APPRAISAL OF THE SNAP MODEL FOR PREDICTING NITROGEN MINERALIZATION IN TROPICAL SOILS UNDER EUCALYPTUS

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ABSTRACT

The Soil Nitrogen Availability Predictor (SNAP) model predicts daily and annual rates of net N mineralization (NNM) based on daily weather measurements, daily predictions of soil water and soil temperature, and on temperature and moisture modifiers obtained during aerobic incubation (basal rate). The model was based on *in situ* measurements of NNM in Australian soils under temperate climate. The purpose of this study was to assess this model for use in tropical soils under eucalyptus plantations in São Paulo State, Brazil. Based on field incubations for one month in three, NNM rates were measured at 11 sites (0-20 cm layer) for 21 months. The basal rate was determined in *in situ* incubations during moist and warm periods (January to March). Annual rates of 150-350 kg ha^{-1} yr^{-1} NNM predicted by the SNAP model were reasonably accurate (R^2 = 0.84). In other periods, at lower moisture and temperature, NNM rates were overestimated. Therefore, if used carefully, the model can provide adequate predictions of annual NNM and may be useful in practical applications. For NNM predictions for shorter periods than a year or under suboptimal incubation conditions, the temperature and moisture modifiers need to be recalibrated for tropical conditions.

Keywords: forest soil, soil temperature, process-based model.

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RESUMO: *AVALIAÇÃO DO MODELO SNAP PARA PREDIZER A MINERALIZAÇÃO DE NITROGÊNIO EM SOLOS DE PLANTAÇÕES DE EUCALIPTO*

O modelo Soil Nitrogen Availability Predictor (SNAP) prevê as taxas diárias e anuais de mineralização líquida de N (MLN) a partir de medições diárias das condições climáticas, de predições diárias da umidade e temperatura do solo e de índices de correção da temperatura e umidade obtidos durante os processos de incubação aeróbica (taxa básica) para determinar a MLN. O modelo foi desenvolvido com base em medições in situ da MLN em solos australianos sob clima temperado. O objetivo deste estudo foi avaliar a adequação desse modelo para o uso em solos tropicais sob plantações de eucalipto no Estado de São Paulo, Brasil. Com base em incubações de campo por um mês, as taxas de MLN (0-20 cm de profundidade) foram medidas em 10 locais durante 21 meses. Os dados obtidos no período úmido e quente (janeiro a março) proveram as taxas básicas de mineralização. Taxas anuais de MLN in situ variando entre 150 e 350 kg ha^{-1} *ano^{-1} de N foram preditas com boa precisão pelo modelo SNAP* (R^2 *= 0,84). Em outros períodos, sob condições de umidade e temperatura menores, as taxas de MLN foram superestimadas. Assim, com o uso cuidadoso, o modelo pode proporcionar predições adequadas da MLN anual, podendo ser útil em aplicações práticas. Para predições da MLN em períodos menores do que um ano ou se as condições de incubação estiverem fora da faixa ideal, os índices de correção da temperatura e umidade precisam ser recalibrados para condições tropicais.*

Palavras-chave: solo florestal, temperatura do solo, modelo com base em processo.

INTRODUCTION

A quantitative understanding of nitrogen (N) pools and fluxes can underpin improved N fertiliser management in plantation forestry (Smethurst and Nambiar, 1990; Smethurst et al., 2004; Corbeels et al., 2005; Laclau et al., 2010) and agriculture (Keating et al., 2003; Manzoni and Porporato, 2009; Sansoulet et al., 2014; Thorburn et al., 2010). Net N mineralization (NNM), a key component of the N cycle, can be measured reliably using an unsophisticated *in situ* core technique (Raison et al., 1987). However, this technique is labour-intensive, which often precludes its use in N cycling research or fertiliser management.

Many models that incorporate predictions of NNM in forest soils are mechanistic or process-based, but none have been well-studied, and they require calibration and considerable input data, making them labour-intensive (Kirschbaum and Paul, 2002). A hybrid approach between measurement and modelling of NNM may be more cost-effective. Paul et al. (2002; 2003a,b; 2004) used a large Australian database of NNM measurements, from 33 native forest and plantation sites, to develop the SNAP (Soil Nitrogen Availability Predictor) model that is much less labour-intensive, and provided reasonable estimates of daily and annual NNM rates. The method was based on laboratory incubations at non-limiting soil water and warm temperatures (e.g. 37 °C), which provided a 'basal rate' for NNM. Sub-optimal temperature and water was accounted for using modifiers of the basal rate. Rates of NNM determined in laboratory incubations were standardized to 40 °C using an exponential temperature response function. For the water response, rates were fitted to a sigmoidal function given by the upper and lower limits of field-observed soil water content. Daily soil water and temperature were predicted for field conditions using simple empirical sub-models calibrated for 18 sites in southern Australia. These soil and water predictions were used to adjust the basal NNM rate from which daily rates in the field could be estimated. These rates could then be tallied for a given period, e.g., monthly, seasonal or annual estimates. Annual estimates of NNM agreed well with *in situ* measurements across a range of sites (R^2 = 0.76; Paul et al., 2002). The SNAP model was most recently used at the headwater catchment scale as a component to understand and model the pools and fluxes of mineral N in soil, ground water and stream water (Smethurst et al., 2014).

As the SNAP method was developed using data from a temperate Australian climate, uncertainties remain regarding its usefulness under tropical conditions in Australia and elsewhere. Such uncertainties arose because tropical conditions have a degree of seasonal synchrony of soil temperature and water conditions favourable for mineralization. In the tropics, high soil temperature and water levels can often coincide, whereas in temperate regions favourable conditions are more asynchronous. In addition, parameterization of the SNAP model is subject to a high degree of empiricism. These factors together justify this study.

Brazil has a large and expanding tropical eucalyptus plantation estate with increasing evidence of N deficiency (Pulito, 2009) and rates of N fertiliser have been raised during the past decade to remedy this deficiency (Gonçalves et al., 2004). Part of the Brazilian eucalypt plantation industry currently uses the 3-PG process-based model (Almeida et al., 2010; Stape et al., 2010; Gonçalves et al., 2014), but 3-PG does not specifically include any nutrient. As SNAP was the only model available and largely based on data from the plantation industry, industry partners of this research project were keen to use SNAP to enhance their understanding of NNM and its predictions for their soils.

This report is an evaluation of the SNAP model in soils under eucalyptus plantations in São Paulo State, Brazil. The hypothesis was that SNAP predictions of NNM rates would be comparable with rates estimated from *in situ* incubations.

MATERIAL AND METHODS

Sites

Eleven sites were identified that were expected (based on the soil clay content) to cover a wide range of rates of NNM and N deficiency degrees in the soil surface layers. These sites have been reported previously as a part of other studies that included an N fertiliser experiment at each site with at least three replicates (Gomes, 2009; Pulito, 2009). The experiments were located in the south-eastern part of São Paulo State, Brazil, close to nine cities, and were conducted by plantation companies (Duratex, Suzano, VCP now Fibria) or the Forest Science Department of the University of São Paulo. The experiments consisted of stands of *Eucalyptus grandis* or *Eucalyptus grandis x urophylla,* managed with standard practices of cultivation, watering, weed and pest control, and fertiliser application. Selected site characteristics are provided in table 1. The soil types were the most commonly used for forest plantations in São Paulo State (Gonçalves, 2002; Gonçalves et al., 2013).

Each experiment included one control treatment to which 4 - 42 kg ha^{-1} N was applied, close to each seedling, within a month after planting. Details of other treatments can be found in Pulito (2009), but were not reported here as they were not used to appraise the SNAP model. Plots were arranged in a randomised block design with at least three replicates. Each plot included an unmeasured buffer strip, and at least 16 trees at a spacing of 3.0 × 2.0 m; measured plot area range was 96-360 m^2.

Measurements

The entire plot area, excluding the outer 3 m of each plot, was randomly sampled, using a variation of the *in situ* core technique (Raison et al., 1987; Gomes, 2009) in the 0-20 cm layer, during approximately one month per season (four times per year). *In situ* core measurements were carried out at all sites for

Table 1. Selected characteristics of the experimental sites measured in samples of the 0-20 cm layer

Site	Soil classification$^{(1)}$	Climate type$^{(2)}$	Rainfall$^{(3)}$	Age$^{(4)}$	C:N	Total C	Total N	P$^{(5)}$	pH(CaCl$_2$)$^{(6)}$
			mm yr^{-1}	yr		g kg^{-1}	mg kg^{-1}	mg dm^{-3}	
Agudos (AGU)	Typic Hapludox (Latossolo Vermelho)	Cfa	1170	2.3	20	7.7	387	7.0	4.3
Altinópolis (ALT)	Typic Quartzipsamment (Neossolo Quartzarênico)	Cwa	1517	5.7	22	7.0	323	9.5	4.0
Angatuba (ANG)	Typic Quartzipsamment (Neossolo Quartzarênico)	Cfa	1262	1.8	24	7.1	301	6.5	4.0
Botucatu (BOT)	Typic Quartzipsamment (Neossolo Quartzarênico)	Cfa	1302	2.7	24	9.2	387	3.3	3.9
Capão Bonito (CB1)	Typic Hapludox (Latossolo Amarelo)	Cfa	1210	8.6	12	9.3	810	5.0	4.1
Capão Bonito 2 (CB2)	Typic Hapludox (Latossolo Vermelho)	Cfa	1210	0.9	14	7.9	589	2.4	2.6
Capão Bonito 3 (CB3)	Typic Dystropept (Cambisol distrófico)	Cfa	1210	1.1	18	13.4	774	2.7	3.9
Itatinga (ITA)	Typic Hapludox (Latossolo Vermelho-Amarelo)	Cfa	1308	5.3	19	18.8	981	4.3	4.4
Paraibuna (PAR)	Typic Hapludox (Latossolo Vermelho-Amarelo)	Cfb	1249	10.9	19	24.5	1267	45.9	4.9
São Miguel Arcanjo (SMA)	Typic Hapludox (Latossolo Vermelho-Amarelo)	Cfb	1174	1.3	12	10.8	893	5.2	5.2
Votorantim (VOR)	Typic Paleudult (Argissolo Vermelho-Amarelo)	Cfb	1287	1.3	23	29.7	1276	4.6	4.6

$^{(1)}$ Gonçalves (2002), Gonçalves et al. (2012) for ITA site, Alvares et al. (2011) for CB sites; $^{(2)}$ Alvares et al. (2013); $^{(3)}$ Average annual rainfall from nearby weather stations; $^{(4)}$ Age of plantation in January 2008; $^{(5)}$ Resin-extractable-P; $^{(6)}$ pH measured in 0.01 mol L^{-1} CaCl$_2$.

the year January to December 2008, which was the period used for the comparison of the measured annual rates. Soil cores were randomly sampled from the plots in a diagonal transect using steel tubes (length 30 cm, diameter 5 cm). Five initial soil cores were bulked and mixed, and likewise five field-incubated cores. Soil cores were collected from 11 sites within a period of 8 days, which avoided large climate variations between sites. Incubations were conducted for one month every three months. The tubes were separately wrapped in plastic bags and transported in a vertical position (as originally in the soil) to the laboratory in insulated boxes (temperature 2 °C). Refrigeration was used to minimise microbial activity and N mineralization prior to extraction. Soil samples remained refrigerated until N extraction, and extractions were performed within two days after collection. For mineral N extraction, 10 g of soil (< 2 mm) was sampled, extracted (50 mL 2 mol L^{-1} KCl) and analysed for NH_4^+ and NO_3^- by standard methods (Gomes, 2009). Soil water of each sample was measured by weight loss when dried at 105 °C. Net N mineralization was calculated as the difference between the mineral N content (ammonium plus nitrate) of the final and initial cores.

Soil temperatures were measured hourly using thermistor sensors, of which daily maximum and minimum values for the measurement period were recorded. Measurements were made at a depth of 10 cm at three locations per site for each 1-month *in situ* incubation. Daily maximum and minimum values were averaged for each period to provide an estimate of the average soil temperature at 10 cm depth for the period. Soil water was measured gravimetrically in bulked and mixed initial and final samples, as part of the *in situ* core technique. Bulk density was measured in a separate set of soil cores (n = 3).

Model

The SNAP model estimates field rates by adjusting a basal rate (k, determined by soil incubation) by soil temperature (Tm) and soil water (Wm) modifiers (Paul et al., 2002; 2003a):

$$\text{Nmin} = k \times \text{Tm} \times \text{Wm} \qquad \text{Eq. 1}$$

Ideally, the basal rates are determined in incubations under constant soil temperature and water conditions highly favourable to mineralization, but here instead one period of the field incubations was used. The modifier equations were:

$$\text{Tm} = \exp^{[3.36(T-40/(T+31.79))]} \qquad \text{Eq. 2}$$

where T is soil temperature (°C), and

$$W_m = 1/(1+6.63\ e^{-5.69\text{RFWC}}) \qquad \text{Eq. 3}$$

where RFWC is the relative field water content (defined as the water content relative to the upper and lower limit of water content observed in the field). Inputs required for SNAP were limited to the readily measurable; climatic data are entered on a daily basis, leaf area index (LAI) of the stand, estimated depth of water uptake, litter mass and height, and fraction of soil surface area covered by the canopy, weeds or understorey and litter.

Soil water and temperature at a particular depth and date are predicted through simple sub-models of soil temperature (Paul et al., 2004) and soil water (Paul et al., 2003b), which had been calibrated across many different soil types, depths and textural classes.

Sensitivity analysis

To determine the sensitivity of model predictions to variations in input parameters, the percentage change in NNM rates resulting from a change in an input value within subjective reasonable limits, one input at a time was determined, for simulation of NNM at the Agudos site. Variations in input parameters that were tested are listed in table 2.

Statistical analyses

Relationships between observations and predictions for soil water, soil temperature, and net N mineralization were described by regression analysis and plotted, with a 95 % confidence interval of prediction. SigmaPlot© software was used for these analyses. Regression performance was assessed by using an R^2 value and calculating the model efficiency (EF) = 1 - (SS/MS), where SS is the residual sum of squares, and MS the sum of squares of the differences between each measurement and the mean of the measurements (Soares et al., 1995).

Table 2. Base, low and high values of parameters used for the sensitivity analysis

Parameter	Base value	Low value	High value
Gravel (g kg^{-1})	0	0	500
Bulk density (kg dm^{-3})	1.41	1.00	1.60
Clay (g kg^{-1})	160.7	50	700
Lower water limit (g kg^{-1})	60.63	10	400
Upper water limit (g kg^{-1})	180.81	120	400
Initial moisture (g kg^{-1})	100.35	10	400
Incubation moisture (g kg^{-1})	120.39	10	400
Incubation temperature (°C)	26.1	15	40
Net N mineralization (mg g^{-1} d^{-1})	0.348	0.1	0.8
Canopy LAI (m^2 m^{-2})	3	0	6
Canopy cover fraction	1	0	1
Litter cover fraction	0.1	0	1
Weed cover fraction	0	0	1
Litter mass (Mg ha^{-1})	2	0	20
Litter height (cm)	1	0	20
Depth of water uptake (m)	5	0.2	5

RESULTS

Soil temperature and soil water

Measured and predicted ranges of soil temperature were both approximately 16-28 ˚C, with a linear relationship that approximated a 1:1 fit, 95 % confidence intervals of prediction of approximately ±4 ˚C, and a tendency to overestimate at higher temperatures (Figure 1). Soil temperature in this case was measured as the mean maximum plus mean minimum temperature divided by two, averaged every three months. The SNAP model predicted daily soil temperatures, which were averaged for each 3 month period for comparison with field measurements. Predicted daily soil temperature was lowest in July and highest in January (example for one site shown in figure 2).

The range of measured soil water was 10 to 380 g kg^{-1} (Figure 3). The range for predicted soil water was slightly less (20 to 320 g kg^{-1}), with a linear relationship between the two that approached a 1:1 fit, and with 95 % confidence intervals of prediction of approximately ±90 g kg^{-1}. Predicted daily soil water content was minimal and most prolonged during the dry season, but maximal (saturation) on many occasions throughout the year except in the dry season (Figure 2).

Annual mineralization and seasonality

Measured NNM rates in the surface soil layer (0-20 cm) ranged from 148 to 340 kg ha^{-1} yr^{-1} N and were weakly related to clay content (R^2 = 0.43), which is used as a general indicator of soil fertility in Brazilian forest plantations. Predicted annual rates were not significantly different from rates estimated by the *in situ* core technique up to a predicted rate of 370 kg ha^{-1} yr^{-1} N (R^2 = 0.84), but higher rates were significantly over-predicted (Figure 4). Predicted daily rates of NNM reflected the observed seasonal pattern in temperature and stochastic pattern of soil water (Figure 2). Basal rates (SNAP results, Table 3) were poorly correlated with measured NNM rates (R^2 = 0.34).

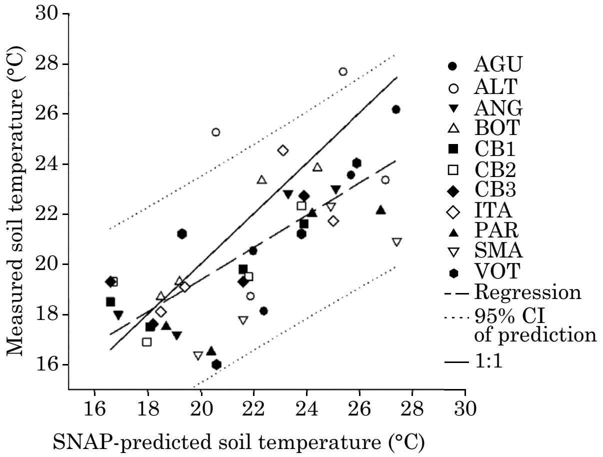

Figure 1. Soil temperature - measured (three-monthly) *versus* predicted value (three-monthly average of daily predictions) [$\hat{y}$ = 6.57 + 0.640 x, R^2 = 0.51, model efficiency (EF) = 0.32].

Seasonality of NNM rates was assessed at a site as the maximum/minimum ratio of measured seasonal rates. Due to the tropical climate, soil water content and NNM rates were lowest in the dry (June-August) and highest in the wet season (Jan-Mar). These ratios ranged from 1.5 to 4.5 across the 11 sites, which was similar for SNAP-predicted ratios (1.8-5.0) (Table 3). There was no significant correlation between these two sets of ratios (n = 11), but average ratios across all sites were similar, i.e. 2.5 measured compared to 2.7 predicted. Although the average SNAP-predicted seasonality was very close to the measured values, deviations at individual sites were substantial.

Sensitivity analysis

The inputs with most influence on SNAP predictions were related to basal rate calculations, i.e. upper limit of water content, water content, temperature, and N mineralization during incubation, which produced 2-4 orders of magnitude of over- or under-prediction in several cases. Litter mass, cover and litter height, initial water content, and clay content had the lowest effects (Figure 5).

DISCUSSION

In general, these results reliably confirmed that the SNAP model can be used to predict annual rates of NNM in tropical soils, aside from the temperate soils for which it was originally developed. As for the original development, incubations from which basal rates are calculated must be conducted under favourable soil temperature and water conditions. If not conducted in the laboratory, such conditions occur *in situ* in these Brazilian soils from January to March, and results based on incubations in this period generated adequate predictions of annual NNM rates and their seasonality.

The range of measured NNM rates was 148-340 kg ha^{-1} yr^{-1} N in the 0-20 cm soil layer. Additional N would also have been mineralized at deeper depths. Considering that the N demand by a fast-growing tropical eucalyptus plantation can be a maximum of 163 kg ha^{-1} yr^{-1} N (Cromer et al., 1993), it is not surprising that few of

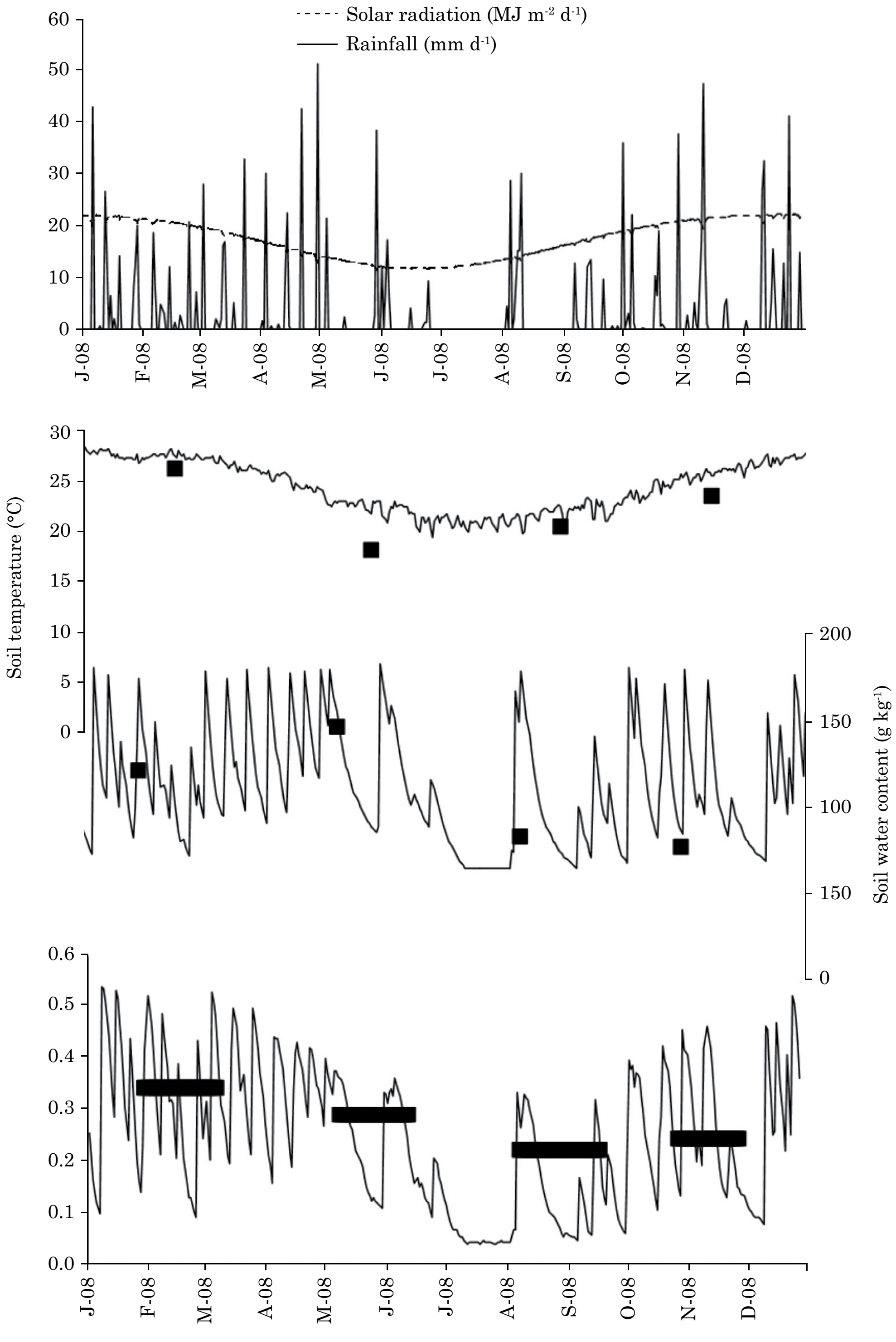

Figure 2. Example of output from the SNAP model for the 0-20 cm layer at the Agudos site. Solar radiation, rainfall and black squares are measured values; other lines are SNAP predictions. Measured soil water values are from initial cores.

the plantations in this study responded to N fertilization (Pulito, 2009).

To assist further studies and the application of this technology, a discussion about the sources of error in the current analysis is indicated. Rates of NNM measured by the *in situ* core technique include errors discussed by Raison et al. (1987), Adams et al. (1989), and Smethurst and Nambiar (1989), which also apply to our study. These errors

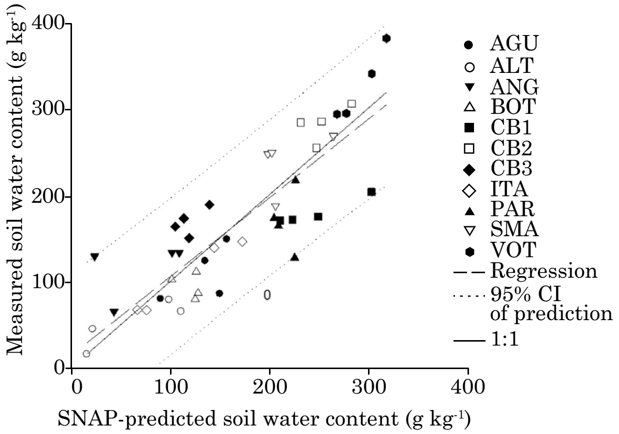

Figure 3. Soil water - measured (three-monthly on initial core soil samples) *versus* the predicted daily value [$\hat{y} = 14.5 + 0.910\ x$, $R^2 = 0.75$, model efficiency (EF) = 0.71].

include potential soil disturbance, root severance, and modified environment (temperature and water) effects on mineralization rates occurring in *in situ* cores, as well as normal sampling and laboratory errors. Hence, our measured NNM rates were probably not completely accurate, and our study included additional error, i.e. the NNM rates in this study were measured only in one month of each three-month period, i.e. one third of the year. The rates in the two unmeasured months of each three-month period were assumed to be identical to those during the measured period, which would not have been completely true. Predicted NNM rates are highly dependent on the incubation conditions, for influencing the estimated basal rate. Deviations from optimal temperature and water conditions would have led to error. Additionally, temperature fluctuations in the field might have affected the measured rates.

Site effects on NNM have several components: climate, soil type, slope, aspect, soil surface roughness, management effects such as forest floor removal, cultivation, thinning, and irrigation. Climate and micro-climate effects are captured by the SNAP model via the temperature and water modifiers and sub-models, and as inputs to these submodels, e.g. leaf area index. Some potential site effects on NNM are captured in the measurement of basal rate, as this is affected by organic matter quality and quantity. Basal rates (i.e. NNM during aerobic incubation) can be expected to change somewhat during a plantation rotation of several years and may require reassessment. Although the frequency of this requirement has not been studied in relation to the SNAP model, there are numerous examples

Table 3. Measured and SNAP-predicted rates and seasonality of net N mineralization (NNM) at individual sites grouped according to clay content

Site	Clay	NNM			Maximum to minimum ratio of NNM rate	
		Measured	SNAP prediction	SNAP basal rate	Measured	SNAP-prediction
	g kg-1	kg ha-1 yr-1		mg kg-1 d-1		
				Clay content 0-100 g kg-1		
ALT	67	210	238	0.96	1.54	2.17
ANG	100	149	75	0.60	2.18	4.95
BOT	100	207	238	1.09	4.45	3.18
Mean	89	189	184	0.88	2.72	3.43
Standard deviation	19	34	94	0.25	1.53	1.41
				Clay content 100-300 g kg-1		
AGU	167	225	254	1.13	2.24	2.90
CB3	272	237	278	1.13	2.36	2.21
ITA	193	148	155	1.01	3.34	2.14
Mean	211	203	229	1.09	2.65	2.42
Standard deviation	55	48	65	0.07	0.60	0.42
				Clay content 300-700 g kg-1		
CB1	478	309	373	1.84	2.02	2.37
CB2	653	264	211	1.01	2.23	2.26
SMA	651	157	187	2.24	2.49	2.89
PAR	365	340	428	1.61	2.74	2.55
VOT	670	264	290	1.20	2.31	1.76
Mean	563	267	358	1.58	2.36	2.37
Standard deviation	136	69	110	0.49	0.27	0.41

of annual changes in rates of net N mineralization or potentially mineralizable N. In seven years of measurement, Mellilo et al. (2011) found that the minimum annual rates of NNM were about 40 % lower than the maximum. In a five-year study, O'Connell et al. (2004) found that minimum annual rates of NNM could be 33 % lower than the maximum. Some differences between annual rates are due to different climatic conditions, but there can also be a change in organic matter quality. For example, in a three year period, Smethurst and Nambiar (1995) found that specific rates of net N mineralization decreased from 207 to 90 g month^{-1} of N t^{-1} C. Such changes in organic matter quality should be assessed by aerobic incubation for quantification of the basal rate and its use in the SNAP model.

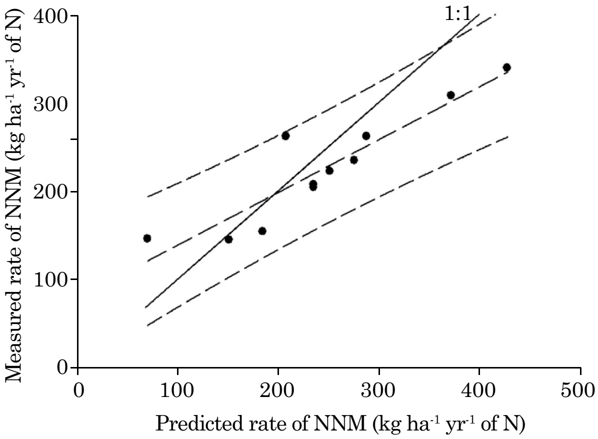

Figure 4. Measured *versus* predicted rates of net nitrogen mineralization (NNM) [$\hat{y}$ = 72.7 + 1.41 x, R^2 = 0.84, model efficiency (EF) = 0.35, n = 11] showing the 95 % confidence interval of prediction in relation to the 1:1 line.

The sensitivity analysis provides an indication of the relative importance of correctly defining SNAP input values (Figure 5). Compared to input values used for SNAP predictions at the AUG site (Table 3), subjectively chosen low and high realistic input values (Table 2, on a one-by-one basis) led to a 2-5 order of magnitude of over- or under-prediction of measured *in situ* rates. Water, temperature and N mineralization during basal rate incubations were critical, which reinforces the need for the choice of favourable incubation conditions and their accurate quantification. When an incubation to determine a basal rate is performed at low water content or low temperature, the further the conditions are from optimum the greater the adjustment required to calculate the basal rate, and the highly non-linear modifier functions used lead to greater error.

Despite potential sources of error, there was good agreement between observed and predicted NNM rates. However, in further model testing and application, caution is required, including the preference of laboratory over field incubations, and *in situ* incubations used at all times of the year. The measured NNM rates were highly correlated with SNAP-predicted rates of NNM (R^2 = 0.84), but not with basal rates (R^2 = 0.09). This result shows that the use of the water and temperature modifiers in SNAP, in combination with estimates of daily soil

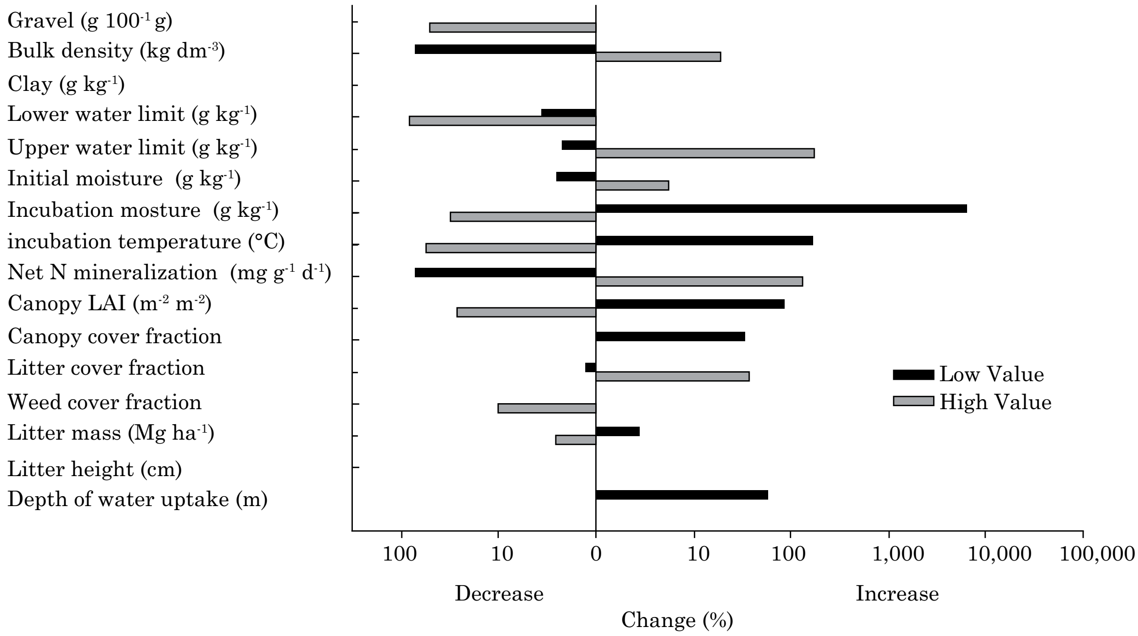

Figure 5. Sensitivity of predicted NNM rates in relation to single-factor variations in input parameters. Where values seem to be missing, the change in input parameter induced no change in output value.

water and temperature in the field, was essential to predict NNM rates, and that basal rates alone were not an index of N availability.

The predicted seasonality of NNM was more or less pronounced than that measured in several cases. This result suggests that the functions used to calculate seasonal trends, i.e. the water and/or temperature sub-models, might need to be modified to suit São Paulo conditions, if reliable daily rate estimates are required or if non-optimum incubation conditions are to be used.

A potentially useful, yet unexplored application of the SNAP model is its use in plant production models that rely on the prediction of NNM and nitrification (Keating et al., 2003; Jones et al., 2003; Battaglia et al., 2004; van Noordwijk et al., 2011). Such models already use daily climate data, which would additionally require aerobic incubation and a few other inputs. The alternatives used in several of these models rely heavily on pH, C:N ratio or on clay content, which were found to be only weakly correlated with measured NNM rates.

CONCLUSIONS

Rates of NNM predicted by the SNAP model were highly correlated with measured rates across 11 sites that covered a wide range of NNM. Hence, the SNAP model proved useful for predicting NNM rates in tropical soils of Brazil.

The SNAP model provides a basis for improving N management of eucalypt plantations in Sao Paulo State, Brazil. Testing in a wider range of temperate and tropical conditions is encouraged.

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