SANREM CRSP RESEARCH BRIEF
Sustainable Agriculture & Natural Resource Management Collaborative Research Support Program
2003 No. 16

SANREM CRSP

ABOUT SANREM CRSP

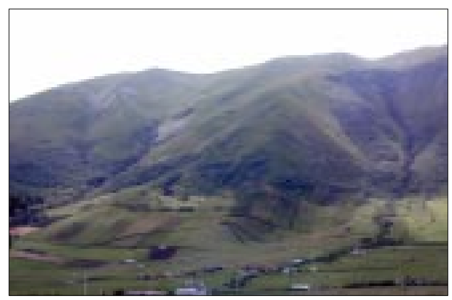
SANREM'S mission is to assist in the analysis, creation and successful application of decision support methods, institutional innovations and local capacity approaches to support participatory sustainable agriculture and natural resource planning, management and policy analysis at local, municipal, provincial and national levels.

TOWARDS SUSTAINABLE CROP PRODUCTION IN ANDEAN COMMUNITIES, ECUADOR: AN ASSESSMENT OF THE SOILS' NUTRIENT STATUS

Volcanic soils have the reputation of being lush and fertile; however, do young volcanic soils supply sufficient plant nutrients for the production of food crops? How can soil fertility be sustainably maintained in Andean peasant communities? Can simulation modeling help encourage sustainable land management decisions?

The volcanic ash soils of northern Ecuador have supported agricultural activities for thousands of years; however, at the dawn of a new millennium, in the peasant communities of Cotacachi, where crop yields have been declining over the past decades, the sustainability of agricultural production seems to be threatened.

Within the SANREM CRSP, researchers Franz Zehetner and Bill Miller analyzed the fertility status of the soils in the Cotacachi area and identified limiting factors to crop growth in different zones of the area. The researchers used crop growth modeling to examine the long-term effects of nitrogen fertilization and residue management on maize yields, and to identify possible avenues for restoring and maintaining soil fertility as the basis of sustainable agricultural production.



The road to Volcano Cotacachi in northern Ecuador, whose slopes are home to over 40 peasant communities.

BACKGROUND

The Cotacachi area of northern Ecuador is located about 35 km north of the equator on what the German explorer Alexander von Humboldt called *The Avenue of the Volcanoes*. The studied communities are situated at elevations between 2200 and 3200 m above sea level, on the slopes of volcano Cotacachi oriented towards the temperate *inter-Andean valley*. The climate in the area is that of an equatorial high-altitude environment, with temperatures almost constant throughout the year, but showing pronounced diurnal oscillations. Variations of climatic parameters over the landscape are largely a function of elevation. The mean annual temperature is about

SANREM CRSP
1422 Experiment Station Road, Watkinsville, Georgia, 30677 USA
Phone (706) 769-3792 - Fax (706) 769-1471 - E-mail: SANREM@uga.edu
Web site: http://www.sanrem.uga.edu

15 °C at 2500 m, and drops by about 0.6 °C per 100 m of elevation increase. The mean annual precipitation is about 900 mm at 2500 m and increases with elevation to about 1500 mm at 4000 m. The climate is characterized by a marked seasonality with a dry season of pronounced water deficit from June to September.

Studying volcanic soil in the field: Dr. Miller surrounded by curious Quichua.

The soils in the southern part of the study area have formed on 3000-year-old volcanic deposits and are in their early stages of development, whereas the soils in the northeastern part have formed on deposits older than 40 000 years and are thus more advanced in their development. Apart from differences in age and composition of parent materials, soil formation in the area is heavily influenced by climatic differences with elevation along the volcanic slopes. At high elevations, the soils are classified as *Andisols*, have high organic matter contents, and clay mineralogy is dominated by amorphous materials. At low elevations, the soils are *Inceptisols* and *Entisols*, in which organic matter contents are low and clay mineralogy is dominated by crystalline constituents.

The region has been largely deforested and the present landscape is dominated by agricultural land use below 3000 m, and high-altitude scrubland and grassland above 3000 m. The major agricultural crops in the area are maize (*Zea mays* L.), bean (*Phaseolus vulgaris* L.), and potato (*Solanum tuberosum* L.).

Agriculture shows marked differences between *hacienda*-type operations on the one hand and smallholder farms in the mostly indigenous peasant communities on the other. The large-scale *hacienda* agriculture is characterized by intensive management with high inputs and a high degree of mechanization. The situation in the peasant communities is different. Many farmers own less than 2 ha of arable land and very little livestock. Due to limited resources and the desire to produce organically, the use of chemical fertilizers and pesticides is uncommon. Manure application rates are generally low, and many farmers don't fertilize their land at all. The limited amount of available land forces many farmers to crop continuously and avoid prolonged fallow periods. Land management operations, such as tillage and cultivation, are generally done by hand or with the use of oxen.

Crop yield data collected by the Ecuadorian *Centro Andino de Acción Popular* (CAAP) indicate comparatively low maize yields in the Cotacachi area, and members of the Cotacachi communities have identified decreasing soil fertility as a threat to their subsistence.

METHODOLOGY

A total of 145 cultivated fields in 41 Andean communities around volcano Cotacachi were randomly selected for soil analysis. Depending on the size of the fields, between 10 and 20 soil samples were taken from the plow layer (0-15 cm depth) and mixed to obtain one composite sample of each field. Laboratory analyses were performed on air-dried and sieved samples employing standard methods.

The *Decision Support System for Agrotechnology Transfer* (DSSAT, version 3.5) was used to simulate maize (*Zea mays* L.) growth in the area under study. DSSAT is an integrated modeling platform that comprises several crop simulation models and databases. It operates on a field-scale and is capable of long-term simulations.

The model was calibrated for the local maize variety *Chaucho Mejorado* (INIAP-122), which was grown in field trials during the 2000-2001 rainy season. In order to analyze long-term effects of land management, 30 years of weather data were randomly generated with DSSAT's weather generator WGEN based on an existing 30-year weather dataset from the nearby town of Otavalo and known altitudinal variations of climatic parameters.

RESULTS

Nitrogen, phosphorus, and potassium are nutrients that plants require in large quantities for normal growth. Shortage of these macronutrients in agricultural soils causes impaired plant development and drastically reduced crop yields. The maintenance of adequate nutrient levels in the soil is a prerequisite to sustainable agricultural production.

The Soils' Nutrient Status

Potassium

The amount of exchangeable potassium held on the charged surfaces of soil particles is a reliable indicator of potassium availability to plants. The distribution of exchangeable potassium in topsoils around the study area is shown in Figure 1. The young, sandy soils in the southern study area have considerably lower exchangeable potassium than the older, finer textured soils of the northeastern part. Differences in age and composition of parent materials are likely responsible for these variations. The young deposits of the southern study area show comparatively low inherent potassium contents, and there has not yet been enough time for weathering to form significant amounts of clay and exchange surfaces for effective retention and storage of potassium, thus making it susceptible to leaching. In field trials conducted during the 2000-2001 rainy season in the southern part of the study area, maize yields showed marked responses to additions of potassium.

Phosphorus

Amorphous weathering products are known for their ability to strongly bind phosphate ions in volcanic soils, limiting the amount of phosphorus available for plants and microorganisms. In the area under study, such amorphous materials only occur in soils of higher elevations, where they are responsible for low plant-availability of phosphorus. This may induce phosphorus deficiency in potato and other crops cultivated in the high zones of the study area.

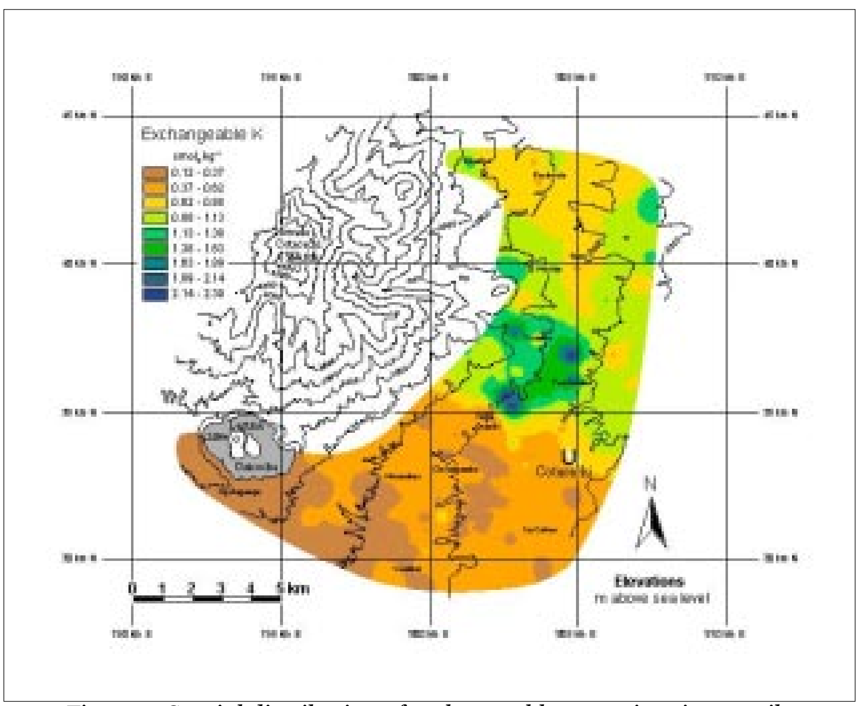


Figure 1. Spatial distribution of exchangeable potassium in topsoils.

Nitrogen

Organic matter is an important source of plant nutrients, with the vast majority of soil nitrogen stored in organic compounds. While the low-elevation soils of the study area contain little organic matter and hence little nitrogen, the organic-rich soils at higher elevations have a considerable pool of nitrogen. However, in order for it to become available for plant uptake, organic nitrogen needs to be converted to mineral forms (mineralized) in the course of organic matter decomposition.

Nitrogen Cycling and Crop Growth Modeling

For two contrasting soils of the high- and low-elevation zones, exhibiting high and low organic matter contents, respectively, an annual maize-fallow rotation was simulated with various nitrogen inputs from residue incorporation and fertilization. Nitrogen cycling was modeled while other factors were assumed not limiting. Despite marked differences in the soil nitrogen pools at the two sites, yield responses to added nitrogen were similar. In the organic-rich high-elevation soil, mineral nitrogen was released too slowly for adequate supply of the maize crop, while in the low-elevation soil, rapid release of mineral nitrogen caused considerable leaching losses and a steady depletion of the soil nitrogen pool.

Figure 2 shows predicted grain yields over the 30-year simulation period for various management scenarios at the low-elevation site. When the fields were never fertilized and all crop residues were removed after harvest, maize yields declined from about 2000 kg ha^{-1} to little over 1000 kg ha^{-1} after 30 years of cultivation. By returning crop residues to the soil, maize yields were generally maintained above 2000 kg ha^{-1} over the 30-year simulation period, and yield declines were less pronounced. Maximum yields of around

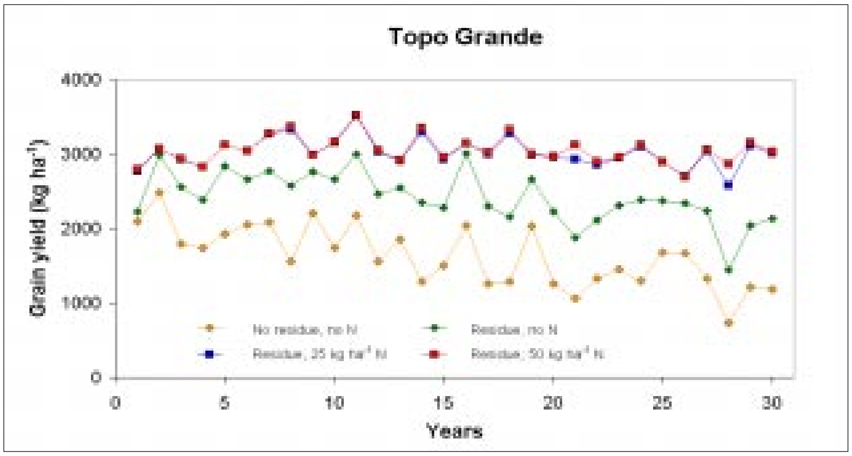


Figure 2. Simulated maize yields for the low-elevation site.

3000 kg ha^{-1} were obtained by fertilizing with 25 kg ha^{-1} of nitrogen in inorganic or organic forms and returning crop residues to the soil.

Implications for Management

Inadequate availability of plant nutrients may limit crop yields in different parts of the study area. The soils on the young volcanic deposits of the southern study area have inherently low potassium contents and require potassium additions for maximum crop yields. Phosphorus does not appear as yield-limiting in the area under study as commonly assumed and often reported for volcanic soils. It is only in high-elevation soils that strong phosphate retention necessitates increased phosphorus inputs for optimum crop growth. This is especially true when potato is grown in the high zones, as it has been traditionally the case.

The simulation modeling suggests that in the long term, crop yields could be significantly improved by returning the residues to the soil after harvest. The peasant farmers in the Cotacachi area often remove crop residues and use them as stock feed, fuel, or roofing material. Some of thus exported nutrients may be returned in the form of animal manure, but most appear to be lost from the production systems. Solutions to this problem would greatly contribute towards agricultural sustainability in the area. However, recycling crop residues alone cannot sustain high productivity. Additional N inputs are needed to compensate for slowed N mineralization in high-elevation soils and leaching losses in low-elevation soils. The N status of the studied soils would greatly benefit from including leguminous plants in crop rotations and managing short, improved fallows.

The replenishment of plant nutrients through organic sources seems preferable over inorganic for a number of reasons:

* Organic nutrient sources simultaneously add several nutrients including micronutrients to the soils and thus prevent potential nutrient imbalances.

* They enhance the plant-availability of phosphorus and micronutrients.

* They increase the soils' organic matter contents and so have beneficial effects on nutrient storage, water retention, infiltration capacity, etc.

* They can be produced locally, are therefore more readily and cheaply available, and create less dependency on uncontrollable external factors.

* And finally, they may be more compatible with local traditions and hence be more widely accepted.

CONCLUSIONS

The volcanic soils in the Andean communities around volcano Cotacachi have the potential to sustainably support traditional subsistence agriculture as well as thriving market-oriented production of niche crops, vegetables, and fruits. In either case, the key to agricultural sustainability is the restoration and maintenance of soil fertility. Nutrient losses need to be minimized, and nutrients that leave

the production systems through harvested products need to be replaced. The soils show marked variations within the study area, and depending on the specific location, different factors may become limiting to crop growth and therefore deserve special attention.

Crop growth modeling proved useful in analyzing various management alternatives with respect to their long-term effects on crop production and on the status of the soil resource. Provided adequate presentation tailored to the local context, it may serve as a valuable decision support tool that contributes to sustainable land management.

This brief draws from Franz Zehetner's dissertation research. His dissertation is entitled: *Genesis, Fertility, and Erodibility of Volcanic Ash Soils in the Andes of Northern Ecuador* (2003. Department of Crop and Soil Sciences, University of Georgia. Athens, GA).

ABOUT THE AUTHORS

Dr. Franz Zehetner completed his doctoral research within the SANREM CRSP in the Ecuadorian Andes. He recently received his Ph.D. in Agronomy from the University of Georgia. He can be contacted at: zefra@uga.edu.

Dr. William Miller is a professor of Soil Science at the University of Georgia. He has worked with the SANREM CRSP in Burkina Faso and Ecuador. He can be contacted at: wmiller@uga.edu.

SANREM is a Collaborative Research Support Program (CRSP) supported by the U.S. Agency for International Development Cooperative Agreement No. PCE-A-00-98-00019-00 and managed by the University of Georgia. The project brings together researchers from eight U.S. universities who partner with host country universities; local and national government officials; international agricultural research centers; and non-governmental organizations.