Developing Improved Cropping Systems for Vegetables and Legumes in the Tropics

2. Change in soil nutrient status

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Abstract Relevant soil nutrients including pH and EC vary easily corresponding to cropping sequences, cultivating time and the amounts of fertilizer and compost applied, soil pH varied only by one unit through ten successive cultivations of different crops, and planting time affected soil EC more than the cropping sequences did.

Available nutrients except phosphorus in soils varied in inverse proportion to the amounts of precipitation. Compost application effectively increased soil total N, available P and K, while rice straw mulch was primarily important not only for overcoming of hazardous heavy rain damage and a decrease in soil temperature, but also for an increase in soil available K and P.

Soil nutrient concentrations after harvest were not closely related to the overall crop yields. It is, therefore, primarily important for the high yields of tropical vegetables and legumes to avoid hazardous high temperature and heavy rain damage in terms of introducing a highly heat-tolerant cultivar and such cultural practices as mulching and high pot cultivation.

Key words Cropping system, heat tolerance, legume, soil nutrients, vegetable

Introduction

Crop rotation is beneficial to the soil: it preserves organic matter, increases nitrogen, balances soil nutrients, improves its physical properties, and suppresses soil-borne diseases1, 2, 8, 9, 10.

Under intensive cultivations of vegetables and legumes in the humid tropics, therefore, an adequate crop rotation should be established to overcome various risks of successive cultivation and to attain their high yields on the same land in successive years3, 4, 12.

This project, which was begun in 1983 and continues up to date, attempts to 1) develop crop rotation system specifically tailored to the tropics; 2) evaluate the effects of previous crops and successive applications of fertilizer, mulch and compost on vegetable and legume yields.

In this paper, the effects of crop sequences,
applications of chemical fertilizer, mulch and compost, and irrigation on soil nutrient status are mainly discussed. Change in the soil nutrient status following different crop cultivations is traced and relation of its change to the crop yields is also described.

Materials and methods

Cropping sequences, cultivars, and fertilizer application rates are all given elsewhere.

Soil analysis

After all the plants were harvested for the determination of the yield and total biomass production, soil samples were collected from the top 10 cm-layer of each experimental plot and were air-dried, and passed to 2 mm-sieve for analyses of available nutrients left in the soil. Neutral 1 N ammonium acetate was used for the available cation extraction from the soils. Total and inorganic nitrogen were measured by the Kjeldahl-distillation method, and an atomic absorption spectrophotometer was used to measure level of Ca and Mg, and a flame photometer for K determination. P was extracted from the soil with 0.5M NaHCO₃ at a constant pH of 8.5 and calorimetrically determined.

Results and discussion

Distribution of soil nutrients

Relevant soil nutrient status in the experimental plots is summarized in Table 1. The soil was sandy clay loam with an average pH of 7.08, and rich in Ca and Mg, but low in total nitrogen (TN) and total carbon (TC). Average concentrations of all the measured items except Ca were slightly or substantially increased by the crop rotation. All the available nutrients possess large standard deviations (SD) while the skewness coefficient and kurtosis coefficient are great positive or negative and greater than 3.0, respectively in all the items measured except TC. These facts indicate that relevant soil nutrients including pH and EC vary easily corresponding to cropping sequences, cultivating time and the amounts of fertilizer and compost applied.

Change in soil pH and EC

Change in soil pH was traced over ten successive cultivations for different cropping sequences. The results were analyzed statistically and plotted against rotation crops, and season in Fig. 1. The soil pH increased significantly after Chinese cabbage planting while

<table>
<thead>
<tr>
<th>Items measured</th>
<th>Average Value</th>
<th>Standard Deviation</th>
<th>Coeff. of Skewness</th>
<th>Coeff. of Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.18</td>
<td>7.08</td>
<td>0.50</td>
<td>-0.95</td>
</tr>
<tr>
<td>EC</td>
<td>0.22</td>
<td>0.25</td>
<td>0.13</td>
<td>1.92</td>
</tr>
<tr>
<td>Total N</td>
<td>0.081</td>
<td>0.083</td>
<td>0.014</td>
<td>2.93</td>
</tr>
<tr>
<td>Total C</td>
<td>0.71</td>
<td>0.71</td>
<td>0.09</td>
<td>0.19</td>
</tr>
<tr>
<td>C/N Ratio</td>
<td>8.70</td>
<td>8.60</td>
<td>1.0</td>
<td>-1.08</td>
</tr>
<tr>
<td>Inorganic N</td>
<td>18.3</td>
<td>20.1</td>
<td>14.1</td>
<td>1.92</td>
</tr>
<tr>
<td>Available P</td>
<td>34.4</td>
<td>39.6</td>
<td>17.2</td>
<td>1.95</td>
</tr>
<tr>
<td>Available K</td>
<td>62.8</td>
<td>72.2</td>
<td>48.0</td>
<td>3.29</td>
</tr>
<tr>
<td>Available Ca</td>
<td>1613.0</td>
<td>1602.0</td>
<td>335.0</td>
<td>0.25</td>
</tr>
<tr>
<td>Available Mg</td>
<td>194.0</td>
<td>202.0</td>
<td>46.7</td>
<td>0.98</td>
</tr>
</tbody>
</table>

* A total of 102 samples was statistically analyzed.

**Total N and total C are expressed in % while other nutrients are expressed in ppm.

The skewness coefficient measures how asymmetric the data distribution is. Positive values of skewness denote that the upper tail of the curve is longer than the lower tail, while negative values denote that the lower tail is longer.

The kurtosis coefficient reveals how flat or steep the distribution of the data is with respect to a Gaussian or normal distribution. For a normal distribution, the kurtosis coefficient is 3.0. When the coefficient is less than 3.0, the curve is flat with short tails. When the coefficient is greater than 3.0, the curve is either very steep at the center or has relatively long tails.
Fig. 1 Means plot for changes in soil pH and EC with planting year, planting season, and crops cultivated. Range of each plot denotes 95 percent confidence intervals for factor means.
decreased by rice cultivations. Compost application slightly lowered the pH but, no seasonal fluctuation of the soil pH was observed. However, soil pH varied only by one unit throughout ten successive cultivations of different crops, and it lay within the desired range of crop growth (between 6.50 and 7.50).

Soil EC varied in the different cropping sequences, mainly corresponding to the amount of fertilizer and compost applied; however, planting time affected soil EC more than the cropping sequences did. Autumn planting (dry season) resulted in higher soil EC than in the other plantings, because more than 90% of annual precipitation was accumulated in both the spring and summer plantings, thereby, salts would be leached out from the top soils. In addition, a large quantity of Ca and Mg was introduced into each experimental plot through irrigation water in the dry season. EC was always higher after spring rice than after summer rice when more than 60% of annual precipitation was accumulated.

Change in soil nutrient concentrations

1) Annual variation

Change in available soil nutrients is plotted against the cultivating year in Fig. 2. Inorganic nitrogen (IN) gradually decreased with an increase in the frequency of crop cultivations while soil P continuously increased in the first three years and then decreased to reach a plateau. Available K had kept its concentration around 80 ppm after the 1984 plantings, and soil Mg started to increase in 1984 and reached a plateau of about 230 ppm by 1986. Since the autumn of 1985, the spring and autumn mungbean were replaced by soybean, and corn and buckwheat which had been cultivated for green manure were replaced by sweet corn for a fresh market, and also the total amounts of N applied per annum in each cropping system were increased up to 200 kg/ha during the 1986 plantings. Thereby, a great fluctuation of the 1986 results can be partly explained by these changes.

2) Seasonal variation

A seasonal variation of the soil nutrients over 1983 to 1987 is summarized in Fig. 3. such divalent cations as Ca and Mg decreased sharply its concentration during the summer planting. Soil K and IN concentrations became higher after the autumn planting because of limited rainfall. Thus, the available nutrients varied in inverse proportion to the amounts of precipitation. The planting time did not affect soil P significantly. Phosphorus fertilizer is easily reacted with soil components and tightly held on them when applied in soils, resulting in substantial resistance to be leached out by rain.

3) Variation with crops cultivated

IN was not increased by introduction of legumes in crop rotation, and decreased significantly by rice cultivation (Fig. 4). Available P accumulated after soybean (SB) and tomato cultivations while decreased with the plantings of sweet potato (SP) and rice.

Soil potassium (K) increased greatly with SB cultivation. Tomato decreased available calcium (Ca) greatly.

Available magnesium (Mg) increased either with cultivation of soybean, Chinese cabbage (CC) or rice while decreased with introduction of mungbean (MB) and tomato. Thus, cultivations of soybean and Chinese cabbage increased soil available nutrients significantly. Two factors are chiefly attributable to this increase; 1) planting time, and 2) compost and/or mulch applications. Soybean has cultivated both in autumn and spring, and not in summer, and the spring planting was mainly adopted to Chinese cabbage. On the other hand, tomato was mostly introduced into various cropping sequences as a summer crop when more than 60% of annual precipitation was accumulated.

Secondly, only three crops, namely, soybean, Chinese cabbage and tomato received compost and mulch which contained substantial amounts of available nutrients (for example, relevant chemical properties of the compost used in this experiment are, pH: 7.54, EC: 2.95, TC (%): 16.47, TN (%): 1.85, NH4-N (ppm): 21.6, NO3-N (ppm): 203.0, Available P (ppm): 2773.7, Available K (ppm): 2487.7).

4) Variation with cropping sequences

Variation in available nutrients is plotted against different cropping sequences in Fig. 5. Cropping sequences did not affect available nutrient status in soil greatly, but compost application increased TN substantially (Rota-
Fig. 2 Means plot for changes in available soil nutrients with planting years
Fig. 3  Means plot for seasonal variations in available soil nutrients
Fig. 4 Means plot for changes in soil available nutrients with crops cultivated
Rotation crops are abbreviated as follows; SB=soybean, MB=mungbean, TO=tomato, CC=Chinese cabbage, SP=sweet potato.
Fig. 5 Variation in soil available nutrients with cropping sequences
Table 2 Relation of relevant soil chemical properties to the yields of rotation crops

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Coefficient</th>
<th>Standard error</th>
<th>T-value</th>
<th>Significant level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-59.30</td>
<td>22.14</td>
<td>-2.68</td>
<td>0.009</td>
</tr>
<tr>
<td>Soil pH</td>
<td>8.67</td>
<td>3.10</td>
<td>2.80</td>
<td>0.006</td>
</tr>
<tr>
<td>EC</td>
<td>0.35</td>
<td>0.11</td>
<td>3.28</td>
<td>0.002</td>
</tr>
<tr>
<td>Available P</td>
<td>0.20</td>
<td>0.10</td>
<td>2.04</td>
<td>0.044</td>
</tr>
</tbody>
</table>

Adjusted R-squared = 0.1798

Model fitting results for soybean yield

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Coefficient</th>
<th>Standard error</th>
<th>T-value</th>
<th>Significant level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3.93</td>
<td>0.24</td>
<td>16.47</td>
<td>0.000</td>
</tr>
<tr>
<td>Soil EC</td>
<td>-2.72</td>
<td>0.84</td>
<td>-3.24</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Adjusted R-squared = 0.2746

Compost application and rice straw mulch were very effective to increase soil K and P. Rice straw mulch, therefore, is a primarily important technique not only for overcoming of hazardous heavy rain damage and a decrease in soil temperature, but also for an increase in soil available K and P. Although compost increases soil K and P, its application associated with deep plowing should be avoided in a rainy season because the deeply-plowed field works as a sort of water reservoir during the heavy rain, and gathers excess water from the surrounding area, thus resulting in serious root damage of rotation crops. Associated application of unamatured compost with the deep plowing aggravates the root damage due to a sharp decrease in soil Eh, thereby, it is highly recommended to use fully-matured compost in this season.

Relation of soil nutrient concentrations to crop yields

Multiple regression analysis was applied to this data set to clarify factors affecting yield. "F-enter", a value for the F-ratio above which variables would be entered into the model, was set to 4.0. The best fit model contains three independent variables, namely pH, IN, and Available P. Although pH and IN are both significant at the 0.01 level and Available P shows also a significant T-value at the 0.05 level, the coefficient of determination (R-squared) equals 20.6%, with an adjusted R-squared of 18.0%, indicating that only 18% of the variation in the yield is explained by the three factors included in the model (Table 2).

Out of this data set, only soybean data were selected and multiple regression analysis was applied to elucidate the effect of soil nutrient status on the specified crop. Nearly one third of the yield variation of soybean is explained by only soil EC and other nutrients are not significant even at the 0.05 level.

As we have previously reported, soil EC had a great effect on soybean yield, and the quadratic equation showed a best fit for each experiment point with regard to soil EC after soybean cultivation \( Y=1.28+0.54 \times (EC)-0.0361 \times (EC)^2 \), and the optimum EC value of soils for soybean could be estimated at 0.135. Therefore, the results obtained in this experiment agree well with those in the previous ones.

Similarly, multiple regression analysis was applied to other rotation crops. The best fit model for tomato contains two variables (IN and available Mg) with an adjusted R-squared of 0.61, and for Chinese cabbage, three variables (Ca, Mg, and K, \( R^2=0.66 \)). To increase tomato yields substantially, timely application of N and Mg is a key technique. However, cations, especially divalent cations availability should be kept high for the high yield of Chinese cabbage. It it reported that Chinese cabbage were very susceptible to Ca deficiency and such cations as Mg and K affected greatly its Ca uptake. Results of the regression analysis also indicate that the uptake of sparingly soluble cations is a rate limiting for Chinese cabbage production.

Next, multiple regression analysis was con-
ducted between the yield of succeeding crops as a dependent variable and nutrients left in soils after harvest of preceding crops. P, K and Mg are included in the fit model with an adjusted R-squared of 0.22. The model does not fit well to the experimental data, and only available P possesses positive coefficient, indicating that the cumulative effect of soil nutrients in the humid tropics may be expected only for P.

The multiple regression analysis was also applied to the data set of each crop. No crop yields, however, could be explained nicely by relevant chemical properties of soils before the crop planting.

The results obtained indicate that the total application rates of N, P and K fertilizer per annum in each cropping system, i.e., 200, 120, 180 kg/ha, respectively are adequate and it is primarily important for the high yields of tropical vegetables and legumes to avoid hazardous high temperature and heavy rain damage in terms of introducing a highly heat-tolerant cultivar and such cultural practices as mulching and high pot cultivation9).

References