USE OF A GEOGRAPHICAL INFORMATION SYSTEM (GIS) TO DESCRIBE SUITABLE PRODUCTION AREAS FOR PEACH

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Additive index words : *Prunus persica*, winter chilling, temperatures, precipitation / evaporation ratio, fruit yield, multiple regression models.

Abstract

The peach production area of North-Central Mexico is based almost exclusively on seedlings; its average chilling accumulation from November to February, calculated as chill units, is 634, although fluctuations from 250 to 1000 units occur in "warm" and "cold" winters, respectively. In addition, average annual rainfall is 383 mm, with 75 % in summer; while average pan evaporation is 2216 mm. The largest differences between rainfall and evaporation are found in March, April and May, during and after blooming of peaches. Despite these dry and fluctuating conditions, 25,000 hectares are being successfully cultivated with seedling peaches, only about 10% of this area has irrigation water. Therefore, annual variations in the regional average yields depend on weather conditions of each year. A multiple regression model to predict crop yield, based on total winter chilling accumulation and the ratio between precipitation and evaporation for July and August, was calculated. Maximum yield for peach in the area was obtained when chilling accumulation reached 550 units and with a precipitation/evaporation ratio of 0.7. A Geographical Information System (GIS) and the generated model were used to identify regions of homology and their attributes, particularly potential yields, and referenced as maps. Suitable production areas for peach were defined on the map located in the vicinity of actual production areas. In the areas cultivated with peach, yields are restricted by insufficient rainfall, rather than by the lack of winter chilling. The scope of applicability of yield prediction models was extended to a regional productivity analysis by combining their capabilities with a GIS.

Résumé

L'aire de production de pêches du centre-nord Mexique est basée, presque exclusivement, sur des plants de semis; l'accumulation moyenne des heures de froid de novembre à février est de 634, quoique des fluctuations de 250 à 1000 unités se produisent lors d'hivers 'chauds' et 'froids' respectivement. En outre, la pluviosité *moyenne annuelle est de 383 mm, avec 75% des chutes en été; alors que l'évapotranspiration moyenne est de 2216 mm. Les plus fortes différences entre les pluies et l'évaporation se trouvent en mars, avril et mai, pendant et après la floraison du pêcher. En dépit de ces conditions arides et fluctuantes, 25 000 ha sont cultivés avec succès en pêchers de semis, seules 10% des surfaces de cette zone sont irriguées. Ainsi, les variations annuelles des rendements moyens régionaux dépendent des conditions climatiques de l'année. Un modèle de régression multiple pour prédire le rendement a été calculé sur les bases de l'accumulation totale des heures de froid hivernales et le rapport entre les précipitations et l'évaporation de juillet et août. Le rendement maximum de la région est obtenu quand l'accumulation de froid atteind 550 unités avec un rapport précipitation/évaporation de 0,7. Un Système Geographique d'Information (SGI) et le modèle généré ont été utilisés pour identifier les régions d'homologie et leurs attributs, en particulier les potentiels de rendements, et référencés sur cartes. Des aires de production souhaitables pour le pêcher ont été définies sur la carte située au voisinage de l'aire de production actuelle. Dans la zone cultivée avec du pêcher, les rendements sont diminués par des chutes de pluie insuffisantes plutôt que par des manques de froid hivernal. Le domaine d'application du modèle de prédiction des rendements a été élargi à l'analyse de la productivité régionale en combinant ses possibilités à celles du SGI.*

1. Introduction

Temperate fruit production in the state of Zacatecas, Mexico is mainly based on peach [*Prunus persica* (L.) Batsch], grape (*Vitis vinifera* L.), and apple (*Malus pumila* Mill.). The peach growing area is located between 22° 40' and 24° 10' north latitude, and 103° 00' and 104° 10' west longitude, where approximately 25,000 hectares are currently cultivated with this fruit tree species, most (90%) under rainfed conditions. In general, an annual yield variation is observed in these orchards; these annual fluctuations are particularly important in regions with wide differences of daily and annual conditions (del Real-Laborde, 1987).

Several climatic conditions may affect annual yields of deciduous fruit trees and account for their fluctuations. Air temperature is the most important climatic factor for the growth and development of plant species, being able to determine the geographical distribution of natural plant communities and agricultural cultivated species. In the case of temperature, it is possible to obtain indexes of biometeorological extraction which may be common to a group of cultivated species, as it is the case for "winter chilling requirements" of temperate fruit trees. Winter chilling requirements of peaches differ among peach types and cultivars (Díaz, 1987); however, when these requirements are not satisfied, lack of chilling is associated with erratic bud break, delayed bloom, abnormal flowers and poor fruit set (Erez, 1987). Temperatures during and after full bloom may also affect yield by reducing fruit set of deciduous fruit trees (Williams, 1970). Another aspect to be considered is the water requirements of crops. In order to carry out a proper water balance, it is necessary to have monthly values of potential evapotranspiration and rainfall of at least 30 years, in order to cover reasonably well the natural variability of these climate factors (Pascale and Damario, 1977). Since most of the peach growing area under study is cultivated under rainfed conditions, these variables were considered to be relevant to explain annual yield variation.

Crop simulation models can predict crop yield, plant growth and development, and nutrient and moisture dynamics based upon site specific characteristics such as weather, soil and agronomic practices. Lal *et al.* (1993) extended the scope of applicability of site-specific models for beans (*Phaseolus vulgaris* L.) to regional productivity analysis by combining their capabilities with a Geographic Information System (GIS). A GIS is a database management system for map-orientated data. For any region, a set of maps can be added to the database in the form of digitised images to represent different data themes describing the region. Within each data theme, regions of homology are identified and attributes describing those regions are stored in tables that can reference a map. Several computer softwares are available for data collection, input, storage, management, analysis, modelling and presentation.

The objectives of this present work were: a) to explain annual fluctuations of peach yields in terms of weather conditions, and b) to use a GIS, along with the model obtained, to find suitable production areas for peach orchards in Zacatecas, Mexico.

2. Materials and methods

2. 1. Location characteristics and yield data.

Data from average regional fruit yields of the peach growing area of Zacatecas, Mexico, from eleven productive years, were used. The peach production area is located at about 2200 meters above sea level and has annual means between 13° and 15° C. Average chilling accumulation from November to February, calculated as chill units (Richardson *et al.*, 1974), is around 600; however fluctuations from 250 to 1000 units occur in "warm" and "cold" winters, respectively. Average annual rainfall (60 % probability) is about 400 mm, with 75 % in summer, particularly in July, August and September; while average pan evaporation is 2200 mm. The largest differences between rainfall and evaporation (150 mm per month) are found in March, April and May, during and after blooming of most peach genotypes.

2. 2. Weather-related records.

Weather data for each annual harvest was included. Temperature-related variables calculated were: chill units (Richardson *et al.*, 1974) in November (Ncu), December (Dcu), January (Jcu) and February (Fcu) and the total amount of chilling by adding individual months; growing degree hours (base temperature 5°C) during bloom (gdhb); number of hours with temperatures above 16° C (nh^{16+}), above 21° C (nh^{21+}) or below 10° C (nh^{10-}) during bloom. In addition, rainfall and free evaporation data for each year and month were included as the precipitation/evaporation ratio (P/E ratio), particularly for the summer months.

2. 3. Data analysis.

Statistical analysis included regression and response surface analysis. Second order polynomial equations were fitted to the yield data using linear, quadratic, and cross-product terms of the weather related records. The regression model used was as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_{11} X_1^2 + \beta_2 X_2 + \beta_{22} X_2^2 + \beta_{12} X_1 X_2 + \beta_{1122} X_1^2 X_2^2$$

where Y = yield, X_1 = variable 1 (for instance total winter chilling), and X_2 = variable 2 (precipitation/evaporation data). Components were deleted from the model if their parameter estimate (β) was not significant (P≤0.05) or if its deletion did not decrease the R^2 of the model. These equations allowed response surfaces to be generated for fruit yield of peach to fluctuating weather conditions. All analyses were carried out with the procedures REG and RSREG included in SAS (SAS Institute, 1987).

2. 4. Potential yield maps.

A GIS was used to generate yield potential maps for plums in Zacatecas state, based on databases of a regional plant productivity project, using the software IDRISI v 4.1. Historic records for at least 30 years where obtained from climatological stations located through the state. The digital elevation model from the National Institute of Statistics, Geography and Informatics (INEGI) of Mexico, with an altitude record every 3 arc seconds of latitude and longitude, was used to generate a 900 m X 900 m grid database of climatic data, from which the yield maps were obtained. The weather database included the daily mean maximum, daily mean minimum and daily mean temperatures for each month. Soil maps (scale 1:1,000,000) were digitised into GIS, using the software ARC/INFO v 3.4; this scale was considered to be adequate since this database included only deep soils (>100 cm depth) and without other limitations, such as salinity, and to exclude mountains, water reservoirs and inhabited areas from the productivity analysis.

3. Results and discussion

Results presented and discussed are divided into two different sections, *i.e.* the annual yield variation and suitable production areas for peach.

3. 1. Annual yield variation

A mathematical function to explain yield annual variation of peaches in the growing area of North-Central Mexico was calculated and the model was capable of explaining 85% (R^2=0.85) of the total variation registered. Average annual yield in the region, for the period 1981 to 1991, was related to the rainfall evaporation index (P/E) in the period of July to August, and the winter chilling accumulation (November to February), measured as chill units (Table 1). The stationary point for the two variables and its interaction indicated that a maximum yield (4.89 ton/ha) may be obtained when 552 chill units are accumulated and with a P/E index of 0.69 registered in July and August (Fig. 1).

This data indicates that on average the chilling requirements of the peach regional seedlings are of approximately 550 CU, and that a lower value reduced the potential yield. In relation to their water requirements, as long as the rainfall value approaches the amount of water evaporated in July and August, by at least 70%, a good fruit yield potential is feasible.

In this study, we determined that the chilling requirements of regional seedling peaches are about 550 units (Richardson *et al.*, 1974). Previously, Díaz (1987) classified the ancestors of the regional cultivated peaches as a medium requirement type (500 chill hours), using the conventional method, of the number of hours below 7°C. Although the conventional method is not longer used, the classification of our regional seedling peaches as a medium requirement type agrees with the to data reported in this present work. As it is observed in Fig. 1, fruit yield significantly decreased as a result of a reduction in winter chilling accumulation; this finding may be related to the abortion of floral buds and poor fruit set associated with lack of chilling (Érez, 1987; del Real, 1987).

Our regional seedling peaches have developed a mechanism of adaptation to drought, which allows them to survive from blooming to the first stage of peach growth fruit; while during the second stage of fruit growth water needs are fulfilled by the July and August rainfall. Evidently, a reduction in the amounts of rainfall during this period gave resulted in a significant yield decrease (Fig. 1). Several morphological and physiological adaptations, associated with drought tolerance or avoidance in these peach genotypes, have been studied, including the stomatal response to prevailing weather and soil conditions (Rumayor-Rodríguez and Zegbe, 1993).

The relevance of the effects of variation of agroclimatic conditions on the agricultural production is shown by an investigation carried out in four plant species and three counties in California (Granger, 1980). Thus, agricultural production of these crops was affected by the changes in the agroclimatic variables, allowing the calculation of the economic impact of these fluctuations. In Zacatecas, México, the effects of diverse temperature parameters on the yield of 12 plum cultivars were studied, suggesting that yield potential is related to high temperature at blooming, to winter chilling accumulation and, in a minor way, to the temperature during the stage of floral structure formation (Rumayor-Rodríguez, 1995).

3. 2. Suitable production areas for peach

The model developed and the use of a GIS, with databases for the area including the digital elevation model, temperature, rainfall, evaporation and soil conditions, allowed set up of two types of images with peach cultivation areas for peach. Potential areas for growing peaches were considered when sufficient chilling accumulation and an adequate P/E ratio were registered and concerning soil restrictions,when land slope was lower than 2% (Fig. 2). Peach yield in the defined areas varied from 2 tons per hectare up to 6 tons per hectare in some regions. Although yields seemed to be low, compared to other production area; these figures are considered adequate, particularly because the regional production systems are under rainfed conditions and include low inputs such as fertilisers. In the map obtained, it is possible to note that the cities of Miguel Auza, Juan Aldama, Sombrerete, Rio Grande, Chalchihuites, Calera and Fresnillo have the suitable climate and soil conditions for the cultivation of this species. When soil maps were not included, for instance lands with steep slopes or low in soil depth, potential regions area increased; however, the establishment of orchards on these lands have to include water and soil conservation techniques, in order to reduce risks of erosion. At present, the areas cultivated with peaches are located in the vicinity of the GIS defined potential areas; this suggests that, in order to improve yields, some cultivated areas will require soil conservation management practices or certain amounts of water irrigation. Therefore, this type of research may also be used, in regional planning, to define future needs of cultural practices in orchards. Lal *et al.* (1993) and Rumayor-Rodríguez (1995), based on the use of GIS and crop models, have brought a high degree of precision into the identification of potential areas for growing beans and plums, respectively.

The relevance of this work relies on the possibility of combining yield prediction models, using climatic data, and GIS to find the most suitable areas for establishing a fruit crop or cultivar. From the research point of view, it may be useful to introduce cultivars with similar characteristics and climatic requirements to cultivars evaluated, with a certain degree of confidence in their adaptation or in that of their limitations. In the future, these types of studies should be focused on predicting other aspects of the fruit production system, for instance pest and disease occurrences, harvest dates, or irrigation needs for a regional analysis in the fruit production areas. Also, a gradient in potential yield in any specific area was observed, allowing users of GIS the opportunity of selecting regions to establish orchards, with expectations of a minimum potential yield.

Acknowledgements

We appreciate the financial support by Consejo Nacional de Ciencia y Tecnología (CONACYT), research grant 9501098 of CONACYT - SIVILLA, México.

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Table 1 - Estimated parameters and T tests for the response surface analysis of peach yield, in relation to winter chilling (CU) and the precipitation/evaporation ratio (P/E). Test for lack of adjustment not significant with $P \leq 0.05$. $R^2 = 0.85$ and coefficient of variation 33.21%.

Variables	**Degrees of freedom**	**Estimated parameters**	**Standard error**	**T test Ho:0**
α	1	-11.34	4.47	-2.54
CU	1	0.038	0.5×10^{-3}	3.77
P/E	1	0.02	9.2×10^{-3}	2.33
CU^2	1	-2.4×10^{-5}	5.05×10^{-6}	-4.69
P/E*CU	1	-8.5×10^{-6}	6.1×10^{-6}	-1.38
P/E^2	1	-1.2×10^{-5}	5.3×10^{-6}	-2.33

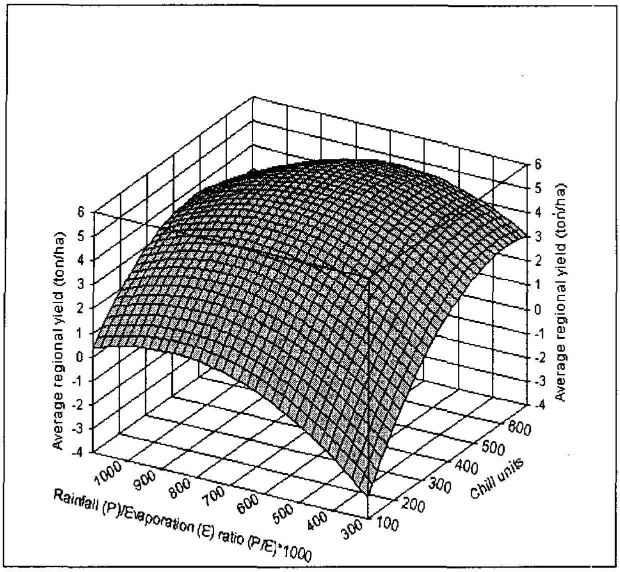

Figure 1.- Response surface of predicted yields (t/ha) for seedling peach, derived from equation in Table 1, as influenced by winter chilling (chill units) and the precipitation/evaporation ratio (P/E) in July and August.

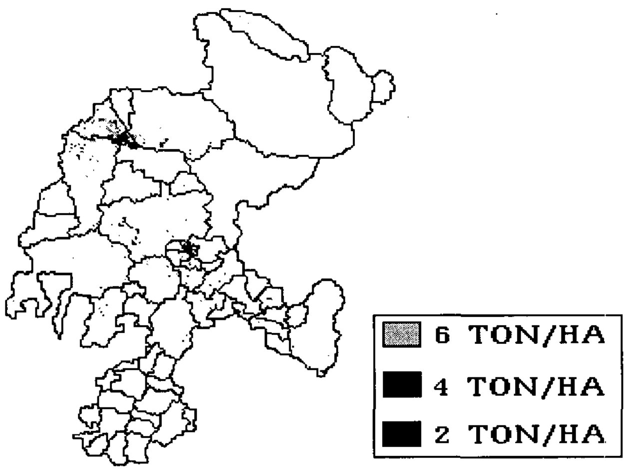

Figure 2.- Potential areas for cultivation of seedling peaches in Zacatecas, Mexico and their yield potential (t/ha).