERES-N model[b]

N Source	Model	Intercept (kg ha^{-2})	Slope	r	M (kg ha^{-2})	S.E. (kg ha^{-2})	RMSE (kg ha^{-2})	MSLOF (kg ha^{-2})	F_{LOFIT}	Prob > F
Soil cores	CERES-N	64.45[c]	0.80	0.70	−56.0	30.7	22.00	4559	18.67	0.0001
Soil cores	CERES-Nf	49.92[c]	0.75	0.73	−39.5	27.3	19.60	2762	11.31	0.0001
Soil cores	CERES-NP	21.56[c]	0.64[c]	0.88	−6.6	18.1	18.06	1716	7.03	0.0001
Soil cores	CERES-NPf	29.78[c]	0.65[c]	0.84	−15.2	20.0	18.40	1941	7.95	0.0001
Residue	CERES-N	−9.31	1.13	0.94	−12.7	9.6	13.60	1151	25.30	0.0001
Residue	CERES-Nf	17.44[c]	0.90	0.95	2.4	11.2	16.86	2062	45.33	0.0001
Residue	CERES-NP	27.51[c]	0.74[c]	0.91	−14.1	12.2	19.18	2825	62.11	0.0001
Residue	CERES-NPf	14.23	0.86	0.92	−7.1	11.1	14.51	1383	30.41	0.0001

[a] Definitions as in Table 3.

[b] Rate constants and pool sizes for each model are given in Tables 1 and 2, respectively.

[c] Significantly different from 0 for the intercept and from 1 for the slope ($\alpha = 0.05$).

out of 22, eight out of 10, and seven out of 10 measured values within ± 15 kg N ha^{-1} for three sets of long-term field experiments. Greater differences among simulated and measured data were associated with times of fertilization (Schaaf et al., 1995; Whitmore, 1995). Results from our evaluations of the modified CERES-NP and CERES-NPf models against field data are similar and indicate potential for the modified models to be used for estimating N needs of crops provided reliable input information is available.

Numerous interacting components affect simulation accuracy and are difficult to consider independently. Using fixed pool sizes in the original model produces similar estimations of decomposition for widely different plant types. Allowing the user to input crop residue chemical characteristic pool sizes improves model simulations as shown in previous work by Quemada and Cabrera (1995) and Quemada et al. (1997). Differences in relative proportions and arrangement of chemical constituents (i.e. distribution of lignin, types of soluble carbohydrates, etc.) among grasses, legumes, and other non-grasses contribute to variation in rates of residue decomposition and may not be apparent from measurements of concentrations (Beguin, 1990; Lewis and Yamamoto, 1990). A potential solution might be achieved by considering the physiological differences among plant groups. Carbon-to-nitrogen ratios along with knowledge of the chemical differences among crop groups (legumes, cereals, brassicas or others) might be used to develop routines within the model that modify residue decomposition rates and pool sizes for the three residue pools. This would add to the complexity of the model but should also improve simulation results.

Altering the model to support decomposition of various soil organic matter pools may also improve simulation of soil net N mineralization (Martin et al., 1980). The SOILN module in APSIM is a modified CERES-N model that divides soil organic matter into a labile pool, representing soil microbial biomass and microbial products, and a humus pool which comprises the remaining soil organic matter (Probert et al., 1998). Asseng et al. (2000) evaluated APSIM with data from the Netherlands previously used to compare 14 models by de Willigen (1991). The pattern of changes in soil N was simulated acceptably ($r^2 = 0.46$ and root mean square deviation = 9). Previous tests of models with data from the Eest, PAGV, and the Bouwing sites indicated problems due to sharp declines in soil mineral N following fertilizer application and overestimation of the relatively low observed mineral N contents later in the season (de Willigen, 1991). In contrast, the APSIM SOILN module adequately reproduced the observed changes in soil mineral N contents for each of the locations. These positive results from a simple modification of the CERES-N model are encouraging and will be useful for our future work and model development.

4. Conclusions

The simulations of in situ net N mineralization in no-till cotton cover crop systems were best with user input of residue carbohydrate, cellulose, and lignin pool sizes (CERES-NP). Simulation of N loss from cover crop residues on the soil surface was best using the pool model for crimson clover while significant loss of N during the first 2 weeks from rye residue resulted in poor simulation with all models (and best predictions by the original model). Overall, prediction of N availability in cover crop conservation tillage systems was improved with user input of pool sizes. Future modifications may be needed to account for differences among cover crop residue chemical structure and between soil organic matter pools. The modified CERES-NP has the potential to be a valuable tool for managing N inputs in cotton production systems. More evaluations are needed to determine if results are consistent across soil types and whether the model output can be used to improve economic returns.

References

Addiscott, T.M., Whitmore, A.P., 1987. Computer simulation of changes in soil mineral nitrogen and crop nitrogen during autumn, winter and spring. J. Agric. Sci. Camb. 109, 141–157.

Asseng, S., van Keulen, H., Stol, W., 2000. Performance and application of the APSIM Nwheat model in the Netherlands. Eur. J. Agron. 12, 37–54.

Bauer, P.J., Busscher, W.J., 1996. Winter cover and tillage influences on coastal plain cotton production. J. Prod. Agric. 9, 50–54.

Beguin, P., 1990. Molecular biology of cellulose degradation. Annu. Rev. Microbiol. 44, 219–248.

Bowen, W.T., Jones, J.W., Carsky, R.J., Quintana, J.O., 1993. Evaluation of the nitrogen submodel of CERES-Maize following legume green manure incorporation. Agron. J. 85, 153–159.

CTIC, 1998. National Crop Residue Management Survey. Conservation Technology Information Center, Purdue University, West Lafayette, IN. http://www.ctic.purdue.edu/CTIC/CTIC.html

Daniel, J.B., Abaye, A.O., Alley, M.M., Adcock, C.W., Maitland, J.C., 1999a. Winter annual cover crops in a Virginia no-till cotton production system: I. Biomass production, ground cover, and N assimilation. J. Cotton. Sci. 3, 74–83.

Daniel, J.B., Abaye, A.O., Alley, M.M., Adcock, C.W., Maitland, J.C., 1999b. Winter annual cover crops in a Virginia no-till cotton production system: II. Cover crops and tillage effects on soil moisture, cotton yield, and cotton quality. J. Cotton. Sci. 3, 84–91.

De Neve, S., Pannier, J., Hofman, G., 1996. Temperature effects on C- and N-mineralization from vegetable crop residues. Plant Soil 181, 25–30.

de Willigen, P., 1991. Nitrogen turnover in the soil–crop system; comparison of fourteen models. Fert. Res. 27, 141–149.

Diekkrüger, B., Söndgerath, D., Kersebaum, K.C., McVoy, C.W., 1995. Validity of agroecosystem models: a comparison of results of different models applied to the same data set. Ecol. Model. 81, 3–29.

DiStefano, J.F., Gholz, H.L., 1986. A proposed use of ion exchange resins to measure nitrogen mineralization and nitrification in intact soil cores. Comm. Soil Sci. Plant Anal. 17, 989–998.

Douglas, C.L. Jr, Allmaras, R.R., Rasmussen, P.E., Ramig, R.E., Roager, N.C., 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Sci. Soc. Am. J. 44, 833–837.

Franzluebbers, K., Weaver, R.W., Juo, A.S.R., Franzluebbers, A.J., 1994. Carbon and nitrogen mineralization from cowpea plant parts decomposing in moist and repeatedly dried and wetted soil. Soil Biol. Biochem. 26, 1379–1387.

Godwin, D.C., Jones, C.A., 1991. Nitrogen dynamics in soil–plant systems. In: Hanks, R.J., Ritchie, J.T. (Eds.), Modeling plant and soil systems, Agron. Monogr. 31, ASA, CSSA and SSSA, Madison, WI, pp. 287–321.

Holland, E.A., Coleman, D.C., 1987. Litter placement effects on microbial and organic matter dynamics in an agroecosystem. Ecology 68, 425–433.

Johnson, A.D., Cabrera, M.L., McCracken, D.V., Radcliffe, D.E., 1999. LEACHN simulations of nitrogen dynamics and water drainage in an ultisol. Agron. J. 91, 597–606.

Kolberg, R.L., Rouppet, B., Westfall, D.G., Peterson, G.A., 1997. Evaluation of an *in situ* net soil nitrogen mineralization method in dryland agroecosystems. Soil Sci. Soc. Am. J. 61, 504–508.

Lewis, N.G., Yamamoto, E., 1990. Lignin: occurrence, biogenesis and biodegradation. Annu. Rev. Plant Physiol. 41, 455–496.

Martin, J.P., Haider, K., Kassim, G., 1980. Biodegradation and stabilization after 2 years of specific crop, lignin, and polysaccharide carbons in soils. Soil Sci. Soc. Am. J. 44, 1250–1255.

McGill, W.B., Hunt, H.W., Woodmansee, R.G., Reuss, J.O., 1981. Phoenix, a model of the dynamics of carbon and nitrogen in grassland soils. In: Clark, F.E., Rosswall, T. (Eds.), Terrestrial nitrogen cycles: processes, ecosystem strategies and management impacts. Swedish Natural Science Research Council, Stockholm, pp. 49–115.

McLellan, T.M., Aber, J.D., Martin, M.E., Melillo, J.M., Nadelhoffer, K.J., 1991. Determination of nitrogen, lignin, and cellulose content of decomposing leaf material by near infrared reflectance spectroscopy. Can. J. Forest Res. 21, 1684–1688.

Mueller, T., Magid, J., Jensen, L.S., Svendsen, H., Nielsen, N.E., 1998. Soil C and N turnover after incorporation of chopped maize, barley straw and blue grass in the field: Evaluation of the DAISY soil-organic-matter submodel. Ecol. Model. 111, 1–15.

Mullins, G.L., Burmester, C.H., 1990. Dry matter, nitrogen, phosphorus, and potassium accumulation by four cotton varieties. Agron. J. 82, 729–736.

Otter-Nacke, S., Kuhlmann, H., 1991. A comparison of the performance of N simulation models in the prediction of N_{min} on farmer's fields in the spring. Fert. Res. 27, 341–347.

Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C., Strong, W.M., 1998. APSIM's water and nitrogen modules and simulations of the dynamics of water and nitrogen in fallow systems. Agric. Syst. 56, 1–28.

Quemada, M., Cabrera, M.L., 1995. Using the CERES-N model to predict N mineralized from cover crop residues. Soil Sci. Soc. Am. J. 59, 1059–1065.

Quemada, M., Cabrera, M.L., McCracken, D.V., 1997. Nitrogen release from surface-applied cover crop residues: evaluating the CERES-N submodel. Agron. J. 89, 723–729.

Ranells, N.N., Wagger, M.G., 1997. Nitrogen-15 recovery and release by rye and crimson clover. Soil Sci. Soc. Am. J. 61, 943–948.

SAS Institute, 1989. SAS/STAT User's Guide, Ver. 6, 4th edn., Vol. 2. SAS Inst. Inc., Cary, NC.

Schaaf, T., Priesack, E., Engel, T., 1995. Comparing field data from north Germany with simulations of the nitrogen model N-SIM. Ecol. Model. 81, 223–232.

Schomberg, H.H., Ford, P.B., Hargrove, W.L., 1994. Influence of crop residues on nutrient cycling and soil chemical properties. In: Unger, P.W. (Ed.), Managing Agriculture Residues. Lewis, Boca Raton, FL, pp. 99–121.

Technicon, 1977a. Determination of nitrogen in BD digests. Technicon industrial method 334-74W/B. Technicon Industrial Systems, Tarrytown, NY.

Technicon, 1977b. Nitrate and nitrite in soil extracts. Technicon industrial method 487-77A. Technicon Industrial Systems, Tarrytown, NY.

Thompson, J.M., Varco, J.J., 1996. Fertilizer N and legume cover crop management effects on no-till cotton production. In: Proc. Beltwide Cotton Conf., Nashville, TN, 9–12 Jan 1996. National Cotton Council, Memphis, TN.

Touchton, J.T., Rickerl, D.H., Walker, R.H., Snipes, C.E., 1984. Winter legumes as a nitrogen source for no-tillage cotton. Soil Till. Res. 4, 391–401.

Tsuji, G.Y., Uehara, G., Balas, S. (Eds.), 1994. DSSAT v3. University of Hawaii, Honolulu.

Varco, J.J., Frye, W.W., Smith, M.S., MacKown, C.T., 1993. Tillage effects on legume decomposition and transformation of legume and fertilizer nitrogen-15. Soil Sci. Soc. Am. J. 57, 750–756.

Vigil, M.F., Kissel, D.E., Smith, S.J., 1991. Field crop recovery and modeling of nitrogen release from several winter annual cover crops. Soil Sci. Soc. Am. J. 55, 1031–1037.

Whitmore, A.P., 1991. A method for assessing the goodness of computer simulation of soil processes. J. Soil Sci. 42, 289–299.

Whitmore, A.P., 1995. Modelling the mineralization of nitrogen from crop residues during three successive growing seasons. Ecol. Model. 81, 233–241.

Wilson, D.O., Hargrove, W.L., 1986. Release of nitrogen from crimson clover residue under two tillage systems. Soil Sci. Soc. Am. J. 50, 1251–1254.