農業氣象資訊系統之發展及利用
(邀請論文)

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摘 要

本文係討論農業氣象資訊系統的重要性，它在農業上可以用來推算蒸發散量（Evapotranspiration）、土壤濕度變化、缺水日數（Stress Days）以及土地生產力（Land Productivity）等等。文中亦討論了非穩定流體特性（Dynamic Hydraulic Characteristics）與氣象之關係，以及氣象資訊系統的結構。我們也簡單的介紹了把分布稀疏的測站資料合成氣象紀錄的有效方法。

引 言

環境決定農作物及家畜的生產行爲，而氣候和土壤爲自然環境的本質。當今世界各國花在土壤測量及維護氣象測站上的經費，極爲可觀。然而農業學家却未能有效的利用土壤和氣象資料，顯然是有某些障礙阻遏了人們使用這些資料資源，究其原因可能如下：

(一)資料不全（Data Gaps）：由於氣象測站分布不均勻，造成很大區域缺乏氣象資料報告，見圖1。

(二)氣象資料單一（Weather Data Isolated）：若相關的資料（例如土壤性質）亦可供利用，且以一致的方式儲存，則氣象資料會變得更爲有用。

(三)缺乏有效的空間分析和模式（Spatial Analysis and Models）：氣象資料常用來描述土質，以及分析比較不同地點的特性。由於必須處理大量資料，因此這些分析或合成便需要有效的模式及計算方法。

一套可以消除這些障礙的資訊系統，無疑地將可提昇氣象資料的使用，以及使原始資料變成有用的資源。本文將舉例證明此一資訊系統的必要性。

應用實例

一九七六年夏威夷大學農業工程系（The Agricultural Engineering Department of The University of Hawaii）夏威夷州政府開發一套資訊系統（Liang, 1986），此一系統已被應用在許多問題上（Khan and Liang, 1986, Ziauddin and Liang, 1986, Liang et al., 1986）。除了氣象資料外，此系統也包含土壤及社會經濟的資料（Soil and Socio-Economic Data）以供查詢（Retrieval）及處理。本文僅包含此系統的一些應用摘要，以證明使氣象資料更易於取得和解釋，是有其功用及必要。

某土塊的位蒸發散量（Potential Evapotranspiration）的大小主要是由聚集於土中的太陽能所決定，而農作物的種類及其他氣象變數（例如風和濕度），則影響實際的蒸發散量。估算單一地點或一小地區的蒸發散量尚屬簡單，而估算某一大地區的蒸發散量却是一件很繁重的工作。當氣象資料無法用於整個地區時，其困難度便更複雜。圖2表示MAUI島上面積七百平方哩（一八一三平方公尺）土地的蒸發散量大小。

土壤濕度（Soil Moisture）對從事農耕者相當重要，水量估計方程式(1)可用來估計某一地點的土壤濕度：

$$M_{i+1} = M_i + P_i + I_i - ET_i - q_i - R_i \quad \cdots\cdots(1)$$

M_i ＝第 i 天開始的土壤濕度（Soil Moisture），單位：cm

P_i ＝第 i 天的降水量（Precipitation），單位：cm

I_i ＝第 i 天的灌溉量（Irrigation），單位：cm

ET_i ＝第 i 天的蒸發散量（Evapotranspiration），單位：cm

q_i ＝第 i 天的滲透量（Percolation），單位：cm

R_i ＝第 i 天的水逕流量（Run-off），單位：cm

除了蒸發散量外，降雨量（Rainfall）及土壤性質（Soil Property）（例如入滲率、作物的覆蓋和坡度等），都是影響土壤濕度的重要變數。圖3表示在MAUI島上某天的土壤濕度分布。

滲透作用（Percolation）是另一重要的資訊，凡關心環境和水文保護者，均會對它感到興趣。所謂滲透作用，即運送過量的肥料及有毒的殺蟲劑（Toxic Pesticide）或化學藥品進入珍貴的地下水中，見圖4。

所謂年缺水日數（Stress Days）是指土壤濕度降至低於枯萎點（Wilting Point），以及植物遭受水份不足的日數。它是決定水份是否足夠的良好指標。圖5標示可能發生嚴重缺水的地區，除非有充足的灌溉水供應，否則應避免農作物的生產。求取圖2至圖4的資料，若在80386微處理機（80386 Microprocessor）或個人電腦上處理，共需約十小時的計算時間。

對某作物而言，土地生產力（Land Productivity）視土壤濕度、溫度及其他土地基本因子而定。圖6表示MAUI島上產澳洲胡桃果（macadamia nut）最多的區域，圖中亦可看出不適生產澳洲胡桃果的地區。方程式(2)是評估土地生產力的迴歸模式（Liang and Wong, 1983）。

$$Y = -136.778 - 0.087X1 + 2.850X2 + 5.359X3 + 1.360X4 - 0.006X4$$
$$(-2.94)\quad(-2.16)\quad(2.31)\quad(12.69)\quad(1.98)\quad(-2.14) \qquad \cdots\cdots (2)$$

X1＝七月、八月及九月的缺水總日數。

X2＝年平均溫度，單位：°C。

X3＝樹齡，單位：年。此數必須大於四年，及小於或等於九年。

X4＝每年總位蒸發散量，單位：cm。

Y＝每株樹年生產量，單位：公斤。

相關係數（R2）＝0.83，標準機差（SE）＝3.56，樣本個數＝58

上述應用實例，是用來說明某一地點的平均數。農業學家希望了解某一地點的動力特性（Dynamic Characteristics），以便規劃田間試驗或種植經濟作物。土壤濕度變化及其他相關水文變數與時間的關係，就是屬於這類例子，見圖7a、7b、7c、8a、8b、8c。圖7及圖8分別表示這些變數在乾燥地方和潮濕地方的變化。此資訊可作爲規劃灌溉及其他作物和家畜生產的管理應用。

資訊系統

前述例子中的資料，若無一套可供處理的資訊系統，則需要花好幾年的時間始能求得。資訊系統可以處理原始氣象資料（Raw Weather Data）、外延或內插這些資料，用以塡補資料空缺、組織（Organize）所有資料，包括普通參考座標的氣象資料、搜集一般常用的合成或分析模式，以及在資料與模式間提供簡易連線，翻譯資料使其成爲有用的資訊。本文中所使用的資訊系統稱爲HNRIS，是Hawaii Natural Resource Information System的縮寫。圖9是HNRIS系統結構及關係圖。

發展農業氣象資訊系統最爲困難的工作是聚集從分布稀疏的測站所得的大量氣象資料，如何將這些資料模式化，使適合資訊系統發展的細節，請參考Singh and Liang, 1988。至於這些資料的合成基本理論及一般步驟，簡單介紹如下：此方法係利用某一氣象測站的氣候特性隨機模式（Stochastic Modeling）的程式（Procedure）；爲了從氣象測站紀錄中估計某一地區的氣候特性，我們使用FASTCLUS（SAS，1982）的副程式，根據該年內某一氣象變數的時間分布相似性，將一地區的氣象測站分類成爲幾個均勻的群集（clusters）。這一程式確保了在群集內的氣象測站，其年內氣象變數的時間分布，較群集間之氣象測站更爲類似。但即使同一群集中之氣象測站的氣象變數時間分布是類似的，而其氣象變數的大小却仍各站不同。此一程式產生的群集是由位置鄰近的測站組成，而各群集的邊界是依共同的地形或地理特徵，或依群集內測站的共同氣象變數範圍而界定；而在一群集內所有測站的氣象變數年總量是用內插法求得。依據分布相似性而得的群集劃分方法，實質上減少了某一地區隨機氣候特性模式化資料儲存的需求。

此一系統在夏威夷已廣泛地用於土地利用規劃、農業技術轉移、環境保護及許多其他相關問題上。

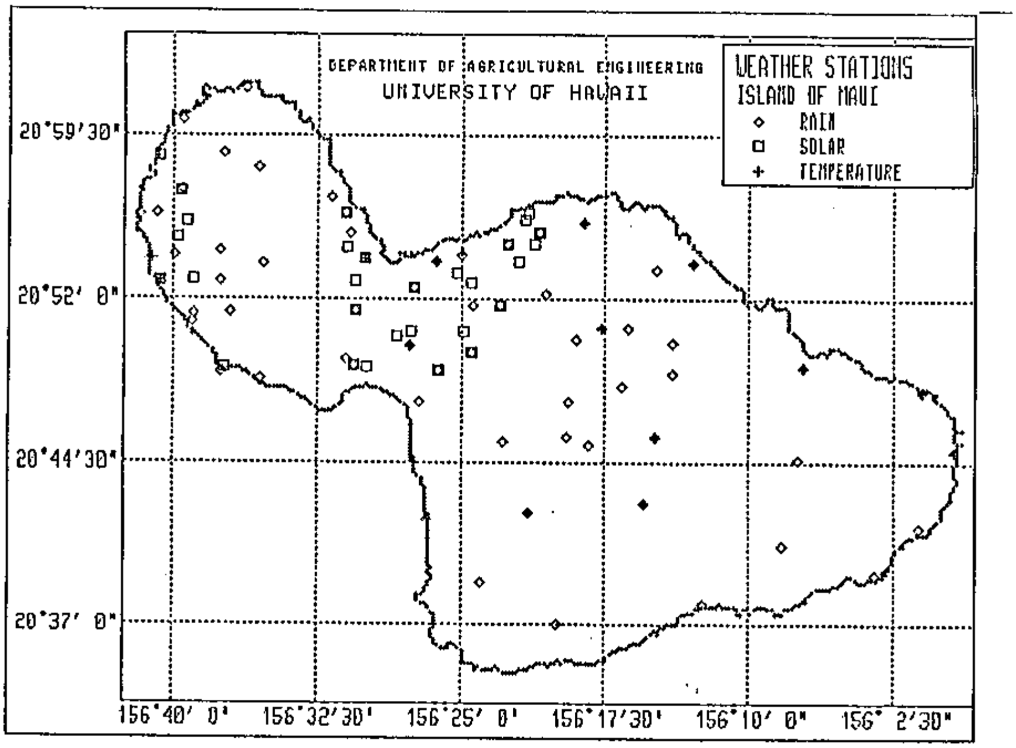

圖 1: MAUI島上氣象測站的分布。

Figure 1 Weather station distribution for the island of Maui.

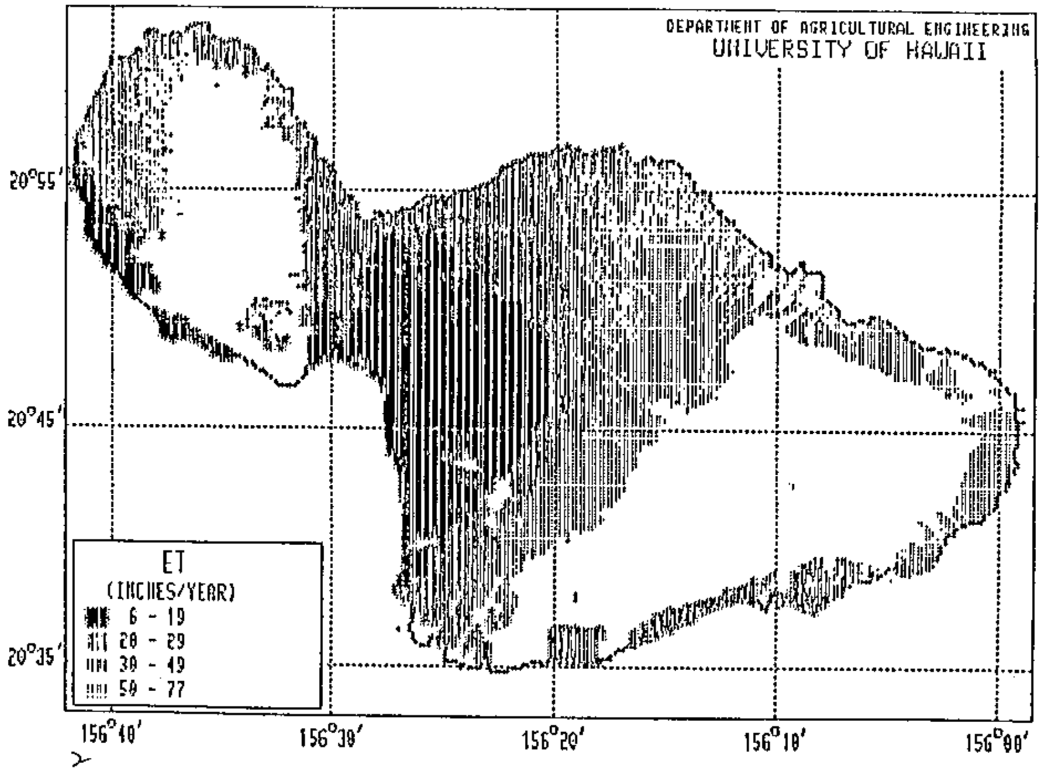

圖 2: MAUI島上蒸發散量的大小。

Figure 2 Evapotranspiration for the island of Maui.

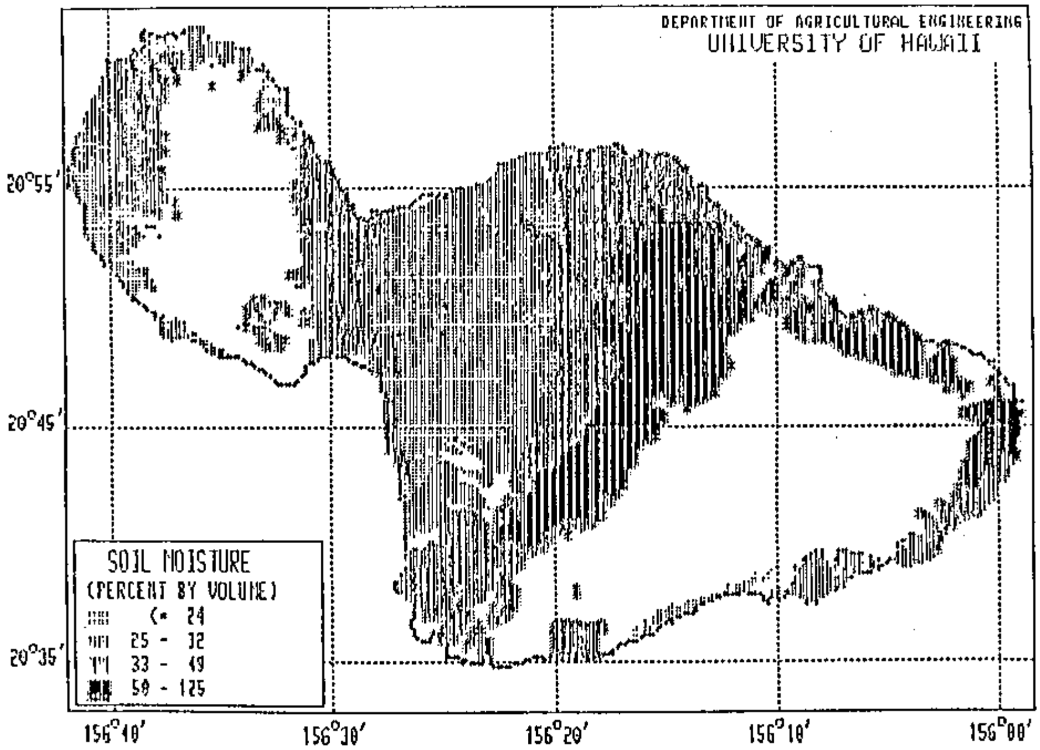

圖 3: MAUI島上土壤濕度分布。

Figure 3 Soil moisture distribution for the island of Maui.

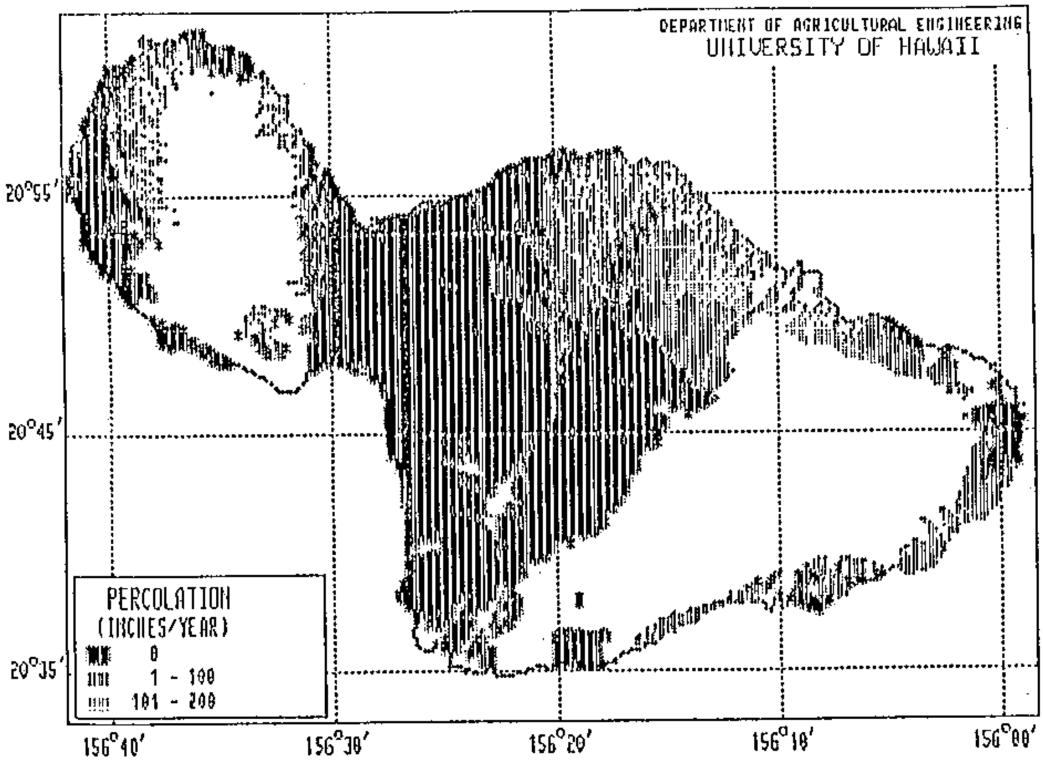

圖 4: MAUI島上土壤的滲透作用。

Figure 4 Soil water percolation for the island of Maui.

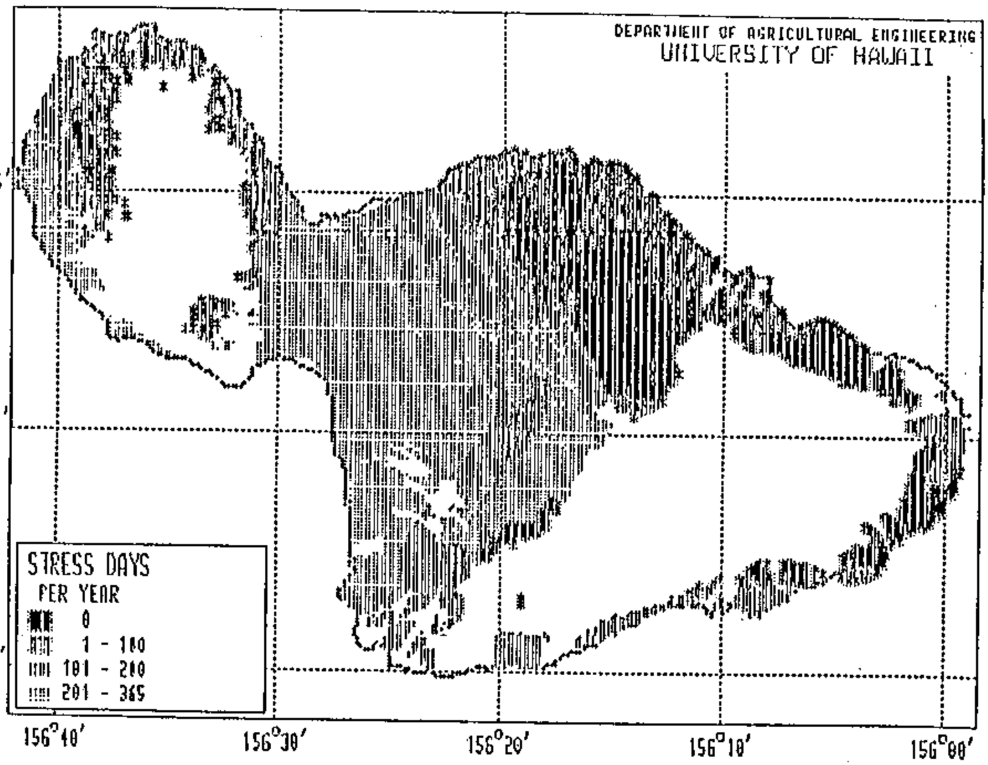

圖 5: MAUI島上缺水日數。

Figure 5 Number of stress days for the island of Maui.

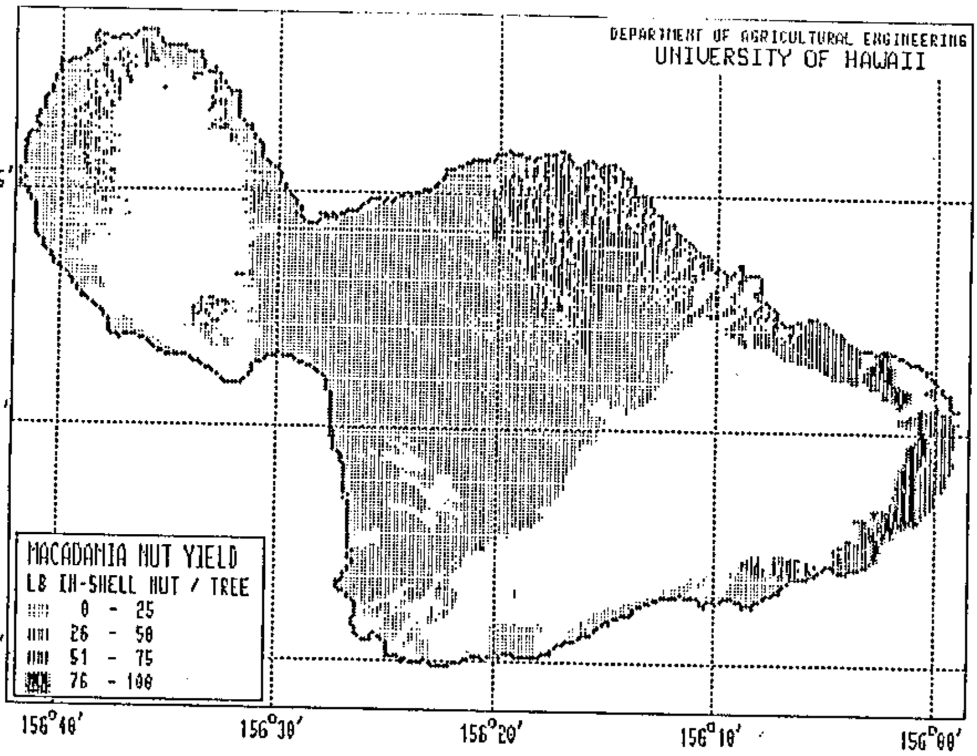

圖 6: MAUI島上澳洲胡桃果之預估產量。

Figure 6 Estimated macadamia nut yield map for the island of Maui.

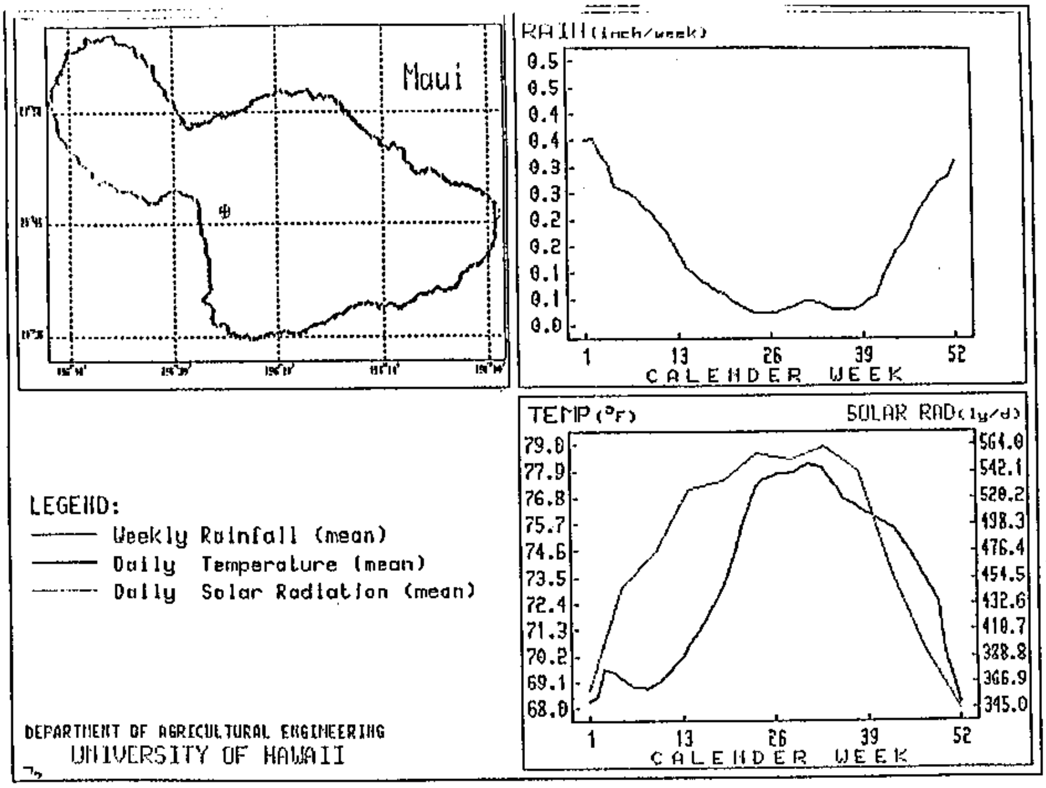

圖 7a: MAUI島上乾燥地區的降雨量、溫度及日射量分布。

Figure 7a Rainfall, temperature and solar radiation distribution for dry

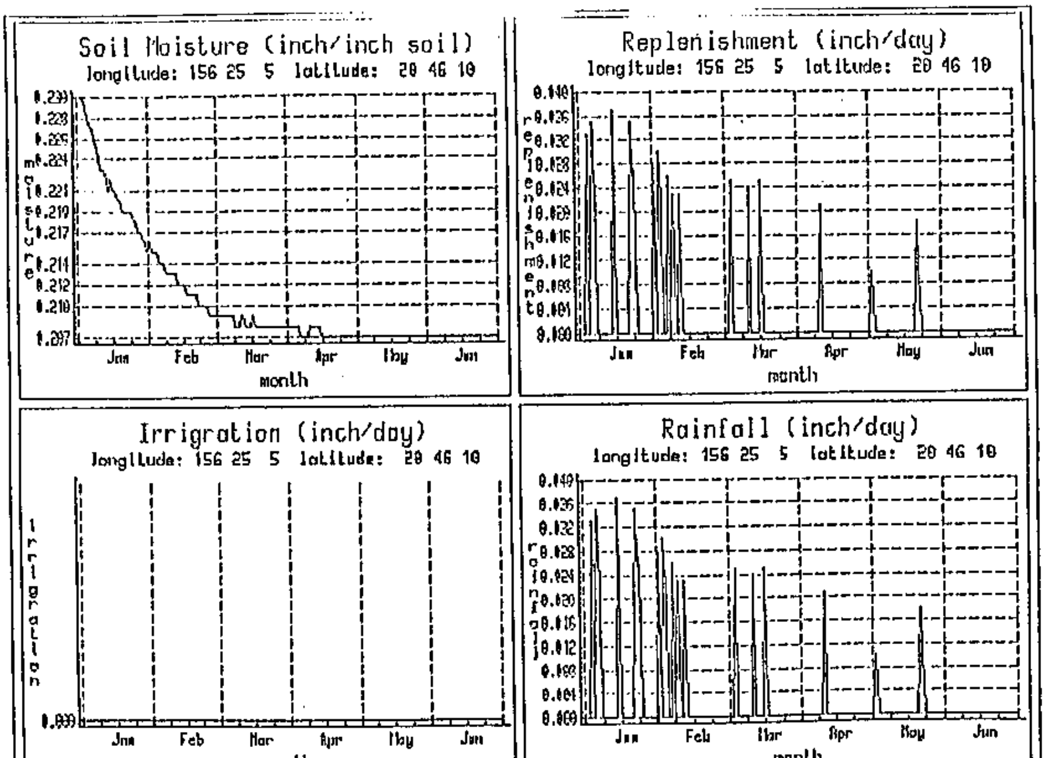

圖 7b: MAUI島上乾燥地區六個月的土壤濕度、補充、灌溉及降雨量分布。

Figure 7b Soil moisture, replenishment, irrigation, and rainfall distribution for six months for the dry site.

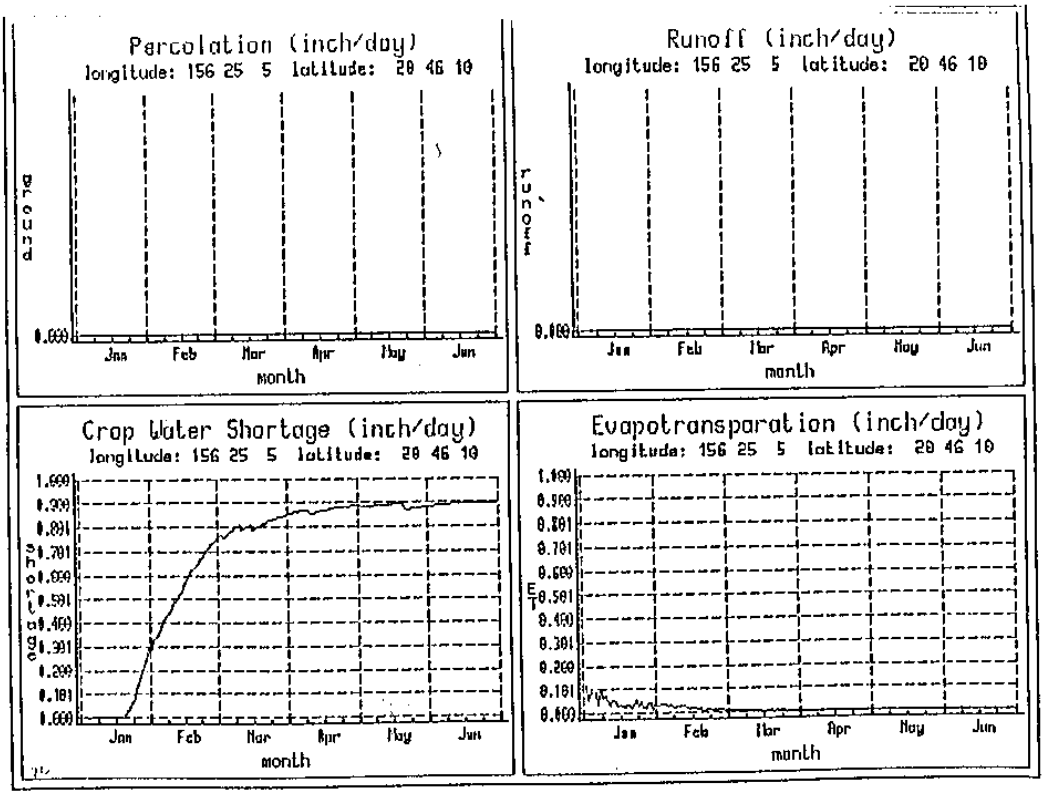

圖 7c: MAUI島上乾燥地區六個月的滲透、逕流、農作物水量儲存及蒸發散量。

Figure 7c Percolation runoff, crop water shortage and evapotranspiration for six months for the dry site.

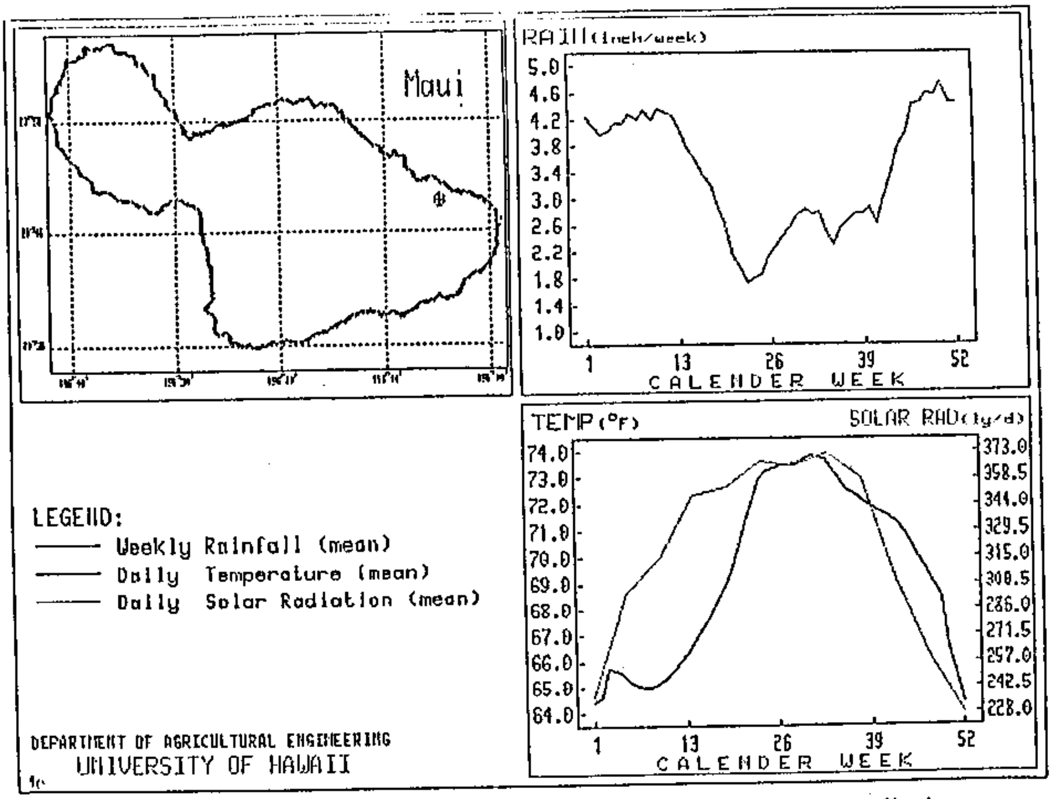

圖 8a: MAUI島上潮濕地區的降雨量、溫度及日射量分布。

Figure 8a Rainfall, temperature and solar radiation distribution for wet site for the island of Maui.

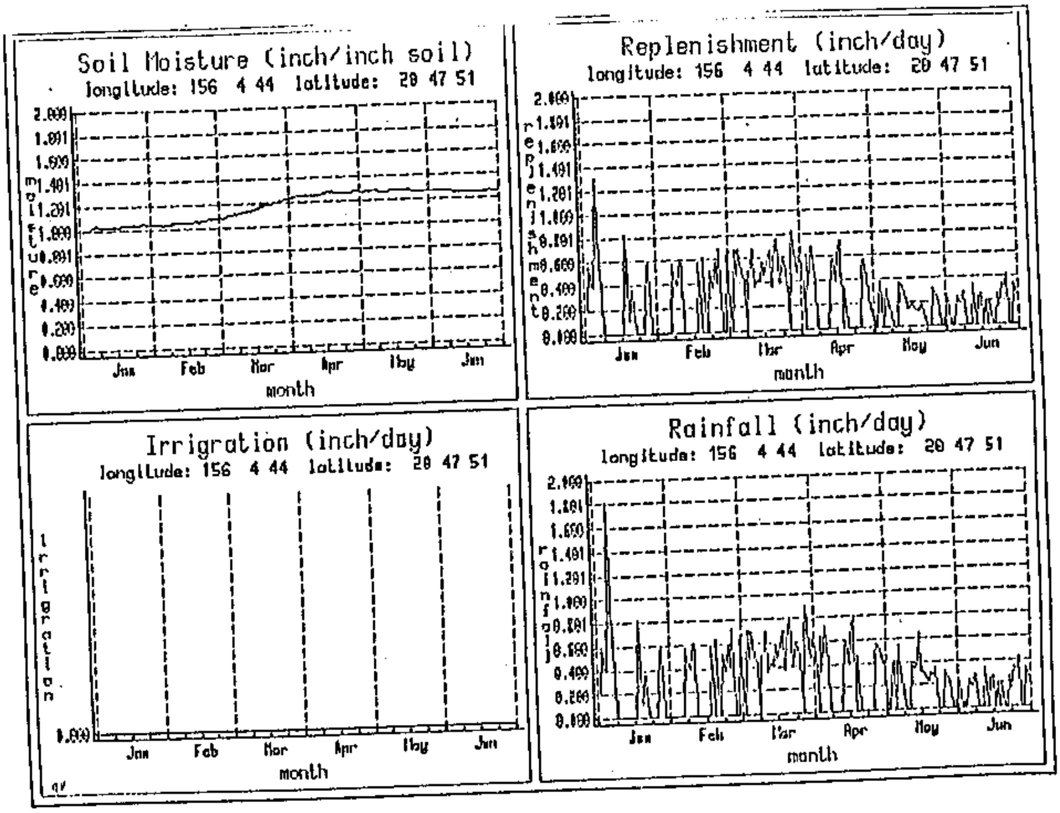

圖 8b: MAUI島上潮濕地區六個月的土壤濕度、補充、灌溉及降雨量分布。

Figure 8b Soil moisture, replenishment, irrigation and rainfall distribution for six months for the wet site.

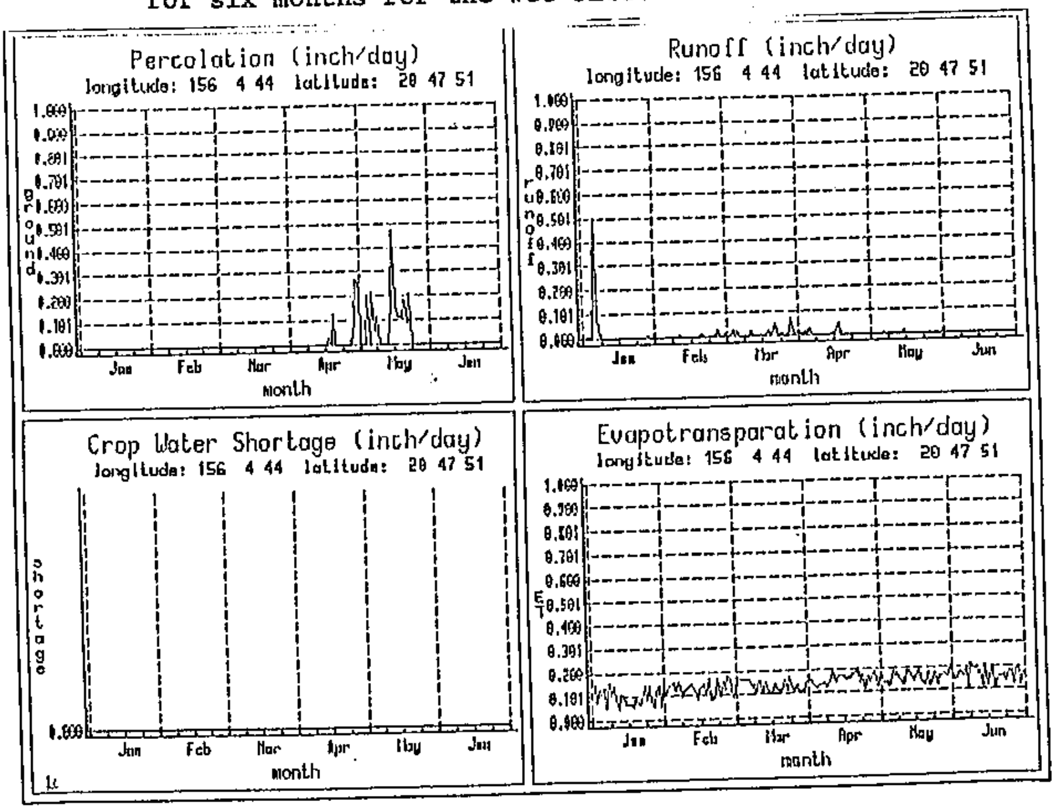

圖 8c: MAUI島上潮濕地區六個月的滲透、逕流、農作物水量儲存及蒸發散量。

Figure 8c Percolation, runoff, crop water shortage and evapotranspiration for six months for the wet site.

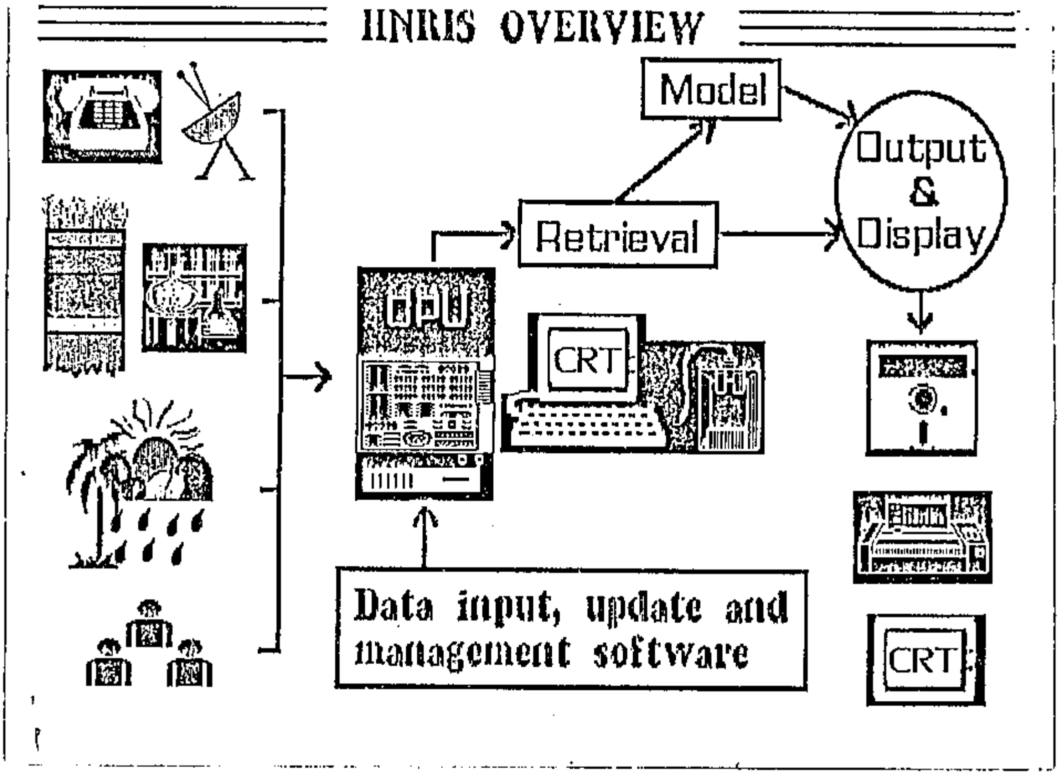

圖 9: HNRIS系統結構及關係。

Figure 9 Various components of HNRIS and their relationships.

AGRICULTURAL METEOROLOGY INFORMATION SYSTEM AND ITS APPLICATION

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ABSTRACT

The need for an agricultural meteorology information system was discussed. Its application to agriculture was illustrated by demonstrating the capability of using such a system for simulating evapotranspiration, soil moisture change, water shortage or stress days and land productivity. The dynamic hydraulic characteristics of sites as a result of weather influence, were also displayed. The organization of a meteorology information system was discussed and a rational approach for synthesizing weather records from sparsely located weather stations, to provide simulated weather variables for all sites in an area, was also briefly explained.

INTRODUCTION

Environment determines the production performance of crops and livestocks. Climate and soil are essentially the environment. All countries survey their soils and maintain weather stations at a considerable cost. However, soil and weather data are not actively used by agriculturists. Obviously, there exist obstacles which prevent people from using these data resources. The following seem to be the reasons for the underuse of these valuable data:

1. Data gaps: weather stations tend to be unevenly distributed leaving large areas with no weather data at all (see Figure 1).
2. Weather data isolated: weather data becomes more useful when related data such as soil properties are also available and stored with reference to a common coordinate system.
3. Lack of efficient spatial analysis and models: weather data are most frequently used for land quality delineation and other comparative analysis of the characteristics of different sites. These analyses or synthesis, requiring handling of large amount of data, require efficient models and computation methods.

An information system capable of eliminating these obstacles will, undoubtedly, promote the use of weather data and turn this raw data into a valuable resource. A few examples are provided to demonstrate the need for such an information system.

APPLICATION EXAMPLES

The Agricultural Engineering Department of the University of Hawaii has been developing such an information system for the State of Hawaii since 1976 (Liang 1986). This system has been applied to many problems (Khan and Liang, 1986, Ziauddin and Liang, 1986, Liang et al., 1986). In addition to weather data, the system also includes soil and socio-economic data for retrieval and processing. Only a summary of some applications of this system is included in this paper to demonstrate the usefulness and the need for making weather data easy to access and interpret.

Potential Evapotranspiration magnitude from a land parcel is determined primarily by the solar energy impounding the land while type of crop and other climatic variables such as wind and humidity influence actual ET. Calculation for estimating ET for a single site or a small area is simple. However, it can be a major task when a large area must be evaluated. The difficulty is compounded especially when weather data are not available for the entire area. The map in Figure 2 shows magnitude of ET for the island of Maui with an area of 700 square miles (1813 square kilometers).

Soil Moisture is of concern to anyone engaged in agriculture. A water budgeting computation can be performed to estimate soil moisture at a given site using Eq. 1.

$$M_{i+1} = M_i + P_i + I_i - ET_i - q_i - R_i \tag{1}$$

where

M_i = soil moisture at the beginning of day i (cm)

P_i = precipitation on day i (cm)

I_i = irrigation on day i (cm)

ET_i = evapotranspiration on day i (cm)

q_i = percolation on day i (cm)

R_i = water runoff on day i (cm)

Besides ET, rainfall and soil properties such as infiltration rate, crop cover and slope are important variables which affect the soil moisture. Figure 3 maps the soil moisture distribution of the island of Maui on a given day.

Percolation is another important piece of information which is of interest to those who are concerned with environment and water conservation. Percolation is largely responsible for carrying excessive fertilizer and toxic pesticide or chemicals into precious groundwater (Figure 4).

Stress Days per year, usually referring to the number of days when soil moisture falls below wilting point and plants suffers from insufficient water, is a good indicator for determining water adequacy. The map in Figure 5 shows the areas where high stress days are likely to happen and to avoid for crop production unless supplemental irrigation can be supplied. The computation time for obtaining the information in Figures 2 to 4 took approximately 10 hours on a 80386 microprocess or based personal computer.

Land Productivity for a given crop depends on soil moisture, temperature and other land based factors. The map in Figure 6 shows where the most productive lands for macadamia nut are situated on the island of Maui. The map also identified the areas where macadamia nut production should be avoided.

The regression model used to evaluate land productivity is presented in Eq. 2 (Liang and Wong, 1983).

$$Y = -136.778 - \underset{(-2.94)}{}\ \underset{(-2.16)}{0.087X_1} + \underset{(2.31)}{2.850X_2} + \underset{(12.69)}{5.359X_3} + \underset{(1.98)}{1.360X_4} - \underset{(-2.14)}{0.006X_4} \qquad (2)$$

Where:

X_1 = Total number of stress days in July, August and September.

X_2 = Mean annual temperature (°C).

X_3 = Age of the tree (years). This variable must be greater than 4 and less or equal to 9.

X_4 = Total annual potential evapotranspiration (cm).

Y = Annual yield per tree (kg in-shell nut).

R-squared = 0.83 SE = 3.56 sample size = 58

The above applications are examples for characterizing the averages of a site. Often, agriculturists like to know the dynamic characteristics of sites for planning of either field experiments or economic planting of crops. *Soil moisture change* and other related water variables over time are examples of this nature (Figures 7a, 7b, 7c, 8a, 8b, 8c). Figures 7 and 8 display these variables for a dry and a wet site respectively. This information can be used to plan for irrigation and other management practices associated with crop and livestock production.

THE INFORMATION SYSTEM

The information in the examples shown previously may take years to obtain without an information system, which can process raw weather data, extrapolate/interpolate these data to fill data gaps, organize all data including weather data according to a common reference frame, collect commonly used synthesis or analysis models and provide easy linkage between data and models for interpreting data into useful information. The information system used in this publication is called HNRIS which stands for Hawaii Natural Resource Information System. The various components of HNRIS and their relationship are displayed in Figure 9.

The most difficult task of developing an agricultural meteorology information system is to condense the large amount of weather data from sparsely located weather stations. The details of modeling these data for information system development are described elsewhere (Singh and Liang 1988). The rationale and the general approach in the synthesis of these data are briefly discussed below. The methodology used the procedures developed for stochastic modeling of climatic characteristics of a weather station (Richardson 1981). For estimating the climatic characteristics of an area from records of weather stations, the FASTCLUS (SAS 19821) procedure was used to group the weather stations in an area into uniform clusters based on the similarity of the time distribution of a weather variable over the year. The procedure ensures that the time distributions of the weather variable (in fraction of total annual value) over the year for the stations within a cluster are more similar to each other than to stations belonging to other clusters. Even though the time distributions of a weather variable within a cluster were similar for all the stations, the magnitude of the weather variable varied from station to station. The procedure generally produced clusters of stations spatially in the vicinity of each other. The boundaries around the clusters were determined by the common topographical or geographical features, or by the range of climatic variables that was common to most of the stations within the cluster. The annual total magnitude of the weather variables for all parcels within a cluster were estimated by interpolation. This clustering approach based on distribution similarity reduced the data storage requirements for modeling stochastic climatic characteristics of an area substantially.

This system has been used extensively in Hawaii for land use planning, agricultural technology transfer, environment protection and many other resource related problems.

REFERENCES

1. Liang, T. and M. A. Khan. 1986. A natural resource information system for agriculture. Agricultural System 20: 195–217.
2. Khan, M. A. and T. Liang. 1986. Grouping soils with similar properties for areal water budgeting and soil moisture mapping.
3. Ziauddin, A. M. and T. Liang. 1986. A weather risk model for grain drying system design and management in a developing region. Trans of ASAE 29(5): 1441–1446.
4. Ziauddin A. M. and T. Liang. 1986. Sizing a grain drying system for adverse weather conditions. Trans of ASAE 29(5): 1441–1446.
5. Liang, T., M. A. Khan, L. A. Manrique and R. Parmer. 1986. Rating land for crop introduction. Agricultural Systems 21: 107–127.
6. Singh, D. and T. Liang. 1988. Spatial modeling of climatic variables for natural resource management. Department report. Agricultural Engineering Department, University of Hawaii at Manoa, Honolulu, Hawaii 96 822 USA.
7. Richardson, C. W. 1981. Stochastic simulation of daily precipitation, temperature and solar radiation. Water Resources Research 17(1): 182–190.
8. SAS User's Guide: Statistics. 1982. SAS Institute Inc., Box 800, Cary, North Carolina, USA.
9. Liang, T., W. Wong and G. Uehara. 1983. Simulating and mapping agricultural land productivity: An application to macadamia nut. Agricultural Systems 11: 225–253.