SANREM CRSP RESEARCH BRIEF
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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.

PLANT – WATER RELATIONS IN AN ANDEAN LANDSCAPE: MODELING THE EFFECT OF IRRIGATION ON UPLAND CROP PRODUCTION

Which elevation zones are most prone to drought stress in inter-Andean environments? Can an expansion of irrigation systems substantially improve upland crop production? Can simulation modeling help devise effective extensions to existing irrigation systems?

Volcano Cotacachi in northern Ecuador

In the inter-Andean valleys of northern Ecuador, irrigation systems have long been used to minimize drought risk and secure the production of food crops during dry periods. However, not all Andean communities have access to irrigation water. Increasing population pressure has forced many peasant farmers to move higher up the volcanic slopes and cultivate more marginal land under rainfed conditions.

In the SANREM CRSP research site of Cotacachi, local community members and officials of the local water authorities (*juntas de agua*) have been seeking to expand existing irrigation systems to a wider area. University of Georgia's researchers Franz Zehetner and Bill Miller analyzed the potential benefits to crop production that such expansion could bring about in different zones of the Cotacachi area that currently do not have access to irrigation water. The scientists used crop growth modeling to quantify the improvement of wet-season and dry-season maize production that would occur if irrigation water was available.

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BACKGROUND

The study site is located on the slopes of volcano Cotacachi (4939 m) in northern Ecuador, approximately 35 km north of the equator. Temperatures in the area are almost constant throughout the year but show pronounced diurnal oscillations, as characteristic for equatorial high-altitude environments. Climatic parameters show significant variations with elevation on the volcanic slopes. The mean annual temperature is about 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. Mean annual PET (potential evapotranspiration) amounts to about 900 mm at 2500 m and decreases with increasing elevation due to lower temperatures and higher humidity. The annual distribution of rainfall and PET for the nearby town of Otavalo (2550 m) is shown in Figure 1. The climate is characterized by an expressed seasonality with a dry season of pronounced water deficit from June to September. With increasing elevation on the volcano, the climate becomes more humid, the dry season shorter, and the summer water deficit less pronounced.

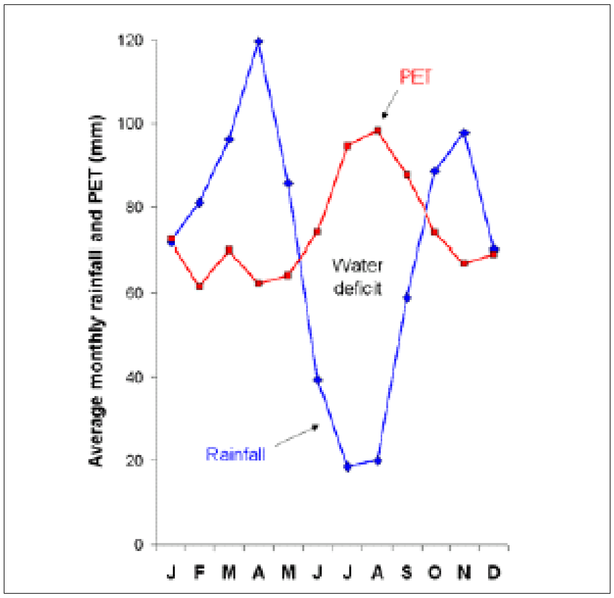

Figure 1. *Annual distribution of rainfall and potentail evapotranspiration (PET) for Otavalo*

The soils of the study area are of volcanic origin and show marked altitudinal differences. At higher elevations, more intensive weathering and slowed organic matter decomposition have resulted in soils with finer texture and higher organic matter contents, whereas at lower elevations, the soils have sandy textures and low organic matter contents.

The region has been largely deforested and the present landscape is characterized by agricultural land use. 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 large-scale *hacienda* operations and smallholder farms in the peasant communities. The *haciendas* are typically located in the lower zones with access to irrigation water and are characterized by intensive management with high inputs and a high degree of mechanization. In the peasant communities, the use of agrochemicals is uncommon and manure application rates are low; land management operations are generally conducted without heavy machinery, and irrigation is only available in some low-elevation communities.

METHODOLOGY

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 components of the water balance simulated by the model are presented in Figure 2.

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 irrigation on

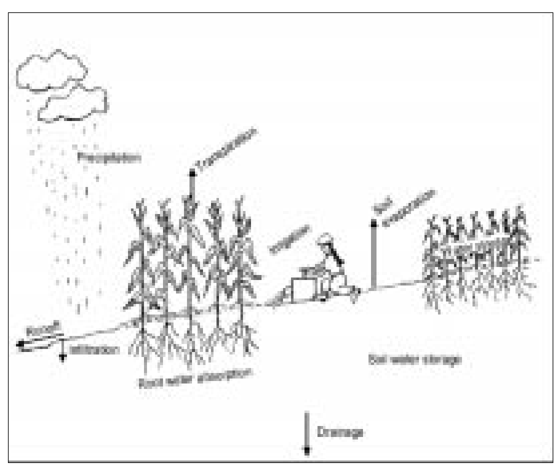

Figure 2. *Water balance simulated with the DSSAT model.*

wet-season and dry-season maize production, 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

Plants use large amounts of water during growth and daily water use of an actively growing crop may be several times its own mass. Inadequate water availability especially during the development and fertilization of the reproductive organs can drastically limit crop production. The zones most likely affected by drought in the area under study are the low-elevation zones. Compared to the high zones, they receive less rainfall and show higher evapotranspiration, and their soils have lower water-holding capacity due to lower organic matter contents and sandier texture.

Water Balance and Crop Growth Modeling

Two sites in different zones of the study area were chosen for the simulation modeling, both presently without access to irrigation water. The Topo Grande site is located at 2550 m, has a mean annual precipitation of about 900 mm and soils with low water-holding capacity. The Morochos site lies at 2750 m, receives about 1100 mm of mean annual rainfall, and has soils with higher water-holding capacity.

An annual maize-fallow rotation was simulated with and without irrigation for a duration of 30 years at both sites. In a first model run, the maize crop was grown during the rainy season as traditionally practiced by the local farmers. Maize was planted at the onset of the rainy season in October and harvested in the summer dry season. In a second model run, maize was grown over the summer dry season, as sometimes practiced when irrigation is available. Maize was planted towards the end of the rainy season in April and harvested in the short winter dry period. Between harvest and the next planting, the land was fallow for several months. The water balance was modeled while other factors were assumed not limiting.

At neither site did water availability in the rainy season limit crop growth during the 30-year simulation period. Consequently, irrigation had little to no effect on maize yields, which fluctuated around 3000 kg ha^{-1} at both sites. The situation was different when maize was grown over the summer dry season, as shown in Figure 3.

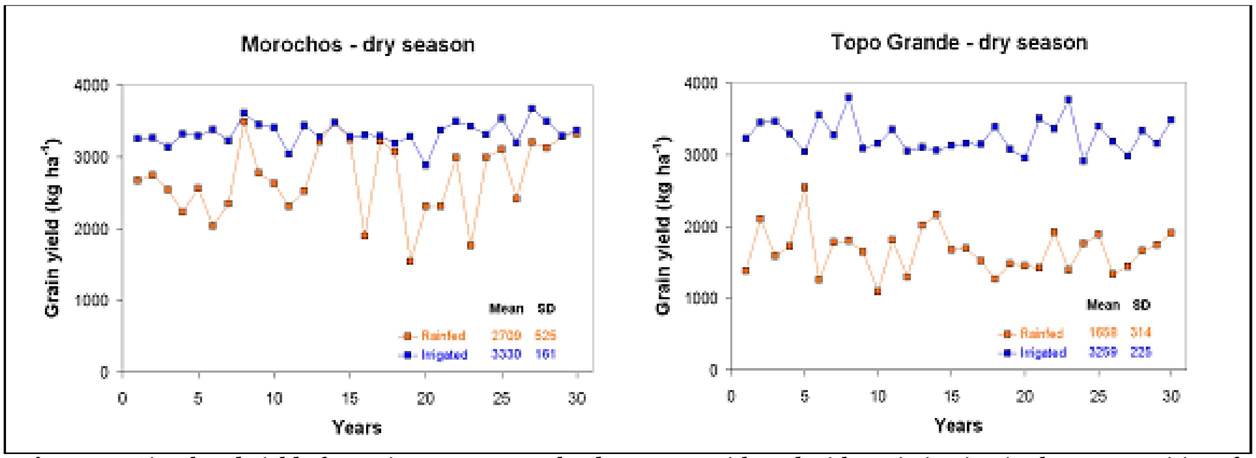

Figure 3. Simulated yields for maize grown over the dry season with and without irrigation in the communities of Morochos (2750 m) and Topo Gradne (2550 m); SD = standard deviation

In Morochos, rainfed cultivation of maize resulted in near maximum yields only in wet years, and drought stress significantly lowered crop production in dry years. Irrigation resulted in an average yield increase of over 600 kg ha^{-1}. In Topo Grande, crop growth was drastically limited by water stress in each of the 30 simulated years, and maize yields could on average be doubled with irrigation.

Implications for Management

The simulation modeling suggests that water stress will seldom (only in exceptionally dry years) be limiting to crop growth during the rainy season – even in the drier low-elevation zones of the study area. An expansion of the irrigation systems seems therefore unnecessary if crops are grown during the rainy season and the land is fallow during the dry season. On the other hand, water stress can drastically limit crop growth during the dry season – especially in the drier low-elevation zones of the study area, where the soils are sandy and low in organic matter. Availability of irrigation water could therefore greatly benefit dry-season crop production, particularly in these low zones.

However, the feasibility of expanding present irrigation systems may be constrained by the following:

*Physical limits, such as total streamflow and location (elevation) of fields relative to water sources.

*Conflicting demands by the growing urban population, industries, and emerging floriculture enterprises in the valley.

*Decisions not to irrigate despite sufficient water supply, as reported by [1]Gilot et al. (1997) for nearby Urcuqui. There, many farmers pursue extra-agricultural occupations outside of their villages and seemingly take the risk not to irrigate, thus saving time and/or money for labor. The occupational situation is quite similar in Cotacachi, where many peasant farmers leave their communities in the pursuit of jobs in the urban centers.

CONCLUSIONS

The volcanic landscape in the Cotacachi area is characterized by its verticality, with climate and soil resources showing pronounced altitudinal variations. Depending on the specific location within the study area, different factors may be limiting to crop production. One such factor, that is quite apparent if one visits the area in the dry season, is water availability.

The zones most likely affected by drought are the low-elevation zones of the study area. There, potential water stress caused by lower rainfall and higher evapotranspiration, is aggravated by low organic matter contents and sandy textures of soils, whichå therefore have little water-storage capacity. Crop growth modeling suggests that, while water availability during the rainy season is generally sufficient for rainfed agriculture, an expansion of existing irrigation systems would considerably improve dry-season crop production, particularly in these low-elevation zones.

Crop growth modeling proved a powerful tool for evaluating the benefits to upland crop production that expansions of irrigation systems could bring about in different zones of the study area. It could serve as a valuable decision support tool helping local authorities devise irrigation systems that make the best use of the limited water resources. It is important to note that in the present study, the simulated climate was based on past weather patterns and did not take into account potential future climate change. However, the crop growth model could be linked to climate change models and thus examine the effects of irrigation under various climate change scenarios.

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[1] Gilot, L., R. Calvez, P. Le Goulven, and T. Ruf. 1997. Evaluating water delivery in tertiary units. Part 2: A case study, Urcuqui, a farmer-managed irrigation system in the Andes. *Agricultural Water Management* 32:163-179.

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 Gerogia. Athens, GA).

ABOUT THE AUTHORS

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