Modelling nitrogen dynamics in tea soils

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Abstract

Nitrogen fertilization is important in tea cultivation due to high removal from the soil through crop harvesting. Field investigation was conducted for one year in tea plots at Tea Research Foundation of Kenya (TRFK), Kangaita station in Kirinyaga, Central Kenya, to assess dynamics of nitrogen. In order to support nutrient management in tea, a simulation model which considers the temporal dynamics of nitrogen in the tea environment was used. The model N-Vino was validated to reproduce the nitrogen dynamics in tea soils. Seventy percent of the simulated soil minimum N values ranged within the standard deviation of the observed soil minimum N values. Ninety percent of the soils water content, another variable used for the model validation could be reproduced at this level of accuracy. The results however, are considered sufficient for practical use in tea fertilizer management.

Key words: nitrogen, simulation model, crop growth.

Introduction

In recent years, sustainable agriculture has become a concern due to the pressures of the increasing nitrogen (N) fertilizer costs and increased focus on environmental protection. Any intensification on the use of nitrogen fertilizers in agriculture already has and will continue to have major detrimental impacts on the diversity and functioning of the non-agricultural neighbouring bacterial, animal, and plant ecosystems. There is greater attention being paid to the efficient use of N fertilizers (Hezhong \textit{et al.}, 2010). The need to optimize fertilizer inputs to meet crop requirements have also increasingly been identified as priorities for research in feedback from tea stakeholders.

Nitrogen is the major nutrient of tea plant, \textit{Camellia sinensis} without which it would not be feasible to achieve the commercial level of production (Venkatesan \textit{et al.}, 2005). It plays an important role in increasing the agricultural production and as a constituent of protein, it increases the tea quality (Kalaiselvi and Mahimairaja, 2010). Application of N depending on its form and compound it contains, undergoes a series of transformation including hydrolysis, volatilization, nitrification, denitrification and mineralization.

Nutrient dynamics mainly affect nutrient budget in tea soil. The nutrient budget is partly affected by processes such as fertilizer application; plant uptake and removal by harvesting, accumulation or storage in the standing plant and recycling through litter fall and stem flow (Dang, 2005). Nutrient uptake by plants is inherently inefficient and nutrients remaining in the soil after uptake can cause negative soil, air and water resource impacts depending on their fate. The study of nitrogen dynamics in tea cultivation is therefore required to understand the fate and potential threats of these elements.

Description of the model

The model, in which the plant growth subroutine for \textit{Camellia sinensis} was embedded, was previously presented by Kersebaum (1989, 1995). It considers the main nitrogen turnover processes net mineralization and denitrification as well as transport of nitrate by water and N uptake by plants. To meet the requirements of practical application the model is specially designed to work under conditions with restricted input data. It has been successfully used to assess fertilizer recommendations in Northern German agriculture in the last decade. Detailed description of the sub models for calculating the water balance as well as the transport and turnover of nitrogen were given by Kersebaum (1989, 1995). The plant growth sub model Kersebaum (1985, 1995) used in the model is based on the SUCROS
model of Van Keulen et al. (1982). Plant growth is expressed by daily dry matter production, which is calculated from global radiation and temperature. Photosynthesis response to temperature is taken from Groot (1987). Assimilate demand for organ-specific maintenance respiration is subtracted according to Penning de Vries & van Laar (1982) in dependence of plant dry mass to be maintained. The crop phenological development is divided into different stages, each depending on effective phenological thermal time. The calculation of the thermal time was first realized for winter wheat according to Weir et al., (1984), taking temperature, vernalisation and day length into account. Partitioning of assimilates to different plant organs depends on the phenological development. Furthermore, plant growth can be restricted either by water stress, determined by the ratio of actual to potential transpiration, or by nitrogen deficiency. The crop nitrogen balance is controlled by a thermal time dependent function of critical and maximum nitrogen content of the above-ground plant organs. It is connected to the soil nitrogen balance by an empirical function of root dry matter distribution by depth (Gerwitz and Page, 1974).

Materials and methods

Experimental site

This study was conducted at Tea Research Foundation of Kenya, Kangaita substation in Kirinyaga, Central Kenya. Kangaita (37°, 17.8’ E; 0°, 19.8’ S; 2130 metres above sea level) is located on the slopes of Mount Kenya.

Soil

The experimental soils were acidic clay (montmorillonites) humic loam with high fertility, taxonomically grouped under humic NITISOLS (Jaetzold et al., 2006).

Micro-meteorological variations

The local climate is humid subtropical with annual rainfall which ranges between 1700-2150 mm while temperature ranges between 14.5-17.8°C. A summary of the major values of micro-meteorological parameters during the experimental period i.e. September, 2010 to August, 2011 is shown in Table 1.

<table>
<thead>
<tr>
<th>Month</th>
<th>Total rainfall (mm)</th>
<th>Max. air Temp. (°C)</th>
<th>Min. air Temp. (°C)</th>
<th>Mean Air Temp. (°C)</th>
<th>Soil Temp. (°C)</th>
<th>RH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep</td>
<td>41.6</td>
<td>19.2</td>
<td>9.9</td>
<td>14.6</td>
<td>18.1</td>
<td>87</td>
</tr>
<tr>
<td>Oct</td>
<td>148.9</td>
<td>20.8</td>
<td>11.4</td>
<td>16.1</td>
<td>20.1</td>
<td>83</td>
</tr>
<tr>
<td>Nov</td>
<td>146.4</td>
<td>20.2</td>
<td>10.4</td>
<td>15.3</td>
<td>18.9</td>
<td>90</td>
</tr>
<tr>
<td>Dec</td>
<td>48.4</td>
<td>21.4</td>
<td>9.3</td>
<td>15.4</td>
<td>20.9</td>
<td>77</td>
</tr>
<tr>
<td>Jan</td>
<td>29.7</td>
<td>21.9</td>
<td>8.7</td>
<td>15.3</td>
<td>21.6</td>
<td>67</td>
</tr>
<tr>
<td>Feb</td>
<td>15.0</td>
<td>21.0</td>
<td>10.3</td>
<td>15.7</td>
<td>21.8</td>
<td>56</td>
</tr>
<tr>
<td>Mar</td>
<td>76.2</td>
<td>22.0</td>
<td>12.8</td>
<td>17.4</td>
<td>22.4</td>
<td>62</td>
</tr>
<tr>
<td>Apr</td>
<td>290.7</td>
<td>20.7</td>
<td>15.1</td>
<td>17.9</td>
<td>19.6</td>
<td>69</td>
</tr>
<tr>
<td>May</td>
<td>486.5</td>
<td>20.9</td>
<td>15.1</td>
<td>18.0</td>
<td>17.7</td>
<td>77</td>
</tr>
<tr>
<td>Jun</td>
<td>57.7</td>
<td>15.0</td>
<td>12.3</td>
<td>13.7</td>
<td>17.9</td>
<td>88</td>
</tr>
<tr>
<td>Jul</td>
<td>46.5</td>
<td>18.8</td>
<td>11.7</td>
<td>15.3</td>
<td>17.6</td>
<td>74</td>
</tr>
<tr>
<td>Aug</td>
<td>110.3</td>
<td>17.6</td>
<td>12.0</td>
<td>14.8</td>
<td>16.3</td>
<td>75</td>
</tr>
<tr>
<td>Mean</td>
<td>124.8</td>
<td>20.0</td>
<td>11.6</td>
<td>15.8</td>
<td>19.4</td>
<td>75.4</td>
</tr>
</tbody>
</table>
**N-Vino model inputs**

Input data were organized according to project, which means they are located in the project folder (Figure 1).

*Figure 1: Data structure of N-Vino model*

A project is defined by a common location (same latitude and weather station). The model demands input for soil properties, soil management, weather, crop management and fertilizers.

The simulation period as well as some options (output interval, evapotranspiration method, and precipitation correction) can be defined in the driver file for each project. Within a project folder separate folders are available for annual weather data (\WEATHER\) and output files and measured values (\RESULT\).

**Input and validation data**

The validation procedure for the N-Vino model involved separately validating the different modules i.e. site data, fertilizer parameters and management (Nendel, 2004). The growth parameters for tea were obtained from the field observations of other ongoing research projects in the Tea Research Foundation of Kenya. Model default values for fraction (%) of organic N that was not considered being recalcitrant and thus was available for daily N mineralization, dormancy and bud break were used in the simulation. Since the model was not parameterized for tea crop, the option provided for non-parameterized crops was used to input basic data required for the simulation of plant water and N uptake.

The weather information required by the model were daily mean air temperature (°C) at 2 m above soil level, daily air temperature (°C) at 2 p.m. at 2 m above soil level, daily sum of precipitation (mm), relative air humidity (%) at 2 p.m., and daily sum of global radiation (J cm⁻²) was obtained from weather stations of the Tea Research Foundation of Kenya.

The scatter diagrams and regression analysis of the observed and simulated data for the tea cropped plot are presented in Figures 2 and 3 respectively for soil minimum nitrogen content at 0-30 and 30-60 cm.

*Figure 2: Comparison between observed and simulated soil minimum nitrogen content at 0-30 cm depth*

*Figure 3: Comparison between observed and simulated soil minimum nitrogen content at 30-60 cm depth*

For both Figures, soil minimum nitrogen contents at 0-30 and 30-60 cm depths, the fit between observed and simulated data was more accurate in the lower than in the higher depth. Nevertheless, the medium correlation coefficients (above 0.4) between the simulated and measured soil minimum nitrogen content at 0-30 and 30-60 cm soil depths indicated that the calibration of the model was relatively accurate.

The other variable used in the calibration was soil moisture content. Nitrogen transport in the soil is strongly determined by soil water movement. The scatter diagrams and regression analysis of the observed and simulated data for the tea cropped plot during the monitoring period are presented in Figures 4 and 5 respectively for 0-30 and 30-60 cm.

*Figure 5: Comparison between observed and simulated moisture content at 30-60 cm depth*
The clustering of the observed and simulated soil moisture around the 1:1 line and the high correlation coefficient (0.9) in Figure 5 indicate that the N-Vino model was quite accurate in simulating time changes of the soil moisture. The ability of the model to reproduce the soil water content with some degree of correctness determines the success in simulating N dynamics. From the figures, simulation seems to overestimate the water content slightly throughout the whole simulation period and stronger in deeper layers. The simulation reveals a better match of simulated and observed water content in the 0-30cm depth.

**Results and discussions**

It is difficult to measure the depth and time distribution of fertilizer N which undergoes transformation in tea cultivation, therefore simulation studies were performed with N-Vino model. N-Vino was used to simulate the depth and time distribution of nitrogen in the root zone after it was validated using the measured data from the field experiment.

**Mineral nitrogen content**

The results of the soil minimum N simulations are presented in Figure 6. The monthly simulated soil profile nitrogen content (kg ha⁻¹) behaved almost the same way for depth 0-30 and 30-60 cm.
Figure 4: Monthly simulated soil profile minimum N content (kg ha$^{-1}$) between September, 2010 and August, 2011

For the top profile, simulated nitrogen content stagnated averagely at around 30 kg ha$^{-1}$ from September, 2010 up to May, 2011 when it started rising almost linearly to 90 kg ha$^{-1}$ at July, 2011 and later dropped gradually. For second profile of 30-60 cm, simulated minimum nitrogen content rose slightly from 10 to almost 30 kg ha$^{-1}$ between September and October, 2010, stagnated averagely between 30 and 40 kg ha$^{-1}$ from October, 2010 up to July, 2011 when it started rising sharply up to almost 70 kg ha$^{-1}$ and later dropped slightly. The soil N dynamics show a pattern of increase in the top soil up to July, 2011, which might be due to N mineralization (Figure 9), and a subsequent translocation down the soil as per the second and third depths, where a part of it is consumed by tea roots. With a little time lag the behaviour in the top layer minimum N content affects the deeper layers as well, but not in the same order of magnitude. From this it can be concluded that the peak might be only a short-term mineralization flush, caused either by the organic or by any other external disturbance of the microbial biomass. The released nitrogen was then presumably immobilized again during the following month.

Water percolation

Water percolation in 200 cm depth was simulated as shown in Figure 7.
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Figure 5: Monthly simulated percolation within 200 cm soil profile between September, 2010 and August, 2011

From the simulation there was no percolation from September, 2010 up to January, 2011 when it started rising gradually up to around 105 mm by August, 2011 with little stagnation after 40 mm and extensive stagnation at around 70 mm. The simulation did not show percolation at first, this might suggest that precipitation although high were proportional to plant water uptake.

Nitrogen leaching

N-leaching within 200 cm depth was simulated as shown in Figure 8.

Figure 6: Monthly simulated leached N (kg ha⁻¹) within 200 cm soil profile between September, 2010 and August, 2011
From the simulation, there was no nitrogen leached from September, 2010 up to almost February, 2011 when it started rising gradually up to 21 kg ha\(^{-1}\) by August, 2011 with small stagnation along the simulated leaching line up to 12 kg ha\(^{-1}\) where extensive stagnation occurs between April and July. The residual nitrogen in soil which is present in the form of nitrate is commonly lost through leaching (Figure 8), or denitrification (Figure 10), or a combination of these. Nitrate is easily dissolved in water and once it enters the water solution, it moves with the water, down into the water Table. Proper fertilizer management in terms of selection of fertilizer type, timing and method of application determines the availability of fertilizer N in the root zone for leaching (Prunty and Greenland 1997).

**Nitrogen mineralization**

Nitrogen mineralization was simulated as shown in Figure 9.

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**Figure 7:** Monthly simulated mineralized N (kg ha\(^{-1}\)) within 200 cm soil profile between September, 2010 and August, 2011

From the simulation, nitrogen mineralization rose exponentially from zero at September, 2010 to almost 220 kg ha\(^{-1}\) at August, 2011.

**Nitrogen denitrification**

Denitrification of N per hectare was simulated as shown in Figure 10.
Figure 8: Monthly simulated N denitrification (kg ha\(^{-1}\)) within 200 cm soil profile between September, 2010 and August, 2011

From simulation, nitrogen denitrification rose very slowly up to 9 kg ha\(^{-1}\) at April and started rising almost linearly to 80 kg ha\(^{-1}\) at August, 2011. Figure 11 illustrates simulation behaviour of minimum nitrogen content for soil depth profile.

Figure 9: Simulated minimum N content (kg ha\(^{-1}\) dm\(^{-1}\)) along a 100 cm soil profile

Between surface and 10 cm, simulated nitrogen content was 6 kg ha\(^{-1}\) dm\(^{-1}\) and increased slowly up to 9 kg ha\(^{-1}\) dm\(^{-1}\) around 15 cm. It increased further drastically between 15 and 35 cm up to 15 kg ha\(^{-1}\) dm\(^{-1}\). Simulated nitrogen content along the depth profile started decreasing from 15 to 8 kg ha\(^{-1}\) dm\(^{-1}\) between 35 and 65 cm. It decreased further slowly between 65 and 75 cm from 8 to 2 kg ha\(^{-1}\) dm\(^{-1}\) then stagnated at 2 kg ha\(^{-1}\) dm\(^{-1}\) till end at 85 cm.

The increase in simulated nitrogen content between the soil surface and the 35 cm depth might have been due to leaching and accumulation of N fertilizers (Figure 11).

Conclusion

The following conclusion may be drawn from the results of the N-Vino N simulation in tea. As previously shown for cereals (Kersebaum, 1995), the validated model for Camellia sinensis as well produces sufficient results for practical use in tea fertilizer management. The plant growth sub model, simulated amount and dynamics of monthly nitrogen in tea giving a useful support for the description of the general nitrogen dynamics. Although tea nitrogen uptake varies from about 75 to 150 kg N ha\(^{-1}\), N-mineralization and transport seem to determine the nitrogen dynamics mainly in tea land.

Acknowledgement

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