SOIL SALINITY CONTROL FOR THE GROWTH OF PLANTS WHICH CAN SERVE AS AN ENERGY SOURCE

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ABSTRACT

The study was conducted to investigate the technical feasibility of reclaiming heavily-salinized marine soil to act as "buffer' in preventing salt intrusion into productive croplands from adjacent salt farms in the coastal provinces. Three 40 m x 40 m elevated field plots of salinized soil in Smutsongkram Province were constructed and reclaimed by leaching alone, and by addition of organic materials and gypsum followed by leaching. Physic-nut tree - a salt-tolerant energy-producing plant were grown on the reclaimed soil, and oil was extracted from physic nut as a by-product of the reclamation.

The field experiments were preceded by greenhouse experiments to determine the effects of various additives on changing soil properties when leaching was applied, and to evaluate the effects of rate of applied additives on changing salinity and permeability of the mixed soil during leaching. Two relatively more promising soil-salinity control methods, namely leaching alone and addition of 3% rice husks + 6% gypsum followed by leaching, were then selected and applied in the field plots to compare the efficiency of the two.

It was found that the addition of rice husks and gypsum in 1:2 ratio decreased soil moisture content and EC values more than for nonamended soil (ie, leaching alone). The EC_d-leaching curve increased steeply initially but then reached a plateau. However, the SAR_d-leaching curve changed in the opposite direction. The EC_f-EC_d relationship

was strogly non-linear and appeared like a sigmoidal curve.

Addition of rice husks and gypsum to the field soil before leaching tended to improve infiltration but seemed to decelerate growth of physic-nut trees, affecting a reduction in seed yields eventually. Plants grew non-uniformly in both treated fields because of the spatial variability of the EC values, ESP and the infiltration in the soil, but not of nutrient deficiency. Oil was extracted from physic-nut at 20.1% on a mass basis, and was found to possess similar fuel characteristics with diesel. Bench dynamometer tests on a 7.5 HP diesel engine using the physic-nut oil as fuel were found to be satisfactory with only slightly inferior performance when compared with diesel as fuel.

The use of wind energy as a low-cost pumping substitute for soil leaching and irrigation was found to be not feasible economically, and not reliable for providing a regular daily supply of water for control purposes, although the seasonal total demand could be met as revealed by simulation studies using on-site wind speed measurements and the measured performance of a 4.35 diameter multiblade windmill.

Auto-and cross-correlations for a large number of long-term wind speed data at 15 sites in 3 physio-graphic provinces revealed relatively high degree of similarities and interdependence among the weather stations in two of the three physiographic provinces.

Unfortunately, the one physiographic province which was found to have low interdependencies bracketed the Smutsongkram Province where the experimental site is located.

Overall cost-benefit analysis of the land reclamation project revealed that it may be economically feasible but that the initial cost may be too excessive for the cropland owners.

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I. INTRODUCTION AND BACKGROUND

A. The geographical setting

Smutsongkram is a coastal province located west to the Gulf of Thailand and is 64 kms from Bangkok (Figure 1.1). It's overall area is 413.80km^2. Land utilization includes agricultural activities, aquacultural management, and salt-farming. For the inland region if sufficiently far away from the sea coast, soil nutrient concentrations and cation exchange capacity were high (Rimwanich and Suebsiri, 1984). The fact that this area was originated by deposition of marine sediment over long periods of time, the soil used to be fertile and suitable for cultivation as a result of nutrient enrichment by the decomposition of organic materials. The other part presently imported by sea water, is the coastal land where shrimp culture and salt-farming are the main activities.

The salt farms in this region are low-lying land flooded with sea-water (Figure 1.2), covering an area of approximately 8.35 km^2 in 1982/1983 (Smutsongkram Commercial Information, 1984). By sun drying, large quantities of salt, principally sodium chloride, is left in the land. The thickness of the salt which covers the soil surface in each of a 1600 m^2 area is about 15 cm. After raw salt is removed from the surface of the soil by crushing and sweeping into piles (Figure 1.3), the soil surface becomes barely dry with densely cracked slices (Figure 1.4). Soil salinization prevails to the nearby croplands.

The reach of sea water and a lack of rainfall during the hot season make the soil increasingly more saline. On the other hand heavy rainfall during the six months period of the rainy season leaves water standing on the soil surface. Moreover, soil with a clay content of more than 30% also causes poor drainage. Because of these factors, the water-table has been rising and often damages plants for two reasons : first, the root zone becomes saturated leading to rotting of the trees; and second, the water itself contains a high salt content, so that even short term water-logging can cause substantial tree wilting and ultimately death (Duckstein and O' Brien, 1978).

Russell and Russell (1973) indicated that the salinization grew at the expense of the neighbouring soil during a drough due to the formation of salt patch on the soil surface. This result increased the depth through which water was able to move from the watertable to be evaporated at the surface. The consequent effect was the expansion of salinized soil to the nearby croplands, thereby damaging crop yields. Bear (1965), and Reeve and Fireman (1967) reasoned on the injury of plants grown in salt-affected soil that the high osmotic pressure of the soil solution reduced the availability of the water. In addition, excess salinity delays or prevents seed germination, and lowers the amount and rate of plant growth(Reeve and Fireman, 1967).

Rimwanich and Suebsiri (1984) cited that problems with high salinity level was twofold, firstly the high concentration of sodium and chloride ions made plants difficult to take up nutrients, secondly the soil structure was destroyed by the high concentration of monovalent sodium ions which replaced divalent calcium and magnesium in the exchange complex. The substitution of sodium ion for calcium and magnesium ions in the soil solution accentuated the problem by reducing permeability and hydraulic conductivity, with the result that when rain came, the salt was uneasily washed out. Russell and Russell (1973) explained that as rain removed the salt, the soil condition deteriorated, it became increasingly difficult to work, water began to stand on it, and it dried out to hard lumps; the soil had gone from a flocculated to a deflocculated condition. If this sequence of soil salinization continues to happen, then crop field in this marginal land will be changed to salt-farms ultimately due to a severe limitation on successful crop production.

Controlling or reducing salinity levels in the soil, therefore, is very important not only to agricultural production but also to water resources management. Although the elimination of salinizations requires substantial capital investment, however it is necessary to protect the cropland from salt damage in order to conserve it for world food need. Thus considerable attention has been given to develop a compromised strategy for preventing further spread of salt by controlling soil salinity in the marginal area of the cropland neighbouring the salt-farm. This area then shall represent a buffer state which separates the nearby cropland from the salt-farm. The size of such an area depends upon the extent of soil salinization. Nevertheless the soil condition in this area has to be improved until it becomes less impervious. The salt concentration in the soil solution is to be confined to a level that moderately tolerant crops could still produce optimum yields. Salt-farming in this area is also characterized by the widespread use of windmills for lifting the sea-water needed. According to a survey conducted by Koetsinchai and Suwantragul (1986), there are approximately 667 sale-wing type windmills throughout the 143 square kilometers of the salt production area in the two adjacent coastal provinces of Smutsongkram and Smutsakon. The windmills, which are 7 to 10 m diameter with an average lifting head of 0.7 m, are used to pump the sea-water at the sea shore to brine reservoirs and from there to the drying areas.

B. Diesel oil usage in thailand

For the past 25 years, petroleum fuel consumption in Thailand has been growing at an average rate of 8.5% per annum from annual total of 1,700 million litres (or 29,000 barrels per day) in 1962 to 13,000 million litres (or 225,000 barrels per day) in 1986 (Thailand Oil Quarterly). In per capita terms, it has increased from 62 litres to 250 litres per person per annum, along with an average economic growth of 7% per annum over the same period. Meanwhile, diesel fuel usage which predominates over all other fuel types in Thailand, has been rising at 9% per annum from its share of about 35% in 1962 to the current level of 44%. This high percentage of diesel fuel usage is not surprising is view of the fact that fuel consumption in the transport and agriculture sectors combined accounts for over 60% of the total (56.2% for transport and 9.8% for agriculture over the 1983-1986 period). In these sectors, diesel fuel is chiefly used for powering automobiles, agricultural machinery as well as fishing boats.

During the Sixth Five-Year (1987-1991) National Economic and Social Development Plan, the Thai economy is targetted to grow at 5.1% per annum, along with an energy consumption growth rate of 3.7% per annum. However the dependence on imported energy is to be reduced from 58% of the commercially used volume in 1985 to 49% in 1991. If these targets are to be achieved, indigeneous sources of fuel should be explored and exploited.

C. <u>The physic-nut tree and its oil</u>

The JcL (Jatropha curcus Linn) or physic-nut belongs to the family of Euphorbiaceae. The tree looks like shrub of up to 7 metres in height with thick branchlets. But on arid escarpment the height does not exceed 2-3 metres. The plant can be found easily in various places of Thailand except for newly reclaimed and swamp areas. Its name is called variously depending on the place where it is found. In the south it is called Hong Tes, the northern and north-eastern names are Tei Yu and Ma Yao respectively. In the central region it is called Sabu-Dam.

The fact that the plant has been growing naturally in the draught - stricken area of the North-east, where the majority of land contains saline soil of poor fertility and where the climate is severe, demonstrates that the plant is indeed draught and salt-tolerant. According to the Land Development Department, which has been implementing a five-year (1982-1986) saline soil reclamation scheme in the North-east, about 52% of the total area in this region has soil salinity above 8 mmhos/cm.

The propagation of the plant can be either by seed or by stem germination. In the case of propagation by cutting, the plant can grow up to 2 metres high and bear about 50 fruits after 8 months. Therefore, it might be said that the plant has a rapid rate of growth in spite of its being a perennial plant. Normally, the plant begins to yield at the age of 6 to 8 months and can live up to 50 years. Some may yield twice in a year depending on the area and plant variety. The cultivation of the fruit seems to pose little trouble as it is less susceptible to insects than for caster beans. It has been shown by Pasabutr and Suthipolpaiboon (1982) that the mean yield of a five-year old physic-nut tree is 2-3 kilograms of air-dry seed and that the seed has an oil content of up to 32% (including 1% in the shell). Previously, the oil extracted from the seed had been utilized as light oil and raw material for making candle owing to its non-root formation characteristics. Its latex had also been used as a good medicine for stomatitis by the local people in the North-east. At present however such uses (both fuel and medical) appear to have diminished. Instead, the farmers employ the trees to fence their fields and farmsteads.

A recent study by Takeda (1982) has revealed the potential use of physic-nut oil as a substitute for diesel fuel. According to the study, the fuel characteristics of the physic-nut oil is comparable to that of diesel oil, its calorific value being 9,470 kcal/kg as compared to 10,170 kcal/kg for diesel, and the oil is easily soluble in gasoline and diesel oil. Successful test runs on a small diesel engine using physic-nut oil was also reported.

D. The proposed systems approach

In view of the dual needs for a solution to the problem of soil salinization on the coastal provinces and for the exploitation of indigeneous fuels to reduce the dependence on inported fuel, an integrated systems approach which will fulfill the above needs is proposed. This involves the creation of a "buffer zone", between the salt-farms and normal croplands, where the soil salinity is to be controlled by a leaching process to such a level that the salt-tolerant physic-nut trees can be grown in the area. In view of the wide acceptance of the use of wind pumps in the area, it is proposed that wind energy be used to pump the underground water needed for the leaching process. With the provision of adequate drainage, the buffer area will serve to prevent the proliferation of salinization to the normal croplands. Thus both the salt - farming and crop-growing activities can be continued without the need to sacrifice one activity for another. The oil procuced from the physic-nut can also be used as a diesel fuel substitute for small fishing boats in the area. The net result would be an effective land utilization management.

Finally since the proposed project is to be carried out with the collaboration of U.S. and Thai scientists, a wealth of technical information and knowledge will be shared between the scientists of the two countries. This is especially true in the area of soil salinity control and in the growth and characteristics of physic-nut trees.

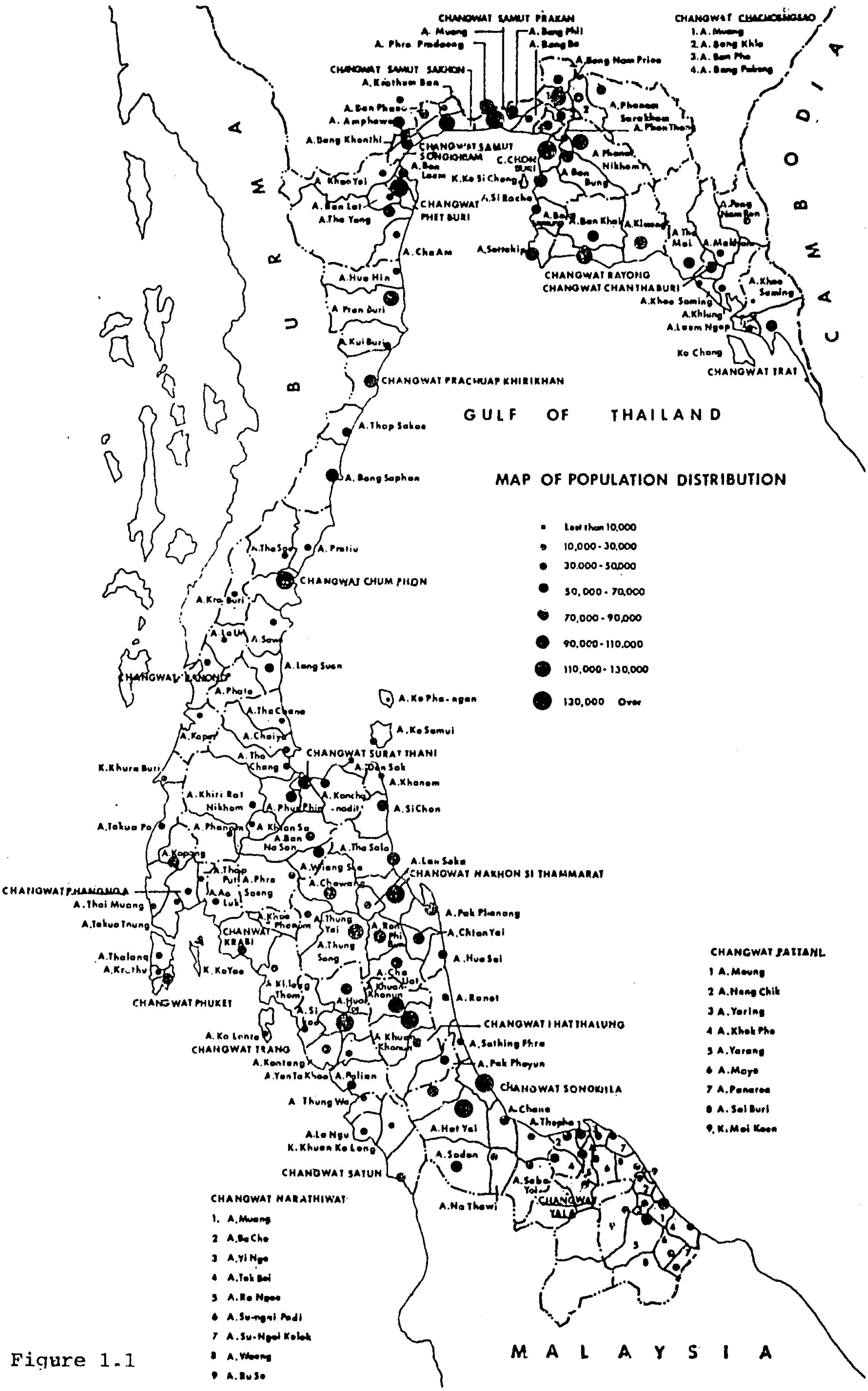

MAP OF POPULATION DISTRIBUTION
GULF OF THAILAND
BURMA
CAMBODIA
MALAYSIA
CHANGWAT SAMUT PRAKAN
CHANGWAT CHACHOENGSAO
1. A. Muang
2. A. Bang Khla
3. A. Ban Pho
4. A. Bang Pakong
CHANGWAT SAMUT SAKHON
CHANGWAT SAMUT SONGKHRAM
CHANGWAT PHET BURI
CHANGWAT RAYONG
CHANGWAT CHANTHABURI
CHANGWAT TRAT
CHANGWAT PRACHUAP KHIRIKHAN
CHANGWAT CHUM PHON
CHANGWAT RANONG
CHANGWAT SURAT THANI
CHANGWAT NAKHON SI THAMMARAT
CHANGWAT PHANGNGA
CHANGWAT PHUKET
CHANGWAT TRANG
CHANGWAT PHATTHALUNG
CHANGWAT SONGKHLA
CHANGWAT SATUN
CHANGWAT YALA
Less than 10,000
10,000 - 30,000
30,000 - 50,000
50,000 - 70,000
70,000 - 90,000
90,000 - 110,000
110,000 - 130,000
130,000 Over
CHANGWAT PATTANI
1 A. Muang
2 A. Nong Chik
3 A. Yaring
4 A. Khok Pho
5 A. Yarang
6 A. Mayo
7 A. Panarea
8 A. Sai Buri
9. K. Mai Kaen
CHANGWAT NARATHIWAT
1. A. Muang
2 A. Ba Cho
3 A. Yi Ngo
4 A. Tak Bai
5 A. Ra Ngae
6 A. Su-ngai Padi
7 A. Su-Ngai Kolok
8 A. Waeng
9 A. Bu Se

Figure 1.1

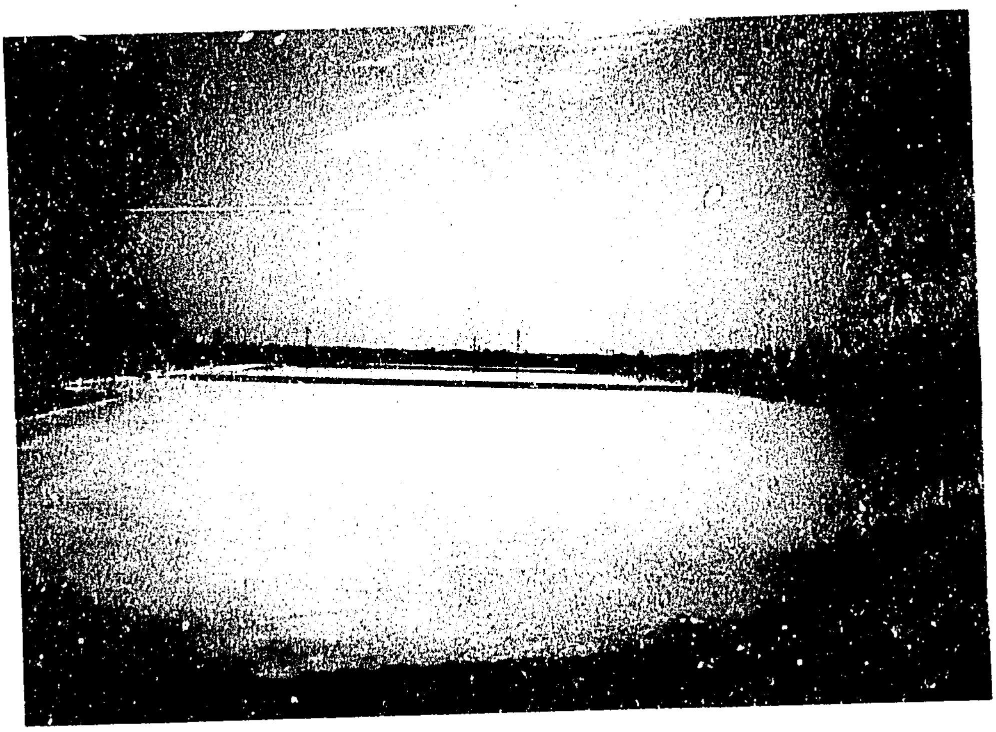


Figure 1.2 Low-lying land flooded with sea-water

Figure 1.3 Salt piles in a salinized land

Figure 1.4 Salinized soil in a salt-farm

II. THE SETTING

A. Thailand : Overview of the country

A.1 General Geography

The Kingdom of Thailand is located in the Indochinese peninsula of Southeast Asia, between 5° and 21° N latitude and 97° and 106 E° longitude (Figure 2.1), covering a total area of 5.18×10^5 km^2.

The area is of an axe-like shape, with a long panhandle extending southward along the Malaya peninsula. The longest distance stretching from north to south is approximately 1658.3 kms, while the widest part spanning from east to west is 805 kms. It is bounded on the west and northwest by Burma, on the north and northeast by Laos, on the southeast by Cambodia, and on the south by Malaysia. Its 2093 kms coastline encloses most of the Gulf of Thailand, and on the western side of the panhandle borders the Indian Ocean.

According to N.Y. Nuttonson's report in 1963, the physiography of Thailand consists of broken upland in the north and northwest, with high granite ridges and limestone patches, and narrow valleys; of an extensive low sandstone plateau cut with flat broad valleys in the northeast; of rolling land and valley relief and a large alluvial plain in the center forming the heart of Thailand; and the geographically distinct long, narrow peninsula of rugged topography, with granite ridges, valleys and plains in the south.

Much of Thailand is undulating. Some parts are hilly and mountainous.

There are numerous small rivers passing the central plain which is of triangle-like shape with 241.5 kms of each side (Nuttonson, 1963). Irrigation canals criss-cross this plain.

Geographically Thailand may be divided into five physiographic provinces : the Northwest Highlands, the Chao Phya Plain, the Korat Plateau, the Chantaburi, and the Peninsula. The Northwest Highlands consist of parallel to subparallel ranges which trend generally north - northeast in the Phi Pan Nam subprovince and the north-northwest in the Tanaosee subprovince.

The Chao Phya Plain occupies the central part of Thailand. It extends from approximately latitude 18^{o}N, where the Ping, Wang, Yom and Nan Rivers emerge from their valleys in the north, to the Gulf.

The Korat Plateau is a gently undulating, saucer-shaped plateau (Sternstein and Bennett, 1963), which is tilted to the southeast. The edge of the plateau is demarcated by the Phetchabun Mountains and the Dong Phya Yen to the west.

The Chantaburi is composed of a mountainous area in the northern and central parts and a coastal plain in the south and west which merges with the Chao Phya Plain and the Gulf. East of the coastal plain along the Cambodian border is a line of flat-topped hills, the Khao Banthat. The elevation of this area is generally below 500 metres.

The Peninsula, the southern Thailand, is a 750 kilometres long and 15 to 200 kilometres wide strip of land. It is composed of short ridges, several hundred metres high, trending approximately north-south, arranged in echelon and separated by small valleys or plains in which isolated peaks rise abruptly from 50 to 100 metres.

The eastern shoreline is generally smooth and regular, mountains being some distance from the sea, but the western shoreline is highly irregular, fringed with islands, and in many places, mountainous.

A.2 Hydrogeography

Hydrogeographically, there are about eight important rivers passing various parts of Thailand. Those are the Chao Phya, Mae Klong, Bang Pakong, Ping, Nan, Mae Khong, Mun and the Pattani Rivers (Figure 2.2). The Chao Phya River is the main watershed in the Central Plain. It branches to the west and to the east which becomes the Mae Klong and the Bang Pakong River respectively. The Ping and the Nan Rivers flow from the north down to the Chao Phya River. The Mae Khong River forms the border with Indochina on the northeast. The Mun River originates in the western hills of the Korat Plateau and flows eastward across the tableland near the Indochinese border into the Mae Khong River. Another important watershed flows southward is the Pattani River. It flows into the Indian Ocean on the west coast, and into the Gulf of Thailand on the east coast. The mean monthly discharge over the period of 20 years (1951-1970) were in the ranges of about 100-300 cms, 25-900 cms, 150-2400 cms, 10-350 cms, 50-1000 cms, 25-250 cms, 50-2525 cms, 800-21600 cms, for the Ping, Nan, Chao Phya, Bang Pakong, Mae Klong, Pattani, Mun, and Mae Khong Rivers, respectively.

A.3 Climate

Climate in Thailand is tropical monsoon with wet and dry seasons. According to the regime of rainfall patterns as interpreted from the rainfall data for a 30 - year period (1951-1980) by the Meteorological Department, Ministry of Communications, Thailand (1984), the general rainfall in this country is considered as sufficiently good with an annual mean of 1700 mm. or 67 inches, except over the two portions of the country namely, the lower portion of the Northern Part and the Central Part, in particular, the leeward side of the Tenneserium Range between Kanchanaburi and Prachuab Khiri Khan Provinces, for which the mean rainfall is some what meagre in comparison with other localities. In some years the rainfall over these regions did not exceed 100 mm. or 39 inches.

The regions of the heaviest rainfall as described in figure 2.3 are those along the West Coast of the Southern Part from Ranong to Phuket and along the East Coast of the Gulf of Thailand from Rayong southwards, where abundant rain occurs during the Southwest Monsoon Season, especially at Ranong and Khlong Yai, the annual amount of rainfall mostly exceeds 4000 mm. or 157 inches. Another region of copious rain is located along the East Coast of Southern Part from Chumpon southwards during the Northeast Monsoon Season. Over the rest of the country rainfall is scanty. Within the above-mentioned region, the annual rainfall is more than 2000 mm. or 79 inches and in some years, the amount may exceed 2500 mm. or 98 inches.

Generally, thunderstorm occurs in Thailand during the period of heavy rainfall. The records of the annual number of thunderstorm days for this country as reported by WMO/OMM (1953) was in the range of 35 to 107, and the mean annual number of thunderstorm days was 60 (Figure 2.4). The distribution of annual mean number of rainy days varies from below 100 to above 200 (Figure 2.5). The mean annual number of rainy days is least-usually below 120 at the east of the Tanaosee Range where it is greatest-usually over 180 around Ranong in the West Coast Region and in the Southeast Region (Sternstein and Bennett, 1963). A monograph of 2 - year 1 hour rainfall as shown in figure 2.6 describes the relationship between mean annual precipitation, mean annual number of thunderstorm days, number of rainy days with rainfall intensity greater than 1.0 mm. and 0.01 inch (0.25 mm.) for estimating 2 year, 1 hour rainfall in Thailand (Hydrology Branch, USDA, 1967). Variations of mean annual precipitation, mean annual number of thunderstorm days, days of rain greater than 1.0 mm. and 0.01 inch (0.25 mm.), and 2 year, 1 hour rainfall distributed in the ranges of 0.25 - 50 hundred mm., 5 days - 200 days, 10 days - 200 days, and 0.25 inches - 3.0 inches, respectively.

Geographically, temperatures of Thailand as reported by the Meteorological Department, Ministry of Communication, Thailand (1981), may be divided into two regions; Upper and Lower Thailand. Upper Thailand which includes the northern, northeastern, central and eastern parts, experiences a long period of hot weather because of its inland nature and tropical latitude location. Except along the coastal regions where the sea breezes have some influence, maximum temperature generally ranges from about 32.0 C (89.6 F) to 38.0 C (100.4 F). During April which is the hottest month of the year, maximum temperature often reaches much higher values.

The daily temperature range over Upper Thailand during this hot period is 11 C to 15 C (51.8 F - 80.6 F). The average minimum temperatures are usually about 21.0 C (69.8 F) over the northern and northeastern parts and 23.0 C (73.4 F) over the central part.

During the northeast monsoon or winter season (November to February), the temperatures over Upper Thailand are much milder. The daily temperature range during this period is quite large, averaging about 12 C to 18 C (53.6 F - 64.4 F) with mean maximum temperature being about 31.0 C (87.8 F) and mean minimum about 15.0 C (59.0 F).

The eastern part of Thailand, on account of its closeness to the sea, experiences a mild weather with rather strong sea breeze during summer. The average daily temperature is about 27 C - 29 C (80.6 F - 84.2 F). However deep into the land where these areas are not influenced by the sea breeze, the maximum temperature of 41.0 C (105.8 F) has been recorded at Aranyaprathet. During winter, the northeast winds from China mainland occasionally penetrate into the eastern part, causing decrease in temperature in general, but hardly affect the temperature along the coast. For lower (southern) Thailand, temperatures are generally mild throughout the year. Because of the exposure of the region to maritime air mass in all seasons, the excessive temperatures which is common to Upper Thailand is seldom experienced. The average daily range of temperature in this area is about 8.5 C (47.3 F) with average maximum temperature being about 31.7 C (89.1 F) and minimum 23.2 C (73.8 F). An average temperature in Thailand over thirty - year period (1951-1980) was described in the map shown in figure 2.7.

A.4 Wind regimes

The surface winds over Thailand are determined mainly by the monsoon circulation pattern. Spatial distributions of the seasonal mean wind speed and direction for the country have been obtained by Exell et al (1981) using published climatological data for the period 1951-1975 of the Meteorological Department (Figures 2.8-2.11). During spring (Feb-Apr) the air over South-East Asia has its origin in the trade winds of the Pacific Ocean. Accordingly, the prevailing winds over north-east Thailand and the peninsula between Burma and Malaya are easterly. In central Thailand and the north, the north-south orientation of the mountain chains, and the effects of solar heating of the land mass, cause the surface air current to turn northwards and southerly winds prevail. By midsummer (Mar-Jul) the south-west monsoon has spread over the area and the winds lie between South and West everywhere. During the autumn (Aug-Oct) the intertropical convergence zone moves from north to south over the country causing the winds to be variable in direction over the north, north-east and central parts of the Kingdom, but south-westerlies persist over the peninsula. In winter (Nov-Jan) the trade winds have re - established themselves giving predominantly north-easterly winds from China.

Average wind speeds over Thailand depend for the most part more on geographical location than on seasonal changes. Winds are very light in the north and much of north-east Thailand, with mean speeds less than 2 m/s. As one moves southwards the winds become stronger and reach mean speeds over 3 m/s at exposed locations near the coast. The maximum wind speeds lie mostly in the range of 20-40 m/s.

A.5 Cropping patterns

M.Y. Nuttonson (1963) classified crops grown in Thailand on the basis of the geographic feature which was divided into 4 zones; northern highlands, northeastern, central, and the southern (Figure 2.1).

The northern highlands extend up into the mountainous areas and covers about 37,720 square miles. Teak production is the most important feature of the economy. Trees grow extensively on mountain slopes and hills. Deciduous forests cover many of the lower mountain slopes, and contain other trees of value. Clearings on the slopes are planted with various crops, chiefly upland rice and opium. Intensive rice cultivation is carried out in the four broad, open valleys of the rivers Ping, Wang, Yom and Nan. The light, sandy soil of the low-lying valley floors is watered and enriched by annual river floods, and irrigation systems have been developed in some sections. The irrigation systems permit earlier planting of paddy before the outbreak of monsoon so that two crops can be grown. Other crops are cotton, of a rough, short-staple Asiatic type, tobacco, which flourishes particularly on soils of the type on which teak grows, soybeans and peanuts, vegetables, peppers, bananas, garlic, pineapples, kapok, corn, sorghum, sweet potatoes, citrus fruits, tung oil trees, bamboo, and some winter plants.

About one-third of the entire area in Thailand is contained in the northeastern zone. Total area is about 63,000 square miles. The land area of this zone represents a large plateau slightly tilted toward the east. The greatest part of the plateau is covered with forest, jungle and grass plains. Rice is grown on jungle hillsides and in the paddy lowlands. Besides sugarcane, sweet potatoes, hibiscus, cotton, and cassava are also grown in the forested areas.

The central zone is the largest and economically the most valuable region of Thailand. It covers an area of over 67,000 square miles. Vegetation and crops grown in the central plain of this zone are teak, rice, sugarcane, tropical fruits, and vegetables. In the southeastern part of the zone black and white pepper, rubber, sugarcane, coffee, fruits, and coconut palm are grown.

The southern zone covers an area of about 26,800 square miles. Major vegetations grown in this region are coconut palm and rubber trees. Paddy rice is also grown on several coastal plains. However the southern zone as a whole does not produce rice other than for local consumption.

A.6 Soils

The natural fertility of the soils of the greater part of Thailand is low, because of leaching by heavy rainfall leading to the development of largely acid soils in the central plain, and because of salinization due to salt farming, construction of reservoirs, and deforestation. Variations in amount, intensity and distribution of precipitation, length of the dry season, wind speed, soil characteristics, drainage, forest, and farm practices throughout the country appear to have been among the major influences responsible for the soil differences encountered in the various region of Thailand. Soil characteristics based on a combination of particle-size, mineralogy reaction, and moisture regimes are classified into 4 groups; lowland soils of the alluvial plain and the lower terraces (poorly drained, aquic moisture regime, mainly used for rice cultivation), upland soils of the higher terraces and the low plateaux (moderately well and well drained, ustic moisture regime, mainly used for upland crops cultivation), upland soils of the higher terraces and the low plateaux (moderately well and well drained, udic moisture regime, mainly used for para rubber plantation and fruit trees), and soils of the hilly and mountainous terrains (>30% slopes) (Figure 2.12). Most of the soil in all groups except in the last one is clayey. Common type of clay mineral containing in those groups is kaolinite. There are some sandy acid families in the soil of the second and the third groups.

According to Nuttonson's (1963) report, characteristics of a considerable part of the country are the laterite soils which is water permeable, red, iron-rich, crumbly and sticky soils. These soils are abundant in the low plains. In the flood plains of Thailand the soil are generally gray, while those developed in the landscapes with high relief belong to the yellow, brown or red earth types. Granite, basalt, limestones, sandstone and clay shales are among some of the common parent material of Thailand. In northern Thailand, the soil is alluvial and stony which is considerably fertile. These alluvial soils vary considerably from sandy loam to silty clay.

In the central plain of the central zone, except for some very fine sandy soils close along the banks of the larger rivers and some of the brownish silt loams and light clay loams on the higher lands on the plain's margins, the soils consist of heavy, poorly-drained and wet dark gray clays.

The soils in northeastern Thailand is saline. Sources of salinization arises from the salt derived from strata of sandstone and shale impregnated with salt, and also from saline ground water with high water table (Rimwanich and Suebsiri, 1984).

The soils in southern Thailand are rather complex, and are interspersed with fine sandy loams as well as with loam. This is because the southern part differs from the other zones of the country not only in its climate but also in its rocks. The core of the main mountain ranges here is composed of granitic batholiths and intrusion (Nuttonson, 1963).

B. The local province

B.1 Geography

Smutsongkram Province is located at the northern most part of the Peninsula on the Gulf of Thailand. It lies approximately between the latitudes 13° 15′ and 13° 31′ North, and between the longitudes 99° 52′ and 100° 05′ East. It is bounded at the north and west by Ratchaburi Province, at the east by Smutsakhon Province and the Gulf of Thailand, and at the south by Petchaburi Province (Figure 2.13). The overall area is utilized both for agricultural and non-agricultural activities. Agricultural regions, which occupy over 59% of the total area as reported by Ludwig (1976), included horticultural-cropped-lands, mangrove forests, and rice fields. The remaining less than 50% of the same area is utilized for domestic estates, grasslands, salt and shrimp farming. The topology is considerably flat. As a consequence, the land is easily waterlogged when heavy rainfall occurs. In addition the intrusion of sea water and high evaporation during the dry season causes rapid expansion of salinization. Dargan et al. (1982) explained that when a high tide was synchronized with heavy rain storms in the coastal area, a relatively large area was affected by inundation due to the comingle saline water.

B.2 Climate

Climate of this province is classified as "Tropical Monsoon" according to Koppen System (Jinda, 1982). The mean annual temperature is 27.8 C and mean monthly temperatures lie between 24 C and 29.7 C. Mean annual precipitation is 103.5 mm and monthly rainfall varies from 0 mm to 308.4 mm. Rainfall is usually concentrated in the seven months from May through November (table 2.1), when the average monthly precipitation exceeds 192 mm. The dry period of the year runs from December through March, with an average monthly rainfall of 20 mm.

B.3 Cropping patterns

Planted lands in this province include forests, cultivated areas for horticultural and agronomial crops, and vegetables. Commercial plants grown commonly are coconut palms, paddy rice, corns, orchards, citruses and onions.

B.4 Salt/shrimp farms

Salt/shrimp farms are conducted on the coastal land closed to the sea - shore. However drought which occurred recently changed most of the paddy fields in the inland region to salt/shrimp farms. The proportion of plant growers and salt/shrimp farmers as reported by the Provincial Office of Agricultural Extension (1979) was about 3:1.

B.5 Climatic factors affecting Salinization

Climatic factors have played an important role in both waterlogging and salinization of this area. During the dry season, between December and April, the average rate of rainfall is low compared to that which occurs during the rest of the year, from May to November (table 2.1). As a consequence, high temperature and lack of rainfall increases salt concentration of the soil water due to evaporation at the soil surface. In the rainy season, heavy rainfall with high frequency then floods the lands.

B.6 Wind energy availability

Although windmills are used extensively for water movement in the salt farm area in Smutsongkram as discussed in Part I, there exists no recorded data on wind energy avilability, such as wind speeds in the area either by the Meteorological Department or the Provincial Authority. For the purposes of assessing weather conditions, the wind data for the Bangkok Metropolis is often quoted as it is the nearest province with a weather station. Recently, an attempt was made by Siripruegpong et al. (1981) to estimate the total wind energy potential in Thailand, based on wind speed records of the country's 53 meteorolgical stations. The result, which contains some gross simplifications, was presented in the form of a map showing the isolines of average wind power per unit land area (Figure 2.14). Based on this map, it can be seen that wind energy potential for Smutsongkram lies roughly between 10 and

20 kW/km^2. For a more accurate assessment of the wind energy potential, historical record of the wind data must then be established.

Table 2.1 Monthly climatological data during 1982 for Smutsongkram province[1]

Month	Rainfall mm	Rainfall days	Mean Monthly R.H. %	Mean Monthly Temperature °C (dry)
January	0	0	62.8	25.5
February	0	0	76.6	27.9
March	19.5	1	76.5	28.5
April	50.2	2	75.0	29.1
May	202.8	5	76.3	29.7
June	74.8	9	78.4	28.5
July	*	*	78.1	28.2
August	111.8	8	79.4	27.8
September	264.6	13	81.4	27.6
October	200.5	13	82.0	27.9
November	308.4	5	75.9	28.5
December	10.0	1	70.4	24.0

[1] Obtained from a meteorological station located 10 km from the research station

* missing data

C. The research site

C.1 Location and size

The research site was selected from the land covering an area of about 2.96 km^2 which was donated to King Mongkut's Institute Of Technology in 1981 by the Provincial Authority of Smutsongkram Province. This land is located on the side of a gravel-surface road passing Ban Lad Yai (Figure 2.15), where heavily-salinized-marine soil has prevailed for decades due to shrimp/salt farming (Figure 1.4).

The research area of 4800 m^2 is located at marginal salt-farm. The reason for choosing this area was to alert coastal land users concerning options for soil conservation and development.

C.2 Field study on salinized-marine soil at the research area soil-sampling approach and the analysis

Field samples of the top 30 cm of soil in the selected area were taken from twelve locations, at 20 m intervals, in July 1983 (Figure 2.16). These samples were analyzed to determine the physical and chemical properties including soil pH; E.C. of a 1:5 soil paste at 25 C; organic matter content; extractable P, K^+, and Na^+; C.E.C; E.S.P.; bulk density; field moisture content; soil texture; and porosity. Methods applied to measure those parameters included a pH meter equiped with electrodes, electrical conductivity meter, dry combustion procedure for oxidizing organic materials, NH_4OAc extraction followed by spectrophotometry and flame photometry, NH_4OAc extraction at neutral pH for C.E.C., oven drying, and mechanical analysis for soil pH, E.C. value, organic matter content, extractable P, extractable Na^+ and K^+, C.E.C., field moisture content, and soil texture respectively. The E.S.P. was calculated from the formula :

$$E.S.P. = \frac{\text{Extractable } Na^+ - \text{Soluble } Na^+}{C.E.C.} \cdot 100 \qquad [2.1]$$

A value for soluble Na^+ was obtained by measuring a water extract of saturated soil using a flame photometer. All mentioned methods were adapted from those given in "A Laboratory Manual for Soil Fertility" (Moodie and Koehler, 1973).

Sampling of standing-water and the analysis

Twelve samples of water taken from water standing on the surface at the soil sampling site at the time of sampling were also analyzed by methods given in the same manual. Values for pH, E.C., and soluble Na^+ and K^+ of the water samples were monitored directly using the same equipment as mentioned before. Soluble Mg^{++} and Ca^{++} were determined by use of atomic absorption equipment. The SAR was calculated as follows :

$$SAR = \frac{Na^+}{\left[\frac{Ca^{++} + Mg^{++}}{2}\right]^{\frac{1}{2}}} \qquad [2.2]$$

Mean results for these soil and water samples, indicating their physical and chemical properties at the selected area for this study, are given in tables 2.2 and 2.3, respectively.

Chemical analysis of water samples from deep well

Ten samples of water were taken at different times from the deep well for determining the average chemical properties including pH; E.C. at 25C; Ca^{++}; Mg^{++}; Na^{+}; $CO_3^{=}$; HCO_3^{-}; Cl^{-}; $SO_4^{=}$; and SAR. Methods used for the analysis were similar to those applied for monitoring the properties of standing-water samples. Average values of all the above are given in table 2.4.

C.3 Formulating system of soil-salinity control

The analysis of all information obtained from both studies in sections B and C was done in order to draw a diagram for soil-salinity control strategy (Figure 2.17).

C.4 Characteristics of Salinized-marine soil

According to the soil grouping, the soil at the research site was classified on the basis of landform as the active tidal flats (Jinda; 1982), which was included in the soil series of Samut Prakan, of very saline phase (Figure 2.15). Its major soil characteristics as described in the map from the same figure indicated that it was in the class of Typic Tropaquepts and alluvial soils. The effective soil depth is very deep and the textural profile is clay or silty throughout. The color profile is greyish brown with reddish brown mottle over light olive grey with brown and yellowish red mottles over greenish grey. Its structure is weak to moderate blocky at the upper A-horizon and structureless at the subsoil below 50 cm from the surface of the soil. The soil is very poorly drained. The soil surface is dry in dry season but there is always ground water at shallow depth. It contains low organic matter. The base saturation, C.E.C., available phosphorus, and potassium at the depth between 0-30 cm and 30 cm are high and very high alternately. Soil pH at both depth is never less than 5.0. Physical and chemical properties of the soil samples taken from the studied area as shown in table 2.2 indicated a saline-sodic nature and a high clay content. Soil pH was never more than 8.0, and E.C. values of a 1:5 soil paste measured at 25 C were in the range of 7.0 $mscm^{-1}$ to 20 $mscm^{-1}$. Field observation suggested that, at the end of the rainy season, water stands about 30 cm to 80 cm deep on this land. When the surface water was then removed by high evaporation and runoff, the soil became grey and the surface cracked into dense slices (Figure 1.4).

C.5 <u>Chemical properties of water standing on the land surface and in the deep well</u>

Results of chemical analysis for water standing on the land surface indicated very poor quality while the properties of deep-well water showed the opposite condition. Low salt concentration in deep-well water makes it suitable to be used as a substitute for rain water for leaching salt out of the soil as well as irrigating plants during a dry period. High E.C. values and high soluble-sodium content in standing - water implied that salt deposited near the soil surface is soluble in the coming rain water.

C.6 Application of diagram for soil-salinity control strategy

The diagram illustrated in figure 2.17 describes a control system for soil salinity both for engineering design and for field experiments on salt removal. This model suggests that all factors except rainfall and evaporation are controllable by a combination of sound agricultural practice and engineening applications.

C.7 An estimation of leaching requirement for pumpage design

Leaching requirement (LR) was estimated from maximum E.C. value, average field soil moisture content, average soil bulk density, and average porosity. These data were taken from table 2.2. The reason for choosing the maximum E.C. value for this calculation was to obtain high capacity of water supply. The calculated LR was then used as a criterion for pumpage design and for controlling soil salinity in the field plots. The method of calculation was based on a dilution concept, with the assumption that salinity of the fresh irrigation water is negligible. The formula used was :

$$Q_1 = [E.C._{f_1} \cdot E.C._c^{-1} - 1] \cdot \theta_{m_1} \cdot \frac{\rho_b}{\rho_w} \cdot V_P \qquad [2.3]$$

Where

Q_1 = Total volume of fresh water required to leach excess salt per 1600 m^2 plot

$E.C._{f_1}$ = field soil salinity before beginning of rainfall

= 20 $mscm^{-1}$

$E.C._c$ = desired level of soil salinity

= 8 $mscm^{-1}$

θ_{m_1} = soil moisture content wt/wt

= 0.41

ρ_b = soil bulk density

= 1,180 kgm^{-3}

ρ_w = water density

= 1,000 kgm^{-3}

V_p = pore volume

$$V_p = A.h.\bar{p} \qquad [2.4]$$

Where

A = plot area

= 1,600 m^2

h = depth of root zone

= 1.50 m

$\bar{p}$ = average porosity

= 0.56

From equation 2.4,

V_p = 1,344 m^3

Therefore, from equation 2.3

Q_1 = 975 m^3/plot

Table 2.2 Average values for physical and chemical properties of the marine soil at the research site (n= 12)

Properties	Range	Mean	s	Unit
pH	7.4-8.0	7.7	0.2	
E.C.(1:5) at 25C	7.0-20.0	11.0	3.4	$mscm^{-1}$
Organic matter	0.83-2.11	1.31	0.33	%
P	170-340	256	49.4	ppm
K^{+}	33.3-46.2	40.0	4.6	mel^{-1}
Na^{+}	374-1,270	647	261	mel^{-1}
C.E.C.	12.45-21.60	18.18	3.2	me/100gsoil
ESP	> 50			
Bulk density	1,140-1,250	1,178	36.7	kgm^{-3}
Field moisture content	33.56-50.06	41.37	5.1	%
Sand	9-27	16.0	5.1	%
Silt	25-30	28.2	1.6	%
Clay	43-63	55.8	5.9	%
Texture	Clay	Clay		
Porosity	54.2-57.8	56.1	1.2	%

Table 2.3 Average chemical properties of water standing on the surface at the time of sampling the field soil (n=12)

Properties	Range	Mean	s	Unit
pH	8.4-9.1	8.8	0.23	
E.C. at 25C	12.8-28.0	17.8	4.8	$mscm^{-1}$
Ca^{++}	0.23-0.99	0.53	0.25	mel^{-1}
Mg^{++}	0.62-5.56	2.81	1.6	mel^{-1}
Na^{+}	165-487	244	92	mel^{-1}
K^{+}	4.2-11.9	6.5	2.5	mel^{-1}
SAR	126-269	201	52	me

Table 2.4 Average chemical properties of water from deep well (n=10)

Properties	Range	Mean	s	Unit
pH	7.9-8.1	8.0	0.07	
E.C. at 25C	0.74-0.81	0.78	0.02	$mscm^{-1}$
Ca^{++}	1.76-1.80	1.78	0.04	mel^{-1}
Mg^{++}	2.45-2.52	2.5	0.02	mel^{-1}
Na^{+}	4.95-5.01	4.96	0.03	mel^{-1}
$CO_3^{=}$	1.35-1.43	1.4	0.05	mel^{-1}
HCO_3^{-}	6.0-6.20	6.10	0.06	mel^{-1}
Cl^{-}	2.38-2.60	2.43	0.06	mel^{-1}
$SO_4^{=}$	0.24-0.31	0.27	0.02	mel^{-1}
SAR	3.35-3.43	3.39	0.02	me

D. Facilities constructed

D.1 Geneneral descriptions

Prior to conducting the experiment, the following essential facilities were constructed : a field-store building, a deep well, two wind pumps, a greenhouse, and field plots. The field-store building, of approximately 24 m^2 in size, was built with concrete blocks (figure 2.18). The building is divided into two parts, one for the storage of field equipment and materials, the other being a shelter for workers. A deep well of 80 m. in depth was bored near the access road (figure 2.19). Two multiblade (steel) windmills of 4.35-metre diameter, together with piston type pumping units were constructed to pump ground water from the deep well for soil leaching (figure 2.19). The wind pumps are located parallel to the access road with the deep well between them. To supplement shortfalls in wind-pumped water, an air-lift pump, which consists of a 5 H.P. double-stage piston-type ari-compressor driven by a 6.5 HP/2200 rpm diesel engine, was also installed. During operation, the compressed air is injected into the same deep well as that used for the wind-pumps. The deep-well water is pumped to a 1.73 m^3 storage tank located close to the field plot at 3.72 m above the ground. Details of the water supply system can be found in Appendix A. A temporary greenhouse of 5M x 5m area was built near the deep well to facilitate the pot experiment (figure 2.20). The structure of the greenhouse composes of bamboo frame covered with transparent plastic sheets. Three field plots with surrounding roads were constructed (figures 2.21-2.22) with irrigation and drainage systems. Two of the plots were built with surface and subsurface drains while the remaining plot with surface drain only. The size of each plot is 40 x 40 m^2, and each plot contains 400 plants arranged in 40 columns and 10 rows. Water table was controlled down to 1.5 m below the soil surface. Application of irrigation water from deep well or rain fed water causes a recharge to the water table due to deep percolation. Drain pipes of 50-mm diameter were laid at 10-m intervals in each plot for transporting water from the plot soil into a downstream ditch.

D.2 Drainage design

The design of the drainageway involved determination of runoff, selecting cross-sectional shape of the channel and computing flow capacity compared to volume of runoff water. The runoff was estimated from the depth of rainfall in the studied area for a given time period. In case of this study, the 5 year return period storm was chosen and calculated in the following manner :

1. From figures 2.3-2.5, it is seen that the mean annual rainfall or MAR, the mean annual number of thunderstorm days or MANTD, and the mean annual number of rainy days or MANRD around the research area are 1200 mm, 60 days, and 120 days respectively.

2. Being a function of MAR, MANTD, and MANRD, the 2 year 1 hour rainfall as read from a diagram in figure 2.6 is 1.85 inches.

3. By looking at table 2.5, the 5-year 1 hour storm is 1.3 of the 2 year

1 hour storm or .061 mm (1.3 x 1.85 inches x 25.4 $\frac{mm}{inch.}$) which equals to the depth of runoff without infiltration.

4. The estimated peak discharge for the 40 x 40 m^2 plot is equal to 0.027 m^3/s $\left(\frac{.061 \text{ mm} \times 40 \times 40 \text{ m}^3/\text{hr}}{3600 \text{ s/hr}}\right)$. For a drainage ditch, the maximum discharge per ditch is $\frac{1}{2}$ of a peak discharge or 0.0135 m^3/s while the maximum discharge from 3 manholes is 0.009 m^3/s for a main drain. The triangular and trapezoidal shapes were designed for the drainage ditch and the main drain respectively. The cross-sectional areas and the hydraulic radii of both sections were calculated from the following formulae.

For a triangular shape

$$A = Zd^2 \qquad [2.5]$$

and

$$R = \frac{Zd}{2\sqrt{Z^2 + 1}} \qquad [2.6]$$

For a trapezoidal shape

$$A = bd + Zd^2 \qquad [2.7]$$

and

$$R = \frac{bd + Zd^2}{b+2d\sqrt{Z^2 + 1}} \qquad [2.8]$$

While A; R; Z; d; and b represent the cross-sectional area; hydraulic radius; ratio of horizontal to vertical lengths; depth; and the bottom width respectively. When substituting Z = 2.1; and d = 1.5 into the formulae 2.5-2.6, the A and R of the triangular channel become 0.045 m^2

and 0.067 m respectively. By applying a similar method to verify the formulae 2.7-2.8 for Z = 1.1, d = 1.0 m, and b = 1.0 m, the A and R of the trapezoidal channel are calculated to be 2 m^2 and 0.522 m respectively. The capacity of flow through both designed drainageways was calculated from Manning's formula (Schwab et al; 1966).

$$Q = \frac{1.486}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad [2.8]$$

Where Q = flow capacity in m^3/s

n = roughness coefficient of the channel

For straight and uniform conduits, the minimum value of n is 0.017 (Schwab et al; 1966).

A = cross-sectional area in m^2

R = hydraulic radius in m

S = a selected hydraulic gradient

= 0.003

By substituting 0.017; 0.045 m^2; 0.067 m; and 0.003 for n; A; R; and S respectively, the calculated flow capacity through a triangular drainage - ditch is 0.035 m^3/s which is greater than 0.0135 m^3/s, implying a preferable design. By using the same formula for n = 0.017; A = 2 m^2; R = 0.522 m; and S = 0.003 the calculated flow-capacity through a main drain designed in trapezoidal shape is equal to 6.21 m^3/s which is more than the required volume of 0.009 m^3/s.

D.3 <u>The irrigation system</u>

Drip and sprinkler irrigation systems were put in each subplot for applying water to the soil surface. The drip irrigation system includes a main supply PVC - pipe of 50 mm diameter burried at 0.50 m below the soil surface, a gate valve, a water flow meter, 20 mm diameter rubber hoses connected to the manifolds of the supply of PVC pipe. Each hose is separated by a distance of 1.75 m (figure 2.23), and is perforated at 100 mm intervals. The sprinkler irrigation system is a portable rotating-head type. The components include a PVC main line, a portable rubber line, a sprinkler head, and a supporting pole of 1 m high. Components of both irrigation and drainage systems are shown in figure 2.24.

Table 2.5 Ratio for estimating precipitation-frequency values for various return periods and durations from the 2-year 1-hour value.[2] (Thailand)

Return Period (Years)	Duration (Hours)					
	1	2	3	6	12	24
2	1.00	1.68	2.32	4.12	5.65	7.25
5	1.30	2.10	2.90	5.05	6.94	9.35
10	1.52	2.54	3.31	5.94	7.90	10.05
25	1.79	2.88	3.94	6.51	9.02	11.89
50	2.05	3.27	4.46	7.41	9.99	13.08
100	2.41	3.63	5.02	8.50	11.94	14.82

[2] Obtained from Hydrology Branch, Engineering Div., Soil Conservation Service, U.S. Dept. of Agriculture.

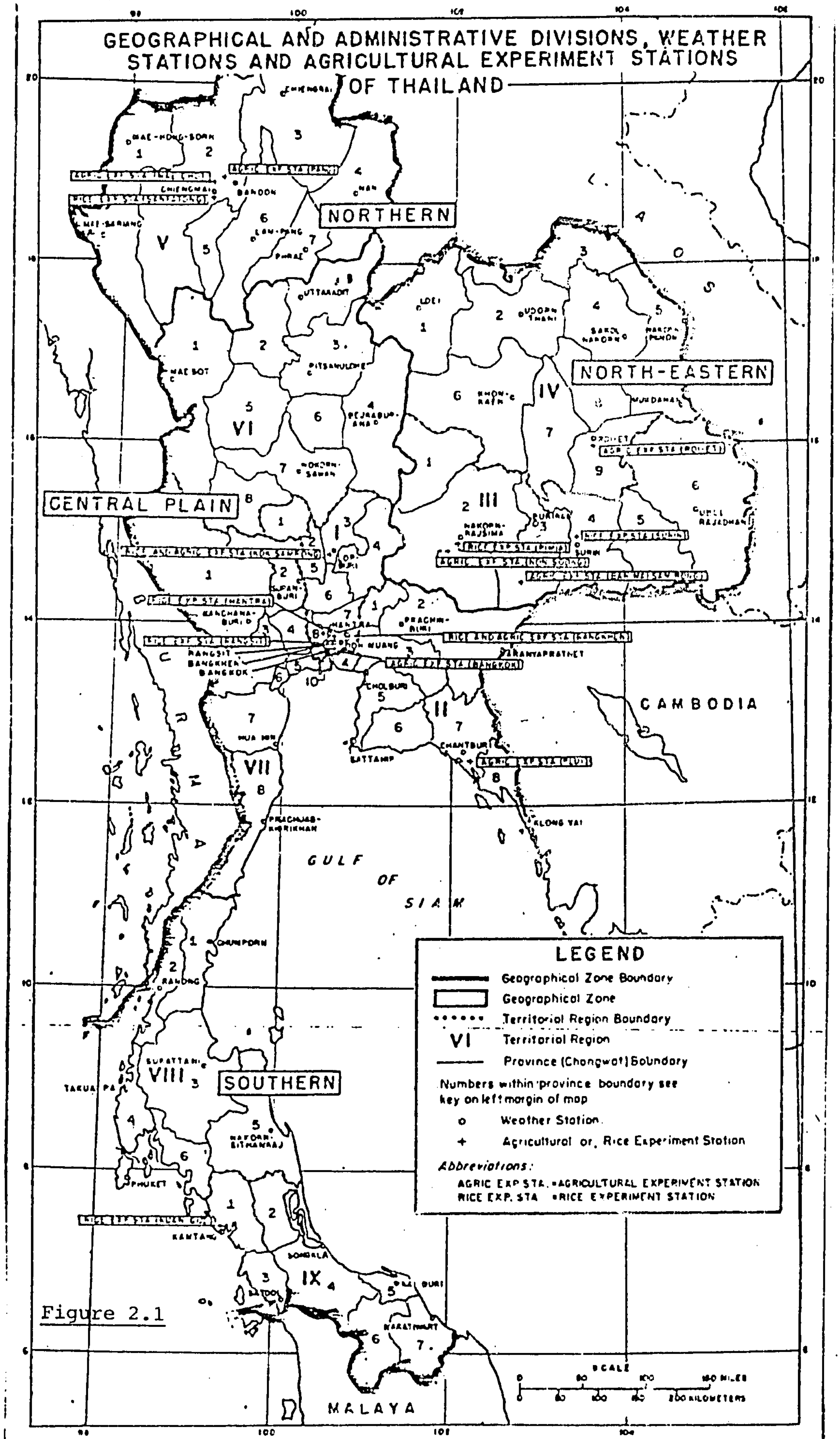

GEOGRAPHICAL AND ADMINISTRATIVE DIVISIONS, WEATHER STATIONS AND AGRICULTURAL EXPERIMENT STATIONS OF THAILAND
NORTHERN
NORTH-EASTERN
CENTRAL PLAIN
SOUTHERN
CAMBODIA
GULF OF SIAM
MALAYA
LEGEND
Geographical Zone Boundary
Geographical Zone
Territorial Region Boundary
VI Territorial Region
Province (Changwat) Boundary
Numbers within province boundary see key on left margin of map
o Weather Station
+ Agricultural or Rice Experiment Station
Abbreviations:
AGRIC EXP STA. = AGRICULTURAL EXPERIMENT STATION
RICE EXP. STA = RICE EXPERIMENT STATION
SCALE
MILES
KILOMETERS

Figure 2.1

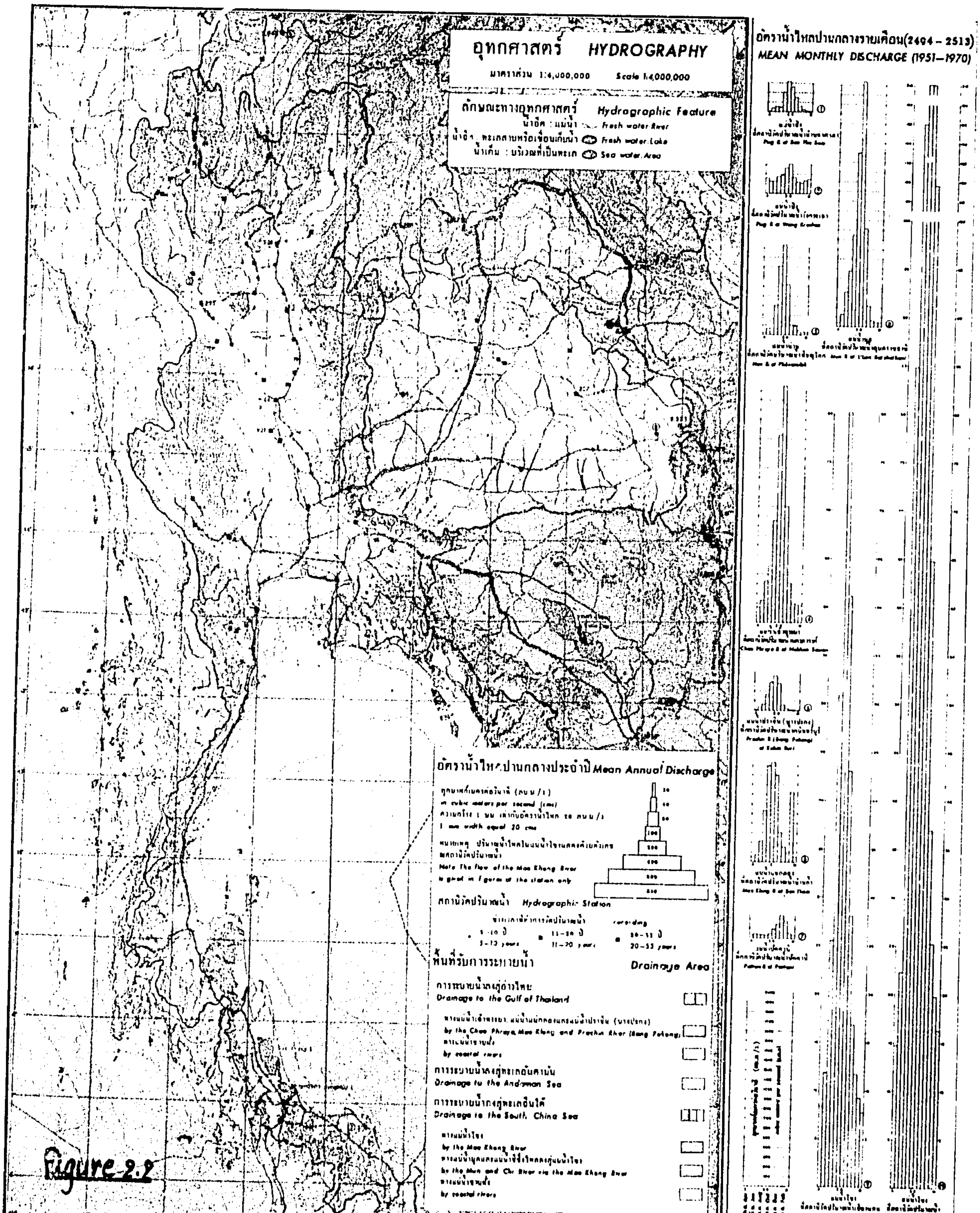


Figure 2.2

Sources at the end of the atlas

Published by Royal Thai Survey Department 1974

ANNUAL RAINFALL

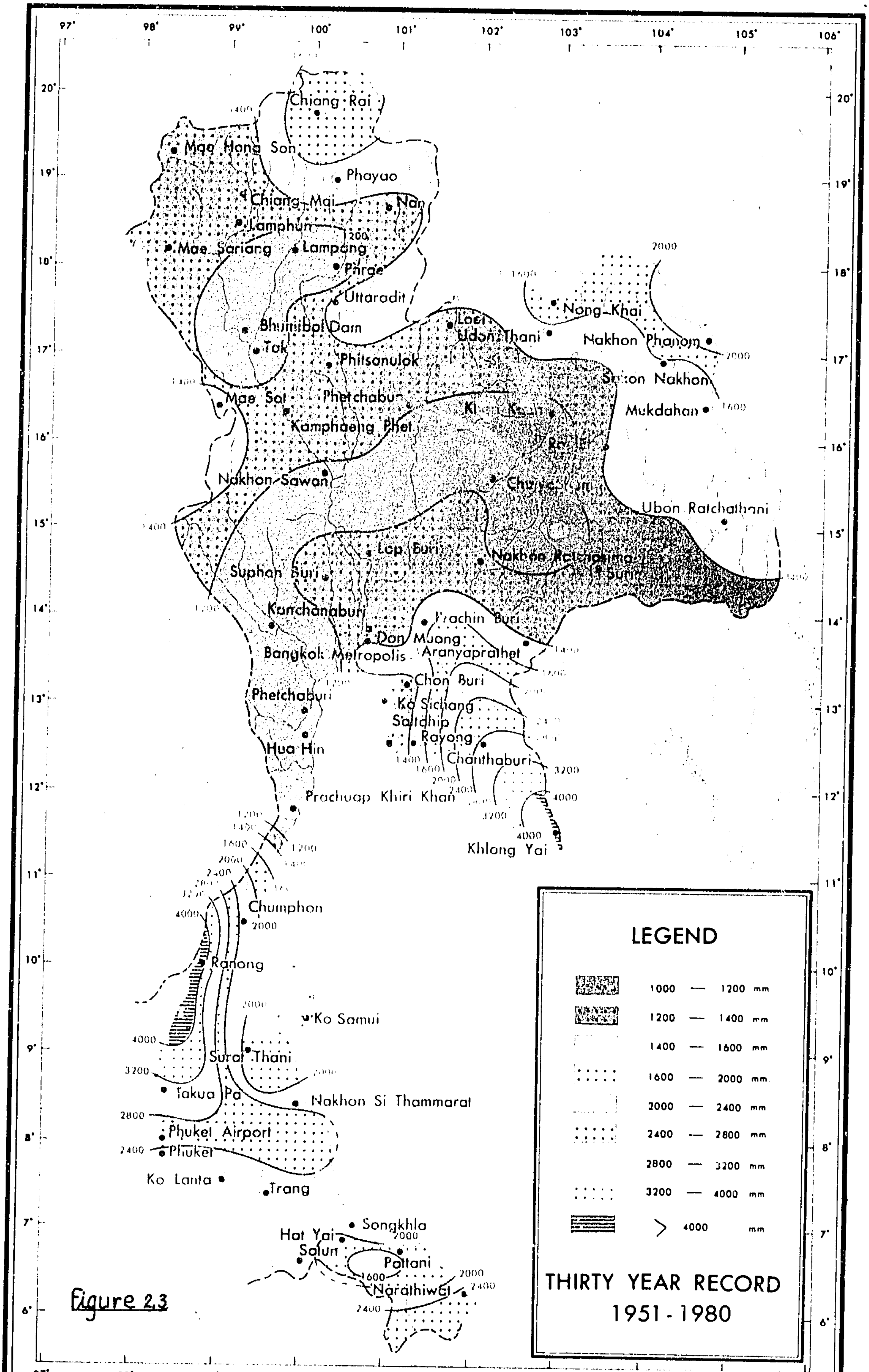


Figure 2.3

Figure 2.4 World Distribution of Thunderstorm Days - Part 2 Table of Marine Data and World Map WMO/OMM No. 21. TP 21

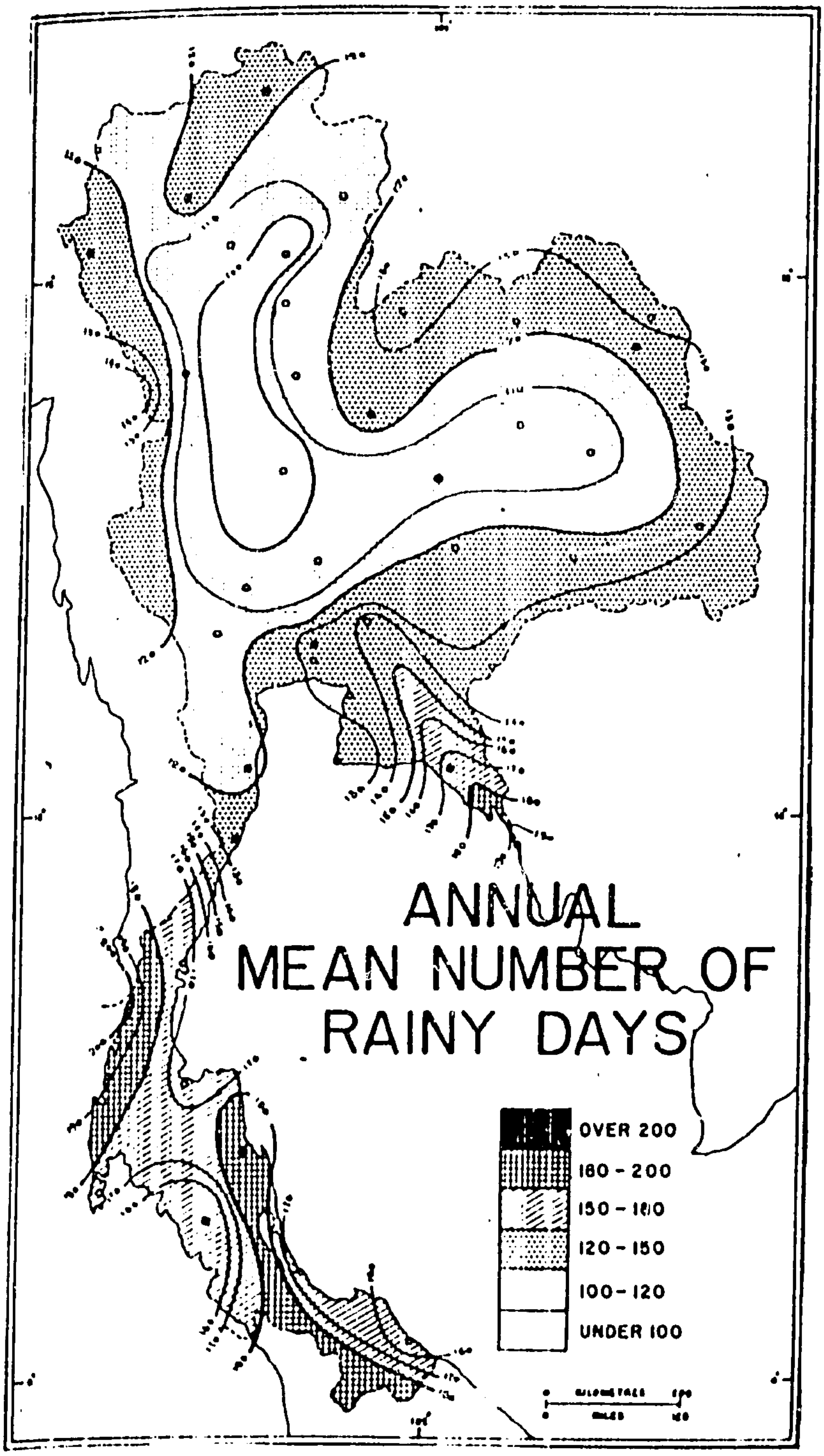

ANNUAL
MEAN NUMBER OF
RAINY DAYS
OVER 200
160 - 200
150 - 160
120 - 150
100 - 120
UNDER 100

Figure 2.5

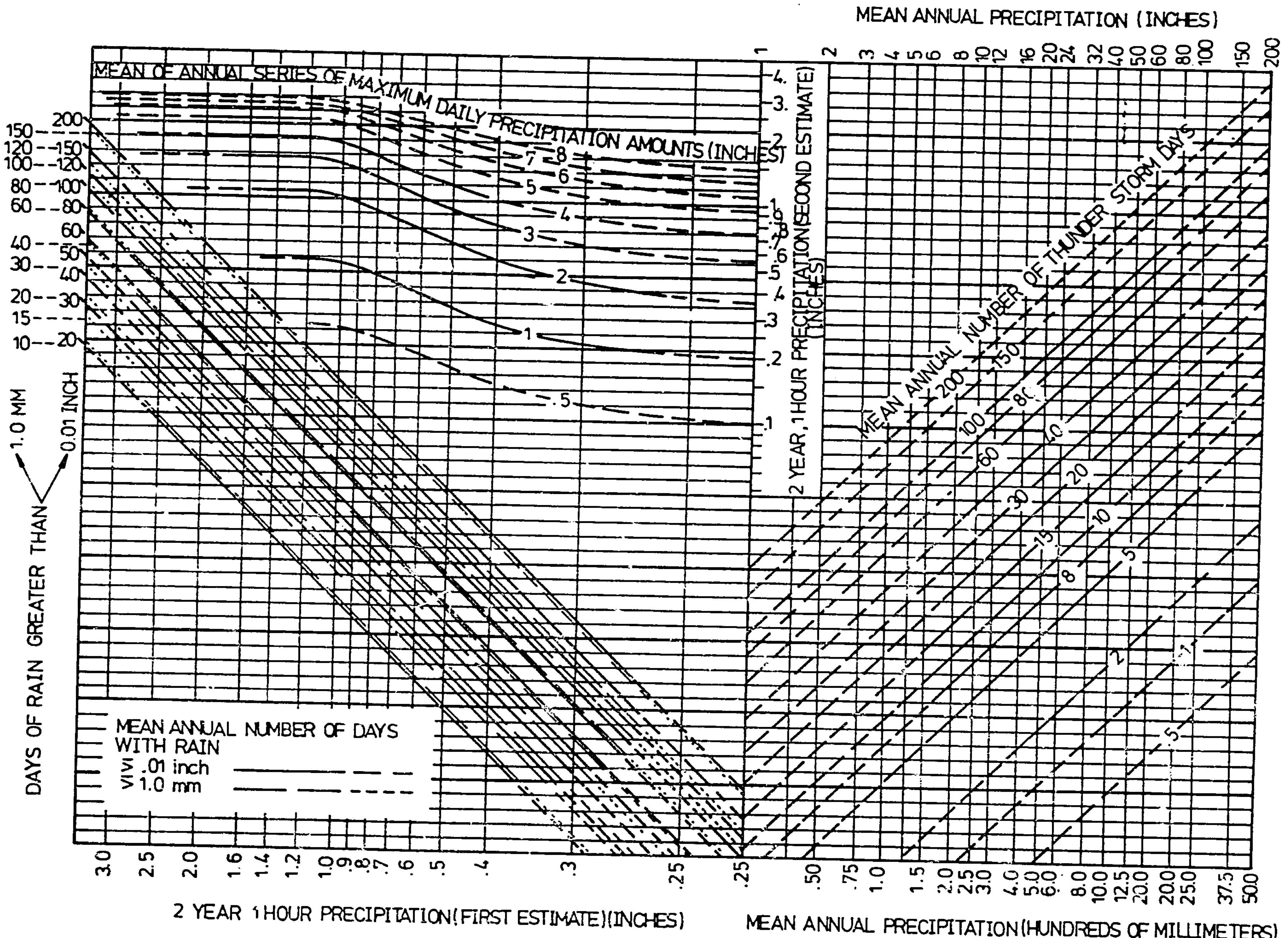


Figure 2.6 DIAGRAM FOR ESTIMAING 2-YEAR 1-HOUR RAINFALL
(Dashed lines are unsupported by data)

AVERAGE TEMPERATURE

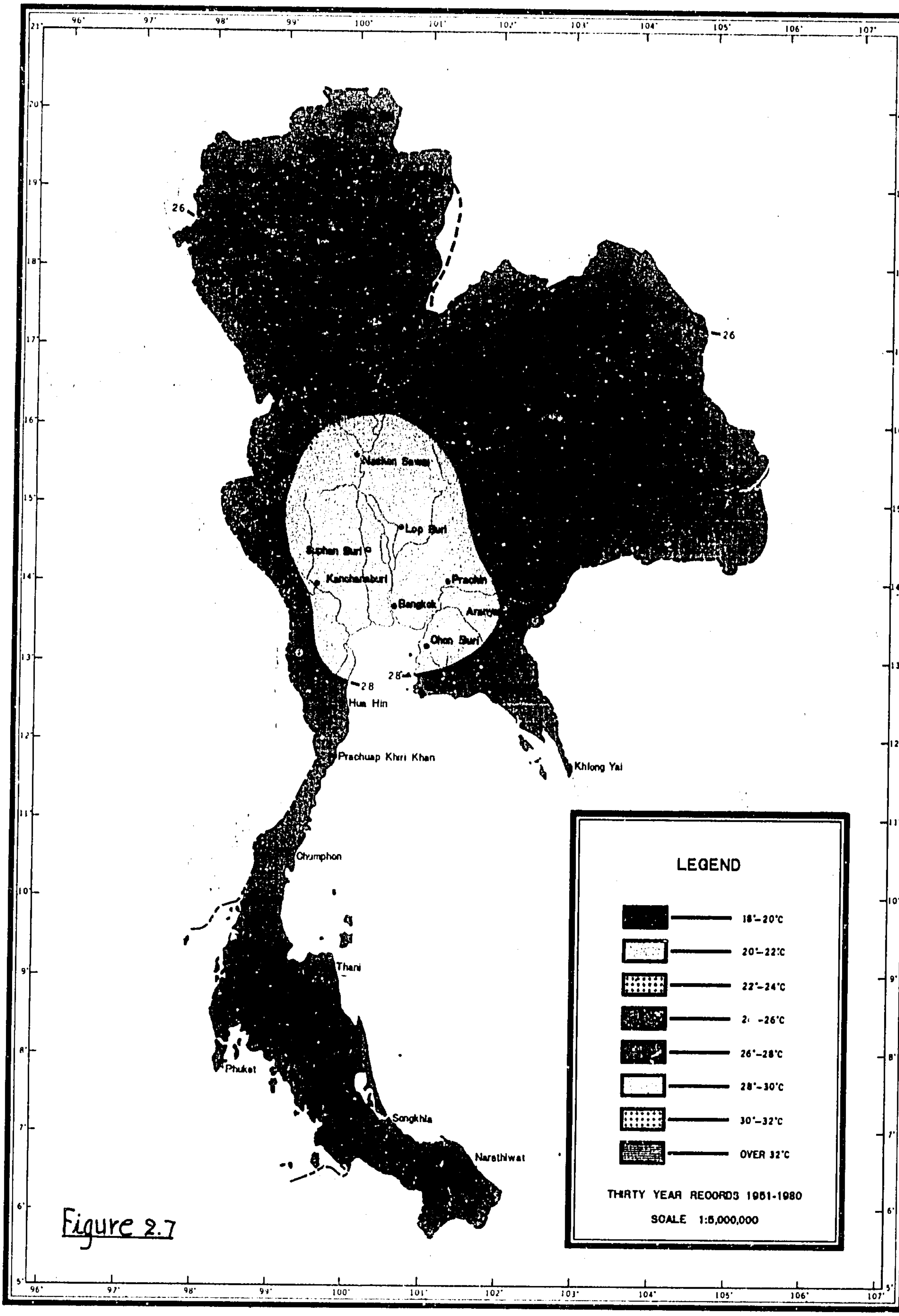


Figure 2.7

Printed By Royal Thai Survey Department 6/81

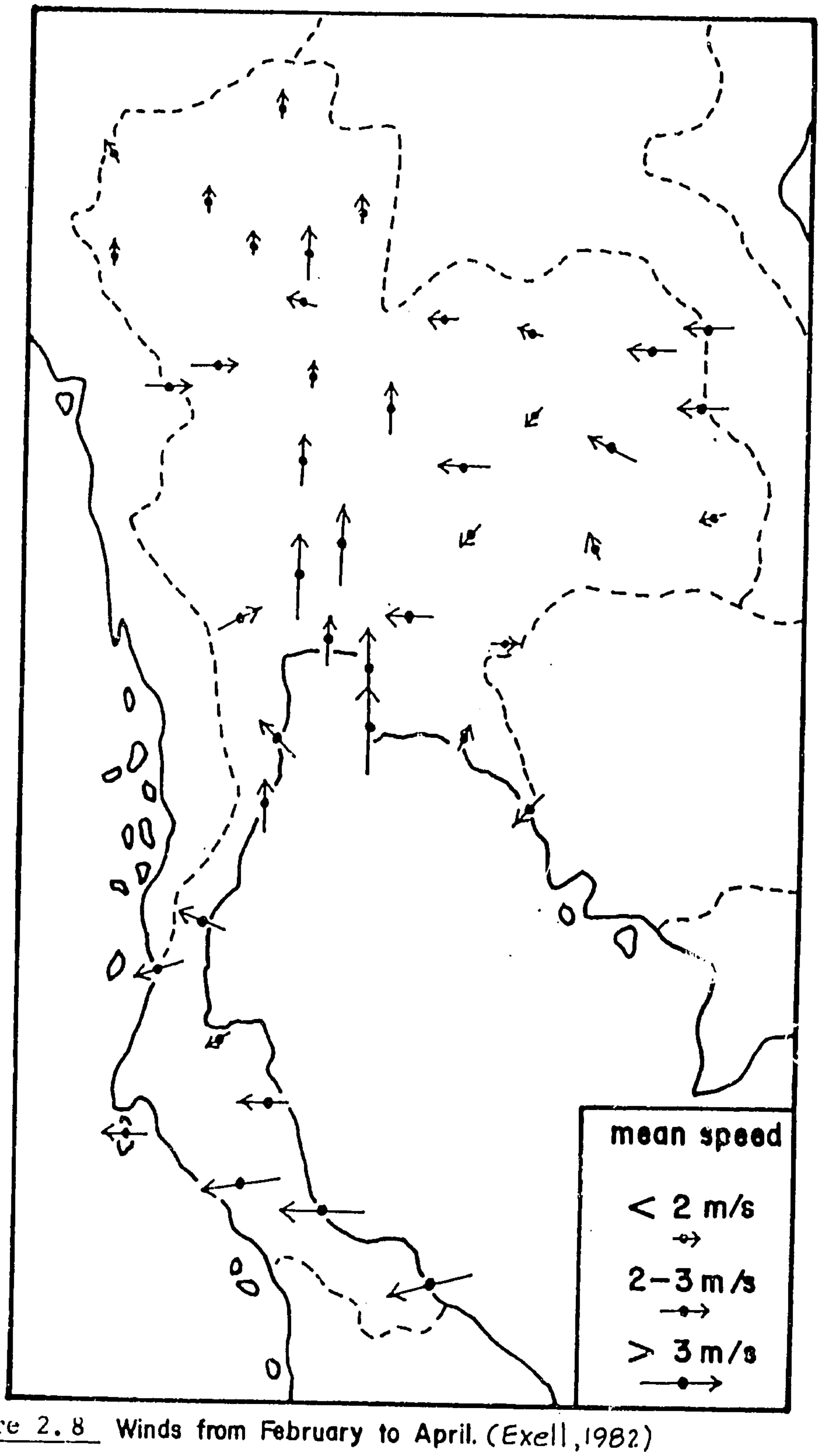


Figure 2.8 Winds from February to April. (Exell, 1982)

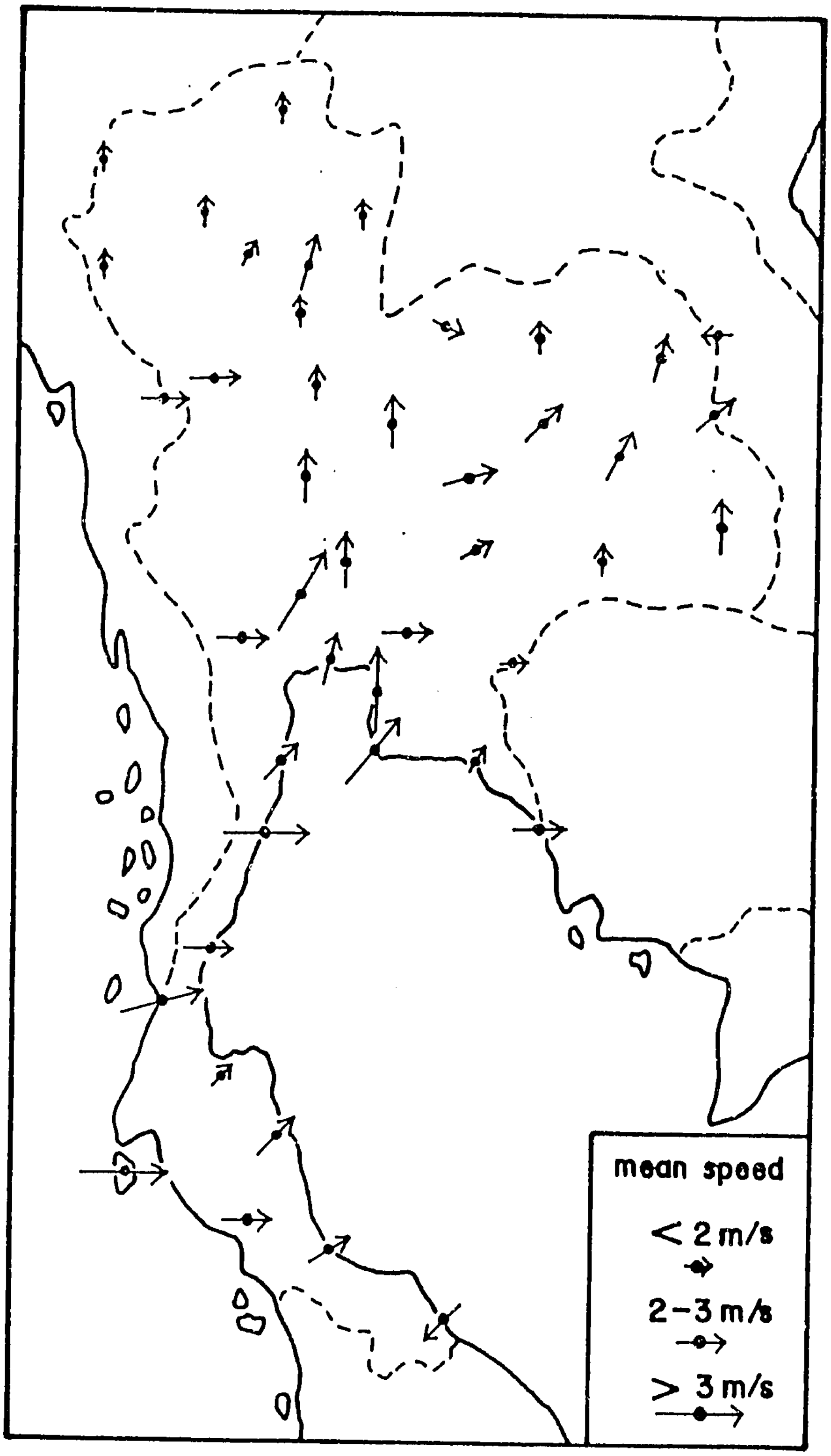


Figure 2.9 Winds from May to July.

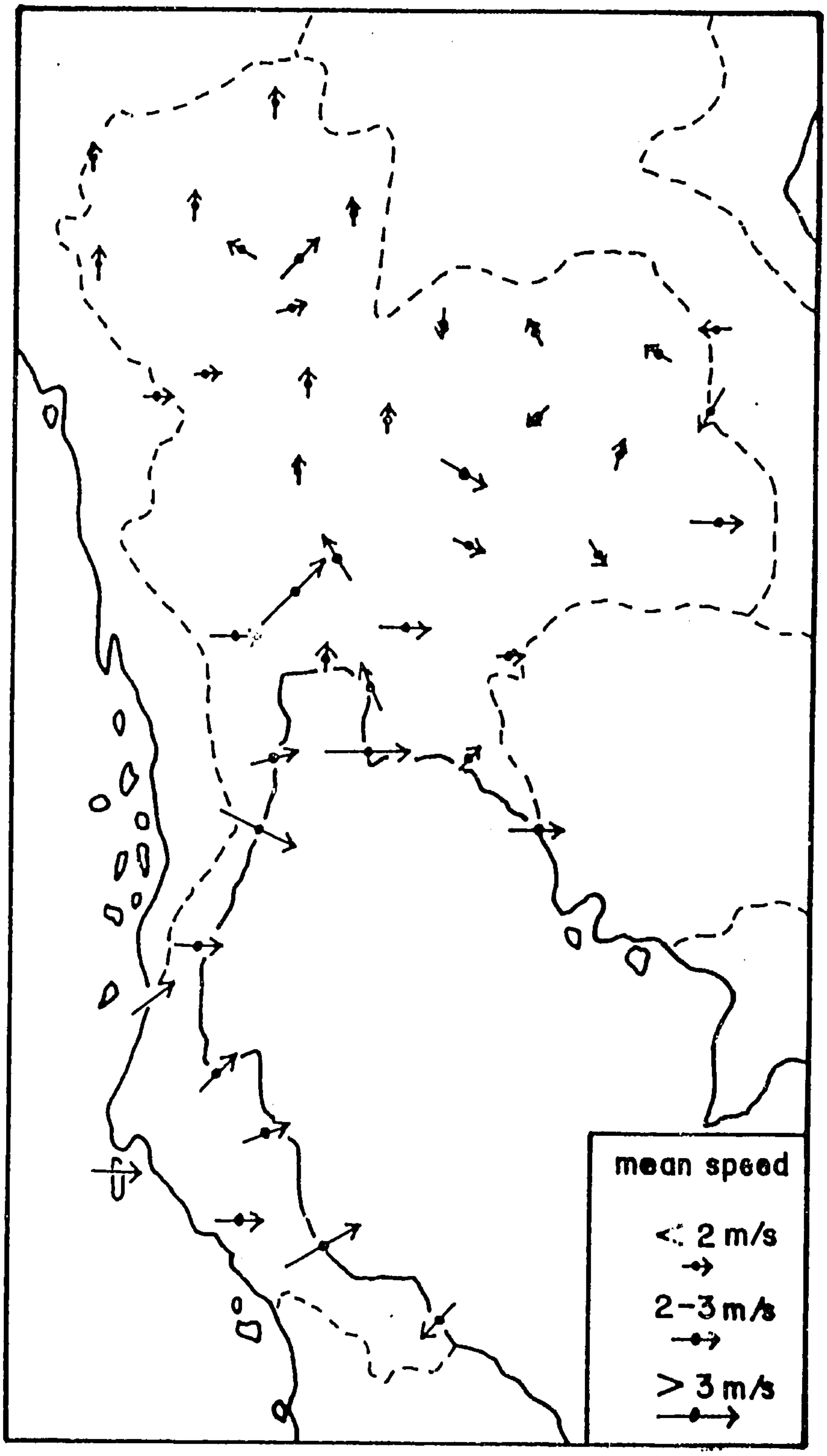


Figure 2.10 Winds from August to October.

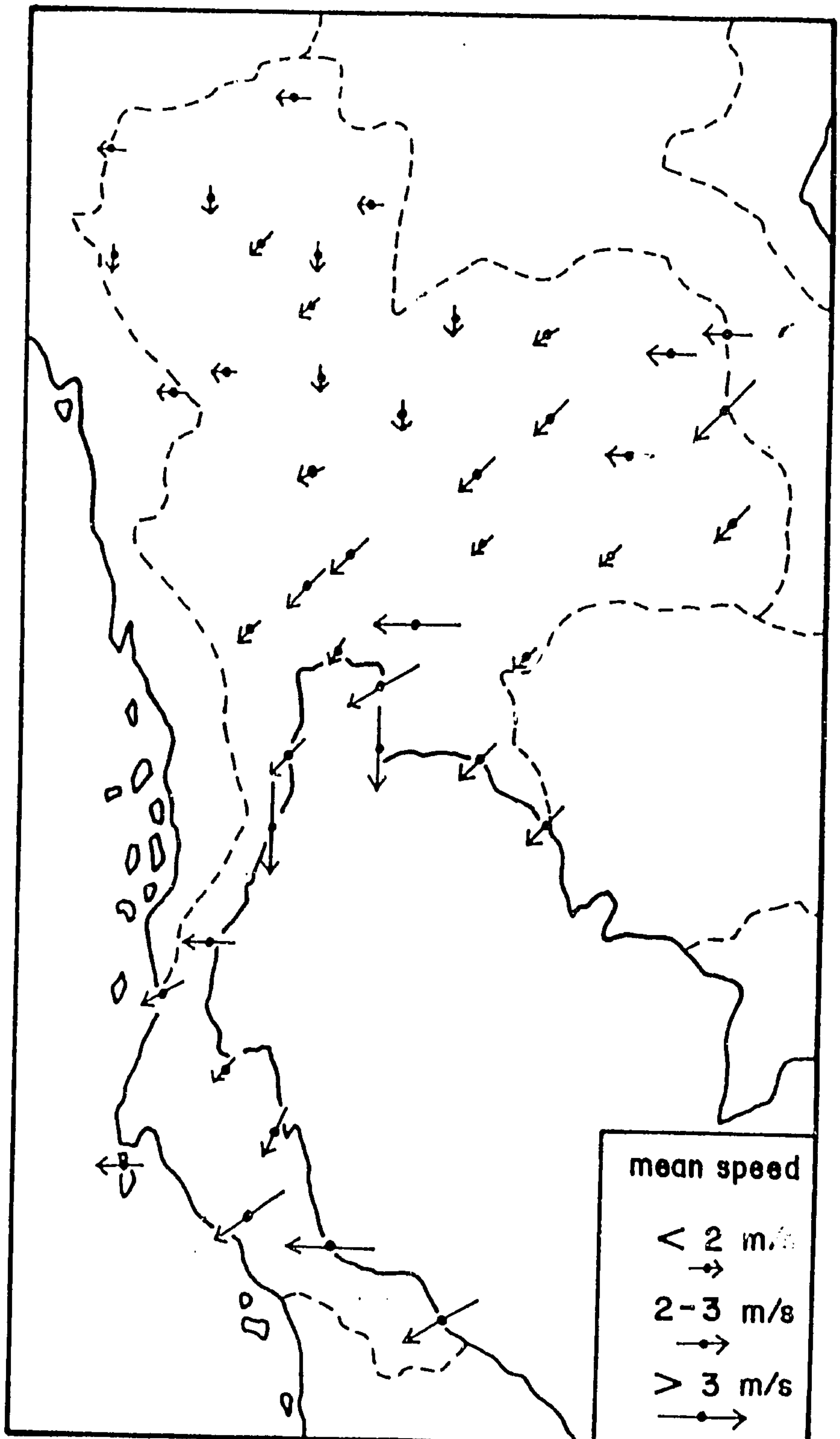


Figure 2.11 Winds from November to January

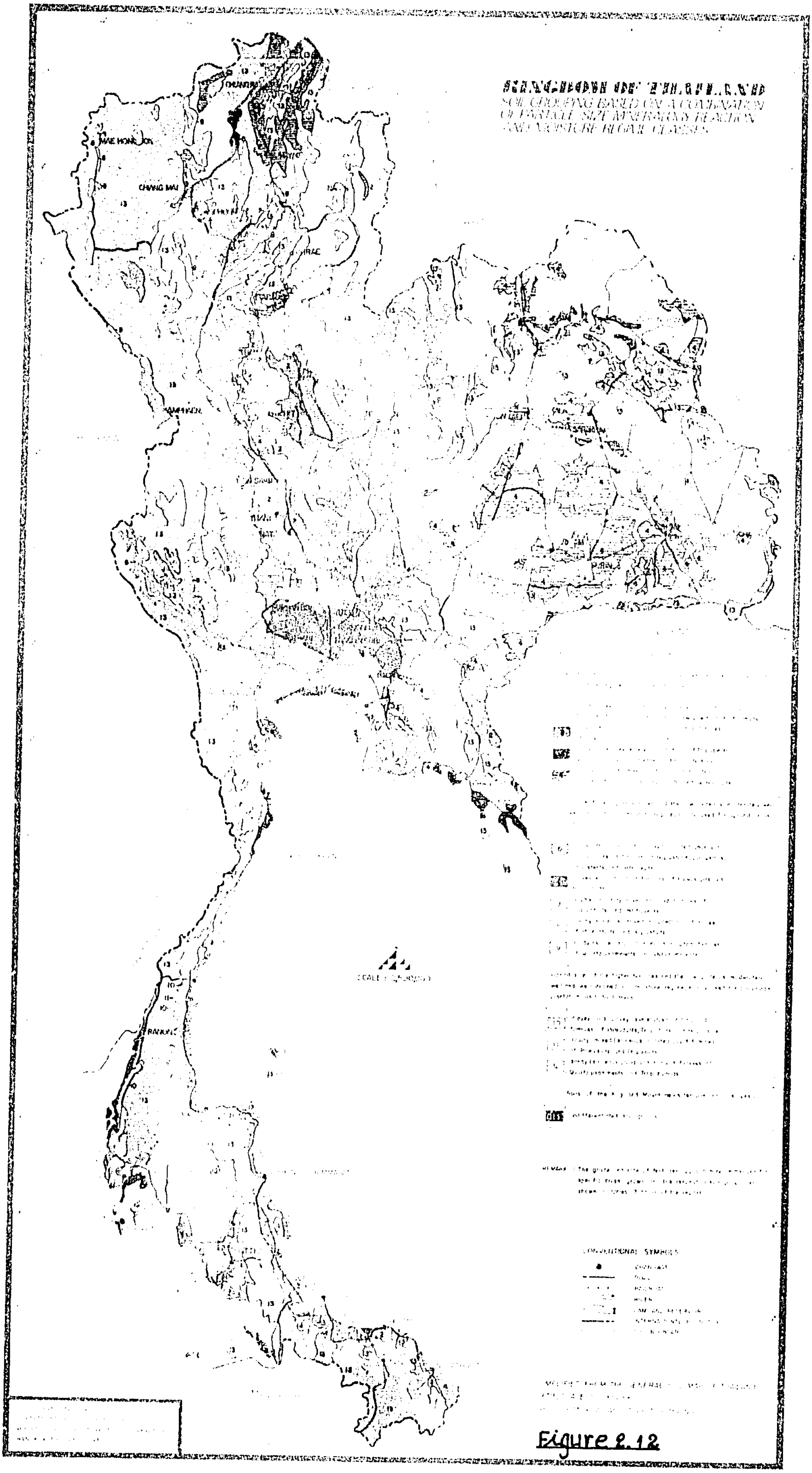

SOIL GROUPING BASED ON A COMBINATION
OF PARTICLE SIZE MINERALOGY REACTION
AND MOISTURE REGIME CLASSES
MAE HONG SON
CHIANG MAI
CONVENTIONAL SYMBOLS

Figure 2.12

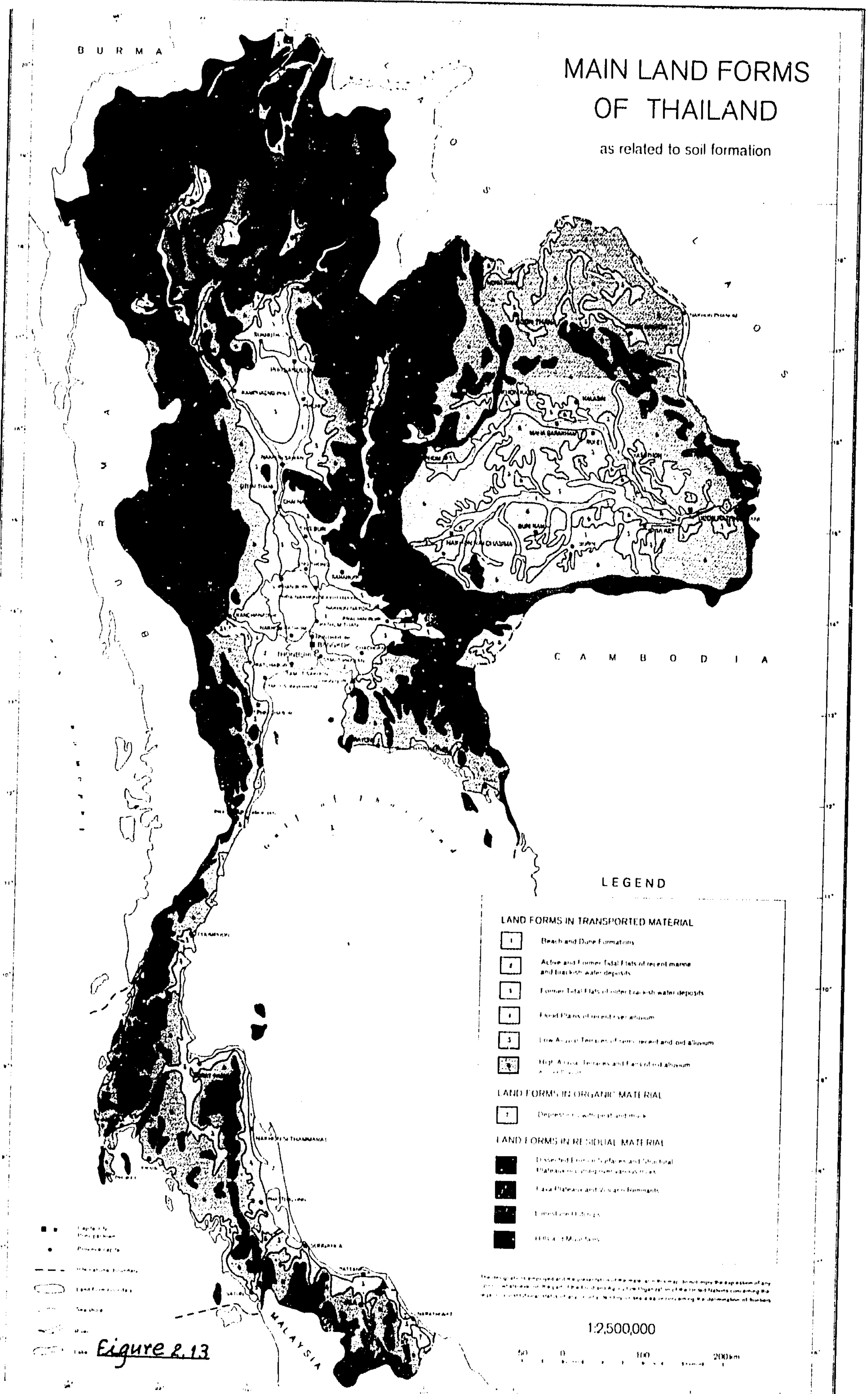

MAIN LAND FORMS
OF THAILAND
as related to soil formation
BURMA
LAOS
CAMBODIA
MALAYSIA
BANGKOK
THONBURI
LEGEND
LAND FORMS IN TRANSPORTED MATERIAL
1 Beach and Dune Formations
2 Active and Former Tidal Flats of recent marine and brackish water deposits
3 Former Tidal Flats of older brackish water deposits
5 Low Alluvial Terraces of semi-recent and old alluvium
LAND FORMS IN ORGANIC MATERIAL
LAND FORMS IN RESIDUAL MATERIAL
1:2,500,000
200 km

Figure 2.13

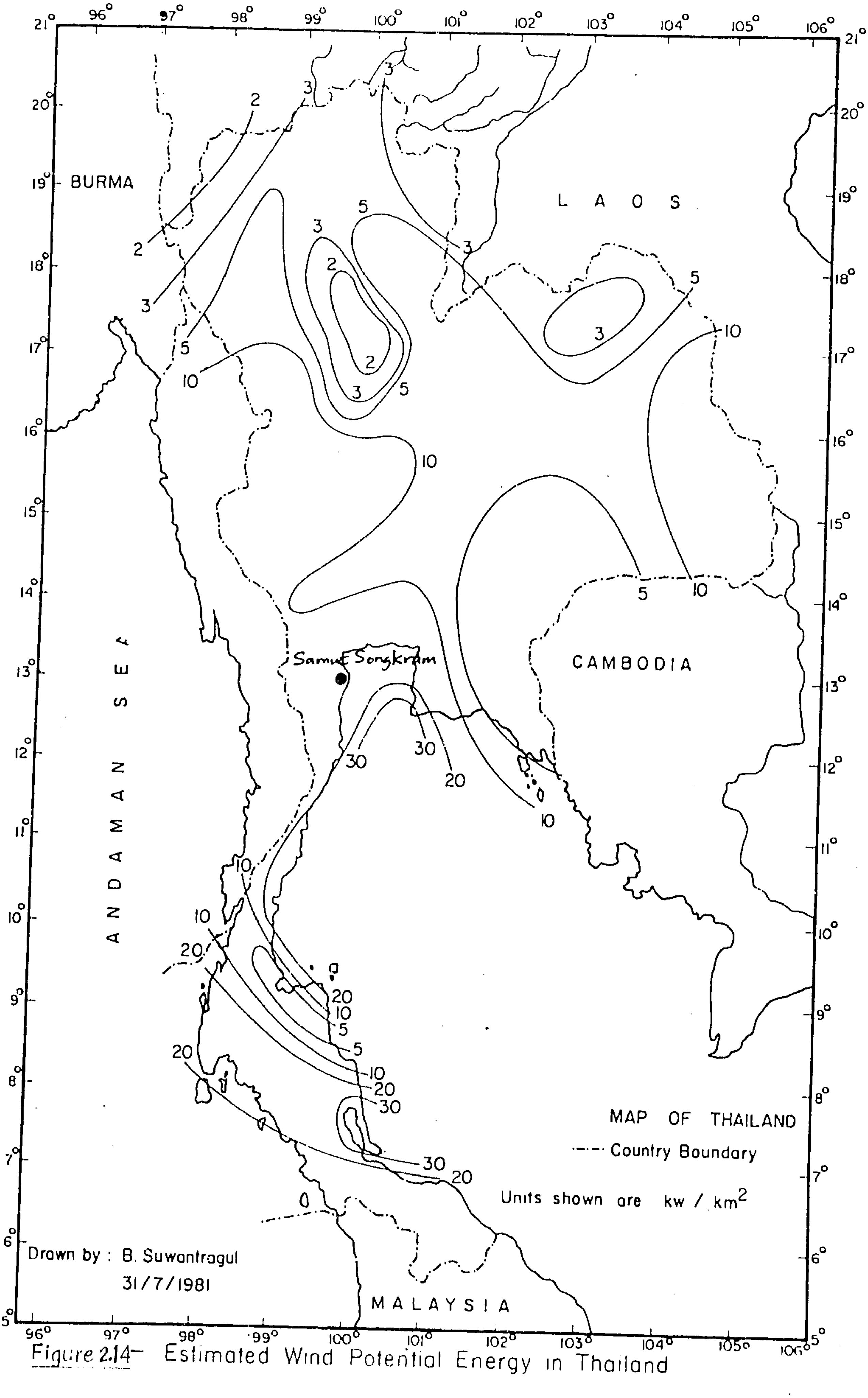
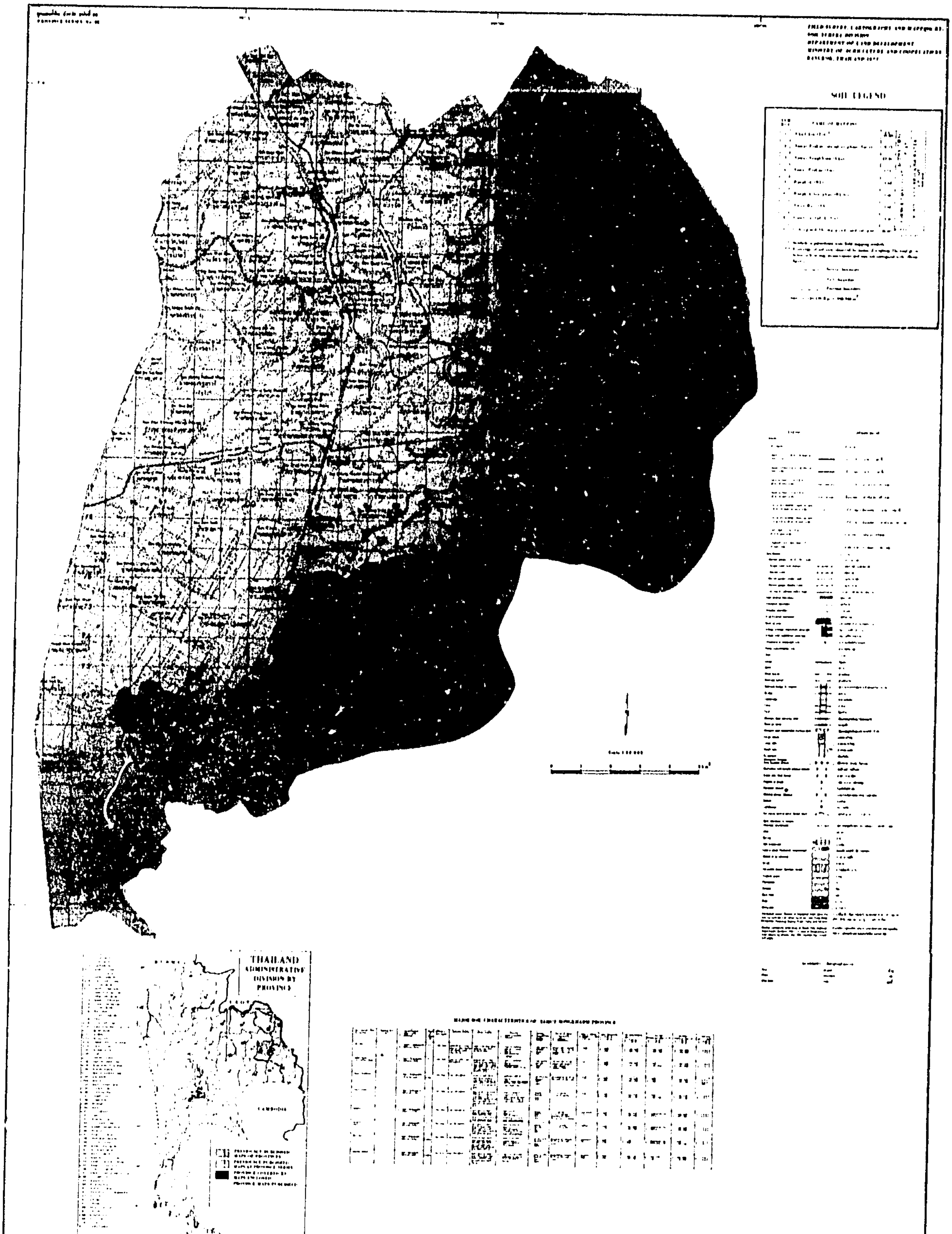


Figure 2.14 Estimated Wind Potential Energy in Thailand



แผนที่ดินจังหวัดสมุทรสงคราม

Figure 2.15 DETAILED RECONNAISSANCE SOIL MAP OF SAMUT SONGKHRAM PROVINCE

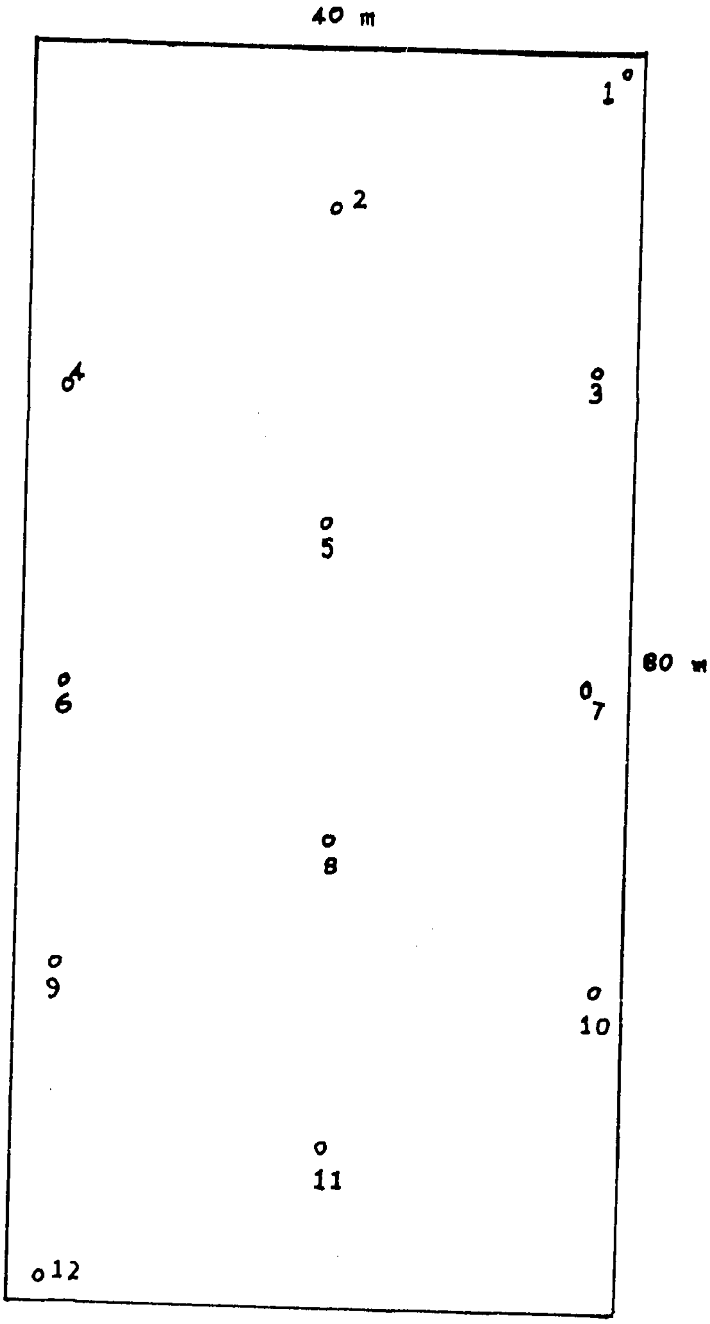


Figure 2.16 Diagram of the soil sampling at research site

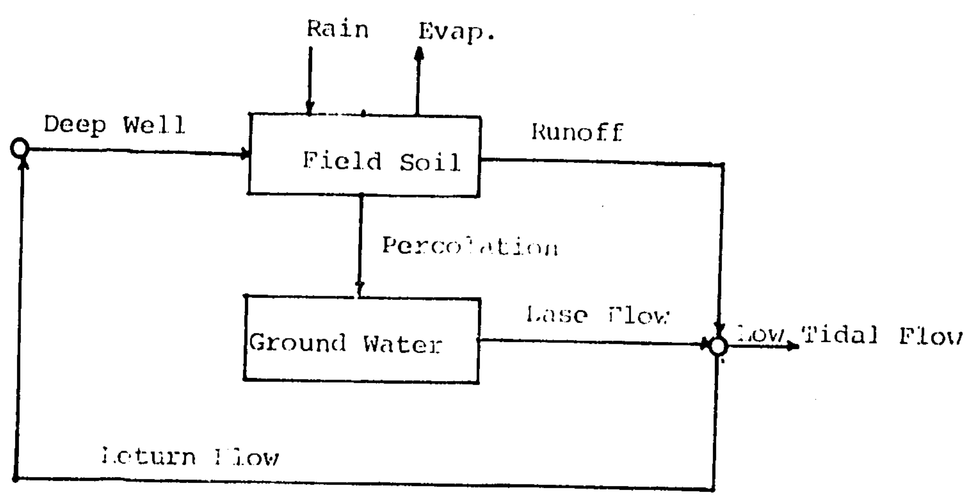


Figure 2.17 Diagram of soil-salinity control model

Figure 2.18 Field-store building

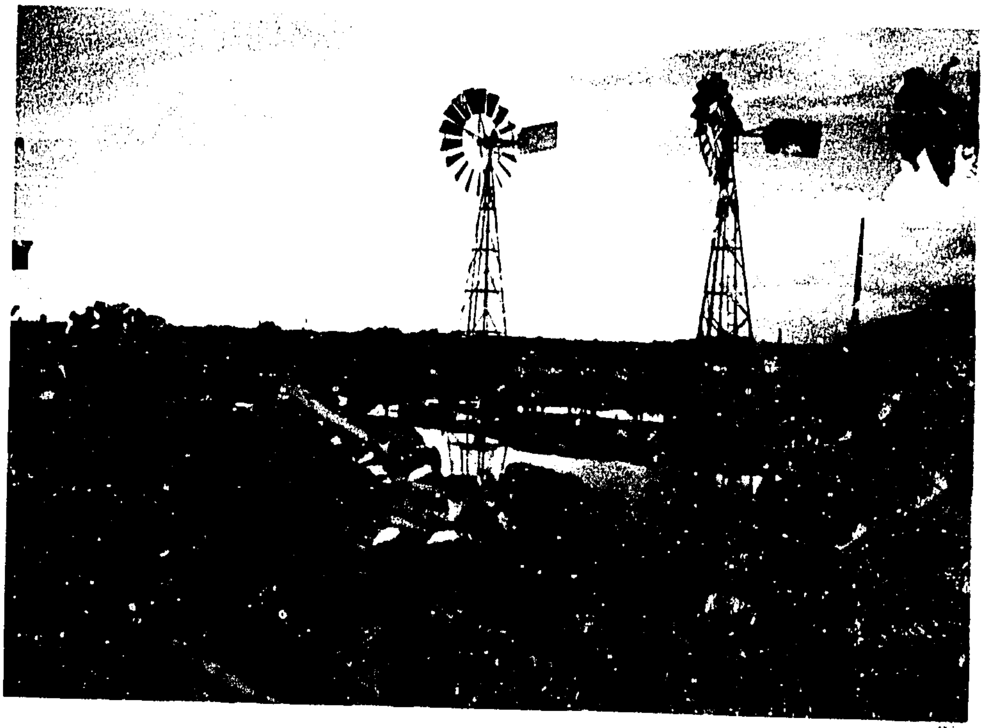


Figure 2.19 Two multiblade windmills

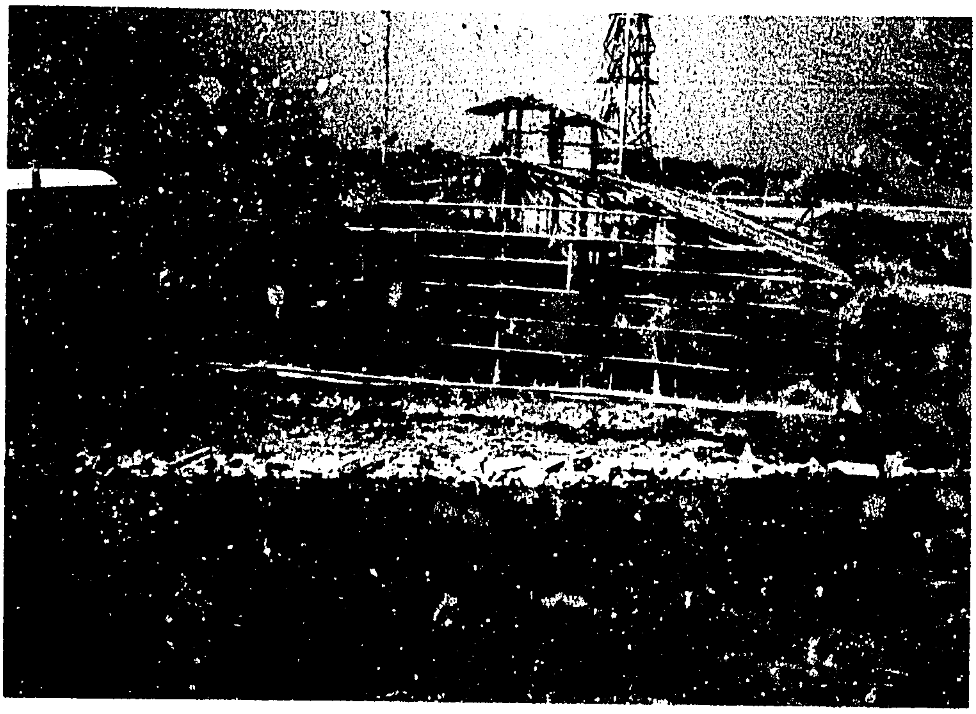
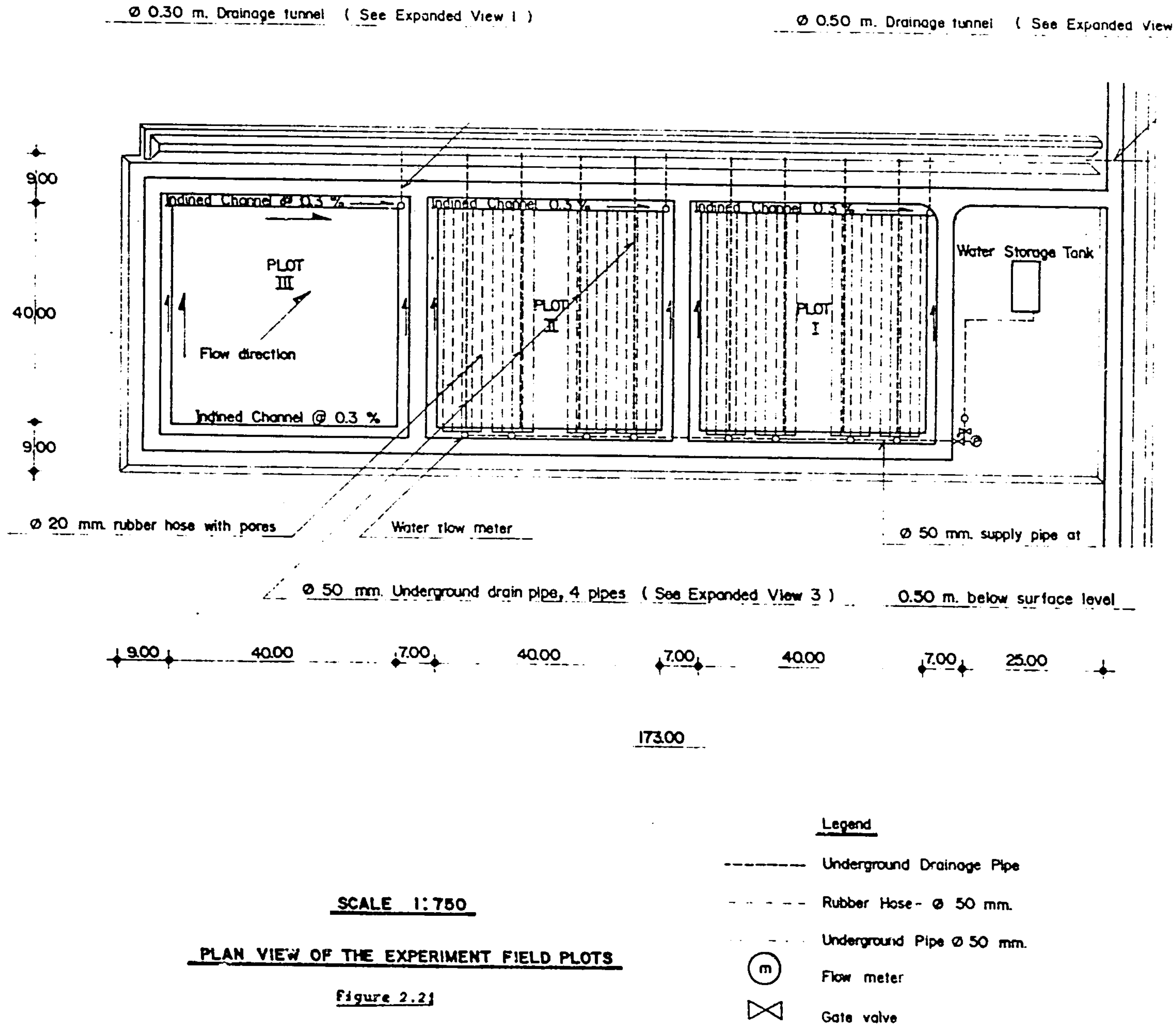


Figure 2.20 Temporary greenhouse



SCALE 1:750

PLAN VIEW OF THE EXPERIMENT FIELD PLOTS

Figure 2.21

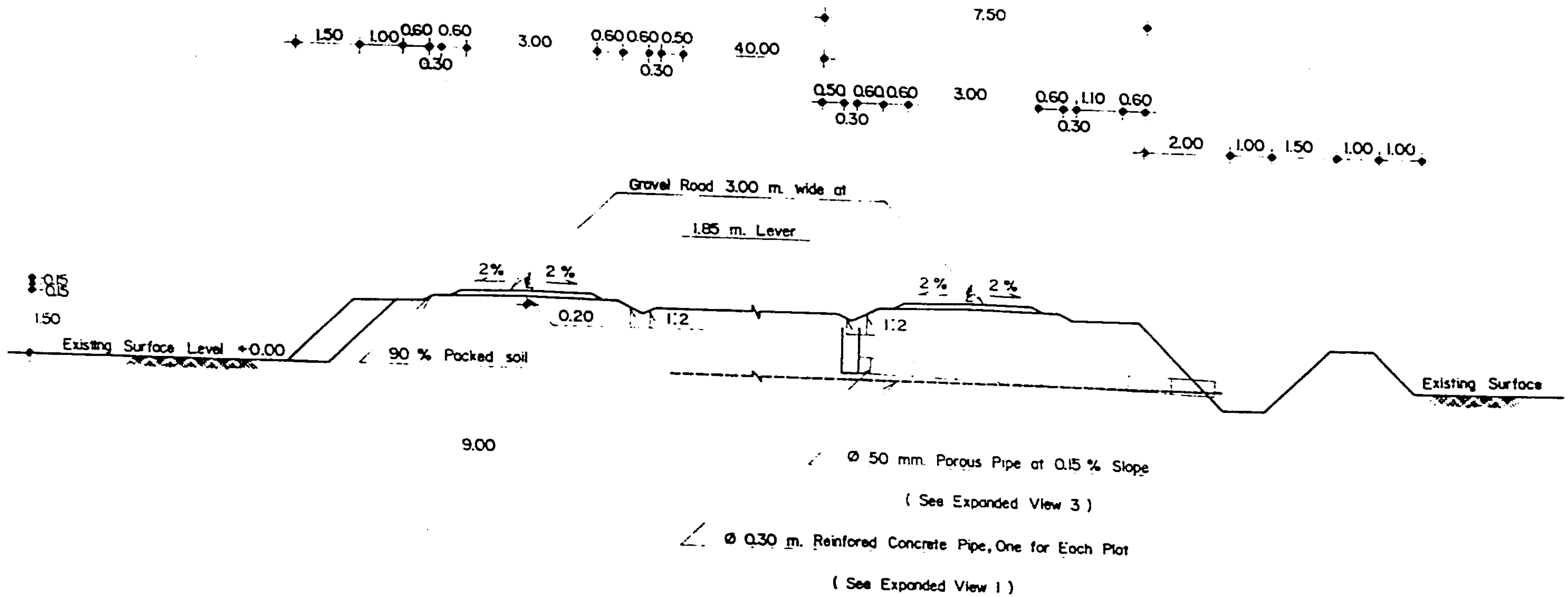
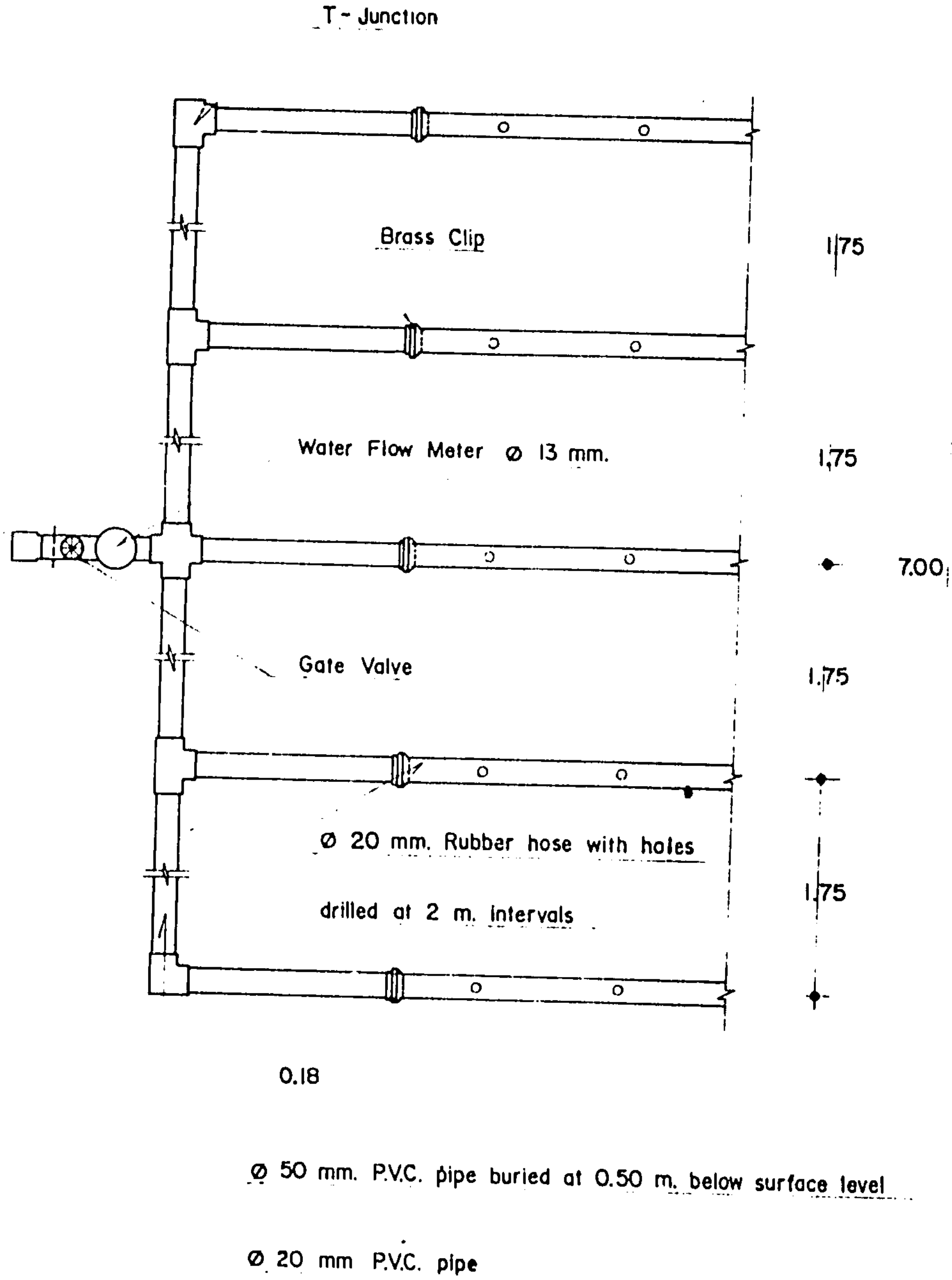


Figure 2.2? CROSS SECTION OF STANDARD ROAD

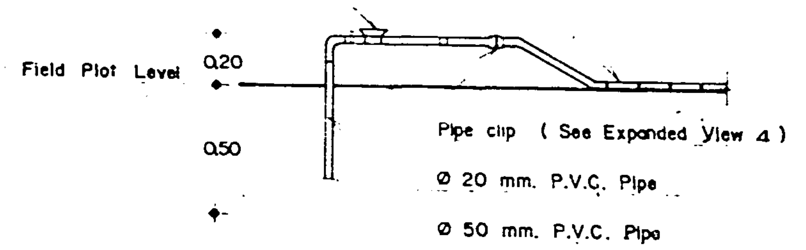
SCALE 1:1000



EXPANDED VIEW (4) DRIPPING WATER SUPPLY SYSTEM

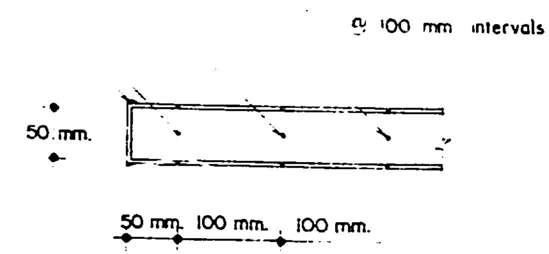
SCALE 1:5

Figure 2.23



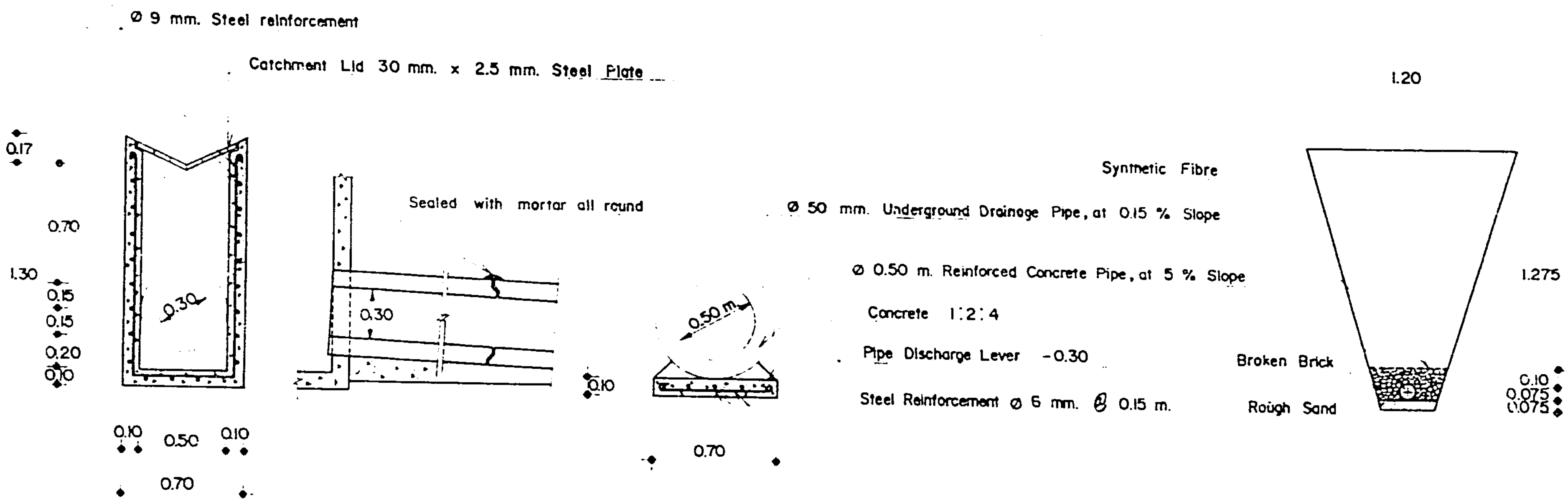
EXPANDED VIEW OF THE DRIP IRRIGATION WATER SUPPLY PIPE

SCALE 1:20



EXPANDED VIEW OF POROUS PIPE

SCALE 1:5



EXPANDED VIEW (1) WATER DRAINAGE CATCHMENT

SCALE 1:25

EXPANDED VIEW (2) DRAINAGE TUNNEL

SCALE 1:25

EXPANDED VIEW (3) UNDERGROUND DRAINAGE PIPE

SCALE 1:25

Figure 2.24

III. THE GREENHOUSE STUDY

Salinized-marine soil in Smutsongkram province is of saline-sodic nature with high clay content. Crops grown on this soil usually are dwarfed and stunted. Russell and Russell (1973) described the effects of high salt accumulation in the soil or plant growth, with stunting becoming more noticeable as the salt content became higher, the leaves of the crop becoming dull-coloured and often bluish-green, and becoming coated with a waxy deposit. Based on the concept of salt tolerance of plants, the U.S. Salinity Laboratory (1954) has used the limits of electrical conductivity of 4 and 8 $mscm^{-1}$ to separate out the salt-sensitive crops for which the conductivity of the soil solution should remain below 4, the moderately tolerant crops for which it can rise to 8, and the very tolerant crops which will give a yield even if it is somewhat above 8, though it must usually be below 16. If crop yields are not to suffer from salinity, the conductivity of the soil solution must be kept below the appropriate value for the crop being grown.

Reducing soil salinity down to the tolerance level of the plant, therefore, is necessarily of concern. Various methods have been used for this management. Prichard, Hoffman, and Oster (1985) leached salt out of a saline organic soil in the Sacramento San Joanquin Delta of California by ponding nonsaline water continuously on the soil surface and by sprinkling. Reeve and Doering (1966) studied the high-salt-water dilution method for reclaiming sodic soil. However; a method of salt removal which is applicable for some areas may not be suitable to another place. A greenhouse pot experiment on amendment of salinized-marine soil while growing physic-nut trees was conducted to improve soil permeability while effecting a reduction of the salinity.

The specific objectives of this study were :

1. to look at the effects of adding compost, rice husks, compost mixed with rice husks, compost mixed with gypsum, rice husks mixed with gypsum, and all those materials mixed together on changing properties of the leached soil mixtures.

2. to determine the effects of rate of application of either compost or rice husks on changing salinity and permeability of the soil mixtures treated by leaching.

3. to examine effects of the ratio of rice husks and gypsum mixtures on improving the soil permeability.

A. Materials and methods

A.1 Experimental design

A completely random design was initially done with thirteen treatments and four replications. These included check pot-soil to be leached without amendment, pot soil mixed with 2% and 4% compost, with 2% and 4% rice husks, with 1% compost and 1% rice husks, with 2% compost and 2% rice husks, with 1% compost and 1% gypsum, with 2% compost and 2% gypsum, with 1% rice husks and 1% gypsum, with 2% rice husks and 2% gypsum, and for a combination of all three materials in the ratios of 1:0.5:0.5, and 2:1:1, respectively.

The reason that compost, rice husks, and gypsum were chosen for improving the permeability of this soil was because they are cheap and are found commonly in local markets. Besides, the compost has a reputation for helping the soil to become friable and for increasing its nutrient content. Rice husks, which are unrotted materials, typically hold little water, and are coarse and fibrous. For this reason it tends to increase the openness of the soil, which is preferable for some heavy soils. The advantage of gypsum, as mentioned by Russell and Russell (1973), is due to its reduction of subsoil impermeability and for replacing exchangeable sodium which may be present. They reported that the peameability of the soil could also sometimes be increased by deep ploughing, particularly if some gypsum was ploughed in at the same time or if gypsum or lime was present in the subsoil.

A.2 A trial experiment

Two hundred grams of the soil mixed with ameliorative materials in the ratios and at the rate as mentioned in the experimental design were weighed and put in thirteen paper-cups. Each cup has a volume of about 1.5 litre, and a hole of 1.0 cm diameter at its bottom. The soil mixture contained in each cup was leached with excess fresh water until it was saturated. The movement of the added water in the soil mixture down through the bottom hole of every cup was then observed and evaluated with respect to the purposes of this experimental study. The initial experimental design was then revised so that two more treatments including a pot soil mixed with 3% rice husks and 6% gypsum, and with the combination of compost, rice husks, and gypsum in the ratio of 1:2:6 were added.

A.3 Greenhouse experiment

The greenhouse pot experiment was conducted according to the revised experimental design. The check pot contained 20 kg soil, while the mixture of soil and added materials in each pot had a net weight equal to that of the check treatment. All pots were kept in a transparent plastic greenhouse in order to prevent rainfall contact. Every pot of soil was leached once each week with 925 ml. of deep-well water (pH 8.0, E.C. 0.78 $mscm^{-1}$, SAR 3.4) until the total volume of applied water reached 7400 ml. This volume was equal to the leaching requirement calculated from equations 2.3 and 2.4.

The leaching process was done in 8 stages. Each stage took about one week, depending upon how fast the water moved down through the subsoil. At the end of the fourth stage soil samples were collected from all pots by using a shovel. These samples were used for monitoring chemical and physical properties of the soil. Because the amount of each soil sample was small, all samples were analysed using microtechniques in the laboratory of Kasetsart University, Kampangsaen Campus. Average values of the analysis are shown in tables 3.1 and 3.2. During the fourth stage of leaching, the leachate of every pot soil was also taken for the E.C. measurement. The results of leachate analysis are shown in table 3.3.

One hundred seeds of physic-nut trees given by the Research Center Of Agronomy in Khon Khaen Province were germinated individually in the sand culture contained in each plastic sack one day prior to the start of the first leaching. Sixty healthy-trees grown for five weeks after seedling emergence were selected and subsequently transplanted to each pot of soil before the fifth leaching. There was one plant in each pot. Leaching was continued in the same manner as in the previous stages. Plant response to this process was observed. During the final stage of leaching, leachate volume from each pot soil was measured over the time in order to determine drainage rate. After all pot soils had become dry, samples were taken for determining E.C. values of the soil paste at a ratio of 1:5 at 25 C compared to the E.C. values of the leachate. Data on the average values of all measurements are reported in table 3.4. Rates of solely-applied compost and rice husks were plotted against the average E.C. values of the leached mixtures and the average drainage rates (figure 3.1). Ratios of mixed rice husks and gypsum were plotted against the average E.C. values of the leached mixtures and their average drainage rates also (figure 3.2).

B. Results and discussion

B.1 Effects of adding compost, rice husks, compost mixed with rice husks, compost mixed with gypsum, rice husks mixed with gypsum, and all those materials mixed together on changing properties of the leached soil mixtures.

Results in table 3.1 show that the average values of soil pH and the content of organic matters from all treatments were only slightly different. The average E.C. values of 1:5 soil pastes at 25 C for all treatments except those representing leaching + 3% rice husks + 6% gypsum, and leaching + 1% compost + 2% rice husks + 6% gypsum, were above 16, a level permitting only growth of very tolerant crops. The average E.C. values, the ESP, and the potassium content of these two treated soils were much lower than those of the others. The NO_3-N in the pot soil mixed with 1% compost, 2% rice husks and 6% gypsum was considerably high compared to the content of this nutrient in the other treated soils, while the pot soil mixed with 4% compost, and with the combination of compost, rice husks and gypsum in the ratio of 1:0.5:0.5 contained much more phosphorus than did the soils from all other treatments.

Results in table 3.2 indicate that soil mixed with 4% rice husks, with 1% compost and 1% gypsum, and with 2:1:1 for compost : rice husks : gypsum, retained more water than did the pot soil from other treatments. The bulk density of the soil for all treatments was slightly different. The porosity of the treatment representing leaching + 1% compost + 2% rice husks + 6% gypsum was above the average value of 36% while that of leaching + 3% rice husks + 6% gypsum was below the average. Although ratios of sand, silt, and clay in all treatment soils were different, those textures were still belonged to the clay group.

B.2 <u>Observation of permeability for all pot soils.</u>

After all pot soils had been leached with 925 ml of deep-well water, at the earlier stages all treated soils, except those mixed with 3% rice husks and 6% gypsum, and with 1% compost, 2% rice husks and 6% gypsum, became saturated, muddy and impervious. This phenomena was similar to that appearing in the trial experiment. Because of this extreme impermeability, water was removed from this pot by evaporation only, as a result of the high temperature of about 38 C to 40 C in the greenhouse. As a consequence, salt concentration in these pots remained high. This problem affected plants grown in those pots, which generally rotted and dicd. However, although the soil in the check pots remained saturated during the earlier stages of leaching, by the latter stages, they gradually became more permeable, causing some plants to recover from their apparently rotted condition (figure 3.3). Plants grew well in the leaching only treatment because of no decrease in permeability due to tilling the soil between irrigations and no energy source for microbes prohibiting the competition of nutrient consumptions among soil microorganisms and plants. Soil in the treatment of leaching + 3% rice husks + 6% gypsum was much more permeable compared to that of the other treatments. During the earlier leachings the movement of water down to the subsoil was slow but; after subsequent leaching with increments of 925 ml of water was completed, then water moved through the subsoil more rapidly. Plants grew rapidly in this treatment, with strong and fat stems, wide blades, and green leaves (figure 3.4). The treatment of leaching + 1% compost + 2% rice husks + 6% gypsum showed similar movement of water and plant behaviour (figure 3.5).

B.3 Effects of rates of applied compost or rice husks on changing salinity and permeability of the soil mixtures after leaching

Figure 3.1 indicates that the E.C. values of the soil paste increased with the application rates of either compost or rice husks, but the effect of either material on drainage rate was different. Drainage rate dropped at the 2% rate of application for either one and then increased once more at the 4% rate of application. This is consistent with the theory that small amount of the organic amendments plugged soil pores, but that larger amounts began to produce beneficial effects on soil structure (Allison, 1973; Rose, 1966; and Tisdall and Oades, 1982). It should be noted that rice husks were a consistently better amendment than manure compost in these studies.

B.4 Effects of ratios of mixed rice husks and gypsum on improving soil permeability.

Figure 3.2 shows that ratios of mixed rice husks and gypsum (1:1) increased the average E.C. values of the soil paste but decreased its drainage rate. However for a ratio of 1:2, the average E.C. values decreased while the drainage rate increased. These results suggest that the optimum ratio of added rice husks and gypsum into salinized - marine soil for both reducing salinity and improving its permeability must be carefully considered before reclamation is implemented. It is encouraging that the beneficial effects of the organic amendement were observed at a lower organic-amendment rate when the gypsum was added concurrently.

C. Conclusions

A greenhouse pot experiment on amendment of salinized-marine soil while growing physic-nut trees was conducted, to improve soil permeability while effecting a reduction of soil salinity. The results can be summarized as follows :

1. All treatments except those representing leaching + 3% rice husks + 6% gypsum, and leaching + 1% compost + 2% rice husks + 6% gypsum, had an average E.C. value which remained after treatment above the level even for very tolerant crops. The average E.C. and ESP values of these two soil treatments were lower than those of the others, however. The porosity of the treatment representing leaching + 1% compost + 2% rice husks + 6% gypsum was above the average value of 36%, while that for leaching + 3% rice husks + 6% gypsum was below.

2. The overall average pot soils treated with leaching + 2% compost, and with leaching + 2% rice husks, allowed water to move down the subsoil slowly, while such treatments as leaching + 4% compost, and leaching + 4% rice husks, permitted water to flow more rapidly.

3. An average ratio of mixed rice husks and gypsum of 1:1 increased the average E.C. value of the pot soil but decreased the drainage rate of the input water. For the pot soil mixed with rice husks and gypsum at a ratio of 1:2, however, the average E.C. value dropped drastically and the average drainage rate rose considerably. Plants grown in soil treated by leaching + 3% rice husks + 6% gypsum, leaching + 1%

compost + 2% rice husks + 6% gypsum, and in the check pot (leaching alone) survived, while plants in all other treatments rotted and died.

Table 3.1 Chemical analysis of soil samples from the experimental pots after leaching with 3700 ml of water per pot (n = 60, r = 4)

Pot Treatment	pH 1:1	E.C. 1:5 at 25 C $mscm^{-1}$	ESP %	O.M %	NO_3-N ppm	P ppm	K ppm
Leaching	7.8 s=0.1	18.1 s=1.8	53.2 s=2.0	1.9 s=0.02	50.5 s=6.8	423 s=21	1966 s=149
Leaching + 2% compost	7.8 s=0.06	18.3 s=1.6	51.2 s=2.8	2.1 s=0.02	60.2 s=7.9	508 s=54	1989 s=261
Leaching + 4% compost	7.7 s=0.2	20.0 s=2.6	50.2 s=3.1	2.2 s=0.02	45.5 s=4.0	716 s=58	1966 s=154
Leaching + 2% rice husks	7.5 s=0.12	19.2 s=2.7	50.3 s=2.7	2.0 s=0.01	60.4 s=5.2	409 s=39	1909 s=262
Leaching + 4% rice husks	7.5 s=0.2	21.7 s=0.7	52.2 s=1.0	2.0 s=0.05	67.2 s=7.9	458 s=64	2222 s=167
Leaching + 1% compost + 1% rice husks	7.8 s=0.1	20.0 s=2.2	51.1 s=1.6	2.0 s=0.04	69.8 s=6.2	429 s=20	1964 s=133
Leaching + 2% compost + 2% rice husks	7.7 s=0.06	19.7 s=1.8	54.2 s=2.3	2.1 s=0.02	35.5 s=2.5	446 s=26	2107 s=203

Continue

Table 3.1 Continued

Pot Treatment	pH 1:1	E.C. 1:5 at 25 C $mscm^{-1}$	ESP %	O.M %	NO_3-N ppm	P ppm	K ppm
Leaching + 1% compost + 1% gypsum	7.5 s=0.08	19.8 s=1.5	55.6 s=2.2	2.1 s=0.03	36.0 s=1.4	521 s=41	2218 s=214
Leaching + 2% compost + 2% gypsum	7.6 s=0.05	18.0 s=1.1	53.8 s=1.6	2.1 s=0.10	40.2 s=6.7	446 s=33	2268 s=186
Leaching + 1% rice husks + 1% gypsum	7.7 s=0.16	17.4 s=2.1	48.8 s=8.9	1.7 s=0.12	36.8 s=3.5	370 s=22	1697 s=323
Leaching + 2% rice husks + 2% gypsum	7.4 s=0.08	18.2 s=1.4	56.7 s=1.2	1.9 s=0.07	78.2 s=6.2	362 s=24	2032 s=69
Leaching + 3% rice husks + 6% gypsum	7.8 s=0.05	10.6 s=1.4	41.0 s=1.9	1.6 s=0.03	42.8 s=8.5	331 s=11	1449 s=16
Leaching + 1% compost + 0.5% rice husks + 0.5% gypsum	7.7 s=0.18	18.2 s=0.3	46.1 s=8.4	1.9 s=0.16	98.0 s=6.5	834 s=42	1695 s=333

Continue

Table 3.1 Continued

Pot Treatment	pH 1:1	E.C. 1:5 at 25 C mscm^{-1}	ESP %	O.M %	NO_3-N ppm	P ppm	K ppm
Leaching + 2% compost + 1% rice husks + 1% gypsum	7.5 s=0.13	18.3 s=1.7	[illegible].6 s=5.7	2.0 s=0.04	45.5 s=7.0	439 s=33	1949 s=325
Leaching + 1% compost + 2% rice husks + 6% gypsum	7.8 s=0.08	8.9 s=0.8	37.9 s=6.8	1.9 s=0.1	234.4 s=143	394 s=24	1508 s=118

[s]Standard deviation for each treatment

Table 3.2 Physical analysis of soil samples from the experimental pots after leaching with 3700 ml of water per pot (n = 60, r = 4)

Pot Treatment	Moisture % w/w	Bulk density $10^3 kgm^{-3}$	Porosity %	Sand %	Silt %	Clay %	Textural Class
Leaching	18.7 s=0.7	1.9 s=0.02	31 s=4.1	18 s=2.5	38 s=1.2	43 s=1.2	clay
Leaching + 2% compost	17.2 s=1.3	1.8 s=1.3	32 s=2.4	16 s=0.2	42 s=1.1	42 s=1.1	silty clay
Leaching + 4% compost	17.2 s=1.5	1.8 s=0.03	31 s=2.8	18 s=4.6	35 s=2.7	47 s=2.3	clay
Leaching + 2% rice husks	21.2 s=2.2	1.6 s=0.1	40 s=4.6	19 s=3.4	32 s=2.5	48 s=4.0	clay
Leaching + 4% rice husks	25.4 s=4.1	1.4 s=0.04	48 s=3.1	21 s=4.3	37 s=3.3	44 s=1.1	clay
Leaching + 1% compost + 1% rice husks	19.2 s=1.1	1.8 s=0.04	33 s=6.0	20 s=3.8	38 s=2.0	42 s=2.6	clay
Leaching + 2% compost + 2% rice husks	21.5 s=6.7	1.8 s=0.04	31 s=6.6	19 s=1.8	38 s=1.6	43 s=1.2	clay

Table 3.2 Continued

Pot Treatment	Moisture % w/w	Bulk density $10^3 kgm^{-3}$	porosity %	Sand %	Silt %	Clay %	Textural Class
Leaching + 1% compost + 1% gypsum	23.0 s=2.4	1.5 s=0.05	40 s=1.0	17 s=0.4	37 s=2.8	46 s=2.3	clay
Leaching + 2% compost + 2% gypsum	21.6 s=2.7	1.7 s=0.06	36 s=1.6	25 s=5.6	34 s=5.8	42 s=1.4	clay
Leaching + 1% rice husks + 1% gypsum	18.5 s=5.7	1.8 s=0.1	32 s=4.9	14 s=2.8	34 s=5.9	53 s=8.2	clay
Leaching + 2% rice husks + 2% gypsum	21.7 s=7.0	1.4 s=0.1	45 s=5.6	14 s=1.3	40 s=5.4	46 s=5.3	clay
Leaching + 3% rice husks + 6% gypsum	18.5 s=1.5	1.8 s=0.1	32 s=7.8	14 s=3.1	40 s=3.0	54 s=3.0	clay
Leaching + 1% compost + 0.5% rice husks + 0.5% gypsum	19.8 s=3.1	1.8 s=0.1	30 s=5.7	14 s=1.2	30 s=5.5	52 s=8.4	clay

Table 3.2 Continued

Pot Treatment	Moisture %	Bulk density $10^3 kgm^{-3}$	Porosity %	Sand %	Silt %	Clay %	Textural Class
Leaching + 2% compost + 1% rice husks + 1% gypsum	24.3 s=5.3	1.6 s=0.02	38 s=7.6	*	*	*	*
Leaching + 1% compost + 2% rice husks + 6% gypsum	17.5 s=6.5	1.5 s=0.02	46 s=3.2	12 s=2.7	29 s=1.8	59 s=2.7	clay

[s] Standard deviation for each treatment

*No data obtained, more accurate method is needed for the analysis

Table 3.3 Leachate analysis after leaching pot soil with 3700 ml

Pot Treatment	$\overline{E.C.}$ $mscm^{-1}$	Number of Pots
Leaching	24	1
Leaching + 2% compost	39	3
Leaching + 4% compost	24	3
Leaching + 2% rice husks	35	1
Leaching + 4% rice husks	32	2
Leaching + 1% compost . 1% rice husks	41	1
Leaching + 2% compost + 2% rice husks	20	3
Leaching + 1% compost + 1% gypsum	41	2
Leaching + 2% compost + 2% gypsum	48	2
Leaching + 1% rice husks + 1% gypsum	35	2
Leaching + 2% rice husks + 2% gypsum	38	3
Leaching + 3% rice husks + 6% gypsum	13	4
Leaching + 1% compost + 0.5% rice husks + 0.5% gypsum	16	3
Leaching + 2% compost + 1% rice husks + 1% gypsum	22	2
Leaching + 1% compost + 2% rice husks + 6% gypsum	12	4

Table 3.4 Average values of soil $E.C._s$, leachate $E.C._w$, drainage rate, and plant growth after leaching with 7400 ml of water per pot (n = 60, r = 4)

Pot Treatment	$E.C._s$ (1:5) at 25 C $mscm^{-1}$	$E.C._w$ at 25 C $mscm^{-1}$	Drainage Rate 10^{-4}. $m^3 min^{-1}$	Plant Growth
Leaching	15.2 s=0.6	21.1 s=0.8	0.26 s=0.08	rotted but not dead
Leaching + 2% compost	17.2 s=1.1	28.3 s=1.5	0.16 s=0.04	rotted and dead
Leaching + 4% compost	18.0 s=0.6	23.8 s=4.0	0.21 s=0.02	rotted and dead
Leaching + 2% rice husks	16.4 s=0.7	31.0 s=0.5	0.18 s=0.02	rotted and dead
Leaching + 4% rice husks	20.6 s=0.7	24.9 s=5.6	0.32 s=0.04	rotted and dead
Leaching + 1% compost + 1% rice husks	18.8 s=1.0	32.2 s=1.5	0.12 s=0.02	rotted and dead
Leaching + 2% compost + 2% rice husks	19.1 s=1.4	16.9 s=0.8	0.40 s=0.01	rotted and dead

Continue

Table 3.4 Continued

Pot Treatment	E.C.$_s$ (1:5) at 25 C $mscm^{-1}$	E.C.$_w$ at 25 C $mscm^{-1}$	Drainage Rate 10^{-4} . $m^3 min^{-1}$	Plant Growth
Leaching + 1% compost + 1% gypsum	19.4 s=1.2	33 s=1.2	0.11 s=0.01	rotted and dead
Leaching + 2% compost + 2% gypsum	17.4 s=0.8	31.6 s=1.0	0.14 s=0.05	rotted and dead
Leaching + 1% rice husks + 1% gypsum	16.8 s=1.6	22.8 s=2.8	0.21 s=0.02	rotted and dead
Leaching + 2% rice husks + 2% gypsum	17.8 s=0.8	28.4 s=1.3	0.18 s=0.02	rotted and dead
Leaching + 3% rice husks + 6% gypsum	7.5 s=0.4	12.2 s=1.9	4.0 s=0.36	moderate
Leaching + 1% compost + 0.5% rice husks + 0.5% gypsum	18.1 s=0.4	16.0 s=0.4	0.32 s=0.04	rotted and dead
Leaching + 2% compost + 1% rice husks + 1% gypsum	18.1 s=1.6	22.4 s=2.6	0.11 s=0.02	rotted and dead
Leaching + 1% compost + 2% rice husks + 6% gypsum	8.4 s=1.0	11.8 s=2.0	3.95 s=0.10	moderate

[s]Standard deviation for each treatment

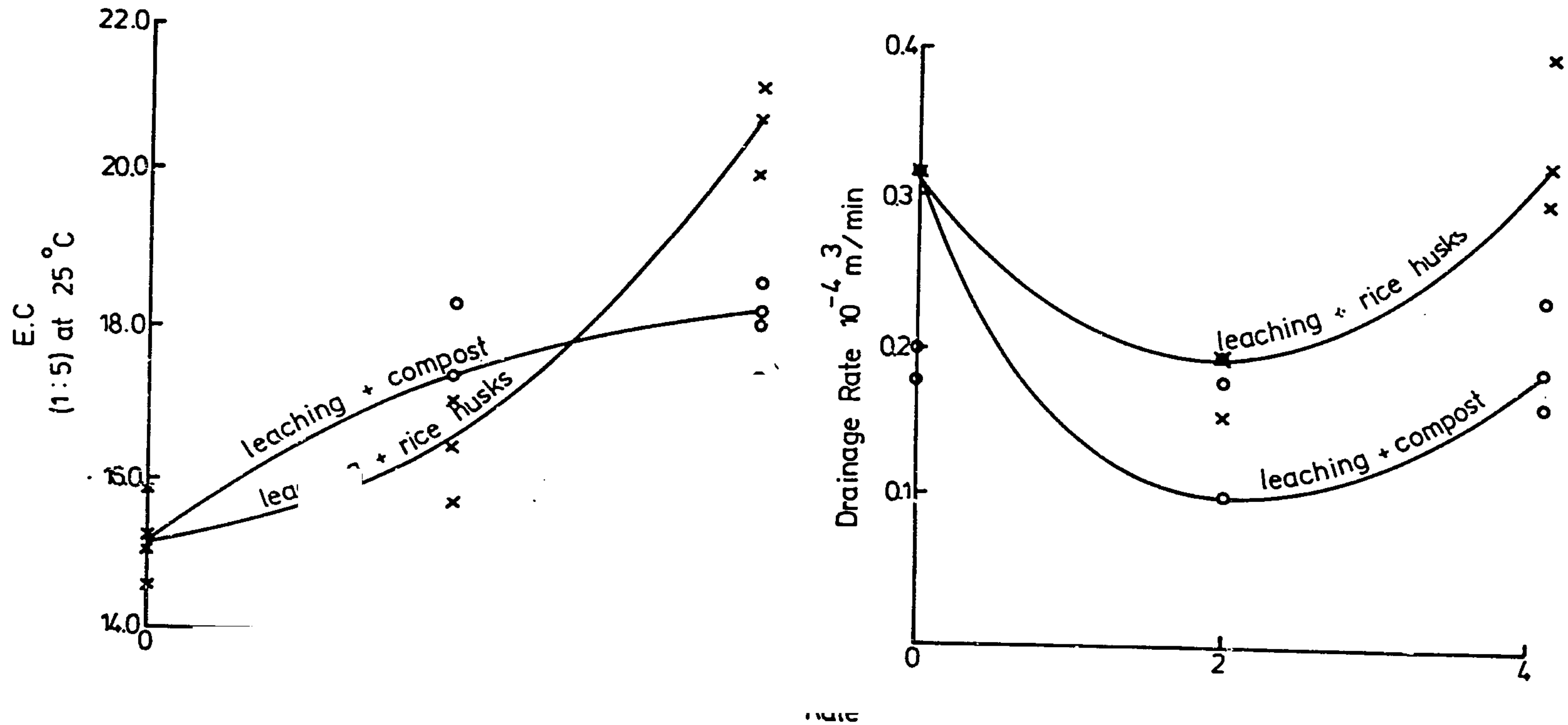


Figure 3.1 Average E.C values and average drainage rates VS application rates of compost and rice husks.

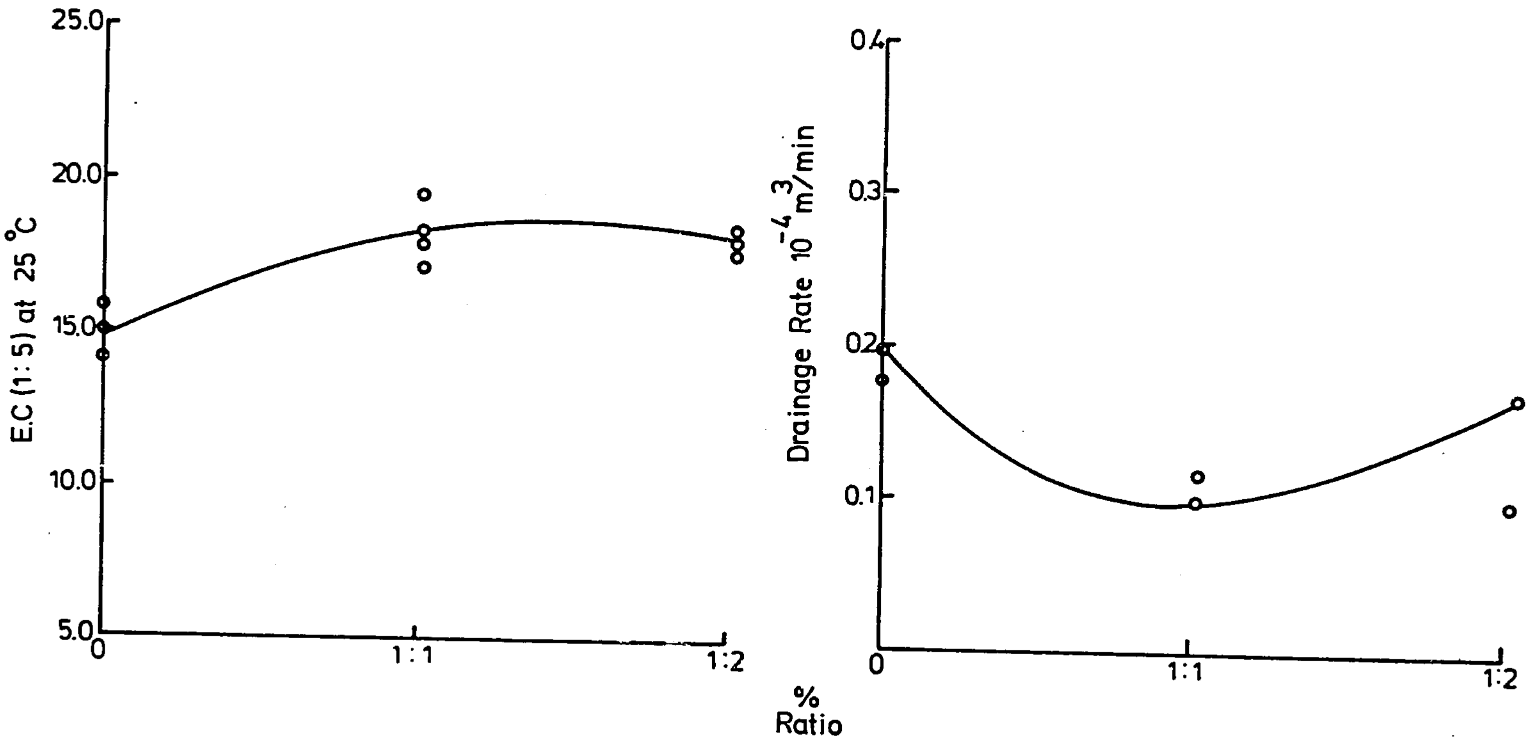


Figure 3.2 Average E.C values and average drainage rates VS ratio of mixed rice husks and gypsum

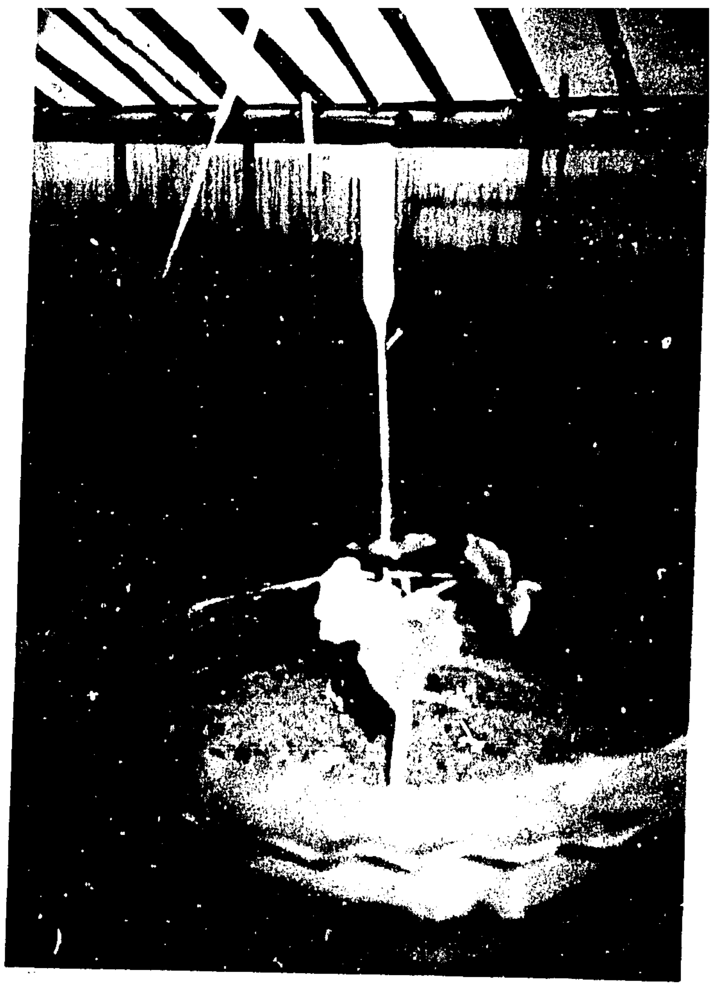


Figure 3.3 Typical plant growth in a check pot

Figure 3.4 Typical plant growth in a soil pot treated by leaching + 3% rice husks + 6% gypsum

Figure 3:5 Typical plant growth in a soil pot treated by leaching + 1% compost + 2% rice husks + 6% gypsum

IV. THE FIELD STUDY

Salinized-marine soil in the coastal cropland is a consequence of man's utilization of water resources in the nearby area. A case in point is salt-farming in Thailand's Smutsongkram Province, whereby paddy fields are flooded with sea-water, allowing salt precipitation on the surface of the soil through sun drying. As the production of raw salt on the coastal land increases without soil conservation, the extent of salinized soil grows. The problem is aggravated by drought and by waterlogging in the wet season. Information on the prevention of further spread of salinization in coastal land by salinity-control procedure is limited. Beyce (1972), in his work on reclaiming peat soils in Turkey by continuous and intermitten ponding and by sprinkling intermittently, reported that a depth of about 1.5 m of water had to be leached through a 1 - m deep profile to remove 70% of the soluble salts. Prichard et al. (1985) found that a reclamation of saline, organic soils in the Sacramento-San Joaquin Delta of California could be accomplished by both sprinkling and continuously ponding water on the soil surface, especially sprinkling, through which 70% of the salt could be removed from the soil profile to a depth of 1.2 m. The experiment of Tyagi (1986) showed that the salinity of the soil in the area irrigated by the Bhakra Canal System could be controlled effectively by reducing the sub-surface irrigation return flow (IRF) that came in contact with the sub-surface sources of salts and reducing the water availability. Abrol and Bhumla (1973) indicated that under conditions of poor soil permeability, leaching of highly saline sodic soil would be best accomplished by continuous ponding when coupled with gypsum. In the present study, a field experiment was conducted in a salinized land in order to search for a suitable method to limit soil salinity to a desired level, that is, a level which physic-nut trees could tolerate and produce optimum yields. The specific objectives included :

1. An assessment of the effects of soil leaching with and without the addition of 3% rice husks plus 6% gypsum on changing some important properties of the soil and the leachate.

2. Evaluations of plant response to the soil treated by leaching only and leaching with the addition of 3% rice husks and 6% gypsum.

3. Observation of non-uniformity of plant growth in both treatments.

A. Experimental design

A.1 A comparison of methods to limit soil salinity for the growth of physic-nut trees.

A field experiment was designed to correlate with the previous greenhouse experiment, and to fit in duplicate plots (each covers an area of 1600 m^2 and is structured with both irrigation and drainage systems). By this manner, two treatments, soil to be leached with and without 3% rice husks and 6% gypsum, were chosen from those in a greenhouse experiment for this design. The selection was based on better results in soil salinity control for physic-nut growth and cheaper cost of operation. According to results from the greenhouse experiment, although the check treatment (leaching alone) did not work well compared to a treatment representing leaching + 1% compost + 2% rice husks + 6% gypsum, it cost less. The cheaper cost of the operation and the recovery of all plants in the later stages of leaching made the check treatment preferable to this selection. By means of a completely randomized design (CRD) with equal plants, both treatments were replicated four times. Each replication or a subplot covered an area of 40 x 8 m^2 and was divided into twenty - five rows and four columns (figure 4.1).

A.2 <u>A study of nutrient deficiency</u>

A cup experiment to study of nutrient deficiency in the soil at the areas of poorly grown plants was designed with nineteen treatments of applying three different fertilizers at seven rates, and four replications by using a similar statistical method mentioned previously. These treatments included cup soils fertilized with $Ca(NO_3)_2$ for NO_3-N; $CaHPO_4$ for P_2O_5; and K_2SO_4 for K_2O; at the rates of 0 ppm; 10 ppm; 15 ppm; 20 ppm; 10,000 ppm; 20,000 ppm; and 100,000 ppm. The reason that these fertilizers were used in this experiment was because they were all nearly common in local markets.

B. <u>Materials and Methods</u>

B.1 <u>Observations of rainfall effects on soil moisture, pH, and E.C. values.</u>

Before a field experiment was conducted, all plot soils were left bare in the years 1984 and 1985 in order to let rainfall leach salt out during the rainy season. Monthly rainfall during two seasons was collected from statistical records at the same meteorological station as mentioned previously. At the end of each rainy month soil samples were taken at five spots to a depth of 30 cm from each plot to determine soil moisture content, E.C. values, and pH. Mean results of all determinations and monthly rainfall are shown in table 4.1. Methods used for soil analysis were similar to those mentioned previously. The E.C. values of the field soil were plotted against accumulated rainfall (figure 4.2).

B.2 Preparation of young physic-nut trees

Two-thousand physic-nut seeds given by the Research Center of Agronomy in Khon Khaen Province were germinated saparately in pots of sand culture in late December 1985. The size of the pot was 6 cm in diameter by 10 cm in height. The variety of all seeds were the same as of those which were grown in pot treatments of the greenhouse experiment for the previous study. The moisture of a seed within the culture contained in every pot was controlled by watering twice a day at 7.30 a.m. and 4.30 p.m. All these pots were kept in a temporary greenhouse where the temperature was about 30 C. Seedlings were allowed to emerge and to grow for further transplantation in the field plots later.

B.3 Leaching experiment

A field experiment was conducted in late November 1985 corresponding to a previous design. Before starting leaching each plot soil, a treatment of leaching with the addition of 3% rice husks and 6% gypsum was prepared by broadcasting 7 tons of rice husks and 14 tons of gypsum on the soil surface of each subplot. After that all subplots belonging to each treatment were ploughed to 0.5 m deep (figure 4.3). Water was pumped from a deep well into each subplot in order to wash salts from the soil profile through the depth between 0 to 30 cm. The volume (Q) of water required to leach soil in each subplot, covering an area of 40 x 8 m^2, was estimated from equation 4.1; a modification of equations 2.3 and 2.4. This equation is :

$$Q_m = \frac{E.C._w}{E.C._h} \left[\frac{E.C._f}{E.C._c} - 1\right] \cdot \theta_m \cdot \frac{\rho_b}{\rho_w} \cdot A \cdot h \cdot \bar{p} \qquad [4.1]$$

where $E.C._w$; $E.C._h$; $E.C._f$; $E.C._c$; θ_m; ρ_b; ρ_w; A; h; and $\bar{p}$; are the salinity of the deep-well water (table 2.4); salinity at an intermdiate of low-salinity-hazard irrigation water as mentioned in Farm-irrigation Manual (Anukulampi et al 1981) being 0.18 $mscm^{-1}$; mean salinity at field condition (table 2.4); salinity at desired control level (8 $mscm^{-1}$); mean soil moisture (table 2.2); mean bulk density (table 2.2); water density (1000 kgm^{-3}); area of each subplot (320 m^2); depth of root zone (1.5 m); and average porosity (table 2.2); respectively. The estimated Q was about 200 m^2 for each subplot. Leaching was applied to each subplot four times at a rate of 50 m^3 per week. Samples of the top soil were taken from every subplot a day after each leaching increment for determining the soil moisture content, $E.C._f$ values, and pH. Results of all analyses are summarized in table 4.2. The $E.C._f$ values were plotted against leaching increment (figure 4.4). In the meantime, the leachate was collected to monitor $E.C._d$ values, pH, and SAR_d in order to study the change of electrolyte concentration in the drainage water with degree of leaching and with soil salinity (table 4.3). Relationships between $E.C._d$ and leaching increment, SAR_d and leaching increment, and $E.C._d$ and $E.C._f$ were investigated, with results shown in figures 4.5,4.6 and 4.7, respectively.

Healthy physic-nut trees were then transplanted from soil to the field in late January 1986. There were 100 trees located 1.0 m apart in each subplot (figure 4.8). All plants were irrigated twice a day at 7.30 a.m and 5.30 p.m. by drip irrigation, alternating with overhead sprinkling. Drip irrigation was applied in order to prevent growth depression caused by uptake of Na^+ or Cl^- to toxic concentrations, osmotic effects, or restriction of the size of the root system (West et al. 1979), while overhead sprinkling was used for reducing effects of drip irrigation in saline soil or with slightly saline water on producing uneven pattern of distribution of the salts present in the root zone (Goldberg et al. 1976). The depth of irrigation water was estimated from mean monthly temperature in the first six months (January to June 1986). The method used for this calculation was modified from the Blaney-Criddle formula, which is :

$$W = 0.14\ K \ . \sum_{m=1}^{6} \frac{t.P}{100} \qquad [4.2]$$

Where W,K,t, and P are depth of irrigation water per day (mm/d), crop coefficient (0.75 from Anukulampi et al. 1981), mean monthly temperature in ^{o}F, and percentage of day-length for each month at 13.4^{o}N (Climatological data for the period 1951-1980, Meteorological Dept. 1982), respectively. Details of this calculation are shown in table 4.4, and a mean result is included in table 4.7.

Duplicate determinations of infiltration, soil moisture, E.C. of a 1:5 soil paste at 25 C, and the E.C. of the leachate at the same temperature were done every month during summer after the completion of daily irrigation at 7.30 a.m.. The infiltration was determined by measuring the head of water placed in duplicate iron cylinders, each 33 cm in diameter and 40.5 cm high, which were pressed into the soil, at the distance of 20 m apart along N-S middle line passing each subplot, to a depth of 30.5 cm below the surface (Figure 4.9). In the meantime average rate of rainfall and evaporation were investigated through out the year from pan data (table 4.7). Variation of infiltration over six months in the hot season is illustrated in figure 4.10 and table 4.5. Differences in E.C. of the field soil and the leachate, as well as in infiltration among the two treatments were tested by using F-statistical method.

B.4 <u>Plant response</u>

After physic-nut trees had been grown in the field plots for six months, the average height of all plants in each row was observed and recorded. Data from these observations were tested for significant differences using similar statistics to those mentioned before (table 4.6). Ripe fruits of physic-nut trees in each plot were harvested and hulled manually in early december 1985. Seed yields were weighed after air drying for a few days (table 4.

B.5 <u>An experiment of nutrient deficiency</u>

A cup experiment on stunted physic-nut trees caused by nutrient deficiency was conducted corresponding to the design after the first harvest. N,P and K fertilizers were added separately to 250 ml cups containing 200 g soil each. This soil was collected through the depth between 0 to 15 cm at 0.5 m apart from stunted plants which were grown in a field plot treated by leaching alone. This treatment field was selected because a retardation of plant growth in another treatment may be caused by either added rice husks or gypsum, or both. Rates of the application for each fertilizer were as mentioned in the experimental design. Seventy-six phusic-nut seeds were germinated individually in each cup. Plants were watered as needed to prevent moisture stress. The height of every plant was measured from ground to tip 8 weeks after seedling in order to obtain information on nutrient deficiency (table 4.8).

B.6 <u>Comparison of some soil properties in the areas of stunted and tall plants</u>

Values of moisture content, pH, E.C., ESP, and infiltration of the plot soil at 0.50 m apart from the most stunted and the tallest physic-nut trees in both treatments (leaching only and leaching + 3% rice husks

+ 6% gypsum) were determined by using the same methods as done in leaching experiment. In the meantime, the height of these plants were measured also. Results of the average measurements were summarized in table 4.9.

C. Results and Discussions

The results of this study are presented in three parts. In the first part, property variations of the field soil and the leachate caused by two different treatments are compared; the second part describes resultant tree growth and seed yields in both treated plots; and the third part discusses the non-uniformity of plant growth in the experimental fields.

C.1 Changing E.C. values, pH and moisture content of field soils with rainfall

Data in table 4.1 indicate that the average rainfall in these two rainy seasons was 12.5 mm/d and 17.6 mm/d, respectively. These values are 40.8% different. Total rainfall for the two years was 1,558.1 mm, whereas leaching requirement of a 320 m^2 subplot was about 625 mm. This implies that rain water should have been adequate to lower soil salinity down to the control level, 8 $mscm^{-1}$, for a well-drained soil. After the rainy seasons in 1984 and 1985, average soil moisture content and pH values were different by only 0.53% and 1.3%, respectively. Apparently, the difference between the two values is insignificant (table 4.1). Only the E.C. values of the soil changed considerably with rainfall. The graph of $E.C._f$ versus rainfall dropped drastically in the early rainy months and then declined more gradually later on (figure 4.2).

C.2 Effects on changing properties of the field soil and the leachate

Results shown in table 4.2 indicate that the addition of 3% rice husks and 6% gypsum to the plot soil decreased soil moisture content while leaching alone did not. However soil pH among both treatments were only slightly different. Besides the $E.C._f$ values of the soil in all treated plots declined as leaching increment increased at the rate of 0.48 $mscm^{-1}$/week for plot soil without rice husks and gypsum as against a rate of 0.68 $mscm^{-1}$/week for plot soil containing such materials (figure 4.4).

Leachate pH from both plots after each leaching were almost equal, whereas the $E.C._d$ and SAR_d values were not (table 4.3). The $E.C._d$ of the leachate for both treatments increased steeply with initial leaching, and then both graphs reached plateaux (figure 4.5). To the contrary, SAR_d changed in opposite manner (figure 4.6). The relationship between $E.C._f$ and $E.C._d$ was strongly nonlinear, and apparently steeply sigmoidal (figure 4.7)

The application of rice husks and gypsum to the field soil only slightly affected infiltration (table 4.5). Soil treated by leaching alone had 15% less infiltration than that of soil treated with leaching plus 3% rice husks and 6% gypsum (figure 4.10). However, the F test indicated no significant differences between them. Soil mixed with rice husks and gypsum not only improved infiltration but also reduced soil salinity more than did leaching alone (tables 4.7 and 4.9). Soil leached aft applying these materials in the ratio 1:2 had E.C. values about 20% less than those of soil without any additions.

According to figures 4.3, 4.4 and 4.6, they imply that leaching with the addition of rice husks and gypsum increased the efficiency of salt leaching by improving the infiltration rate. Allison (1973) reasoned that organic matter mixed with the soil aiding greatly in increasing infiltration by providing better aggregation and structure, and consequently lower bulk density and increased ease of water movement. Abrol and Bhumbla (1973) reported that the addition of gypsum resulted in greater salt leaching due to the changes in pore size distribution in the clay soil. In other words the addition of gypsum to a clay soil and the subsequent replacement of sodium by calcium on the exchange sites improve the air-filled pore space which increases the hydraulic conductivity (Bridge and Tunny, 1973), resulting in a decrease in the time required for reclamation and also a reduction in the period of contact between soil and water (Muhammed et al., 1969).

C.3 Plant response and yields

Although the F test indicated no significant differences in plant response among these treatments (table 4.6), plants grown in soil treated by leaching alone had better growth than did plants in the other treatments (figures 4.11-4.12). In addition seed yields gained from a field soil reclaimed by the first method were 12% more than those obtained from another plot treated by the second one (table 4.7). This phenomena implied that either one or both of these materials might retard plant growth. The retardation could have been resulted from the added salinity of the gypsum, or from some phytotoxic material in the rice husks, or a combination of the two.

C.4 Non-uniformity of plant growth in both treatments.

It was found that about 60% of plants in each subplot grew healthily, but 40% were stunted and their stem tips died initially. These problems may be attributed to spatial variabilify in nutrient deficiency and poor soil properties.

C.4.1 Information on nutrient deficiency

Results shown in table 4.8 indicate that plants in a treatment of 15 ppm P_2O_5 were the tallest in the average as compared to the height of those grown in other. For all treatments except that representing 10,000 ppm NO_3-N, the height of plants increased with rates of applied fertilizer initially and then decreased later. Applications of each fertilizer at 15 ppm rate were preferable to physic-nut growth (figures 4.13-4.15). The average height of these trees in all cup soil without the addition of any fertilizer was 36% shorter than of those in a treatment of 15 ppm P_2O_5. However they still grew well when compared to the other in most treatments. It is concluded that the soil at the areas of stunted physic-nut trees did not lack nutrients.

C.4.2 Non-uniformity of plant growth in each plot

Results in table 4.9 indicate that soils in the areas of stunted trees in the fields treated by different methods had poor E.C., ESP and infiltration compared to those in the area of healthy plants. This emphasized non-uniformity of plant growth in each field caused by spatial variability in the soil properties. In order to allow plants to grow uniformly in each field to increase yields, soil permeability in rooting areas of poorly-growing plants has to be re-improved. Frequent ploughing, and adjusting drip emitters in proper positions before each irrigation are recommended.

D. Conclusions

This field experiment was conducted in order to develop a suitable method for limiting soil salinization in order to grow physic-nut trees. Initial results can be summarized as follows :

1. During the rainy months the E.C. values of the soil decreased steadily. A graph between E.C. values and accumulated rainfall decreased steeply at first and then declined more gradually later.
2. The addition of rice husks and gypsum at a 1:2 ratio to the field soil decreased soil moisture content and E.C. values more than another treatment without these same materials when both were leached.
3. The $E.C._d$ of leachate corresponding to both treatments increase steeply during initial leaching, and then plateaued later. However the SAR_d of the leachate changed in the opposite direction. The

relationship between $E.C._f$ and $E.C._d$ was a strongly nonlinear likely sigmoidal curve.

4. Soil treated by leaching alone had an infiltration rate of 15% less than when treated with leaching plus 3% rice husks and 6% gypsum.

5. Soil which was leached after applying rice husks and gypsum in the ratio of 1:2 had an E.C. value of about 20% less than that of soil without any such additions.

6. Plants grew better with higher seed yields in soil treated by leaching only than in soil treated with the amendments as well. This could be due either to added salinity from the gypsum or to phytotoxic materials in the rice husks.

7. Soil in areas of stunted trees in each field did not lack any essential nutrient, but had E.C. value, E.S.P, and infiltration at unsatisfactory level to prohibit plant growth. Spatial variability in such properties of the soil was the only factor causing a non - uniformity of the growth among these plants in both fields.

Table 4.1 Change of $E.C._f$ values, pH values and moisture content in plot soil with rainfall during the rainy seasons of 1984 and 1985

Month	rainfall		EC_f (1:5) at 25 C		pH (1:1)		moist.Cont.	
	mm	days	$mscm^{-1}$	s		s	% w/w	s
1984								
July	121.2	10	31.29	4.7	8.1	1.2	36.08	6.1
August	60.8	8	19.20	3.8	7.9	1.4	38.54	7.7
September	247.1	16	17.93	4.4	7.7	1.2	36.17	9.0
October	70.9	5	17.50	3.2	7.9	1.6	38.39	7.7
November	39.1	4	14.60	4.4	7.8	2.0	38.60	10.0
1985								
July	123.8	11	13.69	2.1	7.8	1.2	38.79	5.9
August	211.4	13	12.51	2.8	7.9	1.5	40.35	8.1
September	228.5	16	12.40	3.1	8.0	1.8	33.96	7.1
October	356.5	12	11.60	2.1	7.4	1.8	33.96	8.5
November	98.8	6	11.05	3.3	7.7	2.1	39.76	11.1

[s] Standard deviation

Table 4.2 Average moisture, E.C.$_f$ values, pH of field soil and mean stem height of physic-nut trees grown in each plot of 1600 m^2 after each leaching with 200 m^3 of deep-well water (n_t = 16, r = 4)

Soil Properties & Plant Height	Leaching				Leaching + 3% rice husks + 6% gypsums			
	I*	II	III	IV	I	II	II	IV
Moisture in % w/w	33.6 s=0.5	34.4 s=3.4	34.9 s=3.6	33.3 s=2.0	31.1 s=1.0	30.9 s=0.6	30.5 s=0.3	30.4 s=0.2
E.C.$_f$ (1:5) at 25 C in $mscm^{-1}$	10.6 s=0.03	10.1 s=1.4	9.6 s=0.02	8.6 s=0.13	10.4 s=0.10	9.6 s=0.14	9.1 s=0.13	7.9 s=0.3
pH (1:1)	7.6 s=0.2	7.6 s=0.3	7.7 s=0.2	7.7 s=0.1	7.9 s=0.1	7.6 s=0.2	7.5 s=0.1	7.3 s=0.2

[s]Standard deviation in each treatment for each leaching increment

*Leaching step, with 200 m^3 increments of deep-well water

Table 4.3 Average $E.C._d$, pH, and SAR of leachate from each plot soil (n_t = 16, r = 4)

Leachate Properties	Leaching				Leaching + 3% rice husks + 6% gypsum			
	I*	II	III	IV	I	II	III	IV
$E.C._d$ in $mscm^{-1}$	17.9 s=1.8	28.2 s=0.2	27.6 s=0.7	26.0 s=0.8	14.7 s=0.9	31 s=0.1	32 s=0.5	31 s=0.6
pH	8.6 s=0.2	8.4 s=0.2	8.5 s=0.1	8.5 s=0.2	9.0 s=0.2	8.7 s=0.2	8.7 s=0.1	8.6 s=0.3
SAR in me	233 s=174	50 s=1.3	51 s=0.6	50 s=0.5	186 s=59	52 s=3.3	37 s=0.8	40 s=0.5

*Drainage step after each leaching with 200 m^3 increments of deep-well water

[s]Standard deviation in each treatment for each leaching increment

Table 4.4 Calculation of water input to physic-nut field in six months, based on the Blaney-Criddle method

Month	Mean temperature (t) °C	Mean temperature (t) °F	P %	$\frac{t.P}{100}$
January	25.6	78.1	8.02	6.26
February	22.5	72.5	7.41	5.37
March	29.6	85.3	8.43	7.17
April	30.6	87.1	8.42	7.32
May	29.5	84.2	8.91	7.50
June	27.8	82.0	8.73	7.16
			$\frac{\Sigma t.P}{100}$	40.78

Substituting 0.75 and 40.78 for K and $\sum_{m=1}^{6} \frac{t.P}{100}$ in equation 4.2, that is :

$$W = 0.14 \times 0.75 \times 40.78 \doteq 4.3 \text{ mm/d}$$

Table 4.5 Difference between infiltration in soil treated with leaching and with leaching + 3% rice husks + 6% gypsum

Month	Infiltration (mm.)							
	Leaching				Leaching + 3% Rice Husks + 6% Gypsum			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
January	5.0	6.5	6.0	11.1	10.5	4.9	5.0	11.5
February	6.0	7.3	4.9	8.6	8.9	6.2	4.8	9.8
March	4.8	7.0	7.1	9.5	9.0	5.0	5.4	10.3
April	5.3	6.0	5.8	7.6	8.6	5.5	4.6	11.0
May	6.8	5.8	5.5	9.1	9.4	4.1	6.5	12.5
June	5.2	6.3	6.5	8.4	10.6	5.6	5.5	10.9
Total values	33.1	38.9	35.8	54.3	57.0	31.3	31.8	66.0
Trt total x_i	162.1				186.1			
Trt monthly mean $\bar{x}_i$	6.75				7.75			

$\bar{x}_i = 7.25$, $s = 5.79$, $s_{\bar{x}} = 2.36$, $s_{\bar{d}} = 3.34$, $F_{t,\varepsilon} < 1$ with 7 and 1 df

Table 4.6 Mean stem height of physic-nut trees grown in the two treatments

Tree rows	Mean stem height cm							
	Leaching				Leaching + 3% rice husks + 6% gypsum			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
1	22.50	20.0	47.5	21.5	7.5	60.0	12.5	12.5
2	50.0	17.5	51.25	42.5	5.0	67.5	18.5	35.0
3	75.0	12.5	65.0	37.5	7.5	60.0	25.0	10.0
4	75.0	12.5	32.5	20.0	15.0	20.0	15.0	8.5
5	35.0	10.0	62.5	27.5	25.0	20.0	20.0	17.5
6	55.0	25.0	35.0	50.0	22.5	50.0	27.5	12.5
7	65.0	12.5	80.0	50.0	22.5	55.0	80.0	12.5
8	125.0	22.5	87.5	10.0	17.5	70.0	30.0	10.0
9	120.0	17.5	27.5	20.0	17.5	32.5	10.0	32.5
10	15.0	15.0	80.0	10.0	22.5	45.0	2.5	55.0

Continue

Table 4.6 Continued

Tree rows	Mean stem height cm							
	Leaching				Leaching + 3% rice husks + 6% gypsum			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
11	65.0	25.0	52.5	15.0	17.5	37.5	22.5	82.0
12	57.5	27.5	7.5	25.0	15.0	47.5	7.5	85.0
13	17.5	75.0	72.5	7.5	85.0	12.5	22.5	90.0
14	37.5	32.5	10.0	27.5	30.0	10.0	42.5	32.5
15	27.5	17.5	12.5	10.0	17.5	17.5	32.5	57.5
16	27.5	12.5	25.0	10.5	11.0	10.0	10.0	80.0
17	22.5	7.5	5.0	47.5	11.0	10.0	10.0	37.5
18	32.5	27.5	12.5	30.0	5.0	12.5	55.0	20.0
19	15.0	17.5	7.5	22.5	17.5	10.0	52.5	47.5
20	17.5	77.5	10.0	25.0	10.0	30.0	15.0	42.5

Continue

Table 4.6 Continued

Tree rows	Mean stem height cm							
	Leaching				Leaching + 3% rice husks + 6% gypsum			
	R_1	R_2	R_3	R_4	R_1	R_2	R_3	R_4
21	2.5	65.0	7.5	5.0	4.0	7.5	22.5	22.5
22	3.0	10.0	30.0	2.5	7.0	32.5	22.5	40.0
23	4.0	10.0	30.0	7.5	7.5	7.5	10.0	15.0
24	2.5	10.0	47.5	10.0	4.0	12.5	15.0	4.0
25	10.0	10.0	57.5	10.0	40.0	5.0	25.0	17.5
Plant total	979.5	590.0	956.25	544.5	444.5	742.5	606.0	879.5
Treatment total	3,070.25				2,672.5			
Treatment means	30.70				26.23			
	$\bar{x}$ = 114.86, s = 42.10, $s_{\bar{x}}$ = 17.19, $s_{\bar{d}}$ = 24.31, CV = 36.6%							
	$F_{t,\varepsilon}$ < 1 with 7 and 1 d.f							

Table 4.7 Depth of irrigation, rate of rainfall, soil moisture content by volume, infiltration rate, salinity of soil and the leachate, and physic-nut yields in soil salinity control system by two treatmets

Treatment	Irrig. W mm/d	Av.rainfall $\bar{P}$ mm/d $n_P = 12$ $s_P = 5.9$	Av.Infilt. at 30.5 cm $\bar{I}$ mm/d $n_I = 24$	Av.Evap. $\overline{ET}$ mm/d $n_E = 12$ $s_E = 2.3$	Soil moist θ_v % v/v $n_\theta = 24$	$\overline{E.C.}_f$ (1:5) at 25C $mscm^{-1}$ $n_S = 24$	$\overline{E.C.}_d$ at 25C $mscm^{-1}$ $n_d = 24$	Seed yields kg/acre
Leaching	4.3	15.2	6.8	7.1	30.0	7.30	17.9	28.41
			s_I=1.6		s_θ=6.9	s_S=1.6	s_d=3.7	
Leaching + 3% Rice Husks + 6% Gypsum	4.3	15.2	7.8	7.1	33.0	5.90	14.7	25.08
			s_I=2.7		s_θ=8.2	s_S=1.3	s_d=4.2	

^{s}Standard deviation for treatments 1 and 2 respectively

Table 4.8 Growth of physic-nut trees in cup soils against rates of applied fertilizers (n_t=16, r=4)

Rate in ppm	Plant Height (cm)		
	NO_3-N	P_2O_5	K_2O
0	22.2 s=3.4	22.2 s=3.4	22.2 s=3.4
10	13.8 s=1.5	25.0 s=3.8	12.5 s=2.5
15	19.2 s=2.9	30.2 s=3.6	15.5 s=2.8
20	17.3 s=2.1	23.5 s=4.2	12.7 s=1.9
10,000	24.0 s=2.3	23.2 s=3.8	11.0 s=2.6
20,000	no seedling emergence	21.5 s=4.1	no seedling emergence
100,000	no seedling emergence	21.5 s=6.7	no seedling emergence

[s]Standard deviation of each treatment

Table 4.9 Averages moisture, pH, E.C. values, ESP and infiltration of the field soil at 0-15 cm depth around poorly and well growing physic-nut trees, and their average hight for both treatments at the time of the first harvest (n_t = 16, r = 4)

Soil Properties & Plant Height	Leaching		Leaching + 3% rice husks + 6% gypsum	
	poor growth	well growth	poor growth	well growth
soil moisture in % w/w	4.1 s=0.2	4.0 s=0.6	3.8 s=1.0	4.0 s=0.2
pH (1:1)	7.9 s=0.2	8.0 s=0.1	8.1 s=0.2	8.0 s=0.1
E.C. (1:5) at 25 C in $mscm^{-1}$	9.8 s=0.2	4.8 s=0.2	7.2 s=0.2	4.6 s=0.4
ESP %	101 s=14.8	44 s=8.9	60 s=12.2	35 s=2.4
infiltration in mm hr^{-1}	5.9 s=0.4	13.2 s=1.7	7.5 s=1.0	24.2 s=0.8
average height in cm	14 s=4.8	125 s=17.3	12.5 s=2.9	120 s=14.1

[s] Standard deviation of each treatment

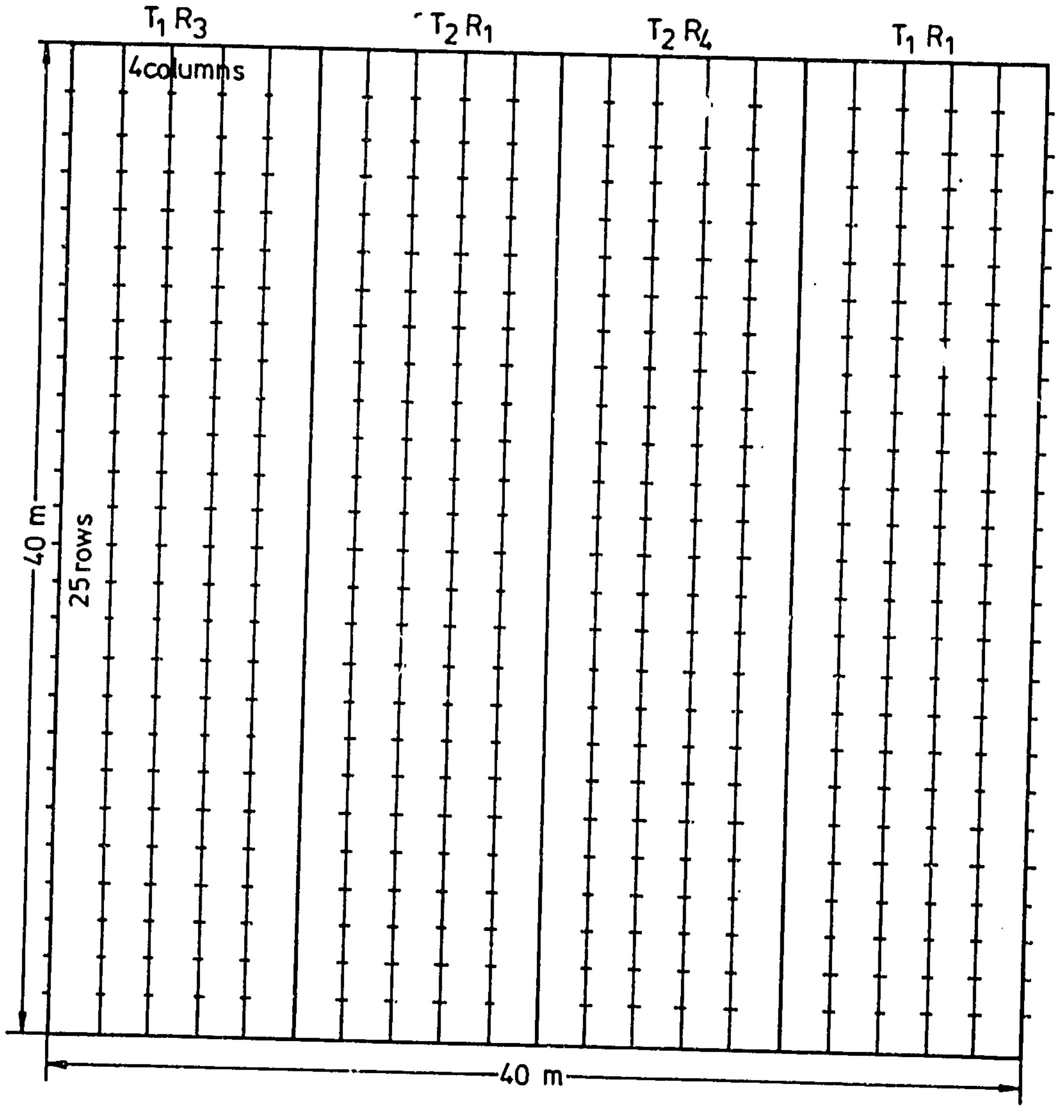


Figure 4.1 Diagram of 25 rows and 4 columns of plants within each subplot for a 1600 m^2 plot.

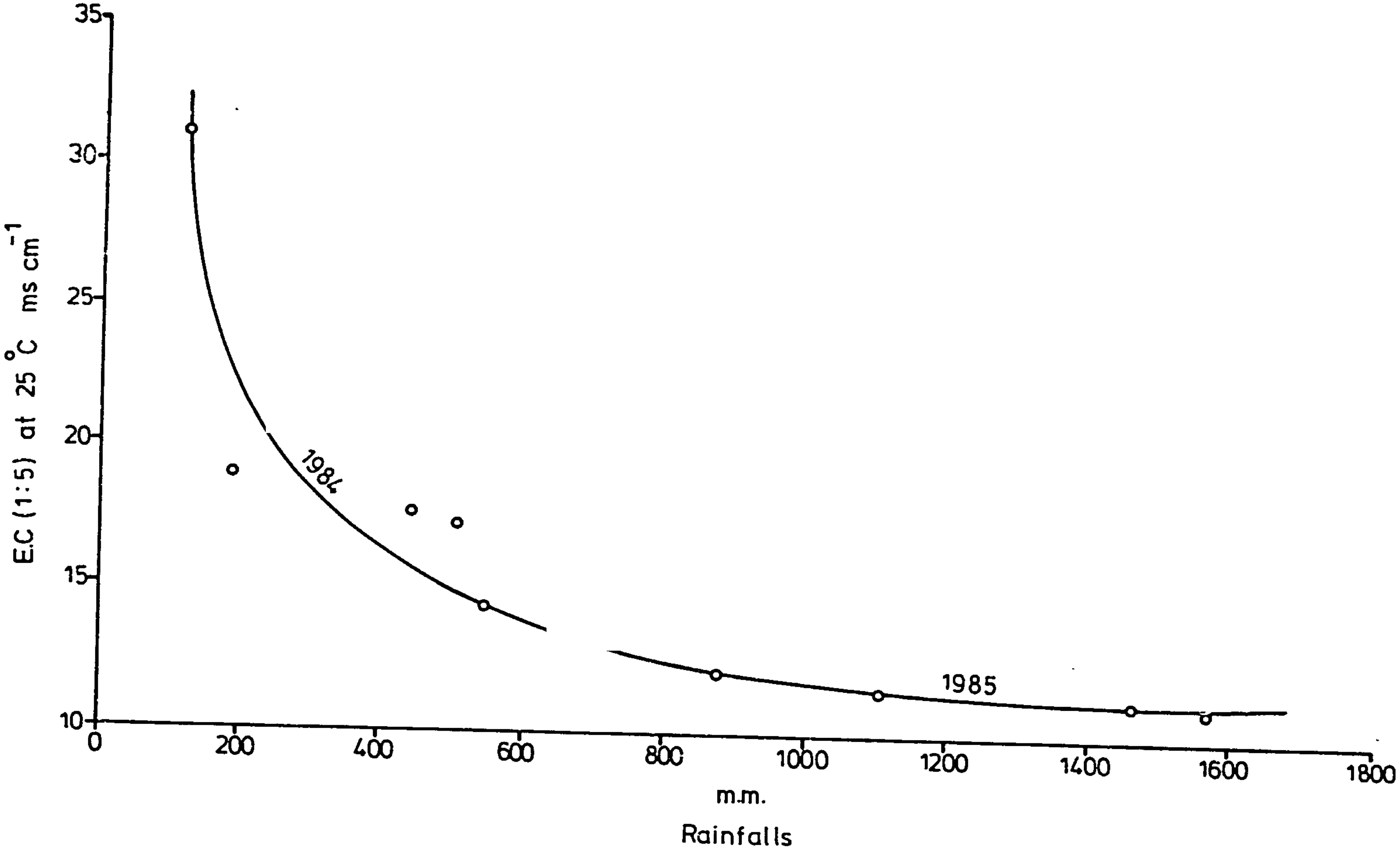


Figure 4.2 Change of salinity in plot soils with accumulated rainfalls

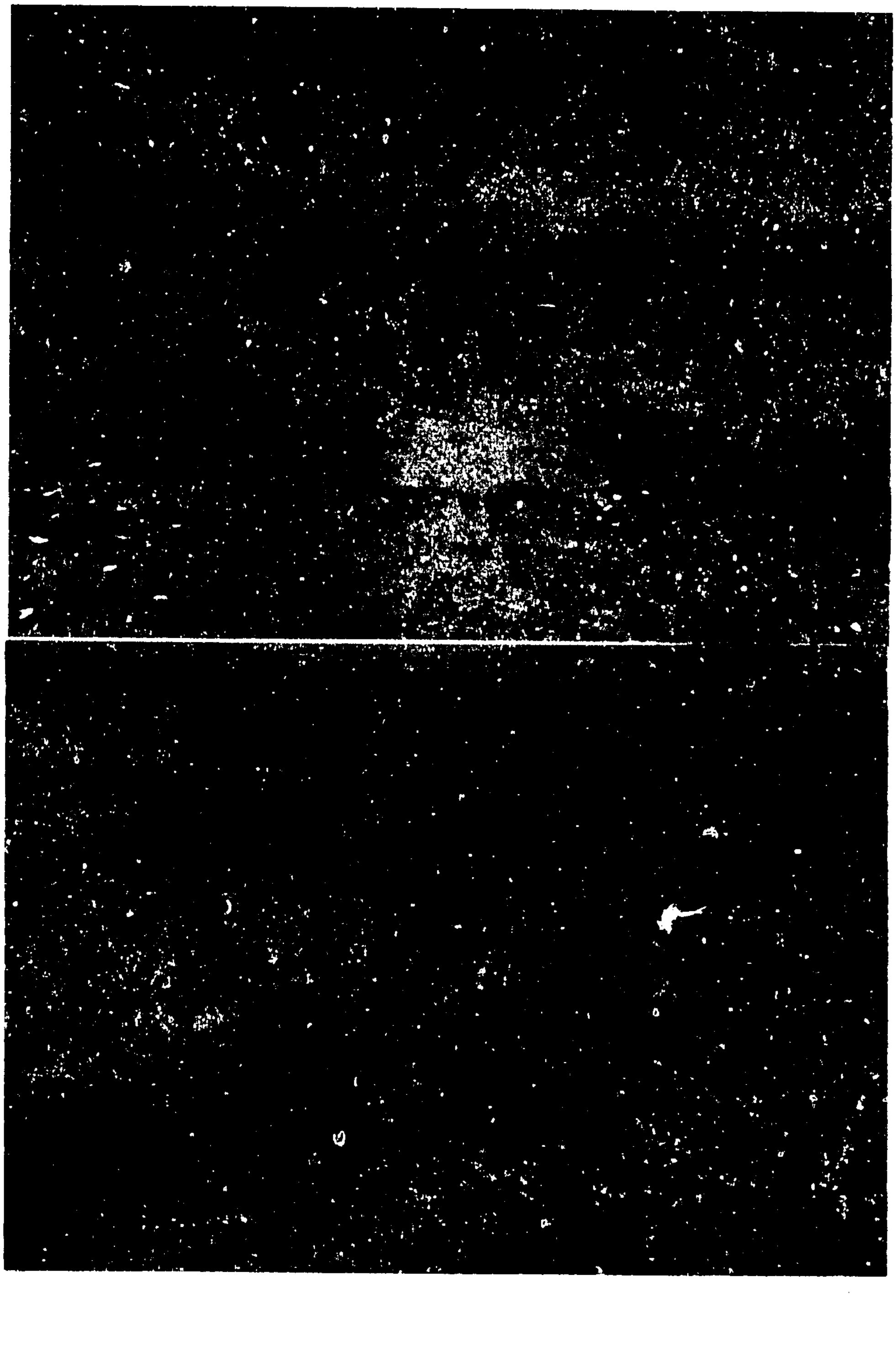


Figure 4.3 Ploughed soils

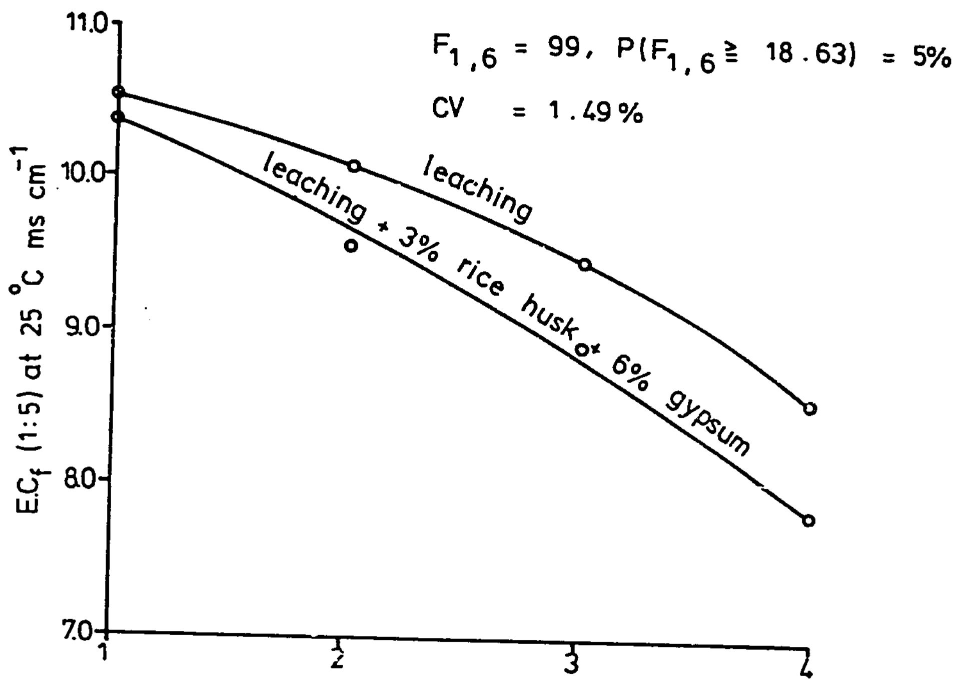


Figure 4.4 Change of $E.C_f$ with leaching increment

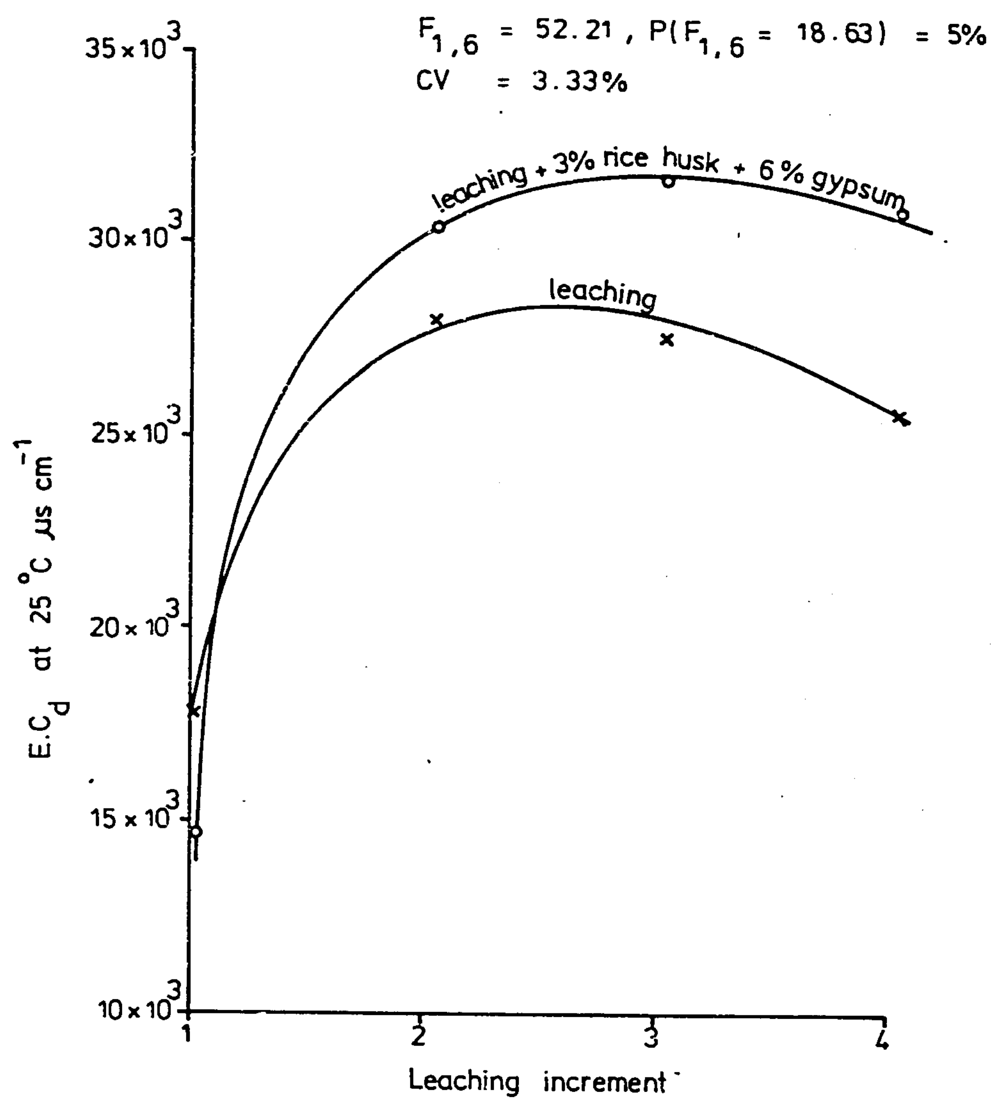


Figure 4.5 Change of $E.C_d$ with leaching increment

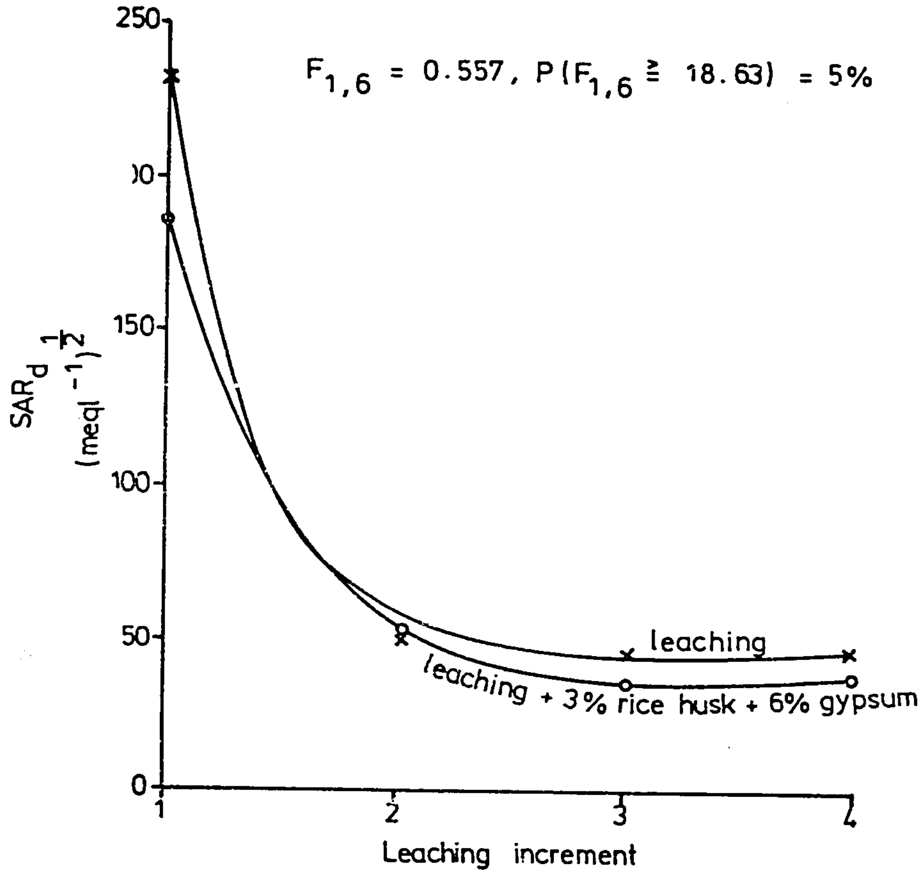


Figure 4.6 Change of SAR_d with leaching increment

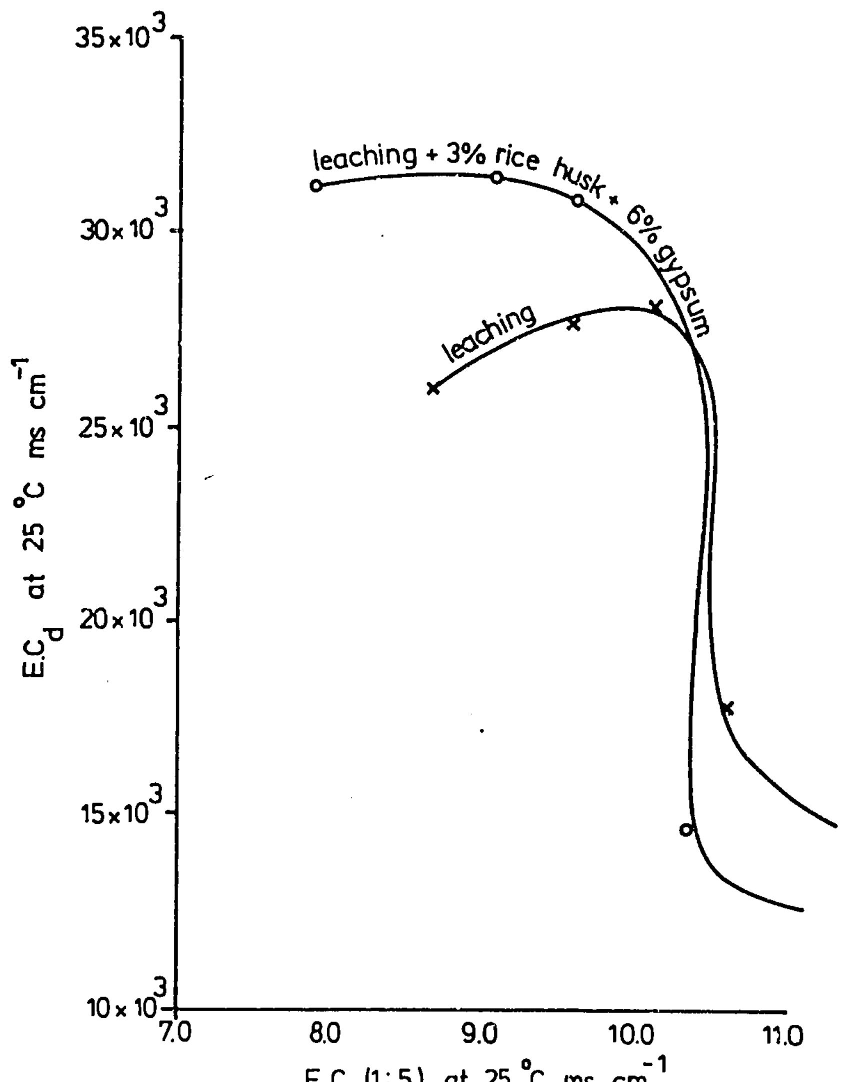


Figure 4.7 Relationship between $E.C_f$ and $E.C_d$

Figure 4.8 Row space of physic-nut trees

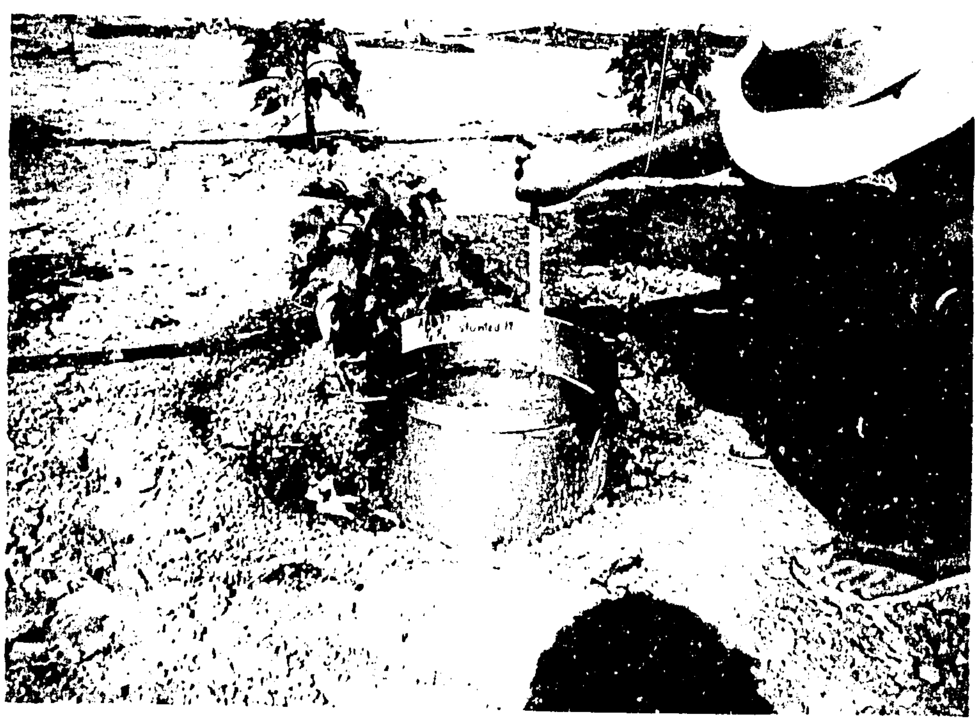
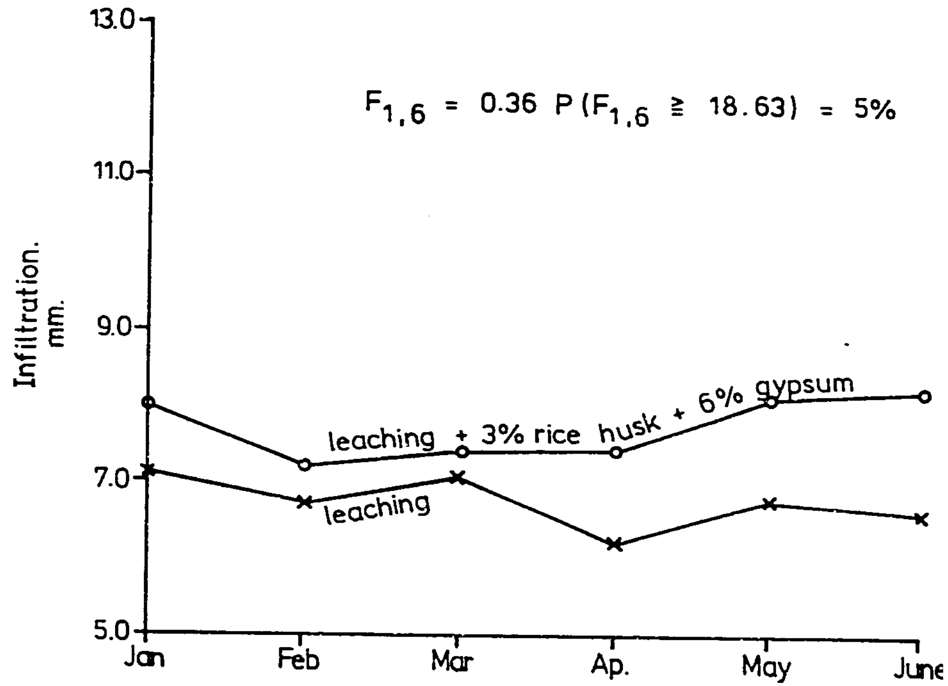


Figure 4.9 Infiltration measurement



<u>Figure 4.10</u> Variation of infiltration in six months.

Figure 4.11 Typical growth of physic-nut trees in a field soil treated by leaching only

Figure 4.12 Typical growth of physic-nut trees in a field soil treated by leaching + 3% rice husks + 6% gypsum

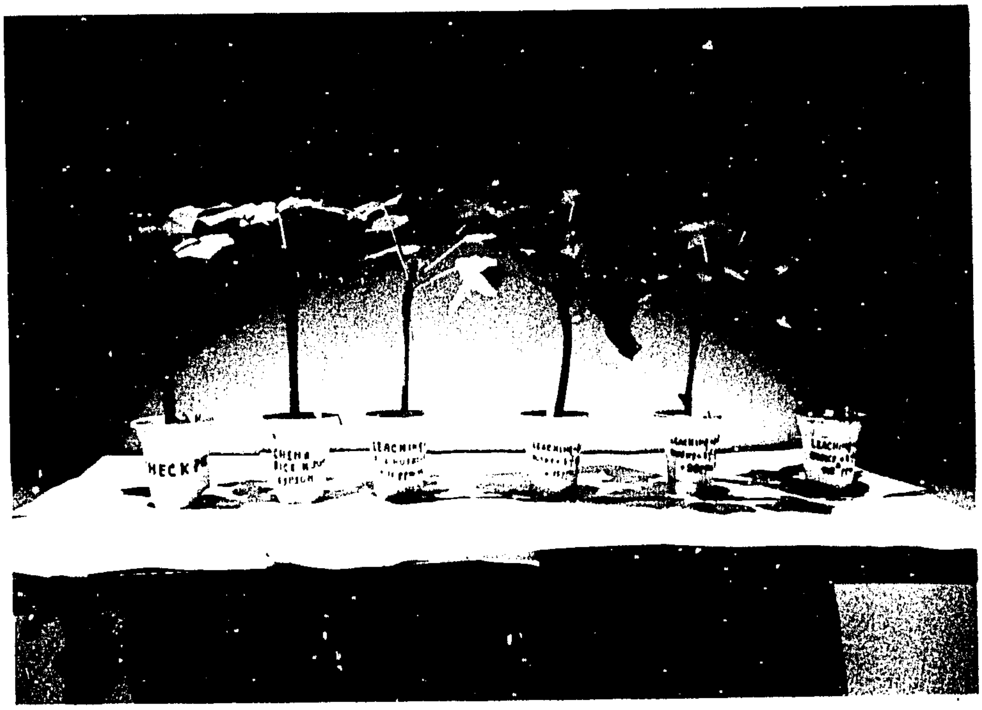


Figure 4.13 Differences in physic-nut growth with rates of applied NO_3-N

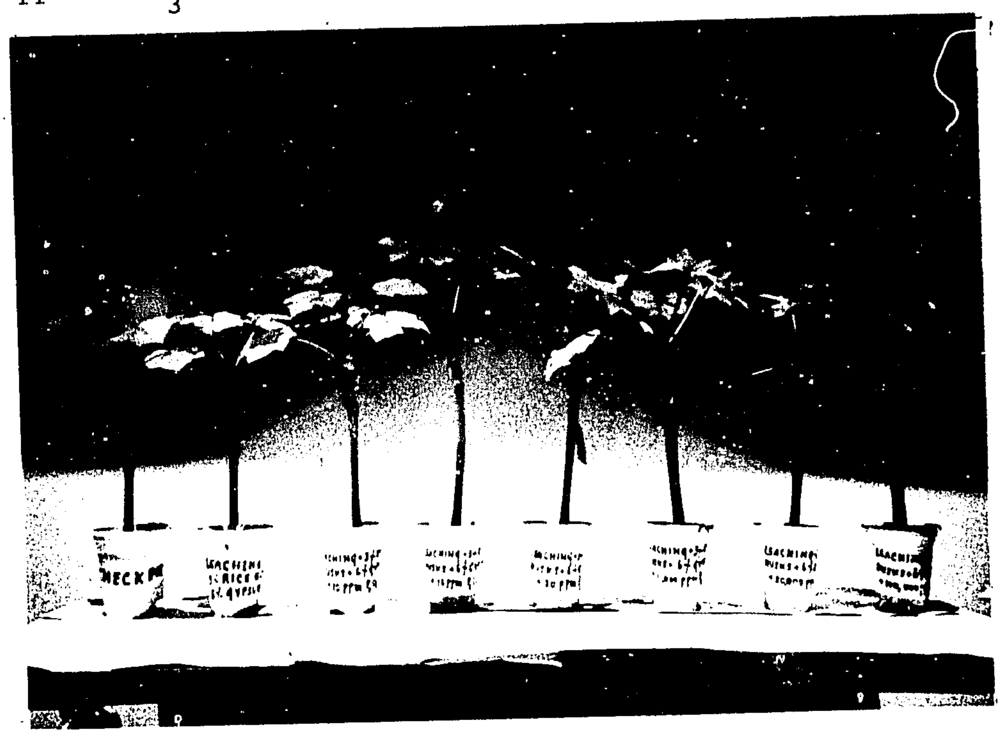


Figure 4.14 Differences in physic-nut growth with rates of applied P_2O_5

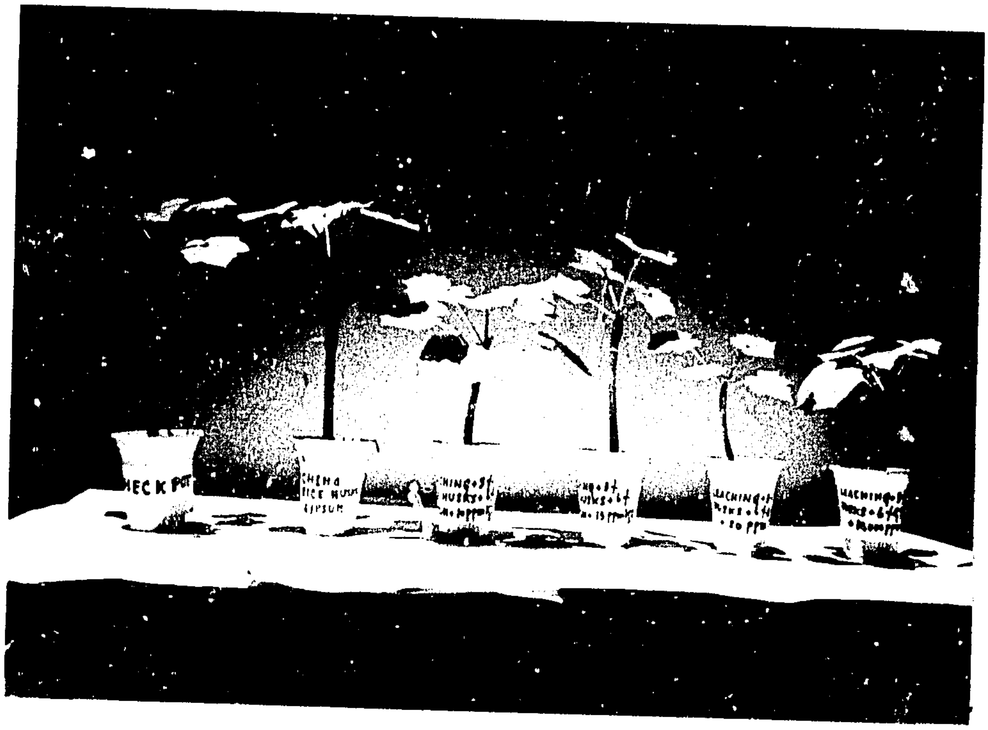


Figure 4.15 Differences in physic-nut growth with rates of applied K_2O

V. PHYSIC-NUT AS AN ALTERNATE-ENERGY SOURCE

Althouth some experimental studies on the use of physic-nut oil as a fuel for small diesel engines have been reported by Passabutr et. al (1980) and Takeda (1982), the amount of useful data available is still scarce, since their results were based on one engine-load condition only. In the following sections, the procedures and results of an experimental study carried out to further investigate the technical feasibility of using such oil in a small diesel engine are discussed.

A. Oil yield

The physic-nut oil used for this experiment was extracted from physic - nut grown at the Samutsongkhram research site. The nut itself is blackish in color with a thin shell, measuring approximately 1.8 cm. in length and 1.0 cm. in diameter (Fig. 5.1). When crushed and subsequently compressed in a 10-cm. diameter cylinder using simple hydraulic jack of 10 ton capacity (Fig. 5.2), yellowish liquid oil was extracted at a rate of 0.221 litres of oil/kilogram of physic-nut (or 20.1% oil on a mass basis). Because of the small number of physic - nut trees grown on the experimental plot, the quantity of physic-nut oil available for this experiment was only about three litres. This then limits the number of experimental runs for the engine test.

B. Experimental apparatus and procedures

Major fuel characteristics of the physic-nut oil such as viscosity, specific gravity and heating value were obtained through standard measuring techniques with the collabration of the Petroleum Authority of Thailand.

Bench dynamometer tests were carried out to determine the performance of physic-nut oil as a substicute fuel for a Yanmar TA 80L engine (Fig. 5.3). The engine characteristics are shown below :

Type :	Horizontal 4 stroke
Number of cylinders :	1
Bore X stroke :	84 mm x 88 mm
Displacement volume :	0.487 litres
Continuous power rating :	7.5 HP/2200 RPM
Maximum power rating :	8.5 HP/2400 RPM
Compression ratio :	22

The engine was used to drive an EA-7C air-cooled eddycurrent electrodynamometer with a maximum power-absorbing cappacity of 5 kW (Fig. 5.3). Breaking force control of the dynamometer was through a D.C. power controller. The shaft-torque was determined by force balance using a spring balance. The tachometer was of a non-slip, directly-connected, power-generator type.

Fuel flow rate was measured by timing the volume of fuel consumed from a 100 ml. calibrated glass tube. Air flow rate was determined using a standard nozzle-plenum installation, whereby the resulting pressure differential was measured using an inclined manometer.

Temperature measurements were performed using K type thermocouples with a multi-input digital indicator.

Exhaust gas conditions (O_2 and temperature) were measured using a Neutronics combustion analyzer (Fig. 5.4) with digital display and printout. The overall measurement arrangement is shown in Fig. 5.5.

Due to the extremely limited quantity of physic-nut.oil available for this test, the engine was confined to run only at two controlled speed of 1200 and 1600 rpm, while loads in the range of 0.5 to 4.8 kW were applied through the dynamometer power controller. Engine injection timing was set for optimum when using diesel fuel only.

C. Results and discussions

C.1 Fuel characteristics

The fuel properties of physic-nut oil as determined in this experiment are shown in table 5.1 against those of diesel, rubberseed oil (Jompakdee, 1986) and physic-nut oil (Takeda, 1982).

It is observed that the properties of physic-nut oil obtained from this study are comparable to that of oil obtained by Takeda (1982), although the viscosity values differ. However, since viscosity decreases with increasing temperature for liquids, the viscosity values of the two studies are actually closer than indicated. When compared to rubberseed oil, the property values are in close agreement. However, when compared to diesel the physic-nut oil is about 8% heavier and the heating value about 8% lower, while the viscosity is about 10 times higher, representing the most significant difference between the two fuels. The sulfur content of the physic-nut oil is lower than for diesel oil.

C.2 Engine performance

The main performance parameter evaluated in the bench dynamometer tests was the thermal efficiency, which was calculated using the relation :

$$\zeta_{th} = \frac{3.6}{BSFC \times HHV} \times 100 \% \qquad [5.1]$$

where 3.6 is a conversion factor (3.6 MJ is equivalent to 1 kW-hr), BSFC is the brake specific fuel consumption (kg/kW-hr) and HHV is the higher heating value of the fuel in MJ/kg. Engine exhaust temperature at the discharge valve exit was also measured during the experimental runs. Other parameters measured include the air/fuel ratio and the O_2 content of the exhaust gas.

Fig. 5.6 shows the thermal efficiency at varying loads for the two engir speeds of 1200 and 1600 rpm. It is clear that higher thermal efficiency was obtained when the engine was run on diesel, the difference being approximately one to two percentage points. The drop in efficiency could be attributed to the fact that injection timing had not been adjusted to optimum for physic-unt oil and that the physic-nut oil is much more viscous than diesel since viscosity is known to affect fuel atomization. Nevertheless, the engine exhibited similar efficiency - load relations for the two fuels.

Fig. 5.7 shows the comparative brake-specific fuel consumption (BSFC) of the engine at varying loads. As expected, the BSFC for physic-nut oil is higher, since its heating value is lower, than for diesel. However, the difference in BSFC for the two fuels is only about 15% (or 7% in terms of volume), which does not warrant a larger fuel tank for the physic-nut oil. Again the BSFC-kW relations for the two fuels are similar.

Engine exhaust temperatures at varying loads are shown in Fig. 5.8, which indicates no significant difference between the two fuels.

Fig. 5.9 shows the air/fuel ratio (kg/kg) for the two fuels. It is clear that higher air/fuel ratio was needed for diesel combustion at all load conditions because of the fuel's lower density.

A comparison of the O_2 content in the exhaust gas for the two fuels is shown in Fig. 5.10, which indicates that slightly higher O_2 content was observed for physic-nut oil than for diesel. Again, this could be attributed to injection timing which was set at optimum for diesel and not for physic-nut oil.

Table 5.1

Camparison of fuel characteristics

Fuel Type	Viscosity (Centipoise)	Specific Gravity	Heating Value (kJ/kg)	Sulfur Content (%)
Physic nut oil (present study)*	29.5 (40°C)	0.910	39,193	0.0
Physic Nut oil (4,5)	40.4 (31°C)	0.919	39,647	0.13
Rubberseed oil (3)	34.0 (40°C)	0.914	39,224	NA
Diesel	2.8 (40°C)	0.845	42,500	<1.2

* Test conducted in collaboration with the Petroleum Authority of Thailand (PTT).

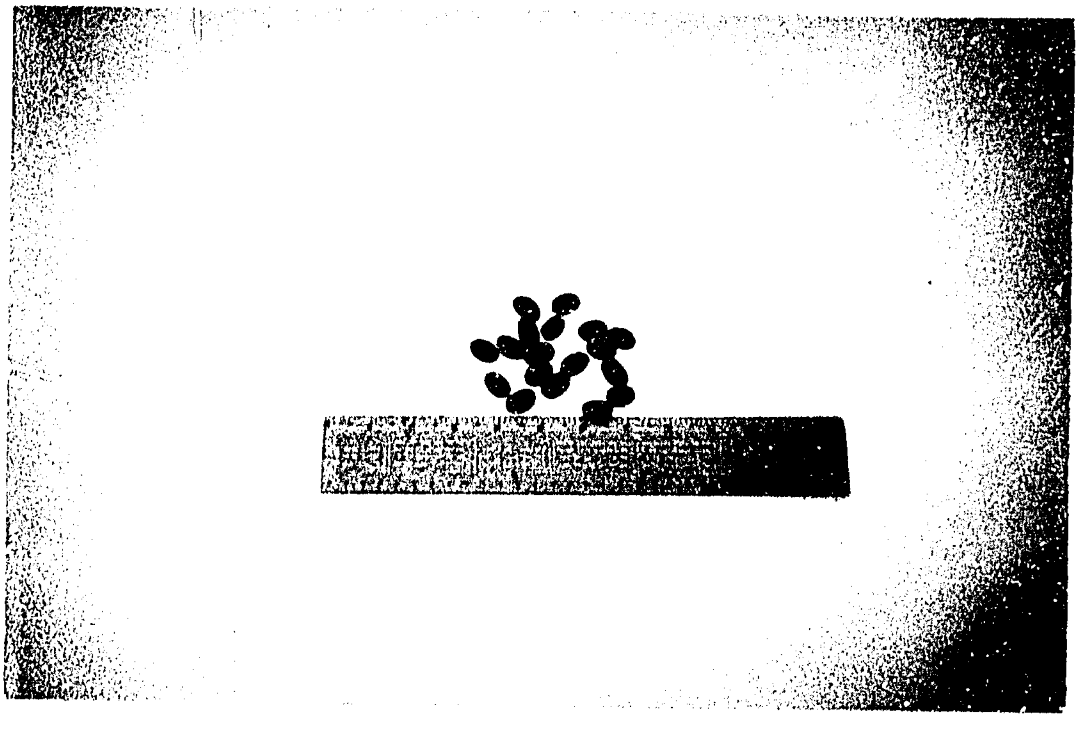


Figure 5.1 Physic nut (or Jatropha curcas)

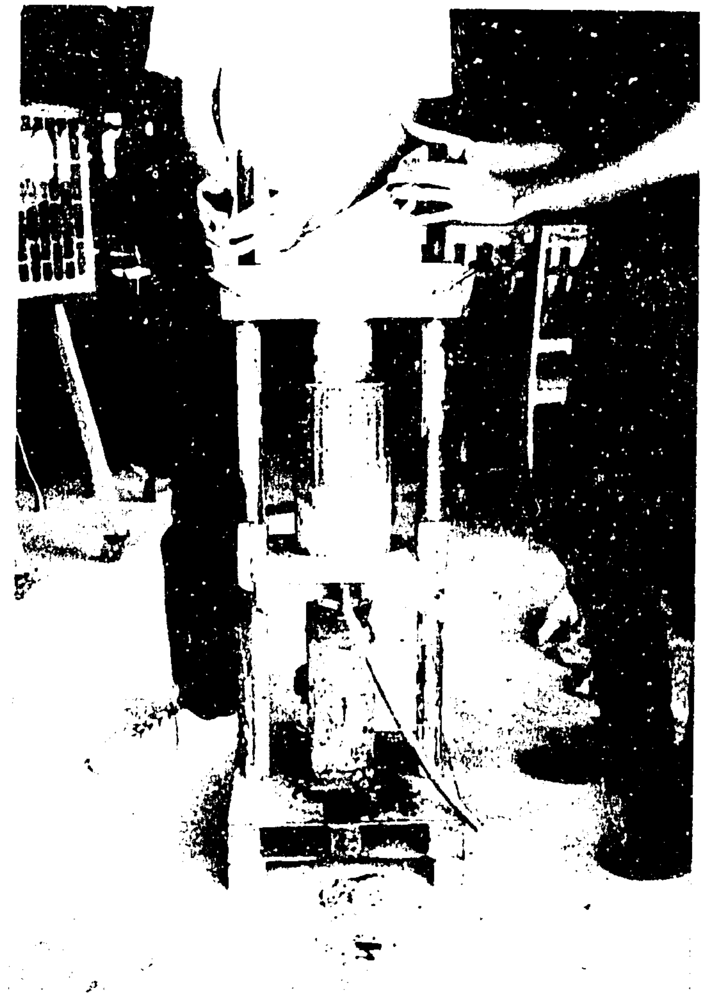


Figure 5.2 Physic-nut oil extractor (Dept. of Agriculture)

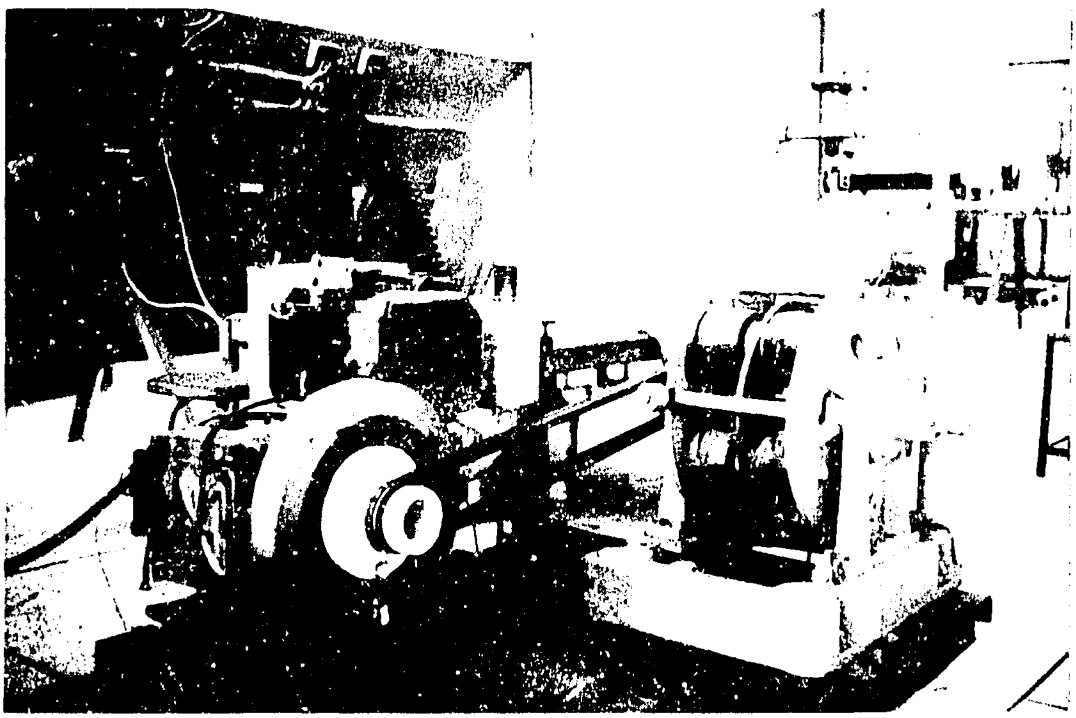


Figure 5.3 Engine - dynamometer setup

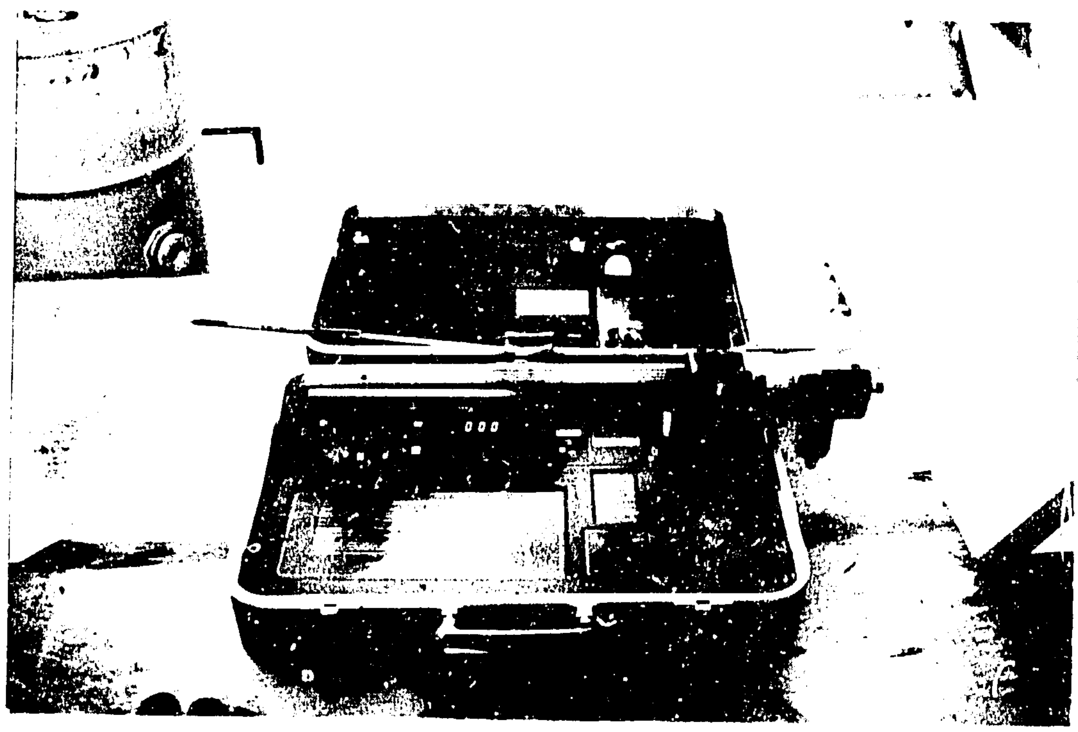


Figure 5.4 Combustion Analyzer

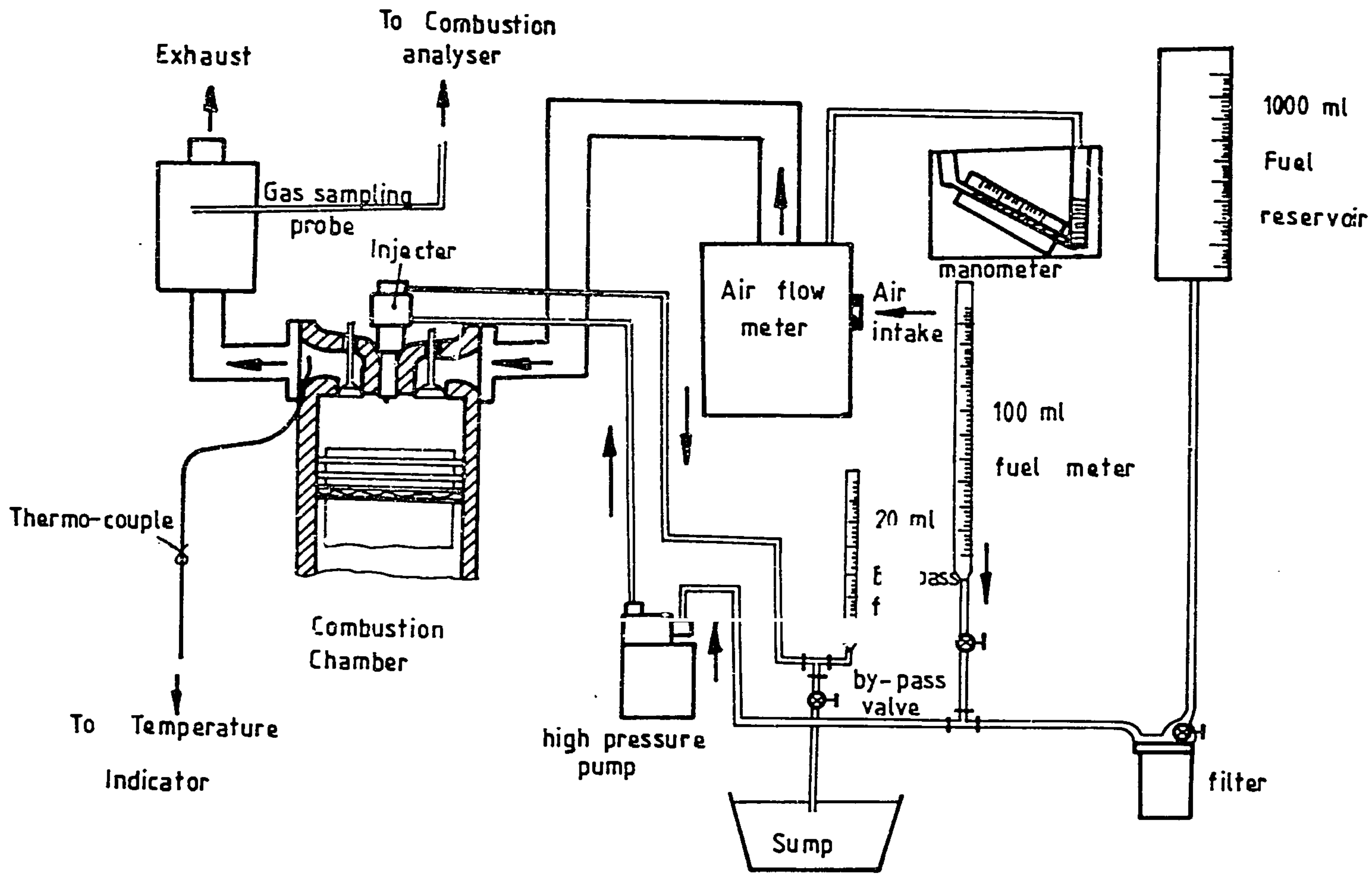


Figure 5.5 : Overall measurement set-up (excluding the dynamometer)

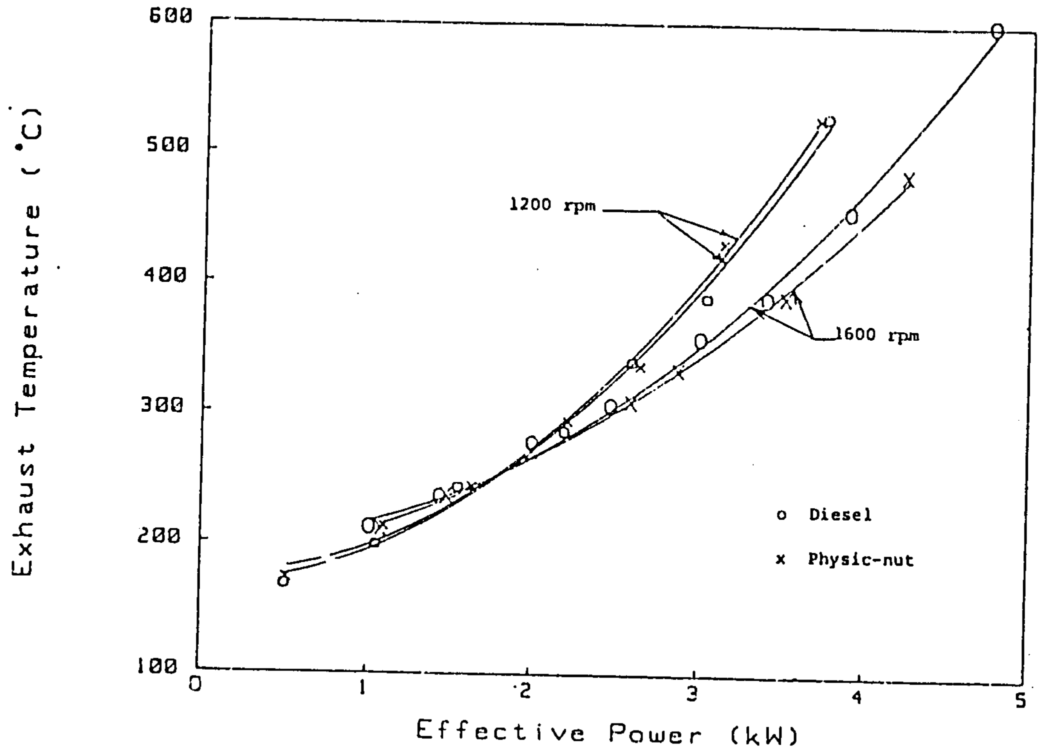


Figure 5.6 : Exhaust temperature at varying loads.

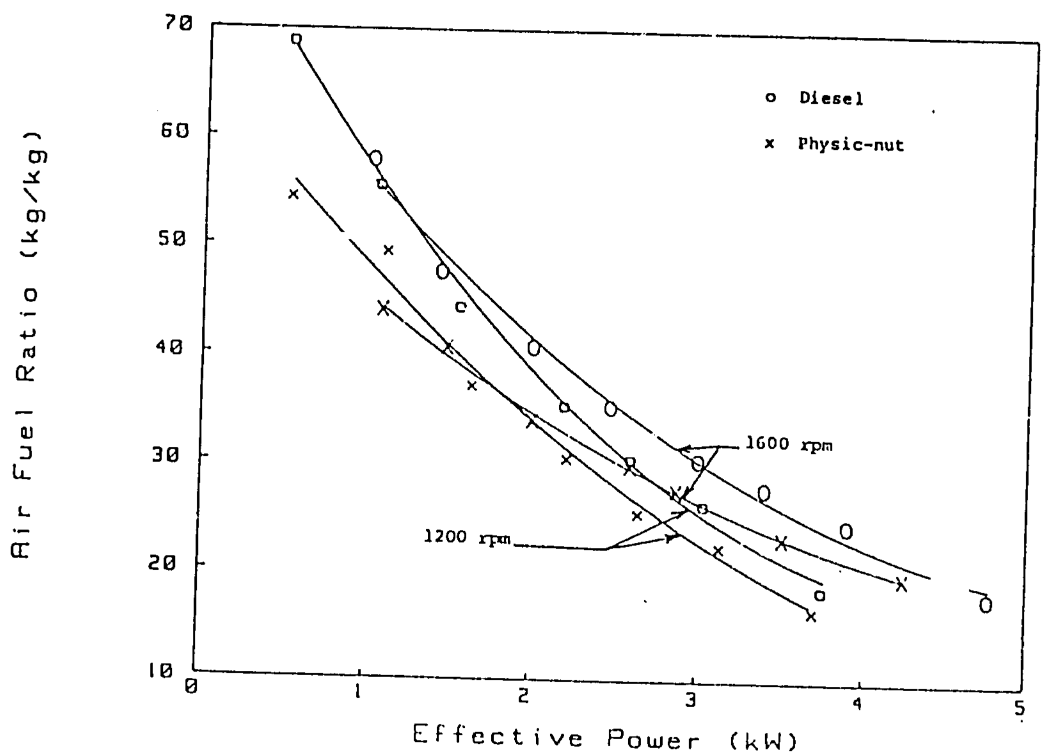


Figure 5.7 : Air fuel ratio at varying loads.

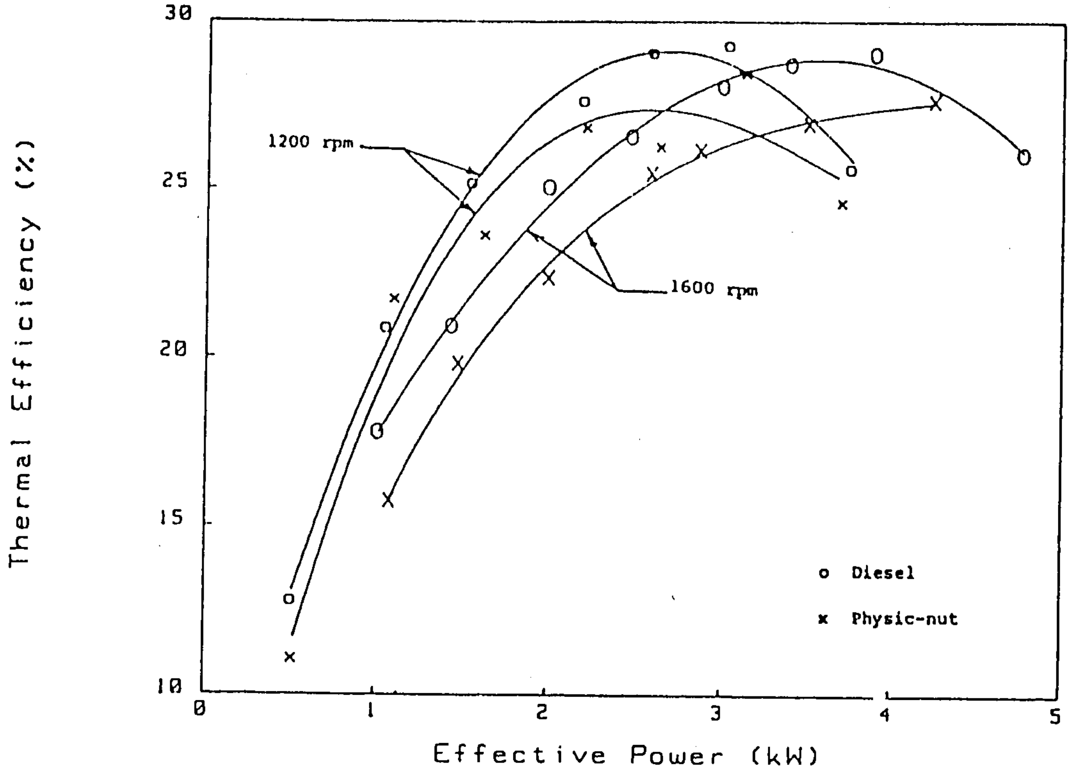


Figure 5.8 : Thermal efficiency at varying loads.

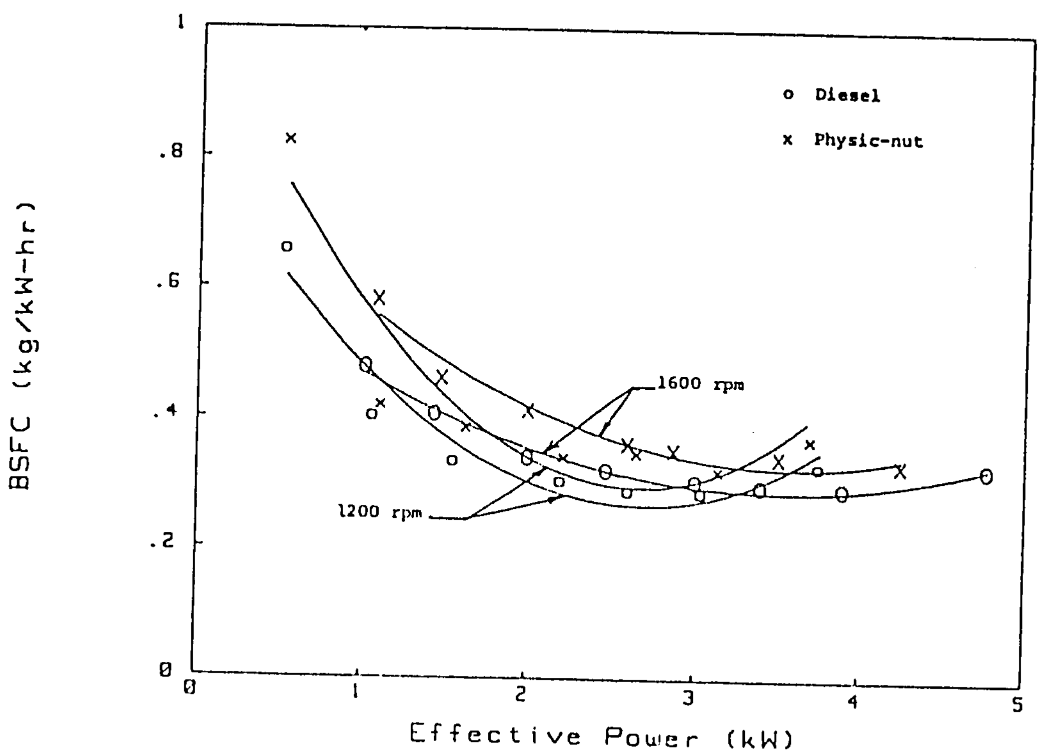


Figure 5.9 : Brake specific fuel consumption at varying loads.

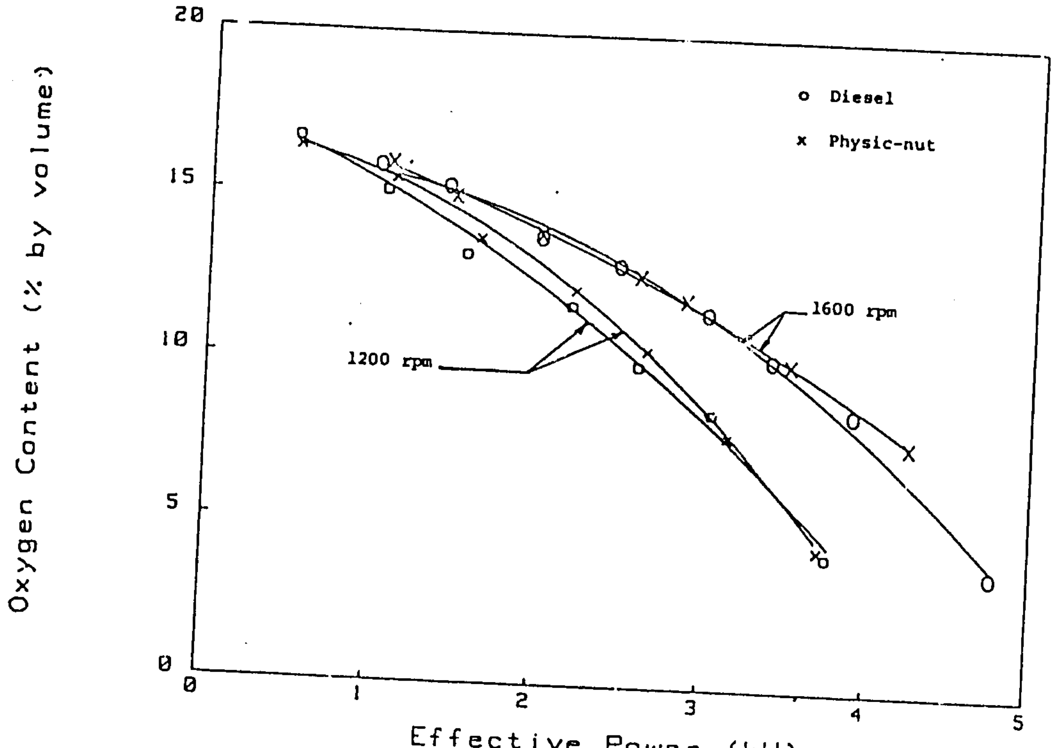


Figure 5.10 : Oxygen content in flue gas.

VI. ECONOMIC CONSIDERATIONS

Economics is the critical factor in considering whether the method of creating a controlled buffer area to inhibit the spread of salinization as described previously, should be implemented commercially. In the sections to follow, approximate analyses of the cost and berefits of such a project are discussed. The analyses are based on actual costs or cost estimates incurred for the establishment and maintenance of the experimental land-elevated buffer strip, and on projected values of land-use with and without the buffer strip.

A. Total installed cost

The total installed cost of the reclaimed area takes into account a number of items, including the following : land-forming, drainage and irrigation systems installation, boundary road, deep well, diesel pump, water tower. Note that the costs of the field store and greenhouse are excluded since they are not likely to be used in a commercial set-up. The costs of the above items, calculated on the basis of one 1600 m^2 plot are listed in table 6.1. The total investment amounts to \$ 17,390/1600 m^2 (or \$ 43,996/acre) which is rather high. Even when allowing for the benefits of economy of scale, say a 30% across-the-board discount on the cost items for a 40-acre strip, the figure of \$ 30,797/acre still appears on the high side, as compared to other soil reclaim methods such as the dike and ditch approach. However, the land-elevated approach used in this study cost less to operate and maintain and has many technical advantages over the dike and ditch approach, as will be pointed out in the following sections.

Firstly, a land-elevated buffer strip convering such a broad area has higher stability, hence less erosion, than does the presence of an earth dike along a ditch. Secondly, land formed with sub - drainage system and aquaduct restricts salinization and water logging through the improvement of soil permeability, which help accelerate the leaching of salt down through the soil profile to a desired depth and thus removing surface surface water following heavy rain. In contrast, the dam-ditch approach, because of surface treatment, permits the upward movement of the under ground water from the subsoil to be evaporated at the soil surface, hence increasing the likelyhood of surface salinization. In addition, with the presence of a highly compacted boundary road around the elevated land, it will not only facilitate on-farm handling of plant materials, fertilizers and equipment, but also prevents seepage and return flow of salty water flooding the other side of the buffer.

B. Operation and maintenance costs

Essentially, the O & M costs are the costs required to sustain the growth of physic-nut plants on the reclaimed soil. These are the water pumping costs (assuming the use of a diesel pump), irrigation labour, harvest labour and oil extraction costs. The total amounts to \$ 2,896/1600 m^2 (or \$ 4,856/acre) per annum. Again, allowing for economy of scale, say a 40-acre plot, by applying 30% discount for

Table 6.1: Cost estimates for land reclermation

	$US\$/1600\ m^2$	US$/acre
Land forming	7,735	19,570
Drainage system	1,415	3,580
Irrigation system	1,690	4,275
Boundary road	2,910	7,362
Deep well	1,000	2,530
Diesel pump	1,270	3,213
Water tower	1,200	3,036
Leaching	170	430
Total	17,390	43,996

Table 6.2: Annual operation and maintenance costs

	$US\$/1600\ m^2$	US$/acre
Water pumping :		
fuel	433	1,096
O & M	63	160
Labour		
irrigation & harvesting	1,200	2,400
oil extraction	1,200	1,200
Total	2,896	4,856

all items except fuel, the total O & M costs would be about $ 3,728/ acre per annum, or about 12% of installed cost.

C. Value of competing land uses

The original context of this study was the problem of competing land uses between bordering cropland owners and salt/shrimp farm owners with the land use of the latter causing soil salinization problem to the former. On the other hand, if productivity on the cropland are to be maintained salt/shrimp farming in the immediately vicinity must be halted. Therefore the gains and losses with and without the presence of the salinity-inhibiting buffer are evaluated as follows.

Scenario I :

In the absence of the buffer (ie, adopting the do-nothing approach) and allowing the destruction of the cropland throngh continued salt/ shrimp farming, the cropland productivity loss, calculated on the basis of loss of coconut production which is the most significant component of agricultural activity in the area as well as being the most severely affected by salinization (Thailand Institute of Scientific and Technological Research 1982), would be about $ 1,144.6/ acre per annum (Table 6.3).

Scenario II :

If, in the absence of the buffer, the cropland production were chosen in favour of the salt/shrimp farming, and the leatter activities were forced to be abandoned, the loss to shrimp-farm production, say, could be estimated at $ 605/acre, which appears more valuable than cropland production.

Scenario III :

With the presence of the buffer, the production activities on both sides of it can be allowed to continue. Furthermore, there would be an additional gain from the yield of physic-nut trees grown on the buffer strip. Assuming that the buffer is meant to salvage cropland production, and that a stretch of 100 m long by 40 m wide (ie 1 acre) buffer strip could have prevented the spread of salinization 500 m deep into the cropland, the area of the salvage cropland would be 12.5 acres. Therefore the salvaged value of the cropland would be $ 14,307/100 m stretch of buffer strip. At the same time, the gain due to physic-nut yield would be $ 1,113/100 m of buffer trip, assuming that the physic-nut oil could be sold at the same price as diesel fuel on heating value basis. Thus, the total gain can be estimated as follows (per 100 m of buffer strip)

value of coconut production saved	$ 14,307
+ value of physic-nut yield	$ 1,113
- O & M costs for the buffer	$ 3,728
Total gain (per annum)	$ 11,692

Using a simple payback period measure, the investment of $ 30,797 could be recouped in 2.6 years. Note that the above analysis is based on the total loss of production for the coconut plantation in the affected area, and that the accuracy of the analysis depends very much on the accurate prediction of the size of cropland affected. In conclusion, although the result of this cost-benefit analysis may sound attractive enough, the initial outlay is rather high for a coconut plantation owner. In view of the high cost involved in mechanised land-forming operations, it may be possible to reduce this cost by employing a more labour-intensive approach. Alternatively, the provincial authority may have to subsidise part of the investment cost or provide incentives conducive to such an investment, in view of the magnitude of the problem and of the fact the salinization is a result land by salt/shrimp farmers, not by the coconut plantation owners themselves.

Table 6.3 Estimation of yearly land-use values

Cropland (coconut plantation)

$$3{,}668.5\ \frac{\text{kg}}{\text{acre}} \times 0.312\ \frac{\$}{\text{kg}} = \$\ 1{,}144.6/\text{acre}$$

Shrimp farm

$$126\ \frac{\text{kg}}{\text{acre}} \times 4.8\ \frac{\$}{\text{kg}} = \$\ 604/\text{acre}$$

Buffer area (physic-nut oil production)

$$5\ \frac{\text{kg - nut}}{\text{tree}} \times 4{,}048\ \frac{\text{trees}}{\text{acre}} \times 0.21\ \frac{\text{kg - oil}}{\text{kg - nut}} \times$$

$$\frac{1}{0.91}\ \frac{\text{litre}}{\text{kg-oil}} \times 0.238\ \frac{\$}{\text{litre}}$$

$$= \$\ 1{,}113/\text{acre}$$

VII. USE OF WIND ENERGY AS A LOW-COST PUMPING SUBSTITUTE

As mentioned in Part I, wind energy has been widely used in and around Samutsongkram area for low-head water movements in the salt farms. For the purpose of pumping ground water, a high-head wind turbine is required. In this part of the report, the suitability of using such a wind turbine as a low-cost pumping system for the control of soil salinity is investigated. However, as there is a general lack of wind data for a reliable estimation of wind system parameters at the research province and in the coastal provinces as a whole, it was decided that an assessment of the statistical characteristics of the wind climate along the southern coastal area be made in conjunction with the wind-pumping system study.

The statistical analysis of the wind data took the form of autocorrelation of wind speeds over time in the coastal provinces, cross-correlation of wind speeds between provinces and the statistical distribution of the wind speeds recorded at the research site. The correlation studies were carried out to determine the seasonal variations, and dependencies of the various stations, with a view to explore the possibility of using long term wind records from a nearby weather station to predict the wind characteristics at a site where long term wind data does not exist. The wind-pumping system study included the design and performance testing of the system.

A. Correlation studies

The local wind climate is an important factor in the siting and design of wind systems. Unfortunately the records necessary for reliable estimation for wind system parameters exist for only relatively few long-established regional weather stations. In this case, siting and design of wind systems must rely heavily on short-term (e.g. one year) wind data collected at the proposed site. While such short-term data is certainly valuable for the said purpose, long-term records from an established weather station (or stations) near the site of interest may also be useful if it can be shown that there exists strong interdependence between the wind records at the station and the proposed site.

In order to determine the inter-site dependence of wind data, the magnitude of annual and monthly autocorrelation and spatial (inter - site) cross-correlations were investigated. In this study, wind data for 15 sites (10 from the south coast and 5 others which are outside the south-coast region but are in the proximity of the research site) are examined. These sites are shown on the map in figure 7.1 and their longtitudes and latitudes shown in table 7.1. Each of these sites has a 32-year period (1951-1982) record of monthly and annual wind speed data, their long-term mean speed being shown in table 7.2. Since the anemometer height varies from station to station, the wind speeds are converted to a common height of 10 m using a power law.

A plot of long term averaged wind speed of the month in figures 7.2 - 7.4 show three different trends of variation. This information together with geographical proximity of the sites then serve as the basis for grouping of these sites into three sub-groups of regional sites. The correlation groups are : Region I (CHB, DoM, HHN, KCB, STH), Region II (CHP, NST, PRC, RAN, SRT), Region III (NTW, PHK, SKL, TRA, PTN).

In figure 7.5, an example is shown of the time-history records of the monthly average wind speed data for a pair of stations, namely Prachuab Kirikhan (KCB) and Chumpon (CHP). Quantitatively, they indicate seasonal variation for each record and a relatively high degree of inter-site dependence. However, whether this correlation is really significant can only be judged in the light of their autocorrelation functions and the magnitude of the cross-correlation coefficients.

A.1 Autocorrelation

An important gvide to the properties of a time series is provided by a series of quantities called sample autocorrelation coefficients, which meausure the correlation between observations at different time - lags apart. These coefficients often provide insight into the probability model which generated the data.

Given N observation $x_1, \ldots\ldots\ldots\ldots, x_N$, on a discrete time series, such as monthly-averaged wind speed, we can find the correlation between observations at time-lag k apart, which is given by

$$R_{xx}(k) = \sum_{t=1}^{N-k} (s_t - \bar{x})(x_{t+k} - \bar{x}) \Big| \sum_{t=1}^{N} (x_t - \bar{x})^2 \qquad [7.1]$$

This is called the autocorrelation coefficient at lag k (see Chatfield, 1984, for example).

The time history records of the monthly wind speed averages, taken during a period of 13 years (1970-1982), at all the selected locations are shown in figures 7.6. Although all the records tend to exhibit some kind of seasonal variation, their definite periodicities are not immediately recognizable. Thus autocorrelation functions, R_{xx} of the sample records have been estimated and are shown in figure 7.7. It is interesting to note that in Region 1, distinctive positive and negative peaks are observed for Don Muang (DoM), and relatively less distinctive ones for Sattahip. This reflects the relatively regular nature of the wind speed fluctuations from the long term mean. For ChonBuri (CHB) and Hua Hin (HHN), the peaks at 12-month intervals are somewhat obscured by persistent positive R_{xx}, and large time shifts are required before R_{xx} values drop off significantly. Thus, they indicate the presence of a slowly varying (low-frequency) component, which may be characterised by annual mean winds in the time history records (see figure 7.6). The low frequency component of fluctuation may be thought of here as being superimposed on the more rapid (high-frequency), month-to-month variations. The absence of a dominant peak for the Kanchanaburi (DCB) data suggests an irregular pattern of monthly wind speed variation from year to year.

In Region II, the autocorrelation function for Prachuab (PRC) exihibits regular peaks at 12-month periods. The function for Nakorn-Srithammarat (NST) shows dominant peaks at 12-month periods, and smaller spikes are also evident at 6-month intervals from the dominant peaks. This indicates, as is confirmed by the time history record, that there are generally two high wind periods in a year, with the amplitude of one being considerably greater than the other. For the remaining stations, namely Cnumphon (CHP), Ranong (RAN) and Surathani (SRT), correlation function peaks are evident at 6-month intervals. Indeed, a plot of the long term climatic mean wind speeds of each month presented in figure 7.3 showed that high wind periods occurred twice yearly (June-August and December-January) for these stations. The absence of negative correlation function values for the time lags considered indicates the presence of low frequency fluctuation components typified by the data for HHN in Region I.

In Region III, definite periodicities at 12-month periods can be observed for all stations. However, the data for Phuket (PHK) and Pattani (PTN) showed emerging peaks at 6-month intervals from the dominant peaks as well, indicating the occurrence of two high wind periods in a year with the amplitude of one being higher than the other. The correlation function peaks are particularly distinctive for Songkhla (SKL), Trang (TRA) whose wind speed averages over each year appear to be nearly constant for the entire 13-year period (figure 7.6). Narathiwat (NTW) on the other hand, showed strong positive correlation over the time lags considered, which is consistent with the fact that its annual means are considerably lower in the latter years than in the beginning of its sample record (see figure 7.6). In other words, a low-frequency component of fluctuation is also present. Thus with the aid of the time history records and autocorrelation functions of monthly wind speed averages, it is possible to characterise, quantitatively, certain aspects of the nature of wind speed fluctuations for a given climatological station. For the cases considered above, it can be seen that there may be four distinct type of fluctuation characteristics :

a. regular variations, at 12-month periods, about a mean value which is almost constant over a long term (DOM SKL, TRA)

b. regular variations, at 12-month periods, together with low-frequency components, (CHB, STH, HHN, PRC, NST, PHK, NTW)

c. regular variations, at 6-month periods, together with low-frequency components, (CHP, RAN, SRT)

d. almost irregular variations (KCB)

A.2 Cross-correlation functi

A measure of the correlation between two time series is the cross - correlation function. With N pairs of observations $\{(x_i, y_i); i=1$ to $N\}$ or "realizations" on two time series, the sample cross - correlation function is

$$R_{xy}(k) = \frac{1}{N} \sum_{t=1}^{N-k} (x_t - \bar{x})(y_{t+k} - \bar{y}) \Big/ \Big[\sum_{t=1}^{N} (x_t - \bar{x})^2 (y_t - \bar{y})^2 \Big]^{\frac{1}{2}} \quad [7.2]$$

where k is the time lag

Cross-correlation functions, R_{xy}, of the monthly wind speed deviations from a long term mean (in this case, a 13-year mean) were estimated for each pair of stations within a regional group. The results are shown in table 7.3 and figure 7.8.

In Region I, only 3 out of the 10 station-pairs are found to have significant correlations. These are KCB-STH, DOM-STH, and CHB-HHN which has the highest R_{xy} (0) value at 0.73. However, the seemingly strong correlations for the KCB-STH pair may be misleading since the two stations were shown to have independent autocorrelation patterns. Therefore, this strong indication of relationship between the two stations may have been caused by the presence of significant autocorrelations within one of the time series, in this case, STH.

In Region II, 6 out of the 10 station-pairs appear to have significant correlations, with R_{xy} (0) values ranging from 0.56 to 0.77. These station pairs are CHP-RAN, CHP-SRT, CHP-NST, RAN-SRT, RAN-NST, and SRT-NST. The wind speed record for PRC does not correlate well with any of the stations in the same regional group (R_{xy}(0) ranges from 0.26 to 0.35), which is consistent with the fact that its autocorrelation function is significantly different from those of other stations.

In Region III, 5 out of the 10 station-pairs showed significant cross-correlation with $R_{xy}(0)$ values ranging from 0.50 to 0.86. The strongest correlation is between the SKL-TRA pair, which are located at 110 km apart. The correlations between PHK with all the other stations in the region are not significant ($R_{xy}(0)$ values range from 0.32 to 0.49), since the autocorrelation function for PHK was seen to be significantly different from those for the rest of the stations. We also note in passing that the correlation between PTN and NTW is not significant ($R_{xy}(0) = 0.45$) despite their relative proximity(73 km).

The cross-correlation coefficients $R_{xy}(0)$ for the various station pairs are listed in table 7.3 along with the separation distance between them. When these values are plotted in figure 7.9, it reveals that there is a tendency for the correlation coefficient to increase at shorter separation distance between stations in Regions II and III but not in Region I. Thus, contrary to our expectations, a short separation distance between two stations does not always ensure a high correlation coefficient. For the purpose of identifying similarities of wind speed fluctuation characteristics between one station and another, it would then be necessary to make correlation studies for a number of neighboring stations.

B. <u>Short-term to long-term wind data conversion</u>

As will be shown later in this section, the wind data obtained for a site over a short term, say one year, could be substantially different ...

from its long term climatic mean. To enable one to assess the long term availability of wind energy at a particular site, it is then necessary to convert the measured short term wind data to estimate the long term mean wind. A few methods are available for making such an estimation (Justus et. al., 1979). Here, a variant of Corotis' (1978) "method of differences" is proposed. The conversion technique predicts, for a given site, the long term mean wind speed of the month and the long term climatic mean by using the short term wind data obtained for that site in conjunction with the short and long term data obtained for a nearby climatological station which has shown to have significant correlation with the site. The conversion formular is given as

$$\bar{V}_m = V_m + (\bar{V}_{m_c} - V_{m_c})\ \sigma_m / \sigma_{m_c} \qquad [7.3]$$

where $\bar{V}_m$ is the desired long-term mean wind speed for month m at the site, V_m the observed monthly mean wind speed for month m for the one - year that short-term data was recorded at the site, $\bar{V}_{m_c}$ the long-term mean wind speed for month m at the nearby climatological station, V_{m_c} the short-term monthly mean wind speed at the climatological station (corresponding to V_m at the site), σ_m^2 and $\sigma_{m_c}^2$ the variances of the mean wind speeds for month m at the site and the climatological station respectively. Whilst the Corotis method takes into account the cross - correlation coefficient (R_{xy}) by multiplying the correction term (the second term on the right of equation (7.3) with R_{xy}, the present method does not. This is because the degree of correlation does not in any way indicate that the amplitude of wind speed fluctuation at the site is greater or smaller than that at the climatological station.

When equation (7.3) is used to estimate the long-term mean wind speed for a given site, the only known variable at that site is the short-term monthly mean wind speed V_m, whereas the variance σ_m^2 remains an unknown. It is then necessary to obtain an estimate of σ_m. This was achieved by correlating the values of the coefficient of variation $(\sigma_m/\bar{V}_m)$ (table 7.4) against $\bar{V}_m$ for a given regional grouping. Using the least square analysis procedure, the regression coefficients (a and b) for each month can be obtained (see table 7.4), so that the coefficient of variation may be estimated in terms of $\bar{V}_m$ through the relation

$$\sigma_m/\bar{V}_m = a + b\bar{V}_m \qquad [7.4]$$

When this equation is substituted in equation 7.3 for σ_m, a quadratic equation which can be solved for $\bar{V}_m$ explicitly results. That is,

$$\bar{V}_m = V_m + (\bar{V}_{m_c} - V_{m_c})(a + b\bar{V}_m)\bar{V}_m/\sigma_{m_c} \qquad [7.5]$$

Examples of application of the above technique are illustrated in table 7.5. Station pairs with high cross-correlation coefficients were selected from each regional group. The short-term data for all cases are for the year 1982, while the long-term data are for 1970-

1982. Data conversion tests were carried out firstly by using the measured (or known) σ_m (equation (7.3), and secondly by using the estimated σ_m (equation (7.4)).

The results show that, by applying equation (7.4), the average discrepancy (Δ_1 average) of the estimated long-term monthly mean wind speed from that of the measured long-term monthly mean is within 20% if the data for NTW-PTN whose cross correlation coefficient is only 0.45, is discarded. The average among these 7 station pairs (excluding NTW-PTN) of the above discrepancy is 14.9%, whereas the average discrepancy of the measured short-term monthly mean from the measured long-term mean (Δ) is 25.1%. When equation (7.3), which requires the knowledge of true σ_m at the site, was used, the resultant average discrepancy is 11.2%, representing an improvement over the used equation (7.4) by only 3.7%.

When each category of the monthly mean wind speeds in table 7.5 are averaged over the 12-month period, it becomes the annual mean. Table 7.6 shown these annual averages together with their discrepancies. It can be seen that the average discrepancy of measured short-term annual mean wind speed from the long-term annual mean is 23.8%, while that of the estimated long-term annual mean is only 6.4%.

Thus considering the highly fluctuating nature of wind speeds, the above results serve to demonstrate that the proposed wind data conversion technique may be useful in reconciling the short-term data with the long-term one.

C. On-site measurement of wind speeds

Smutsongkram is one province where neither the Meteorology Department nor the local provincial authority maintains a wind speed record. In order to determine the statistical characteristics of the wind climate in this area, hourly averaged wind speeds over a one-year period were recorded at the research site.

C.1 Instrumentation

Since the research station is remote from the Institute, a recorder capable of forming time-averaged wind speeds and storing data in a cassette-tape recorder is needed. A Weathertronics M 800 data acquisition system was procured for this purpose. The system consists of wind speed, direction, temperature and humidity sensors; a micro-processor based data logger; a cassette tape recorder and printer. The wind direction sensor is a counter-balanced vane which moves a wiper on a plastic potentiometer, while the wind speed sensor is a 3-cup (poly-carbonate plastics) anemometer assembly which drives an AC generator producing an output of 10 VAC at 45 m/sec (figure 7.10) An electronic hygrometric circuit element senses changes in relative humidity in the range of 0 to 100%. The temperature sensor is a thermistor with a measuring range of -35° to 55°C. Both the temperature and humidity sensor are housed in a radiation shield which protects the sensors from solar effects while assuring adequate air circulation through the sensing area.

The microprocessor-based data logger operates on its own internal battery pack 24 hours a day, sampling the signals at programmed intervals from the four sensors and converting all information into engineering units. It will then calculate averages, maximums, degree growing days, time of event, etc, from a range of selected output data programs. All this is done by a microprocessor with a programmable memory and analog electronics that provide computing power. A control panel and a casstte tape recorder provide the necessary means for programming and recording data. The unit can display the stored measurements directly on the digital readout (LCD) of the control panel or transfer stored data at selected intervals to a cassette tape recorder or a printer (figure 7.11). The system was initially installed for trial runs at the Institute, and later installed at the research site in July 1984 and left unattended except for periodical checks on battery voltage level and changing of tapes which can store approximately 8000 data points per cassette. At the research site, the sensors were located on top of the water storage tower at 7.2 m above ground, while the data-logger itself was installed inside the storage building in an obscured view to avoid burglary. There is, however, a minor problem in the handling of data stored in the cassette recorder. Since the data are transmitted from the data - logger to the recorder serially in the form of standard asynchronous ASCII code, appropriate means to transfer the data to a microcompute has to be developed to enable data processing and analyses on a computer. The necessary interfacing circuitry was worked out with the staff members of the Electrical Engineering Department, and its details are illustrated below.

The objective is to convert the serial output signal from the cassette tape (figure 7.12a) into the ASCII character format (figure 7.12b) through a demodulator circuit. This is done by firstly rectifying the distorted signal output from the recorder (figure 7.13a) to give square pulse signal (figure 7.12b) using an invertor gate (see detailed circuitry in (figure 7.14). The resulting square pulse signal is then used to obtain a constant with square pulse signal (igure 7.13c) through a monostable trigger. Through a D-flip-flop device, this latter signal can be used to generate pulses as shown in figure 7.13d, which indicate the presence of 1's in the original signal waveform. Subsequent processing of the signal, which puts the pulsewidth to be nearly equal to the baud rate of the incoming cassett signal (figure 7.13c), and applying appropriate shift register (figure 7.13f,g) ensures that the output signal is in accordance with the ASCII character format and that it is synchronized with the incoming signal. However, the resulting signal is in 0 and 5 volts which needs to be modified to give + 12V (high) and -12V (low) so that it is compatible with the standard RS232C interface used for microcomputers.

C.2 Data collection

Although the data acquisition system described above could be used to record hourly averaged wind speed, wind direction, temperature and relative humidity, of which sample results are shown in figure 7.15-7.17, Only the former two data types were recorded for the entire year. This is because the recording of all four data types would produce too many data points, which would then necessitate a very frequent change over of the cassette tape and create data handling difficulties when transfered to a microcompater.

Field recording of the wind data actually commenced in Movember 1984. However, the recording was interrupted during the May-July 1985, due to mulfunctioning of the outputing RAM of the data logger. Consequently, a new one-year cycle data recording had to reinitiated, beginning August 1985 to July 1986. Even with this new cycle, four short-term interruptions of no more than one week each were also encounterred due to battery failures, and memory overflow on the cassette tape.

C.3 Statistical analysis

It is well known that the wind speed fluctuations at a given site can be satisfactorily represented by a statistical model called "Weibull distribution", expressed as

$$F(V) = 1 - \exp\left(-(V/c)^k\right), \qquad [7.5]$$

where F(V) is the cumulative distribution function of the wind speed V; c and k are parameters determined to best fit the given data set (See Hennessey, 1977 for example). The frequency distribution function corresponding to the above is given by

$$f(V) = (k/c)(V/c)^{k-1} \exp\left(-(V/c)^k\right). \qquad [7.6]$$

The shape of this distribution is determined primarily by the dimensionless factor k, while the scale factor c which has the dimensions of velocity, indicates approximately the magnitude of the mean value of the data set.

It can be shown that the parameter c is related to the mean wind speed as follows,

$$\bar{V} = c\Gamma\ (1+1/k) \qquad [7.7]$$

where Γ is the gamma function.

For a given wind data set, -say the hourly wind speed record of a given season, a method exists for testing whether the data could "reasonably" be represented by a Weibull model. The testing involves the use of a probability graph paper with a suitably distorted vertical scale, so that the measured cumulative distribution curve can be made to plot as a straight line if the data are sufficiently close to allow the use of the Weibull model. However, when the data set is large, the manual sorting and plotting of data becomes a tedious task. On the other hand, the testing can be handled by a computer with ease. In this case, equation (7.5) is rearranged to give

$$\log_{10}[-\ln(1-F(V))] = k\ \log_{10} V - k\log_{10} C. \qquad [7.8]$$

By plotting values of $\log_{10}$ [-ln(1-F(V))] on the vertical axis against values of $\log_{10}$ V on the horizontal axis from a sorted data set, a straight line would be obtained if the data set did conform to the Weibull model. Hence the value of parameter k can be obtained as the slope of the stra d that of paramenter c obtained as the intercept on the vertical axis.

The wind data obtained at the research site are divided into four three-mont seasons, namely August-October, November-January, February-April and May-July. A histogram plot of the velocity frequency distributions revealed that the number of occurences of calm periods is high for all the four seasons observed. Since this phenomena does not fit the Weibull function, the cumulative frequency distribution F (V) were evaluated with the occurrences of calm ($V < 0.25$ m/sec) omitted. Figure 7.18 to 7.21 show the plot of values of $\log_{10}$ [-ln (1-F(V))] against $\log_{10}$ V for each of the observed seasons. It can be seen that straight lines fit reasonably well with the observed data points. The parameters k and c were then determined by the method described in the previous section, and the results are listed in table 7.7. The k values lie between 1.81-2.17 which indicate that the distributions are relatively steady. The c values range from 2.73 to 3.68 m/sec.

Using equation (7.7), the mean wind speed $\overline{V}$ (excluding the calm periods) can be calculated. The c values are seen to be greater than the estimated mean by approximately 13%

When the calm periods are taken into account, the calculated mean wind speeds have to be adjusted accordingly (table 7.8). They are seen to differ from the measured mean speed by no more than 11% figures 7.22-7.25 show the Weibull distribution curves obtained from equation (7.6) using the k and c values determined above. They are seen plotted over their respective histograms of the seasonal wind data set. They indicate that the most probable speeds are between 2 to 3 m/sec. for all four seasons, and that the speeds rarely exceeded 10 m/sec. When combined with the power performance curve of a given wind system, these distribution curves can be used to generate the energy availability of the system for each of the designated seasons. This will be discussed in section D

D. Windmill design and performance

The original context of the present project-proposed at a time (1983) when oil price was running at its peak, was the potential for replacing a fraction of the imported oil by renewable energy sources, with the focus here on wind energy as a low-cost water pumping substitute in soil salinity control. Thus, based on the water requirement for a 40-acre plot, the investment capital of a wind-pumping system was then estimated to be 5 times the cost of a diesel pump or 24 times that of an electric pump; and the pay off was to be 11.9 and 4.8 years respectively. The wind system was chosen in favour of a diesel pump, despite the economic advantage of the latter, as an experimental study to explore its feasibility so that we may be better prepared in case oil prices further escalates. Seen in this light the exploration for alternatives and dissemination of results is still relevant, though at much reduced urgency, following the dramatic decline in oil prices in 1986.

We therefore present here a description of the wind system design and an evaluation of its performance.

D.1 Windmill design

Locally constructed horizontal axis wind mills have been used for lifting water in Thailand for many years (Excell et al, 1981; NEA, 1984). Particulary along the coastal provinces of Smutsongkram, low speed wind-mills with bamboo matting sail rotor have been used extensively for lifting sea water in salt farms. This type of windmills suffer from the disadvantages of having low pumping head and fixed rotor axis in the direction of the prevailing wind. For the purpose of leaching saline soil, fresh water must be pumped from wells to a storage tank above the ground level. This then requires a windmill with higher pumping head and better performance than that of the traditional sail rotor type. Multiblade steel windmills are becoming increasingly popular for for pumping water in many parts of the world including Thailand. They have the advantage of being self-starting at low wind speed and self adjusting to face the prevailing wind direction. The rotor can also be mounted on a tower high above the ground to capitalize on the higher wind speed. They have also been demonstrated to be capable of lifting water at high heads. In view of these advantage, multiblade windmill design have been chosen to perform the task/of water pumping in this project.

Initially it was planned that a windmill be constructed for pumping rain water from a shallow well for soil leaching and irrigation, and another wind-mill for pumping groundwater from a deep well to augment rain water shortage in the dry season. However, the salinity of the shallow well water turned out to be too excessive. Therefore it was decided to construct two windmills for groundwater pumping.

Two steel multiblade windmills of 4.35 m diameter (18 blades) were constructed and installed using solely student labour, at a cost of approximately $ 2,200 each. The centre of the turbine is locate at approximately 9 m from the ground. Each windmill drives a piston pump of 7.62 cm (3 inch) bore and 10.2 cm (4 inch) stroke, drawing water from a well bored 80 m deep. The water table was found to be approximately 12 m below surface. The underlying assumptions for the windmill design were the following :

1. Leaching requirement of 2,070 m^3 to be fulfilled within a time span of one year (for two 1600 m^3 plots).
2. A design water flow rate of 0.5 m^3/hr for each windmill as a result of (1).
3. A static lift of 20 m.
4. Average windspeed at 3 m/sec.
5. System efficiency at 10%

The installed system is as shown in figure 7.26.

D.2 Performance analysis

Field measurements were carried out to determine the overall preformance characteristics of the wind turbine-water pumping system. The measured data include the rotational speed of the turbine and the water flow rate at different wind speeds. The results are tabulated in table 7.9. Due to its fluctuating nature, the measured wind speeds are five-minute averages of wind speeds sampled at 10 seconds intervals. Similarly, the water flow rate and turbine rotational speed were averaged over five-minute intervals from totalizing meter readings. The data obtained were limited to a very narrow wind speed range of 2.64 to 4.98 m/sec. The measured speed of rotation for the 4.35 m diameter wind turbine varied from 35.1 to 62.0 rpm which is typical of a low speed wind device. The water discharge rate from the pump ranges from 10.8 to 18.0 litre/min. A plot of the pump output versus wind speed is shown in figure 7.27 which exhibit a rising trend for the pump output (water flow rate) as the wind speed increases. Curve fitting using simple linear regression yielded the following quation :

$$Q = 6.1 + 2.14 V \qquad [7.9]$$

where Q is pump discharge in l/min and V, mind speed in m/sec. The scatter of the data could be attributed mainly to the fact that the averaging process fails to account for the fluctuating strength contained in the wind speed and that, due to the high inertia of the system, there is a considerable time lag between the wind energy input and the pump output. The power coefficient (C_p) of the system was calculated as the ratio of the actual power output of the system (P_a) to the available power in the wind at a given wind speed (P_w). That is

$$C_p = P_a/P_w \qquad [7.10]$$

$$P_w = \tfrac{1}{2}\,\rho_a \overline{V}^3 A$$

$$P_a \cong \rho_w g Q H$$

where ρ_a = air density

$\overline{V}$ = average wind speed

A = turbine area

ρ_w = water density

Q = water flow rate

H = Total dynamic head

These results are also tabulated in table 7.9 and plotted against wind speed in figure 7.28. It is seen that the power coefficient varies from 0.05 to 0.19 for the range of wind speed measured, and that the the value decrease as the wind peed increases.

In order to find out whether the wind pump system having the performance characteristics as described above is capable of delivering sufficient quantity of water to meet the soil-leaching and irrigation requirements, the seasonal-total water discharge from the pumps were simulated. The simulation procedure involves the use of equation (7.9) the system performance curve as the modeling equation, with the wind speed probability distribution functions presented in section ? as input. The output is a series curves showing the simulated seasonal pump discharge (or energy) as a function of wind speed (figures 7.29(a)-(d)). It should be noted that in using equation (7.9), the cut-in and cut-out (or rated) speeds of the windmill must be specified. In this case, the speeds are 2 and 10 m/s respectively. Since the calculation involved were lengthy, a general purpose computer program package was developed to perform the necessary data analysis on an IBM-PC computer (Rojanavitsakul and Treevaree, 1986). The user only needs to input the raw wind speed data of a particular location and to specify the performance characteristics of a particular wind-pump system, the corresponding Weibull distribution curve as well as the expected wind energy or pump discharge output will the be graphed on either the monitor or printer.

The simulated pump discharge for the four seasons are 829 m^2 for February-April, 566 m^3 for May-June, 390 m^3 for August-October and 569 m^3 (November-January). The highest discharge is during summer (Feb-Apr.) when there is a strong southerly (or locally known as "kite-flying") wind.

As pointed out in Part IV, the average water requirements for irragating and leaching the saline soil were set at 6.88 m^3 per day (or 1255 m^3 per six months) and 4.38 m^3 per day (or 800 m^3 for the six month leaching period) per one 1600 m^2 plot respectively. If we take the dry periods (Nov-Jan and Feb-Apr), the expected output from one windmill would be 1398 m^3 which matches the 1255 m^3 required. However, due to the fluctuating nature of the wind coupled with the existence of high percentage of calm periods (about 30% on the average), the windmill cannot be relied upon to deliver the daily regulated amount of water in a consistent manner, unless there is a large water storage tank. This then casts doubt on the suitability of using wind energy as a low-cost pumping substitute for irrigating plants grown on saline soil.

E. Failures

The performance of the installed wind-pump system was flawed by several unfortunate and sometimes uncalled for incidents. Firstly, the investigator was unable to get the colleague in charge of windmill manufacture, who in turn was unable to rally the student labour as he wished to deliver the goods on schedule. Secondly, the installation of the windmills was delayed because the local constractor who was supposed to lay the foundation for the windmills and install the water storage tower abandoned the work. Thirdly, there were a series of defects in the windmill itself partly due to design and partly due to poor worksmanship. For instance, the over-speed control device had to be modified twice to bring the system to automatically "turn-off" at a wind speed of 10 m/sec. Misalignement of shafts in the gearbox and excessive deflection of the stoking shaft connecting the transmission and the piston pump were found and had to be rectified. Consequently, when the service of the windmills was called for, the system was not yet ready. It was then decided to switch over to using a diesel-engine driven air-lift pump as discussed in section D of Part II. One other problem of the installation, though not directly related to the running of the windmill, was the excessive salt spray attack on the blade attachments. Alternative materials may have ot be considered in future designs for greater dependability.

TABLE 7.1

List of Sites and Site codes with their Latitude and Longitude

REGION	CODE	STATION	LAT (N)	LON (E)
	CHB	CHONBURI	13°22'	100°59'
	DOM	DON-MUANG	13°55'	100°36'
I	HHN	HUAHIN	12°35'	99°57'
	KCB	KANCHANABURI	14°01'	99°32'
	STH	SATTAHIP	12°41'	101°01'
	CHP	CHUMPON	10°29'	99°11'
	NST	NAKORN SI	08°28'	99°58'
II	PRC	PRACHUAB	11°48'	99°48'
	RAN	RANONG	09°58'	98°38'
	SRT	SURAT THANI	09°07'	99°21'
	NTW	NARATHIWAT	06°25'	101°49'
III	PHK	PHUKET	07°53'	98°24'
	SKL	SONGKHLA	07°12'	100°36'
	TRA	TRANG	07°31'	99°38'
	PTN	PATTANI	06°47'	101°10'

TABLE 7.2

Anemometer Height (Z), Mean Wind Speed ($\bar{V}$) at 10 m height*, Years Recorded, Number of Years (n) for Interannual Variability.

REGION	STATION	Z (M)	$\bar{V}$(m/s)	YEARS	n
	CHB	13.45	2.8	51-82	32
	DOM	5.00	3.8	51-82	32
I	HHN	13.48	2.4	51-82	32
	KCB	15.00	1.8	51-82	32
	STH	3.88	4.4	51-82	32
	CHP	12.10	2.5	51-82	32
	NST	14.50	2.1	81-82	32
II	PRC	11.50	3.2	51-82	32
	RAN	10.20	2.5	51-82	32
	SRT	14.50	1.4	51-82	32
	NTW	12.50	2.5	51-82	32
III	PHK	10.50	2.2	51-82	32
	SKL	18.00	3.5	51-82	32
	TRA	11.15	2.3	51-82	32
	PTN	27.00	1.9	51-82	32

* The mean wind speeds at 10m. height were obtained by the relation $\bar{V} = \bar{V}_z\ (10/Z)^{0.2}$, where $\bar{V}_z$ is the mean wind speed actually recorded at the anemometer height.

TABLE 7.3 Cross - Correlation Coefficients (R_{xy}) for various site pairs.

	Site - pair	Separation distance (Km)	R_{xy}
Region I	DOM - HHN	135	0.01
	DOM - KCB	150	0.30
	DOM - CHB	62	0.14
	DOM - STH	112	0.49
	HHN - KCB	95	0.39
	HHN - CHB	140	0.73
	HHN - STH	103	0.10
	KCB - CHB	157	0.49
	KCB - STH	187	0.54
	CHB - STH	75	0.42
Region II	PRC - CHP	146	0.35
	PRC - RAN	224	0.29
	PRC - SRT	284	0.28
	PRC - NST	338	0.26
	CHP - RAN	82	0.69
	CHP - SRT	148	0.75
	CHP - NST	217	0.56
	RAN - SRT	123	0.74
	RAN - NST	202	0.77
	SRT - NST	82	0.62
Region III	PHK - TRA	142	0.48
	PHK - SKL	252	0.49
	PHK - PTN	316	0.39
	PHK - NTW	400	0.32
	TRA - SKL	110	0.86
	TRA - PTN	174	0.67
	TRA - NTW	245	0.50
	SKL - PTN	67	0.66
	SKL - NTW	140	0.57
	PTN - NTW	73	0.45

TABLE 7.4 Coefficient of Variation and its regression analysis.

Region I

Coefficient of Variation

$\sigma_m / \overline{V}_m$

Site	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
KCB	0.34	0.25	0.20	0.25	0.35	0.31	0.25	0.24	0.35	0.42	0.37	0.29	0.30
DOM	0.30	0.28	0.22	0.29	0.36	0.27	0.27	0.28	0.34	0.40	0.32	0.43	0.31
CHB	0.32	0.20	0.21	0.23	0.31	0.30	0.35	0.26	0.29	0.36	0.33	0.25	0.28
STH	0.22	0.25	0.26	0.28	0.37	0.33	0.42	0.32	0.28	0.37	0.30	0.3[illegible]	0.32
HHN	0.40	0.27	0.20	0.27	0.37	0.34	0.32	0.34	0.34	0.39	0.31	0.35	0.30
Avg.	0.32	0.25	0.22	0.26	0.35	0.31	0.32	0.29	0.32	0.38	0.33	0.34	0.30

Regression Coefficient

a	0.34	0.24	0.15	0.22	0.30	0.26	0.16	0.22	0.40	0.44	0.39	0.37
b	-.01	0.00	0.03	0.02	0.02	0.02	0.07	0.03	-0.05	-0.04	-0.03	0.01

TABLE 7.4 (Cont'd)

Region II

Coefficient of Variation

$\sigma_m / \overline{V}_m$

Site	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
PRC	0.20	0.12	0.18	0.18	0.24	0.14	0.11	0.18	0.19	0.35	0.26	0.22	0.18
CHP	0.22	0.15	0.20	0.19	0.34	0.34	0.29	0.27	0.25	0.32	0.32	0.25	0.26
RAN	0.50	0.39	0.36	0.44	0.41	0.37	0.42	0.24	0.32	0.62	0.49	0.32	0.37
SRT	0.28	0.20	0.22	0.27	0.42	0.33	0.23	0.26	0.26	0.38	0.41	0.34	0.33
NST	0.51	0.34	0.34	0.37	0.33	0.32	0.34	0.34	0.40	0.54	0.67	0.60	0.42
KSM	0.30	0.29	0.30	0.25	0.33	0.26	0.30	0.26	0.19	0.30	0.38	0.32	0.26
Avg.	0.33	0.25	0.27	0.28	0.35	0.29	0.30	0.26	0.27	0.42	0.42	0.34	0.30

Regression coefficients

a	0.47	0.27	0.32	0.47	0.51	0.47	0.48	0.33	0.41	0.59	.62	0.47	
b	-0.07	-.01	-.02	-.10	-.09	-.08	-.08	-.03	-.08	-.12	-.11	-.06	

TABLE 7.4 Coefficient of variation and its regression

Region III

Coefficient of Variation

$\sigma_m/\overline{V}_m$

Site	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average
PHK	0.28	0.26	0.24	0.28	0.27	0.29	0.30	0.36	0.34	0.33	0.32	0.26	0.29
SKL	0.09	0.15	0.17	0.15	0.18	0.20	0.20	0.22	0.16	0.19	0.17	0.10	0.17
TRA	0.25	0.23	0.31	0.36	0.38	0.27	0.31	0.38	0.21	0.31	0.31	0.18	0.29
NTW	0.36	0.25	0.26	0.31	0.38	0.43	0.44	0.44	0.42	0.47	0.44	0.29	0.37
PTN	0.18	0.21	0.19	0.27	0.32	0.30	0.34	0.24	0.28	0.34	0.29	0.13	0.26
Avg.	0.23	0.22	0.23	0.27	0.30	0.30	0.32	0.33	0.28	0.32	0.31	0.19	0.28

Regression Coefficient

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
a	0.48	0.34	0.33	0.43	0.45	0.43	0.46	0.59	0.41	0.47	0.52	0.39
b	-0.08	-0.04	-0.04	-0.07	-0.08	-0.07	-0.07	-0.12	-0.06	-0.08	-0.10	-0.06

TABLE 7.5 Short - term to long - term conversion data

Region I Base station : CHB

Conversion station : KCB

Cross - correlation coefficient = 0.49, separation distance = 157 Km

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg.
$\overline{V}_m$	(m/s)	1.08	1.32	1.53	1.55	1.62	1.58	1.61	1.65	1.24	1.04	1.36	1.45	1.42
V_m	(m/s)	0.72	1.13	1.23	1.44	1.54	1.54	1.70	1.49	1.29	0.82	0.82	1.08	1.23
Δ	(%)	-33.3	-14.4	-19.6	-7.1	-4.9	-2.5	5.6	-9.7	4.0	-21.1	-39.7	-25.5	15.6
$(V_m)_1$	(m/s)	1.00	1.23	1.00	1.94	2.08	1.77	1.84	1.88	1.30	1.35	1.47	1.45	1.53
Δ_1	(%)	-7.4	-7.3	-34.6	25.2	28.4	12.0	14.3	13.9	4.8	29.8	8.1	0.0	15.5
$(V_m)_2$	(m/s)	0.96	1.22	1.08	1.80	2.26	1.79	1.89	2.00	1.46	1.50	1.47	1.64	1.59
Δ_2	(%)	-11.1	-7.6	-29.4	13.9	39.5	13.3	17.4	21.2	15.1	44.2	8.1	13.1	19.5

TABLE 7.5 Short - term to long - term conversion data

Region I Base station : CHB

Conversion station : HHN

Cross - correlation coefficient = 0.73, Separation distance = 140 Km.

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg.
$\overline{V}_m$	(m/s)	2.20	2.43	2.79	2.50	2.21	2.24	2.16	1.97	1.56	1.85	2.51	2.49	2.24
V_m	(m/s)	1.44	2.21	2.67	1.54	1.49	1.95	1.80	1.44	1.23	1.08	1.34	2.16	2.01
Δ	(%)	-34.5	-9.1	-4.3	-38.4	-32.6	-12.9	-16.7	-26.9	-21.1	-41.6	-46.6	-13.2	27.3
$(\overline{V}_m)_1$	(m/s)	2.10	2.42	2.25	2.37	2.26	2.31	2.04	2.10	1.24	1.95	2.35	2.94	2.19
Δ_1	(%)	-4.5	0.0	-19.3	-5.2	2.3	3.1	-5.6	6.6	-20.5	5.4	-6.4	18.1	8.1
$(\overline{V}_m)_2$	(m/s)	1.91	2.39	2.29	2.31	2.20	2.28	2.01	1.98	1.24	1.91	2.28	3.20	2.17
Δ_2	(%)	-13.2	-1.6	-17.9	-7.6	0.0	1.8	-7.9	0.0	-20.5	3.2	-9.2	28.5	9.3.

$\overline{V}_m$ = Recorded Long - term mean wind speed for month m

V_m = Recorded Short - term mean wind speed for month m

Δ = $(V_m - \overline{V}_m)/\overline{V}_m$

$(\overline{V}_m)_1$ = Estimated long - term mean wind speed for month m using equation (1)

Δ_1 = $\{(\overline{V}_m)_1 - \overline{V}_m\}/\overline{V}_m$

$(\overline{V}_m)_2$ = Estimated long - term mean wind speed for month m using equation (2)

Δ_2 = $\{(\overline{V}_m)_2 - \overline{V}_m\}/\overline{V}_m$

TABLE 7.5 Short - term to long - term conversion data

Region II Base station : CHP

Conversion station : RAN

Cross - correlation coefficient = 0.69, Separation distance = 82 km.

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg.
$\overline{V}_m$	(m/s)	1.59	1.40	1.40	1.36	1.43	1.95	1.80	1.84	1.43	1.06	1.23	1.84	1.53
$\dot{V}_m$	(m/s)	1.13	0.93	0.93	0.77	0.72	1.80	1.34	1.29	1.39	0.41	0.41	1.34	1.04
Δ	(%)	-28.9	-33.6	-33.6	-43.4	-49.7	-7.7	-25.6	-29.9	-2.8	-61.3	-66.7	-27.2	34.2
$(\overline{V}_m)_1$	(m/s)	2.26	1.76	1.57	1.42	1.44	2.26	1.90	1.79	1.81	1.40	1.18	1.64	1.54
Δ_1	(%)	42.1	25.7	12.1	4.4	0.0	15.9	5.5	-2.7	26.6	34.0	-4.1	-10.9	15.3
$(\overline{V}_m)_2$	(m/s)	2.09	1.52	1.48	1.24	1.37	2.22	1.77	1.87	1.82	1.22	1.13	1.65	1.62
Δ_2	(%)	31.4	7.9	5.7	8.8	4.2	3.4	-1.7	1.6	27.3	15.1	-8.1	-10.3	10.5

TABLE 7.5 Short - term to long - term conversion data

Region II Base station : CHP

Conversion station : RAN

Cross - correlation coefficient = 0.69, Separation distance = 82 km.

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg.
$\overline{V}_m$	(m/s)	1.59	1.40	1.40	1.36	1.43	1.95	1.80	1.84	1.43	1.06	1.23	1.84	1.53
$\hat{V}_m$	(m/s)	1.13	0.93	0.93	0.77	0.72	1.80	1.34	1.29	1.39	0.41	0.41	1.34	1.04
Δ	(%)	-28.9	-33.6	-33.6	-43.4	-49.7	-7.7	-25.6	-29.9	-2.8	-61.3	-66.7	-27.2	34.2
$(\overline{V}_m)_1$	(m/s)	2.26	1.76	1.57	1.42	1.44	2.26	1.90	1.79	1.81	1.40	1.18	1.64	1.54
Δ_1	(%)	42.1	25.7	12.1	4.4	0.0	15.9	5.5	-2.7	26.6	34.0	-4.1	-10.9	15.3
$(\overline{V}_m)_2$	(m/s)	2.09	1.52	1.48	1.24	1.37	2.22	1.77	1.87	1.82	1.22	1.13	1.65	1.62
Δ_2	(%)	31.4	7.9	5.7	8.8	4.2	3.4	-1.7	1.6	27.3	15.1	-8.1	-10.3	10.5

TABLE 7.5 : Short - term to long - term conversion

Region II : Base station : RAN

Conversion station : SRT

Cross - correlation coefficient = 0.74, Separation distance = 123 km.

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg.
$\overline{V}_m$	(m/s)	1.27	1.27	1.29	1.07	0.89	1.10	1.18	1.26	0.97	0.77	0.97	1.48	1.13
V_m	(m/s)	1.29	1.34	1.29	0.72	0.51	0.93	0.87	0.82	0.72	0.26	0.46	0.98	0.85
Δ	(%)	1.6	5.5	0	-32.7	-42.6	-15.5	-26.3	-34.9	-25.8	-66.2	-52.6	-33.8	28.1
$(\overline{V}_m)_1$	(m/s)	1.50	1.55	1.55	1.01	0.94	1.01	1.11	1.22	0.74	0.55	1.01	1.41	1.13
Δ_1	(%)	18.1	22.0	20.2	-5.6	-5.6	-8.2	-5.9	-3.2	-23.7	-28.6	4.1	-4.7	12.3
$(\overline{V}_m)_2$	(m/s)	1.62	1.70	1.75	1.11	1.02	1.01	1.14	1.27	0.74	0.54	1.31	1.46	1.22
Δ_2	(%)	21.6	33.8	35.6	3.7	14.6	-8.2	-3.4	0.1	-23.7	29.9	35.1	-1.4	17.6

TABLE 7.5 : Short - term to long - term conversion data

Region II : Base station : SRT

Conversion station : CHP

Cross - correlation coefficient = 0.75, Separation distance = 148 km.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg.
$\overline{V}_m$	1.95	1.93	1.94	1.75	1.84	1.97	1.97	2.01	1.79	1.33	1.85	2.23	1.88
V_m	1.34	1.49	1.44	1.39	1.08	1.54	1.54	1.39	1.39	0.72	1.08	1.95	1.36
Δ	-31.3	-25.4	-25.8	-20.6	-41.3	-21.8	-21.8	-30.8	-22.3	-45.9	-25.4	-14.3	27.2
$(\overline{V}_m)_1$	1.32	1.41	1.44	1.79	1.73	1.87	1.99	2.12	1.84	1.49	1.85	2.50	1.78
Δ_1	-32.3	-26.9	-25.8	2.2	-6.0	-5.1	1.0	5.5	2.8	8.0	0.0	12.1	10.6
$(\overline{V}_m)_2$	1.32	1.39	1.44	2.09	1.72	1.82	2.05	2.15	1.87	1.93	2.12	2.80	1.89
Δ_2	-32.3	-28.0	-25.8	16.2	-6.5	-7.6	4.1	7.0	4.5	28.5	12.7	25.6	16.6

TABLE 7.5 Short - term to long - term conversion data

Region III Base station : SKL

Conversion station : TRA

cross - correlation coefficient = 0.86, separation distance = 110 Km

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg.
$\overline{V}_m$	(m/s)	3.28	3.04	2.52	1.56	1.12	1.22	1.27	1.40	1.23	1.63	1.63	2.83	1.85
V_m	(m/s)	2.48	1.75	1.49	1.03	0.57	0.93	0.93	0.93	1.03	0.77	1.29	2.52	1.31
Δ	(%)	-24.4	-42.4	-40.9	-03.9	-49.1	-23.8	-26.8	-26.8	-33.6	-28.7	-20.8	-10.9	29.3
$(\overline{V}_m)_1$	(m/s)	2.83	2.64	2.39	1.77	0.84	1.14	1.18	1.33	1.10	0.72	1.61	2.66	1.68
Δ_1	(%)	-13.7	-13.1	-5.1	13.5	-25.0	-6.5	-7.1	-5.0	-10.6	-33.3	-1.2	-6.0	9.8
$(\overline{V}_m)_2$	(m/s)	2.78	2.52	2.07	1.73	0.76	1.19	0.95	1.37	1.14	0.73	1.65	2.68	1.63
Δ_2	(m/s)	-15.2	-17.1	-17.8	10.9	-32.1	-2.4	-25.2	-2.1	-7.3	-32.4	1.2	-5.3	14.1

TABLE 7.5 Short - term to long - term conversion data

Region III Base station : NTW

Conversion station : TRA

cross - correlation coefficient = 0.50, separation distance = 245 Km

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
$\overline{V}_m$	(m/s)	3.28	3.04	2.52	1.56	1.12	1.22	1.27	1.40	1.23	1.08	1.63	2.83	1.85
V_m	(m/s)	2.48	1.75	1.49	1.03	0.57	0.93	0.93	0.93	1.03	0.77	1.29	2.52	1.31
Δ	(%)	-24.4	-42.4	-40.9	-33.9	-49.1	-23.8	-26.8	-33.6	-16.3	-28.7	-20.8	-10.9	29.3
$(\overline{V}_m)_1$	(m/s)	3.79	2.94	2.60	1.73	0.93	1.34	1.40	1.61	1.32	1.08	1.82	2.55	1.93
Δ_1	(%)	15.5	-3.3	3.2	10.9	-17.0	6.6	10.2	15.0	7.3	0.0	11.7	9.9	6.8
$(\overline{V}_m)_2$	(m/s)	3.62	2.85	2.25	1.69	0.86	1.57	1.58	1.78	1.59	1.17	1.98	2.56	1.96
Δ_2	(%)	10.4	-6.3	-10.7	8.3	-23.2	26.2	24.4	27.1	29.3	8.3	21.5	9.5	17.0

TABLE 7.6 Short - term to long - term conversion data - Annual mean wind speeds

Site pair	Long term mean (m/s)	Short-term mean (m/s)	Δ (%)	Estimated long-term mean (m/s)	Δ (%)
CHB - HHN	2.24	2.01	10.3	2.17	-3.1
CHB - KCB	1.42	1.23	13.4	1.59	12.0
SRT - CHP	1.88	1.36	27.7	1.89	0.0
RAN - SRT	1.13	0.85	24.8	1.22	8.0
CHP - RAN	1.53	1.04	32.0	1.62	5.9
SKL - TRA	1.85	1.31	29.2	1.63	-9.9
NTW - TRA	1.85	1.31	29.2	1.96	6.0
Average			23.8		6.4

Table 7.7 Weibull distribution parameters

Season	k	c (m/s)	$\overline{V}$ (m/s)	Δ%
Aug - Oct	2.01	3.44	3.05	12.8
Nov - Jan	1.81	3.68	3.27	12.[illegible]
Feb - Apr	2.17	3.47	3.07	13.[illegible]
May - Jul	2.05	2.73	2.42	12.[illegible]

Table 7.8 Comparison of estimated and measured mean wind speeds

Season	Frequency of calm f_c (%)	Estimated speed, $\overline{V}_e$ (m/s)	Measured speed, $\overline{V}_m$ (m/s)	Error (%)
Aug - Oct	32.7	2.05	2.01	+0.2
Nov - Jan	30.7	2.27	2.23	+1.6
Feb - Apr	26.7	2.25	2.35	-4.3
May - Jul	32.3	1.85	1.67	+10.8

Note : $\overline{V}_e = (1 - f_c)\,\overline{V}$

where $\overline{V}$ = estimated mean wind speeds with calm period excluded.

Table 7.9

Field test results of the wind turbine-water pumping system

$\overline{V}$ (m/s)	σ^2 (m^2/s^2)	N (rpm)	Q (l/min)	P_w (W)	P_a (W)	C_p
2.64	0.71	43.8	12.4	163.7	31.7	.193
2.70	0.38	35.6	10.8	175.1	27.6	.157
2.79	0.66	35.1	11.2	193.2	28.7	.145
2.97	0.36	48.3	13.6	233.0	34.8	.145
3.34	0.40	52.4	14.2	331.4	36.4	.110
3.49	0.67	44.2	12.8	378.1	32.8	.086
3.52	1.00	45.6	13.2	387.9	33.9	.088
3.68	0.96	49.7	13.2	443.3	33.8	.075
3.91	1.28	48.3	13.8	531.7	35.3	.066
4.04	0.62	50.6	13.8	586.5	35.3	.060
4.26	0.81	51.5	14.0	706.6	43.4	.061
4.42	1.00	54.0	15.1	771.2	46.8	.054
4.51	0.66	56.1	15.4	857.9	47.7	.054
4.85	0.76	60.6	17.7	1018.8	54.8	.055
4.98	0.81	62.0	18.0	1102.9	55.8	.050

$\overline{V}$ = Average wind speed

σ^2 = Wind speed variance

N = Wind turbine rotational speed

Q = Water Flow rate

P_w = Available power at a specific wind speed

P_a = Actual power output

C_p = Power coefficient = P_a/P_w

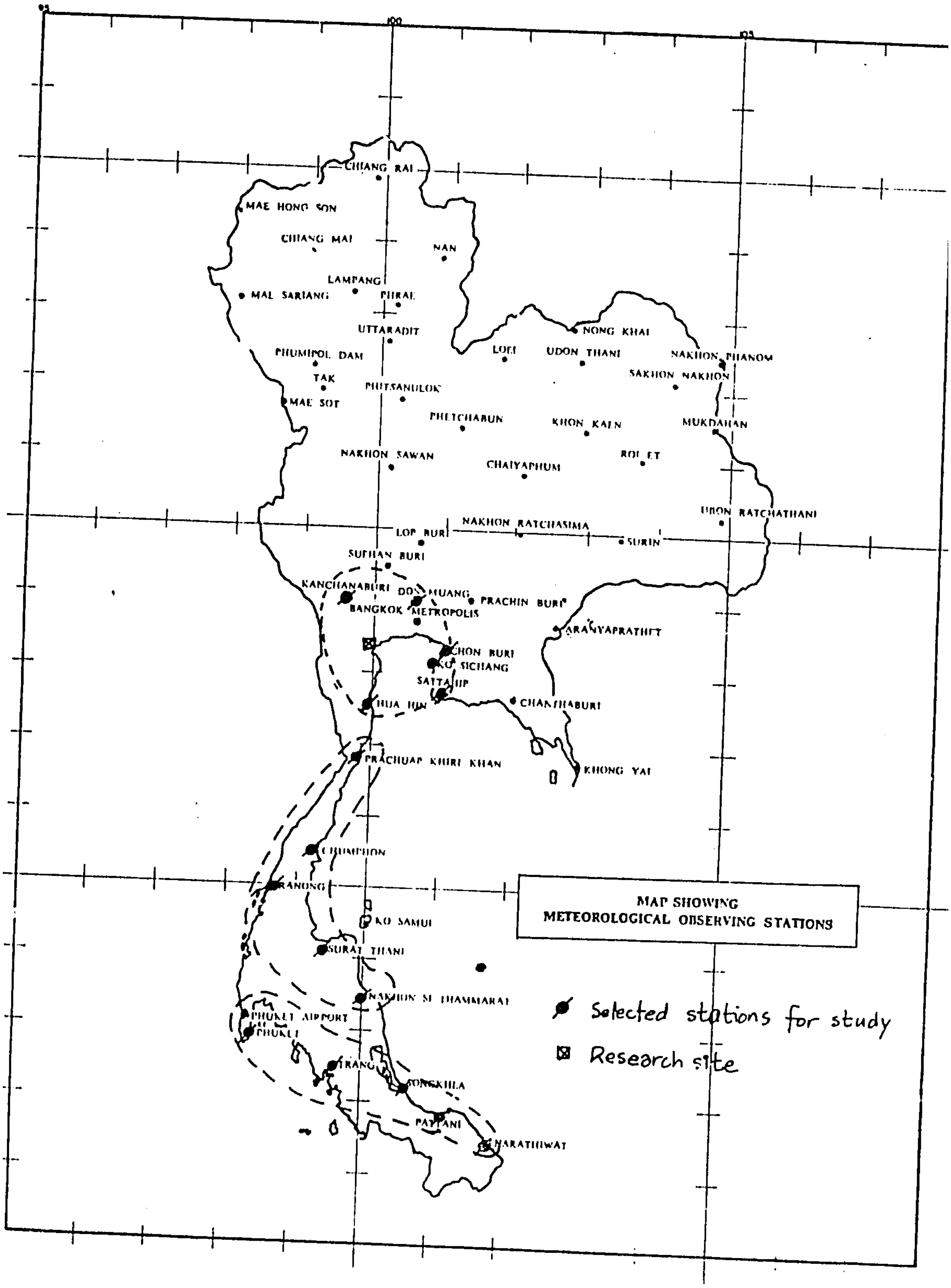


Figure 7.1 : Stations whose wind record were selected for spatial cross-correlation studies.

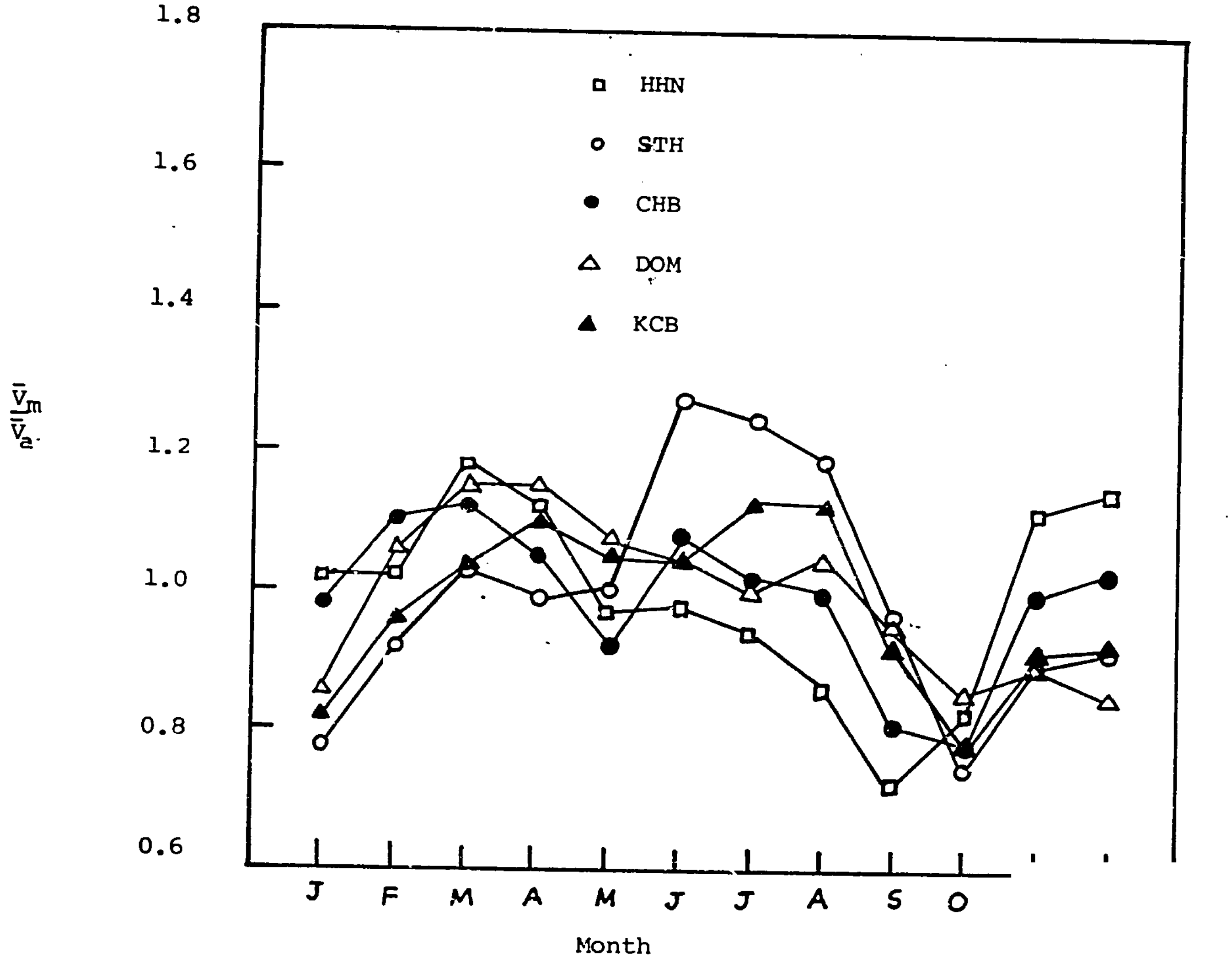


Figure 7.2 : Seasonal variation of monthly mean wind $\bar{V}_m$ relative to annual mean wind $\bar{V}_a$ for region I.

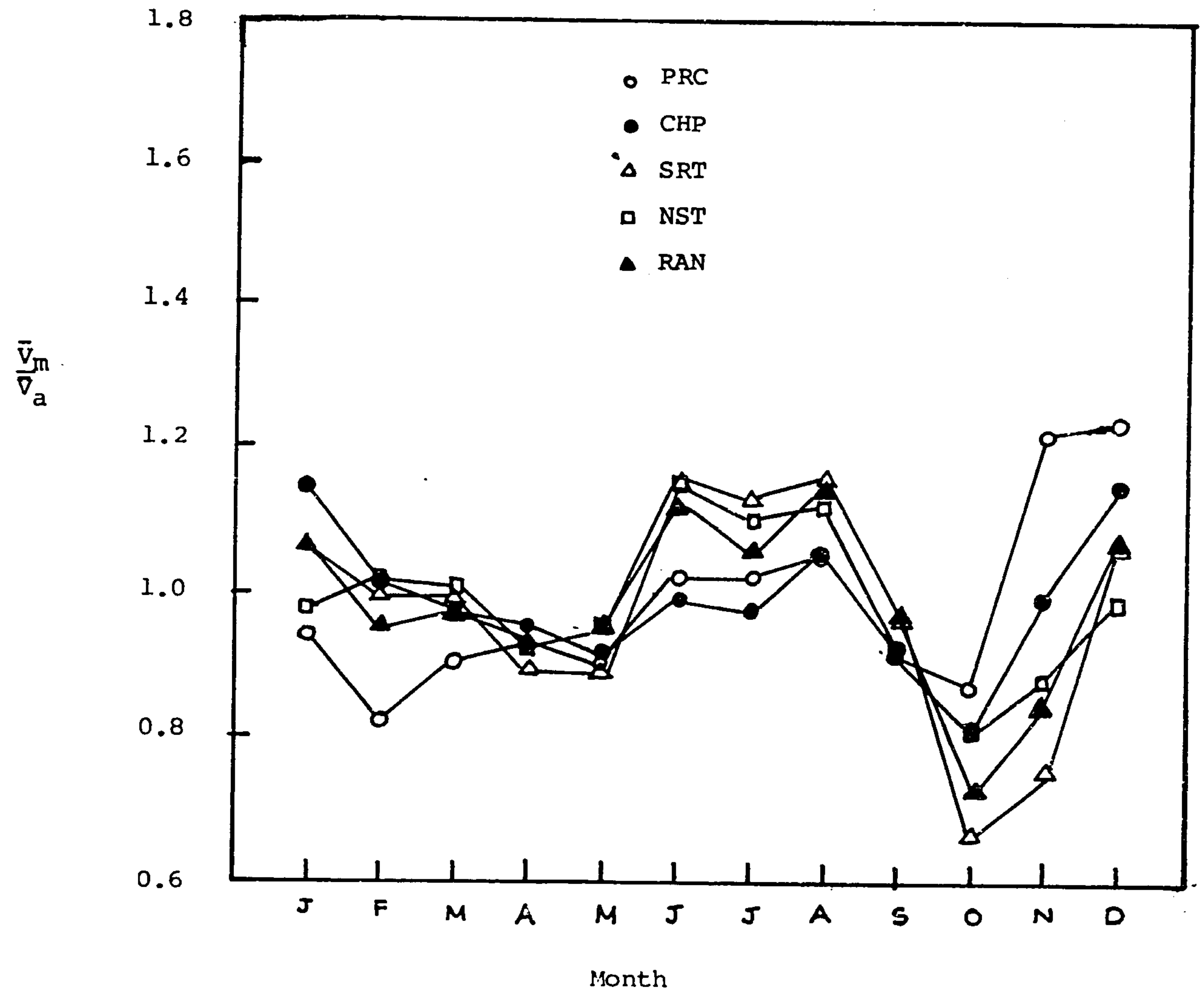


Figure 7.3 : Seasonal variation of monthly mean wind $\bar{V}_m$ relative to annual mean wind $\bar{V}_a$ for region II.

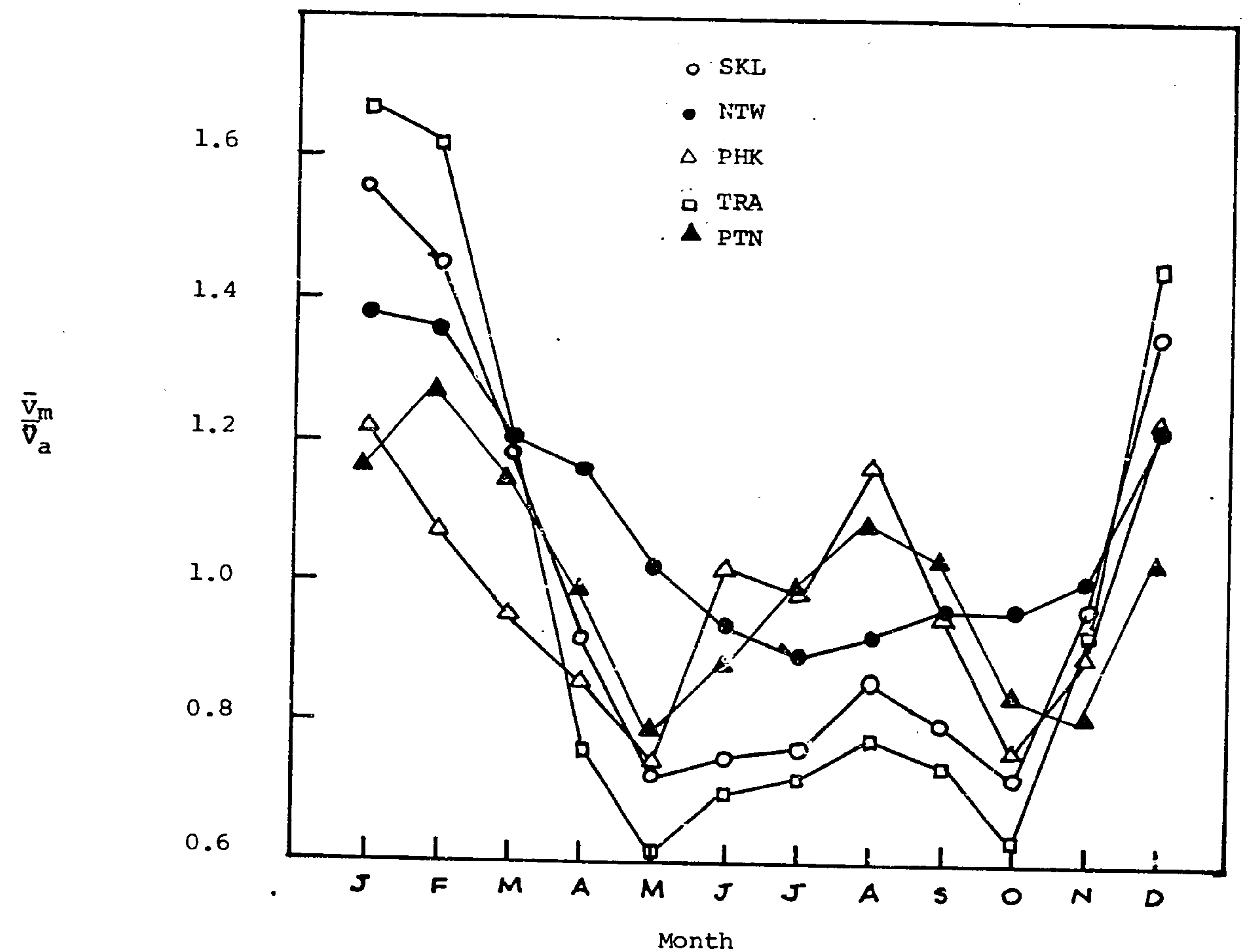


Figure 7.4 : Seasonal variation of monthly mean wind $\bar{V}_m$ relative to annual mean wind $\bar{V}_a$ for region III.

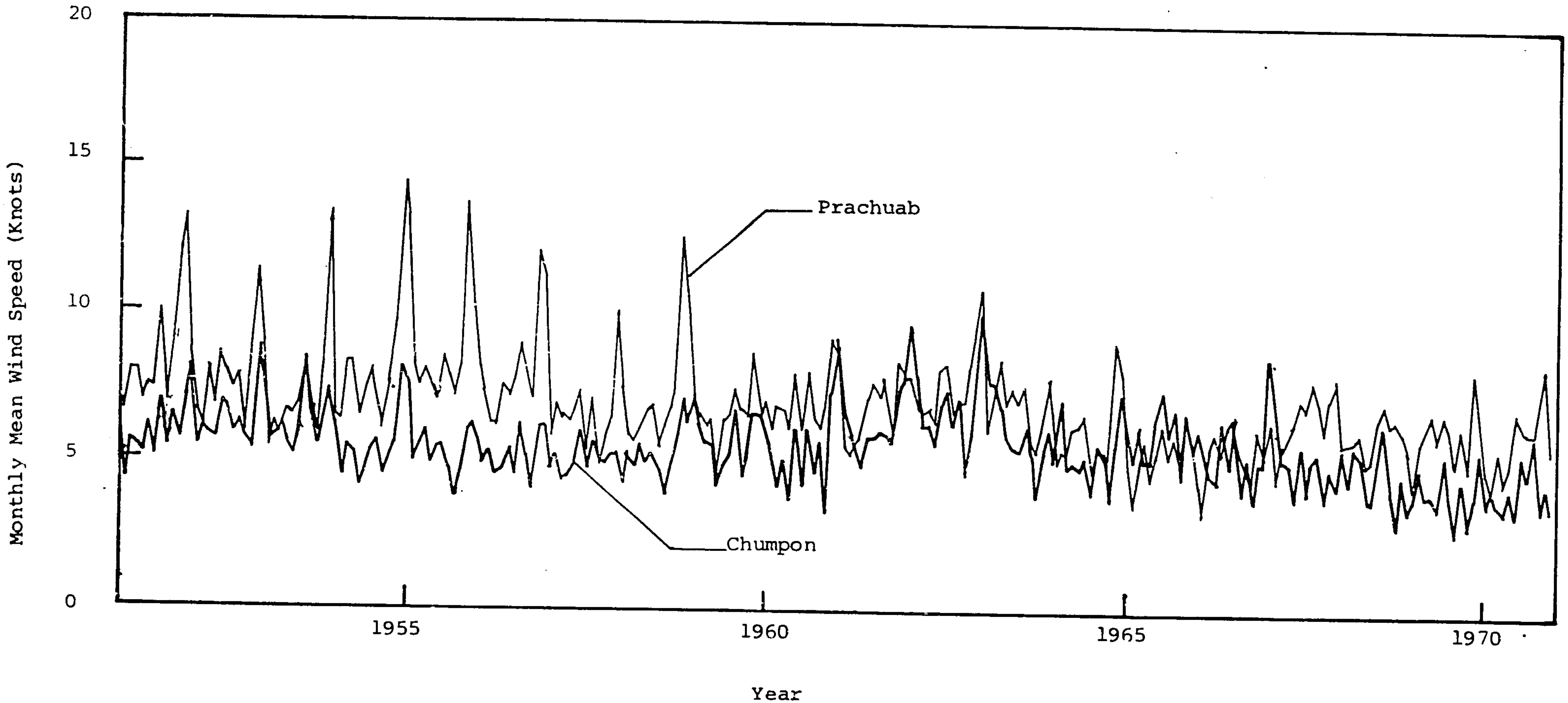
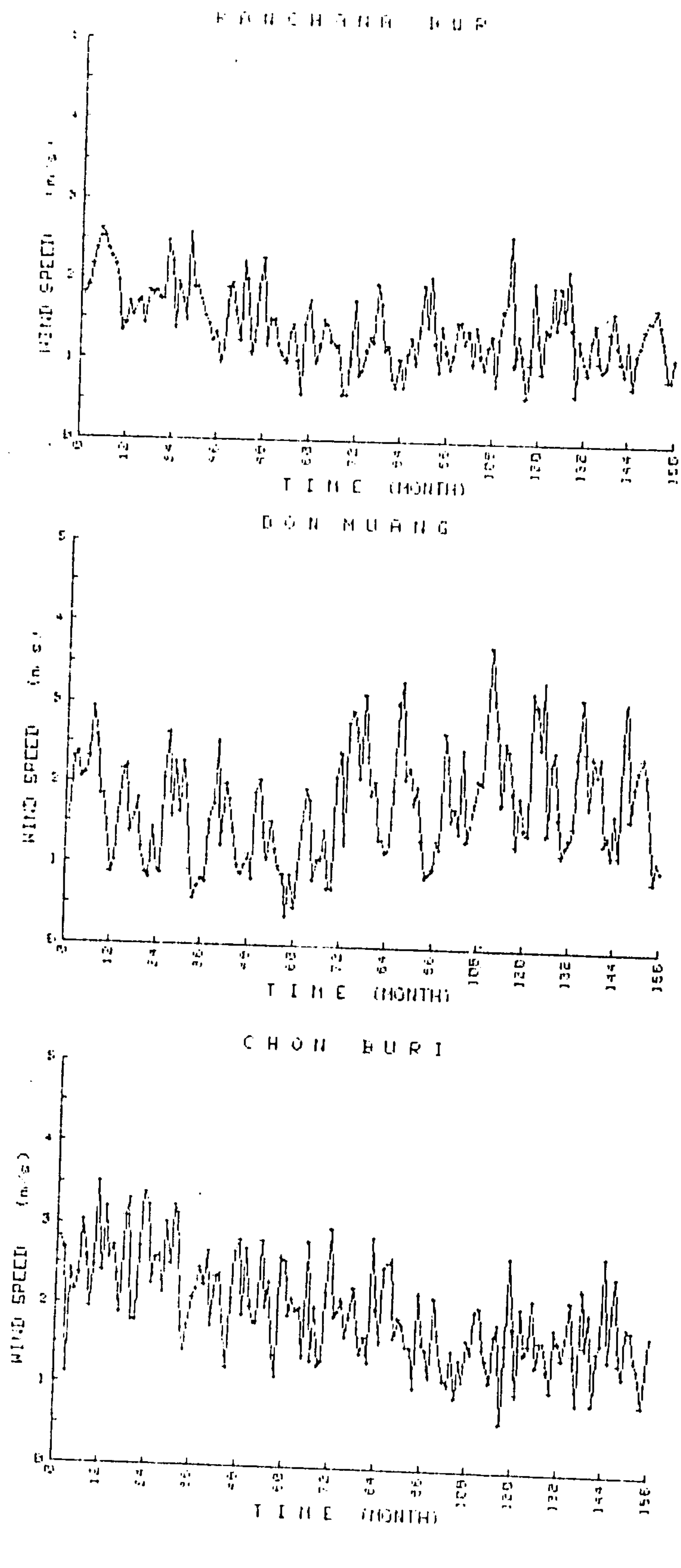
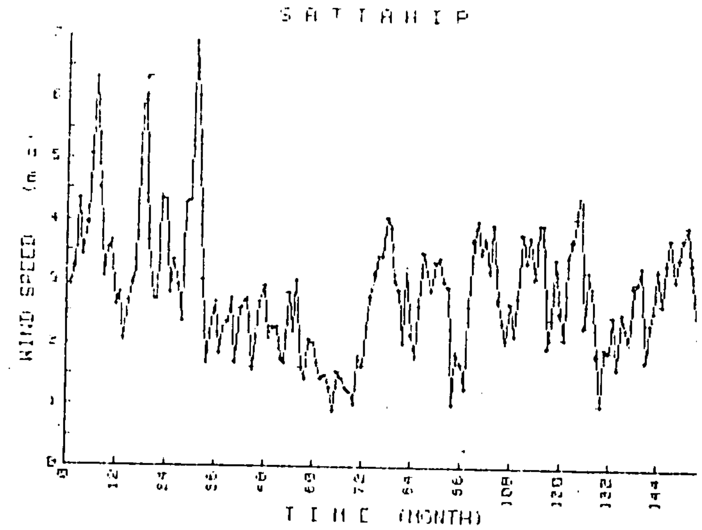
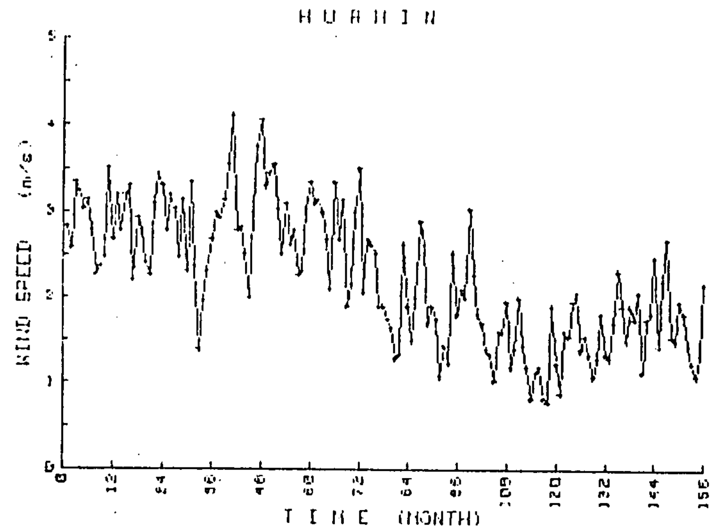


Figure 7.5 : Time-history records of wind data for Prachuab and Chumpon over a 20-year period.



<u>*Figure 7.6 (a)*</u> : *Time history record of monthly wind speed averages at each of the selected locations (Region I).*





<u>Figure 7.6 (a)</u> : Cont'd

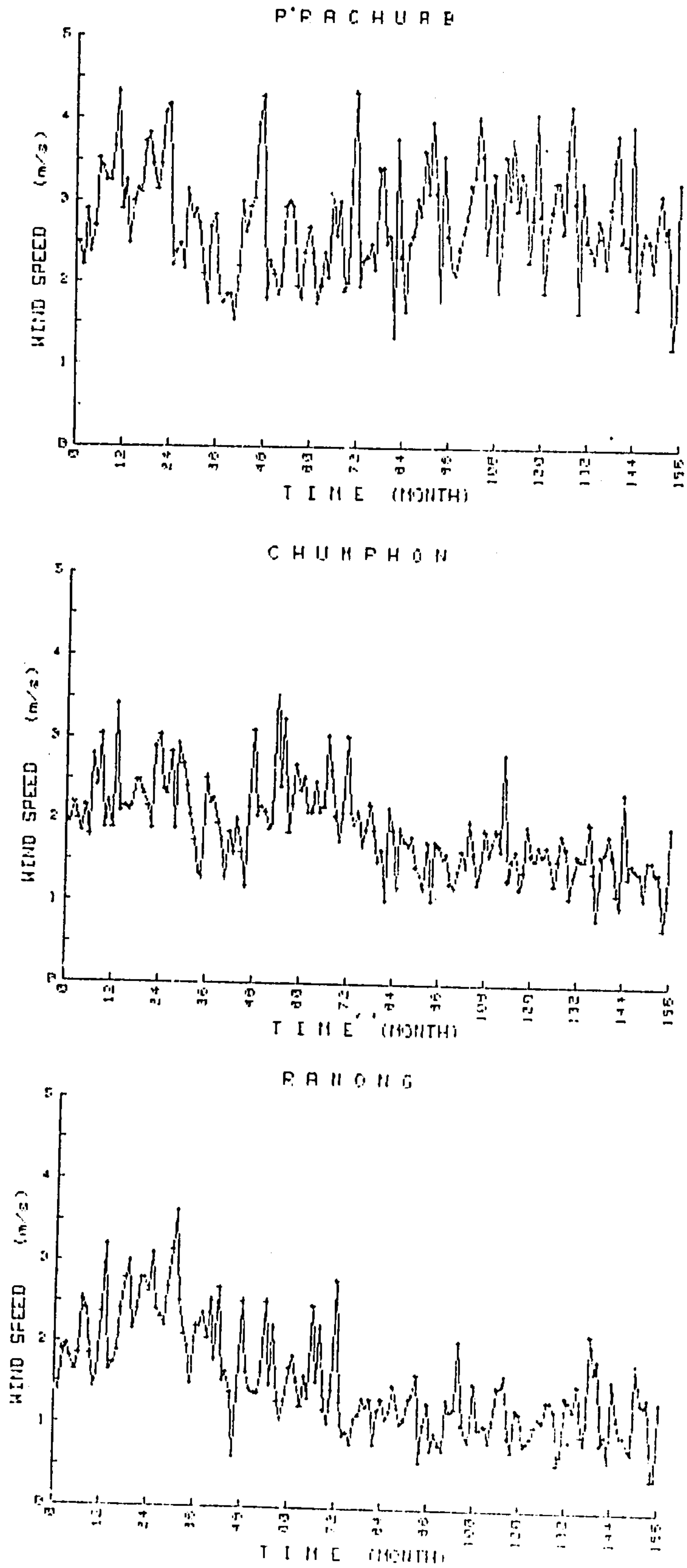
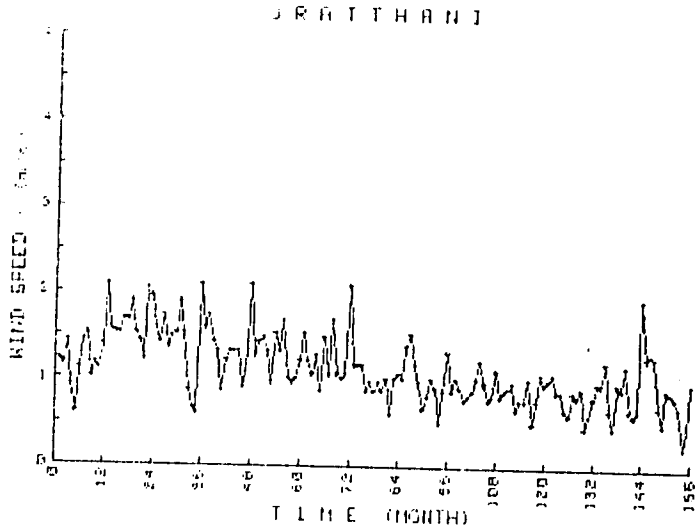


Figure 7.6 (b) : Time history record of monthly wind speed averages at each of the selected locations (Region II).



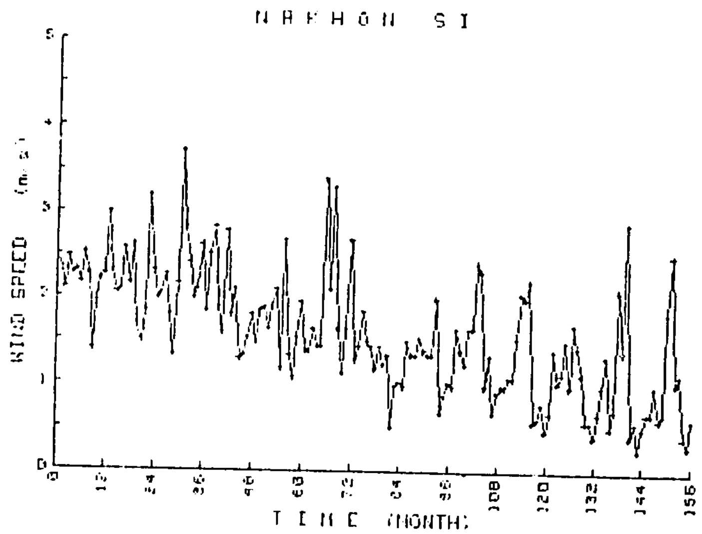


Figure 7.6 (b) : Cont'd

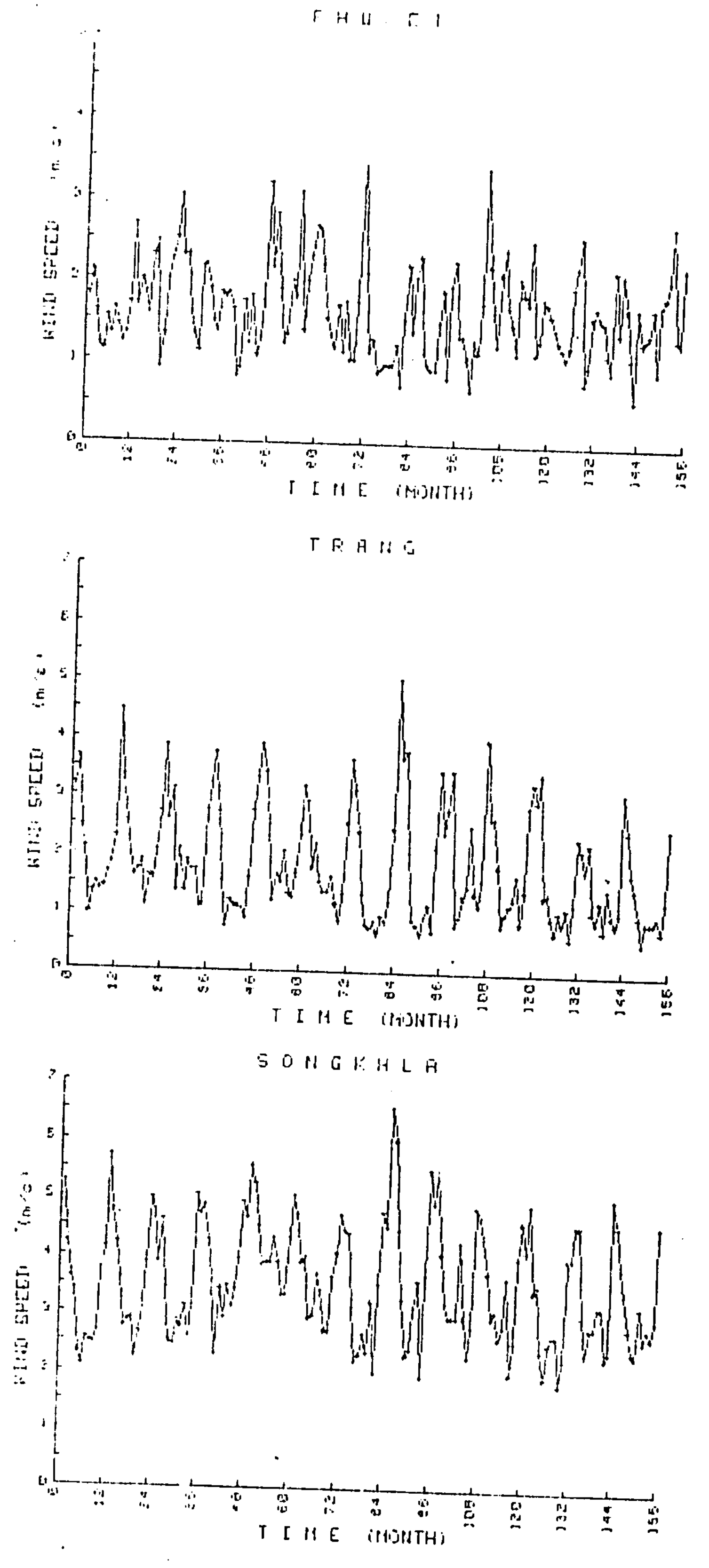
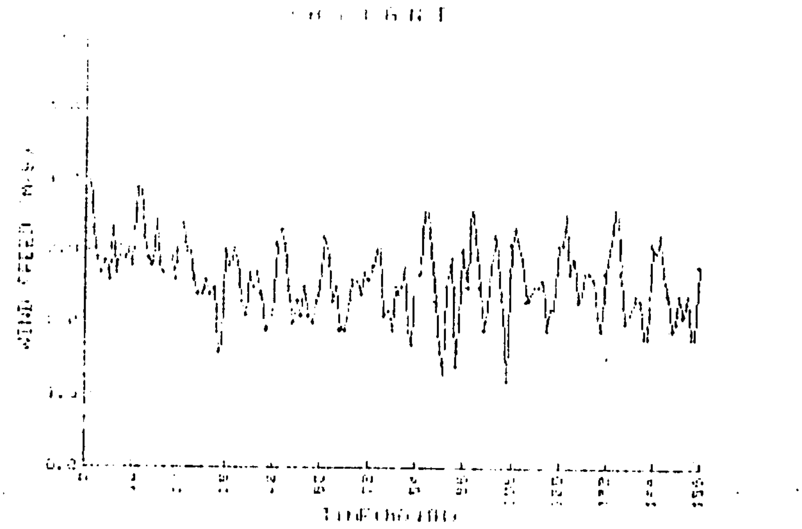
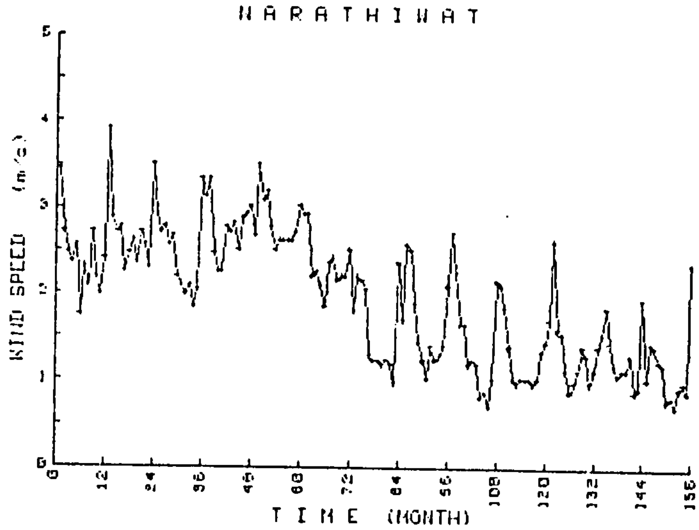


Figure 7.6 (c): Time history record of monthly wind speed averages at each of the selected locations (Region III).





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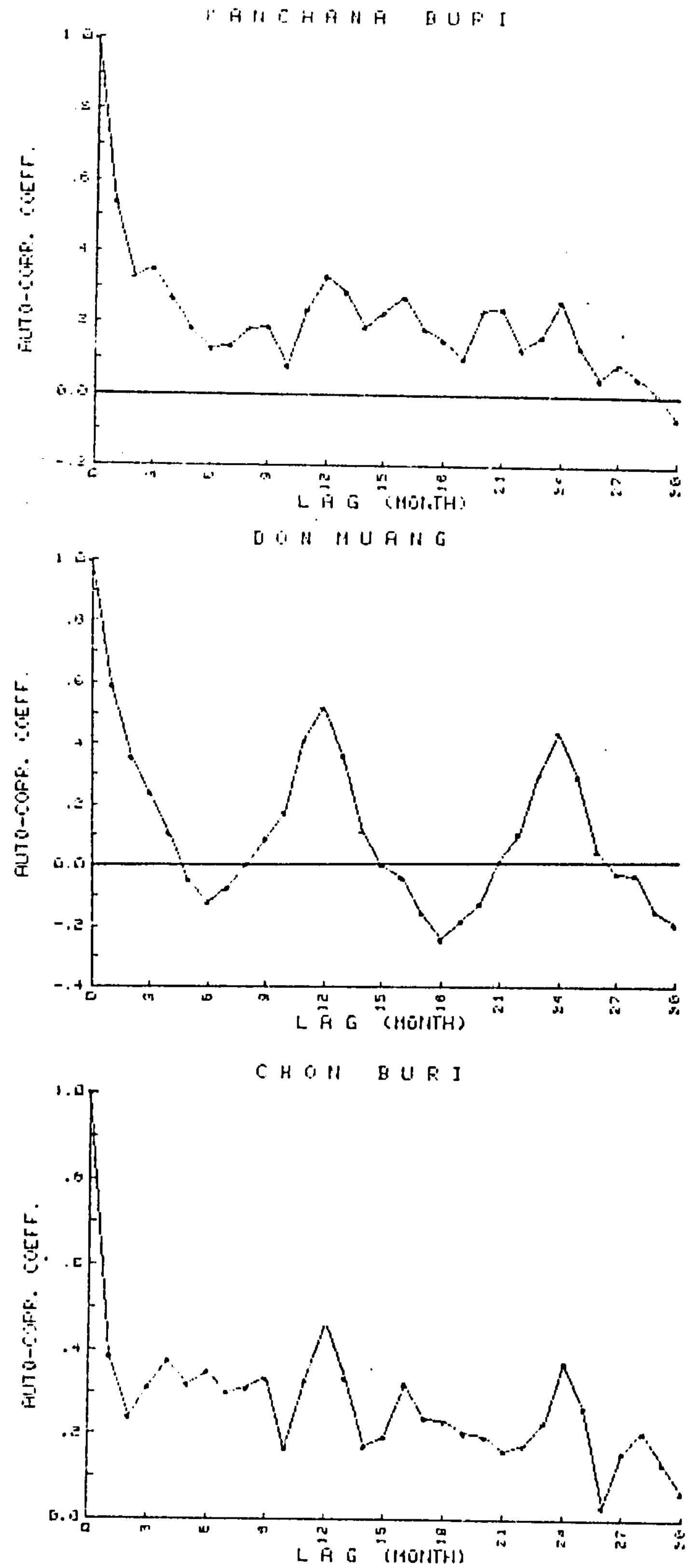
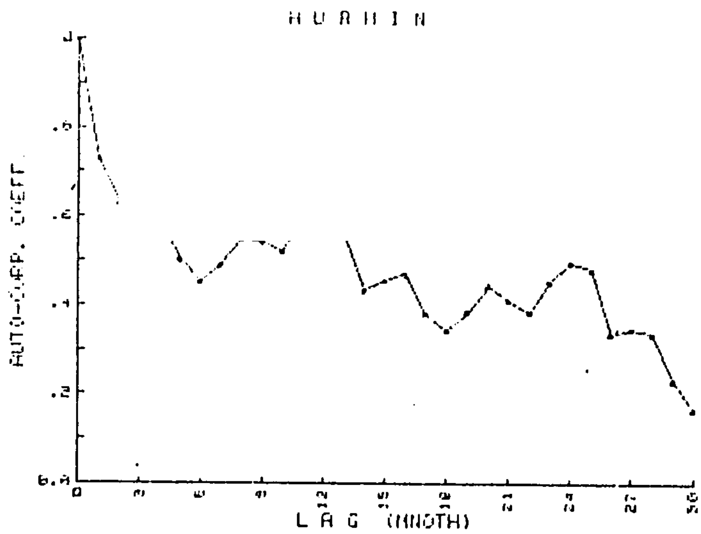


Figure 7.7 (a): *Autocorrelation of monthly wind speed averages, Region*



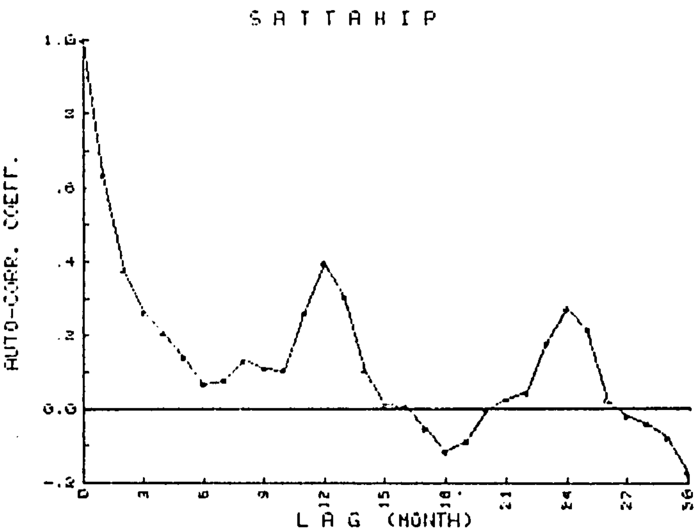


Figure 7.7 (a): Cont'd

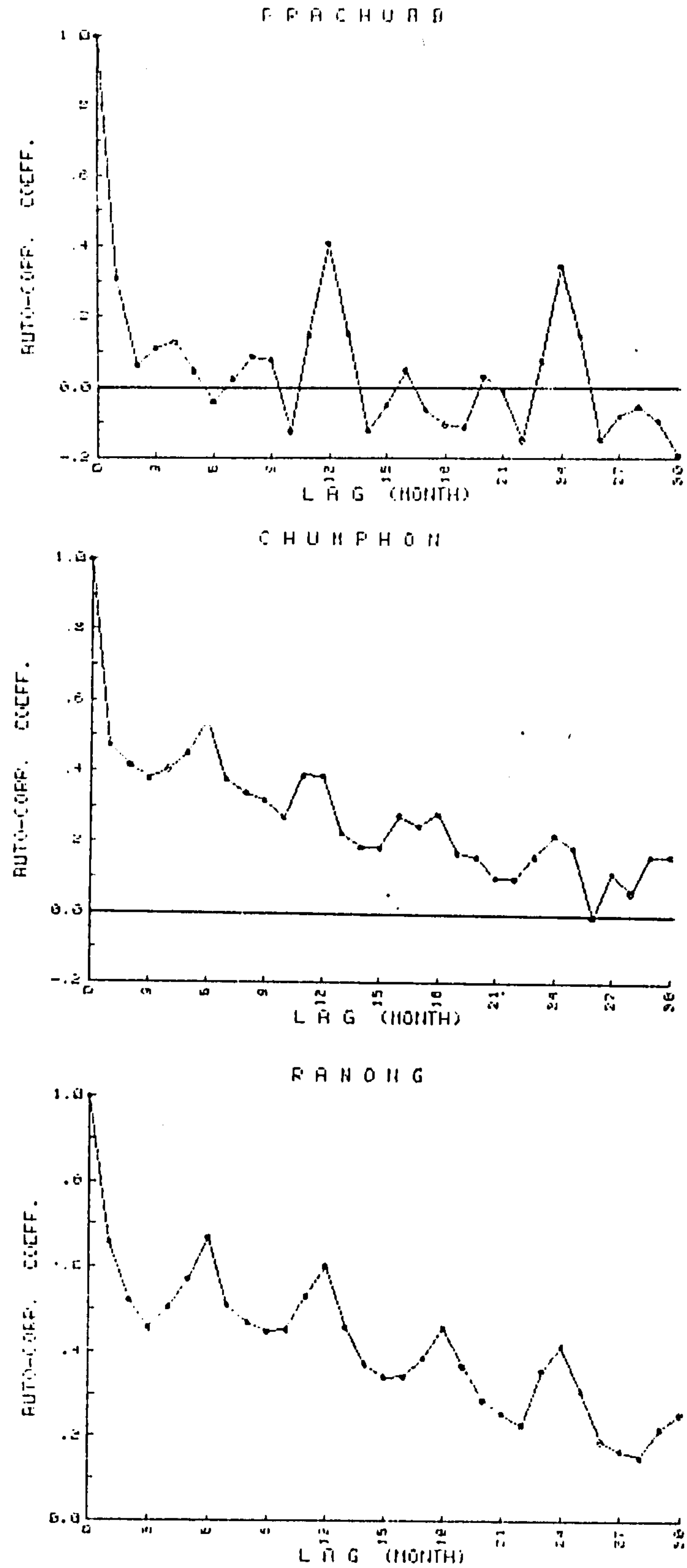
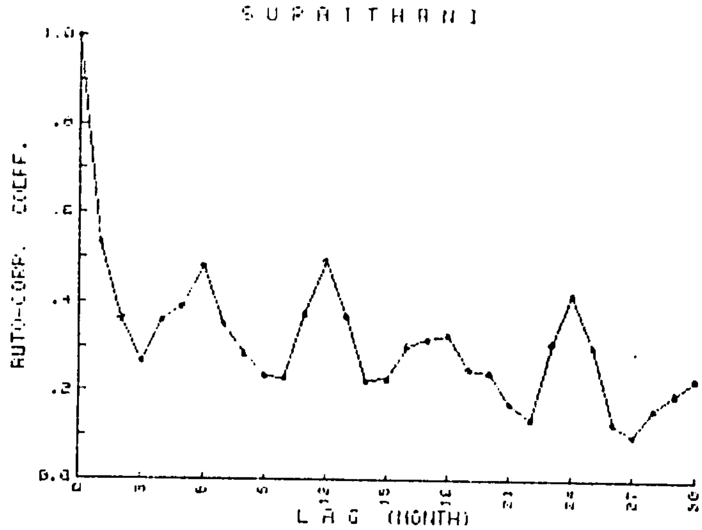
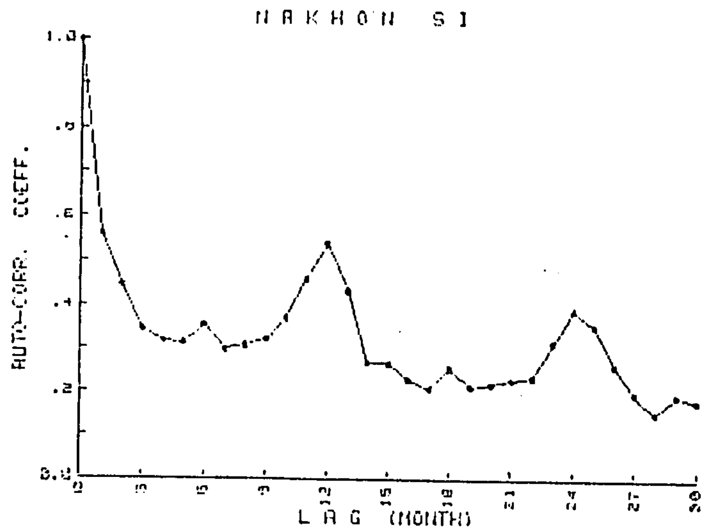


Figure 7.7 (b): Autocorrelation of monthly wind speed averages, Region II.





<u>Figure 7.7 (b)</u>: Cont'd

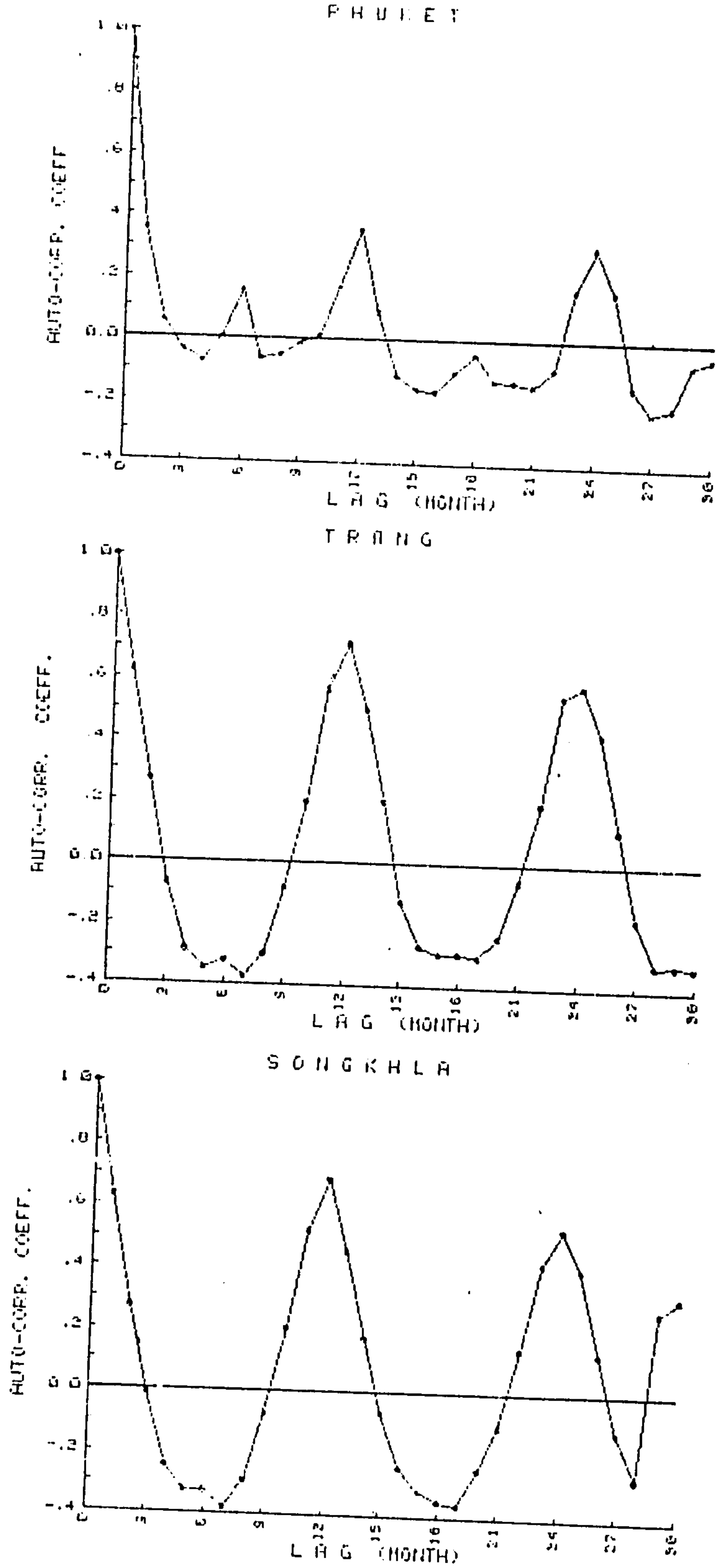
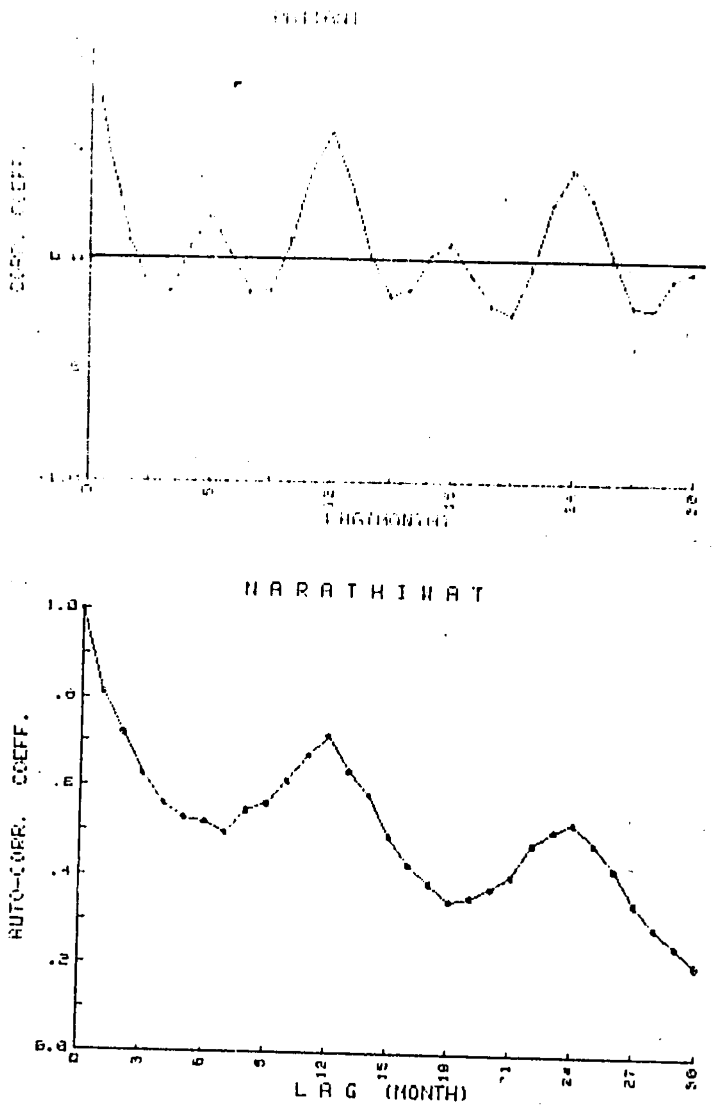


Figure 7.7 (c): *Autocorrelation of monthly wind speed averages, Region III.*



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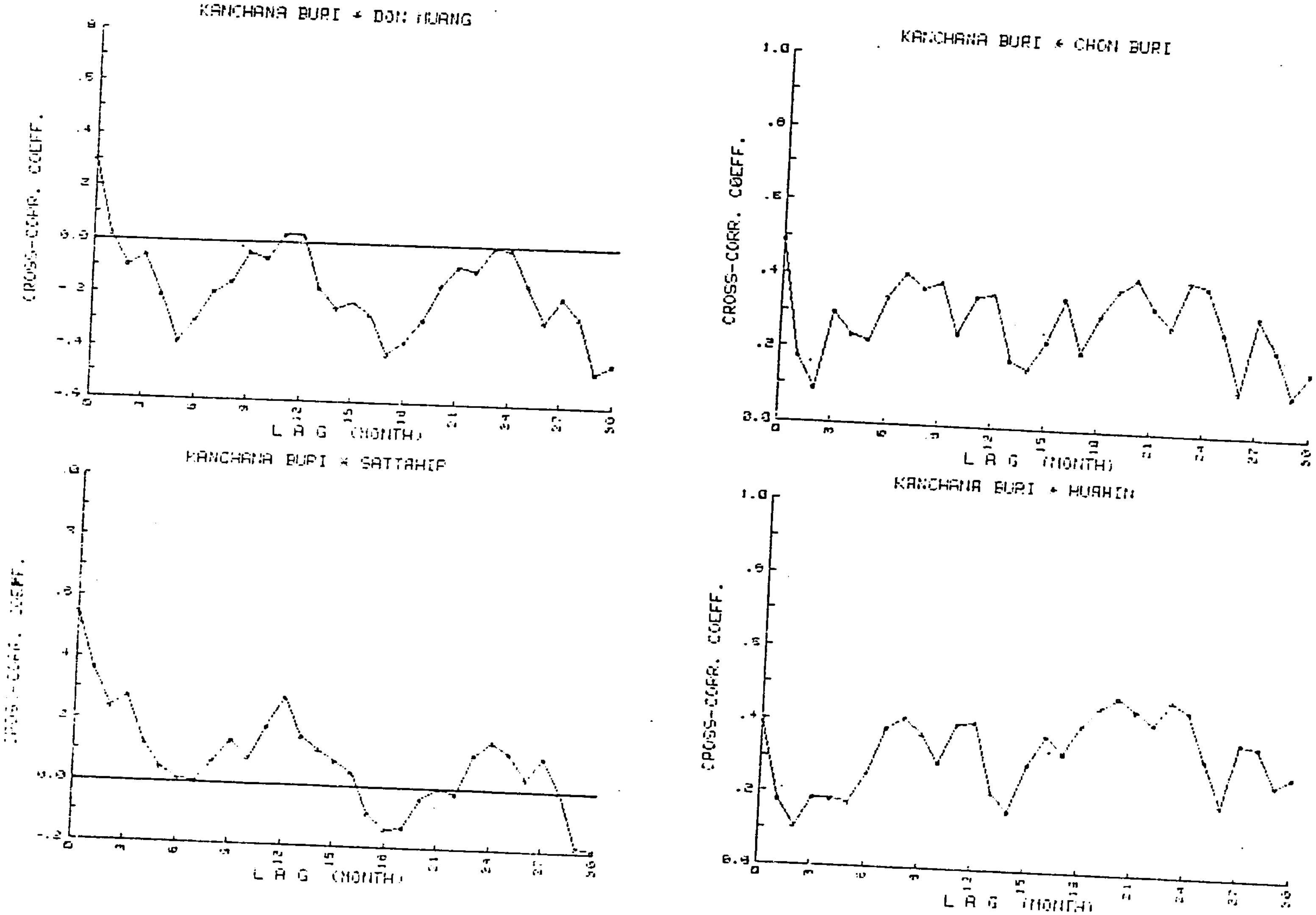


__Figure 7.8 (a)__: Cross-correlation of monthly wind speed averages for each pair of stations, Region I.

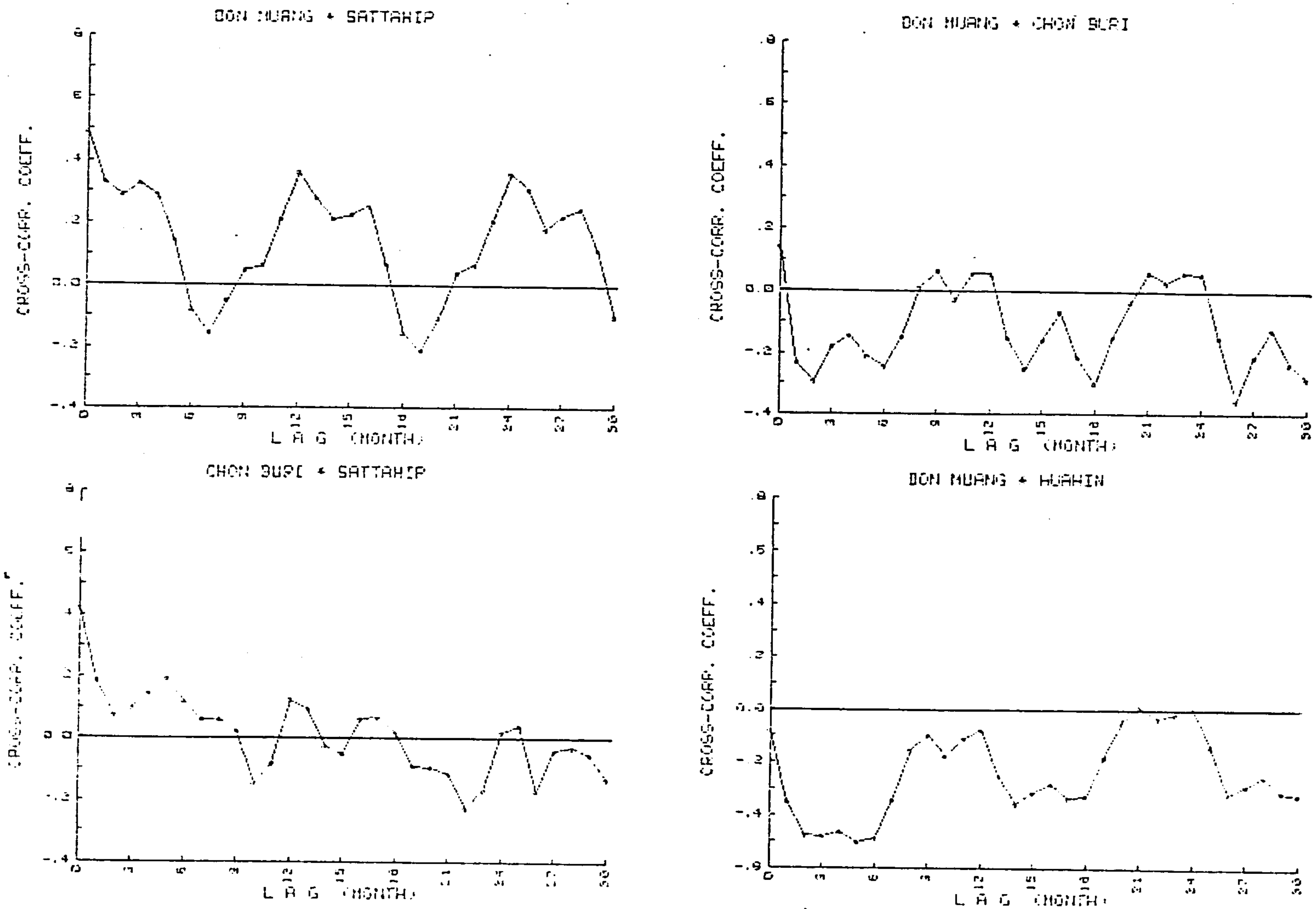


Figure 7.8 (a): Cont'd

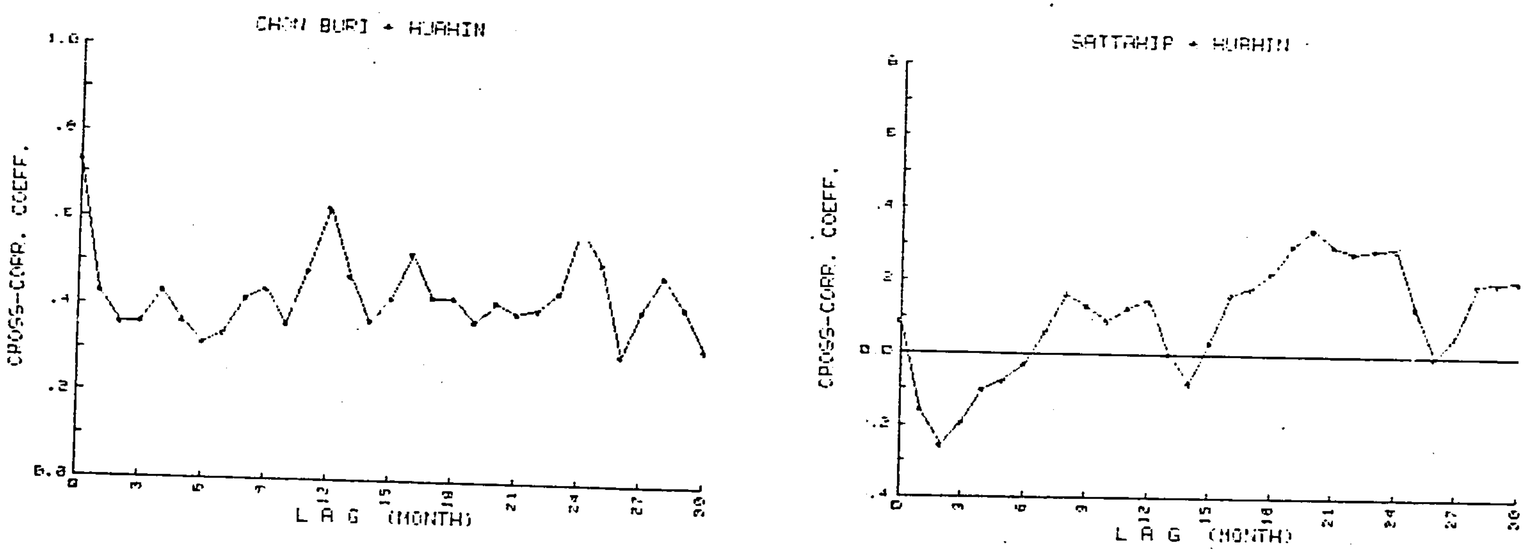
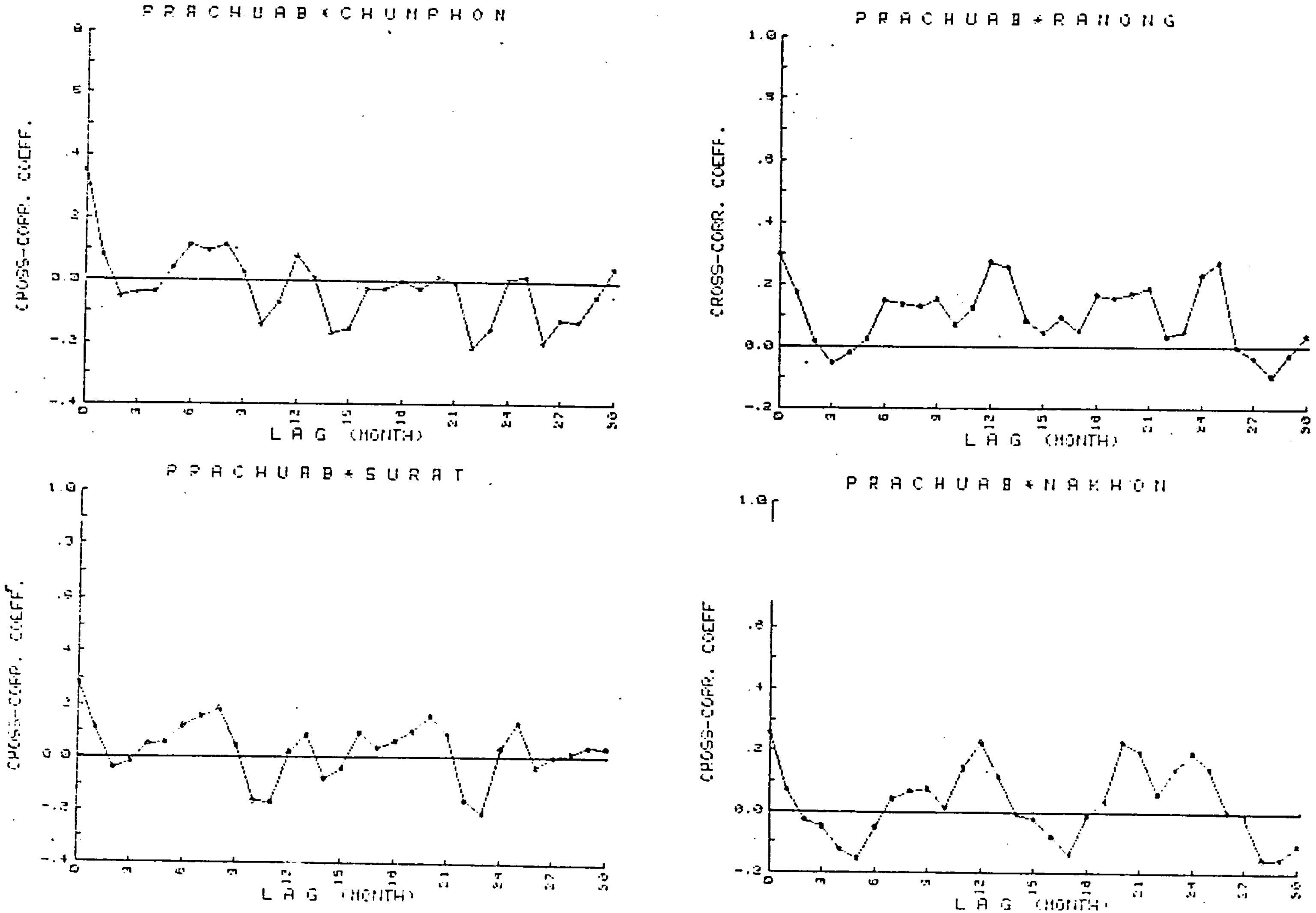
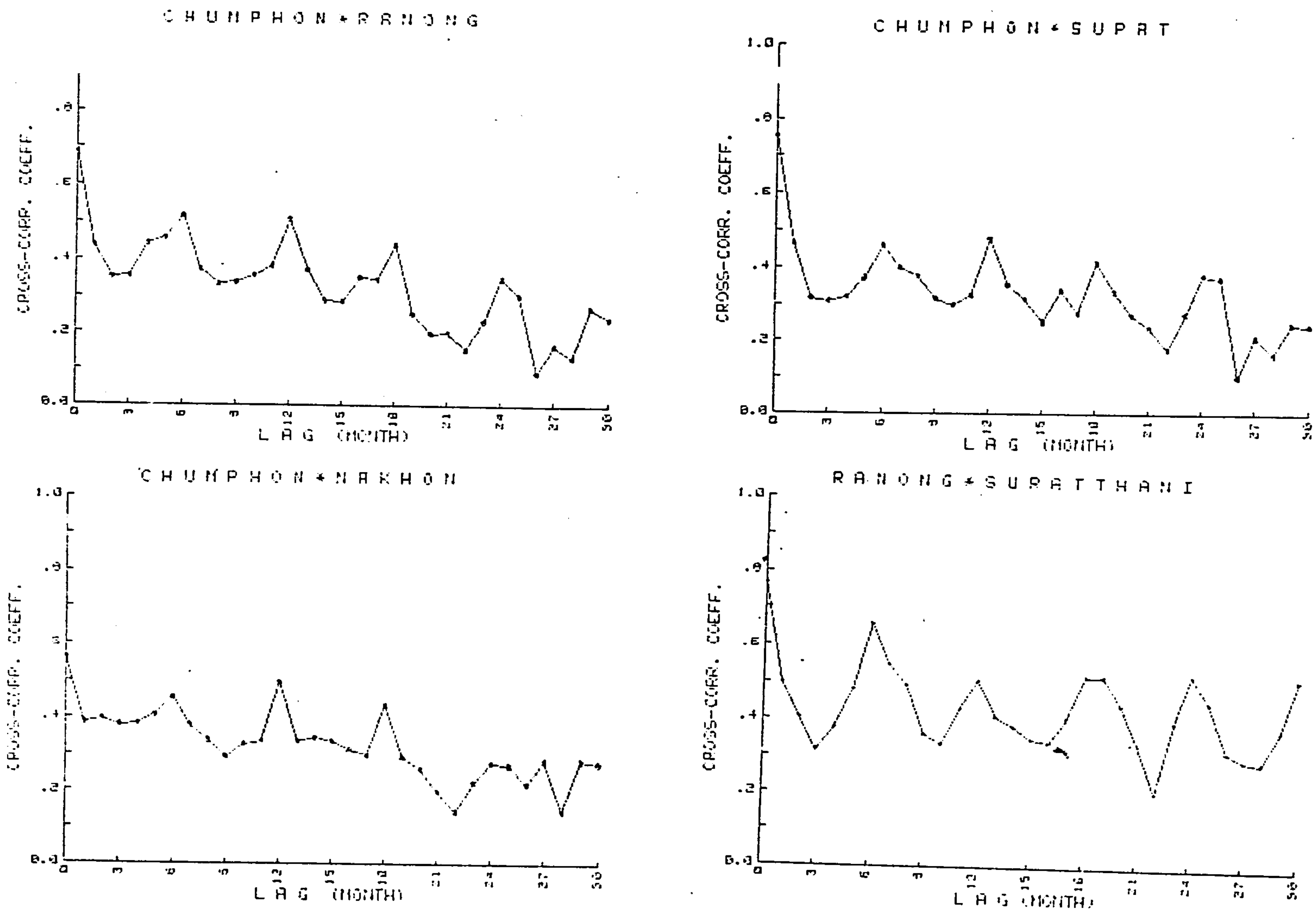


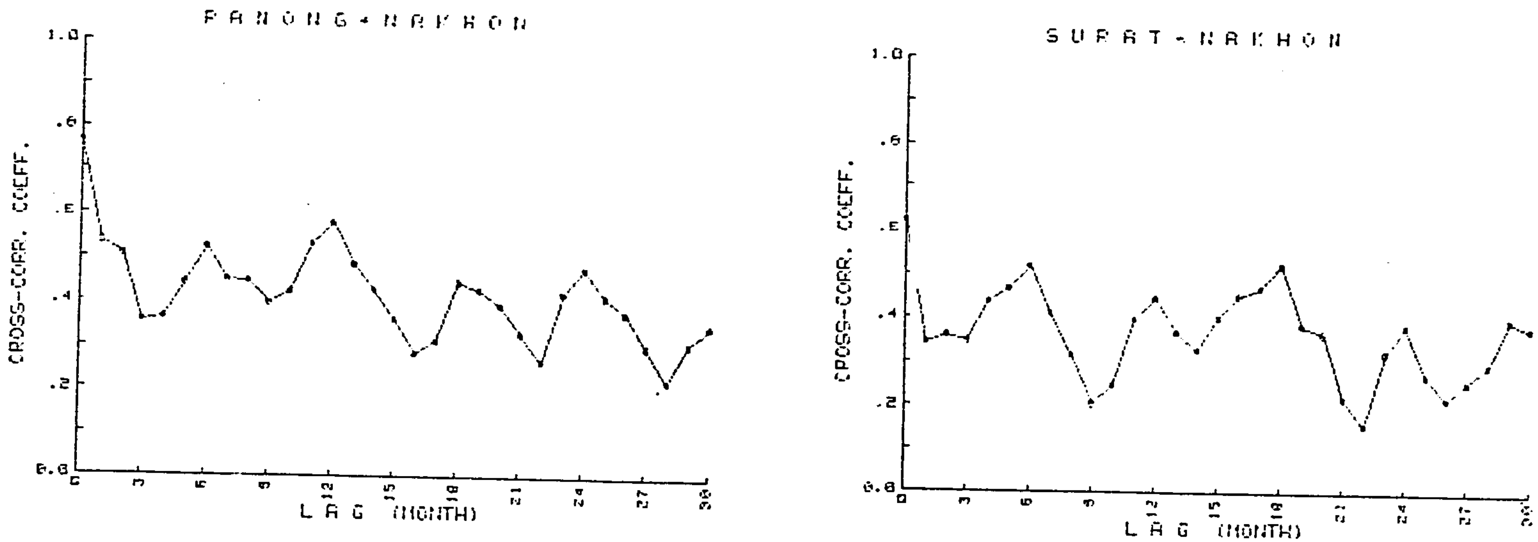
Figure 7.8 (a) : *Cont'd*



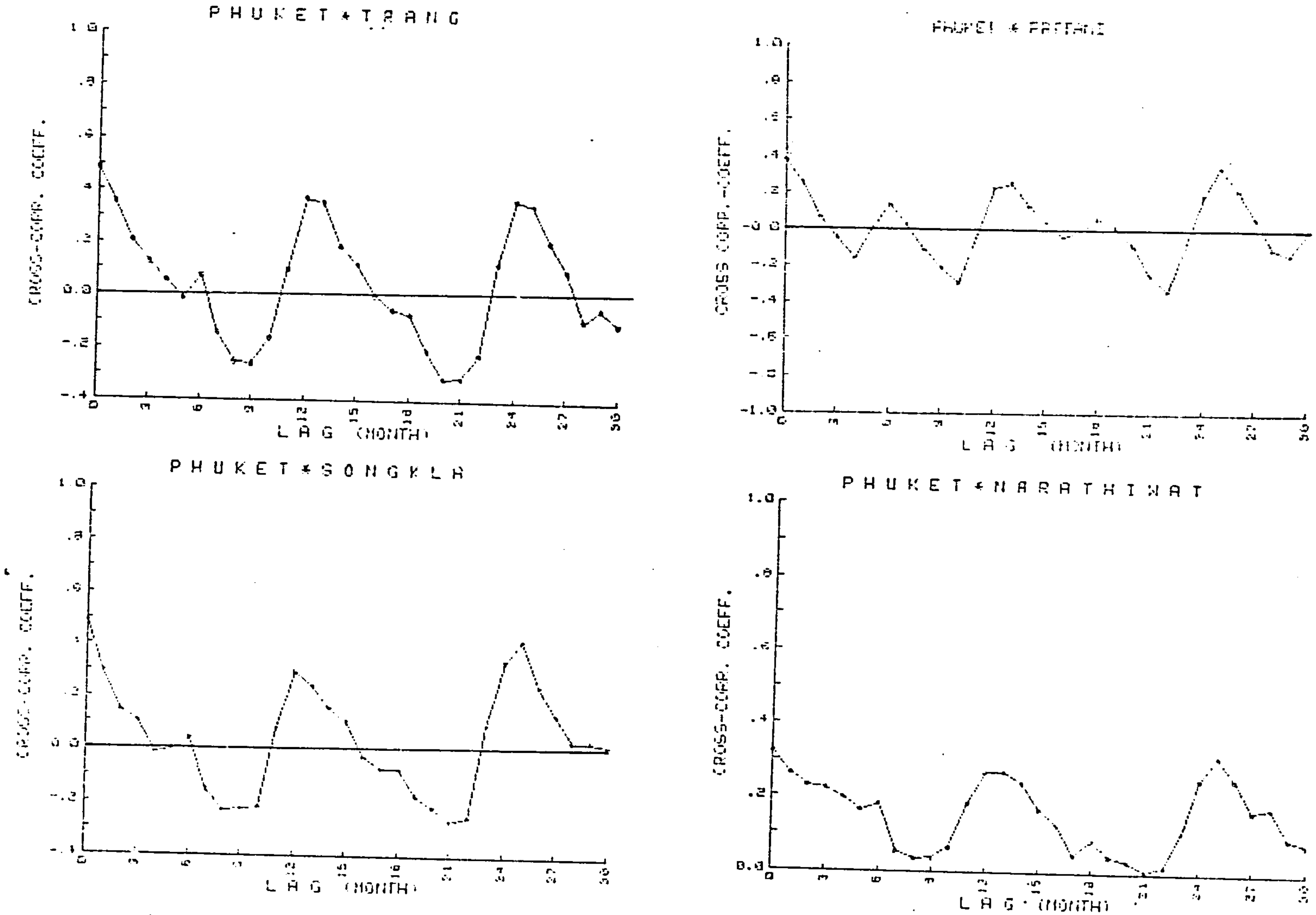
<u>Figure 7.8 (b)</u> : Cross-correlation of monthly wind speed averages for each pair of stations, Region II.



<u>Figure 7.8 (b)</u> : Cont'd



<u>*Figure 7.8 (b)*</u> *: Cont'd*



<u>Figure 7.8 (c)</u> : Cross-correlation of monthly wind speed averages for each pair of stations, Region III.

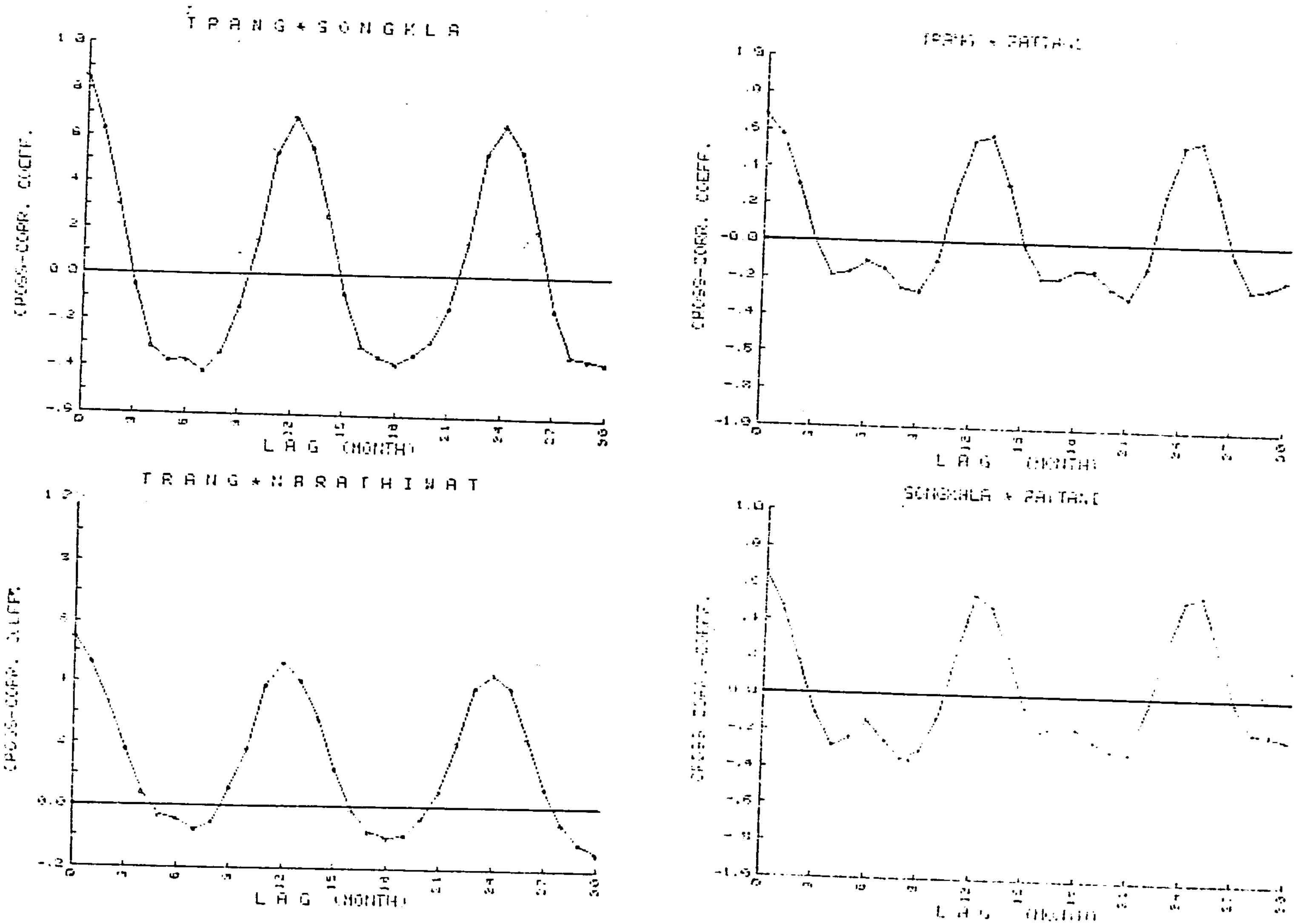
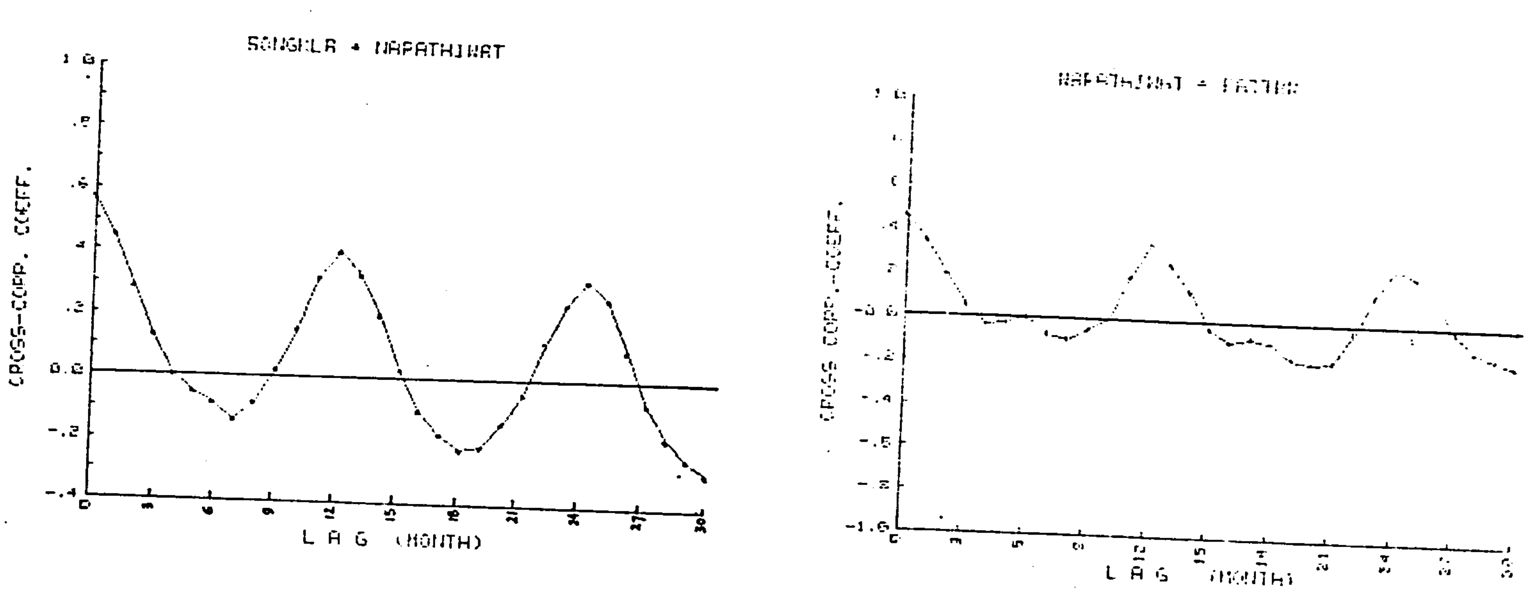


Figure 7.8 (c) : Cont'd



<u>*Figure 7.8 (c)*</u> *: Cont'd*

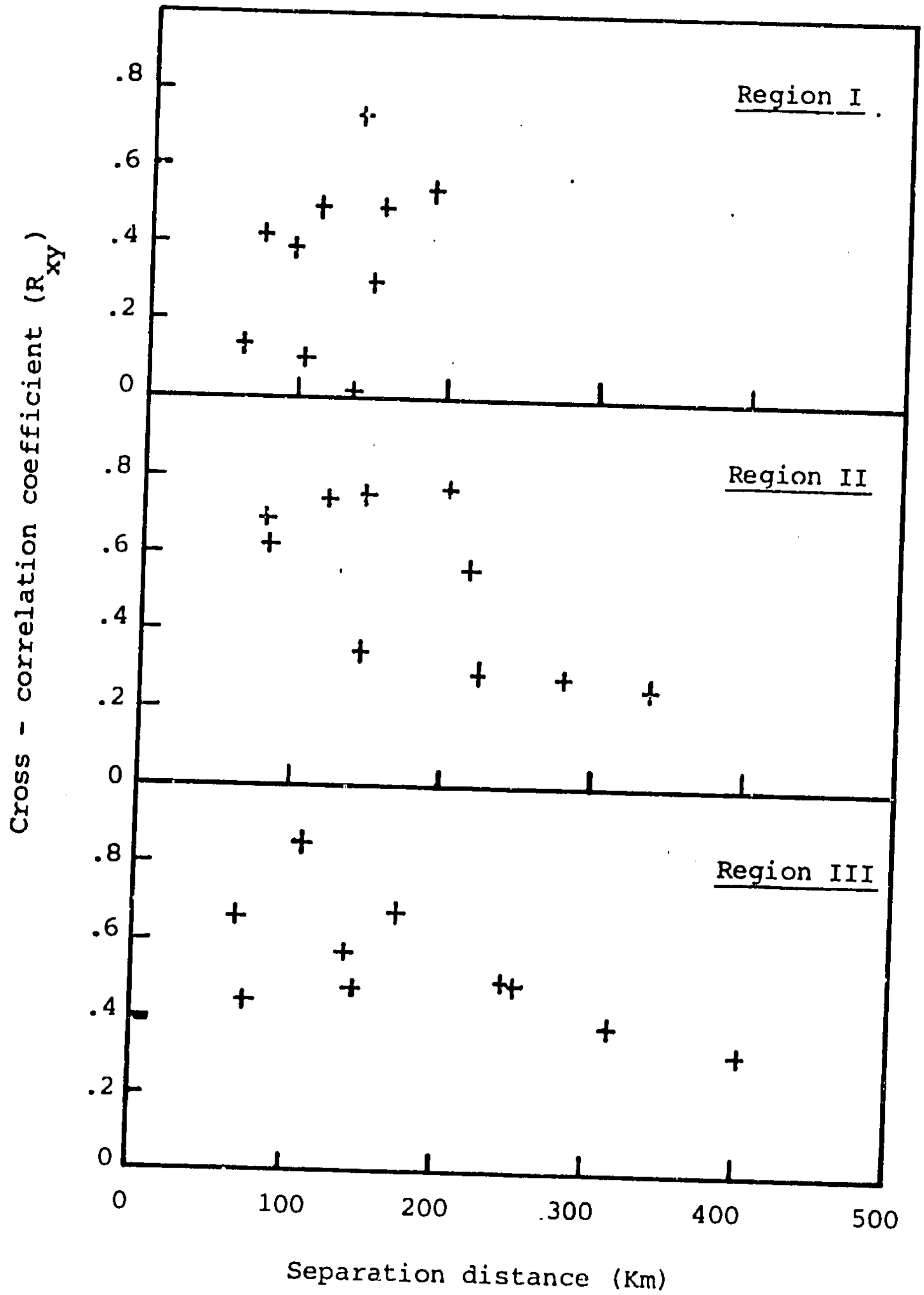
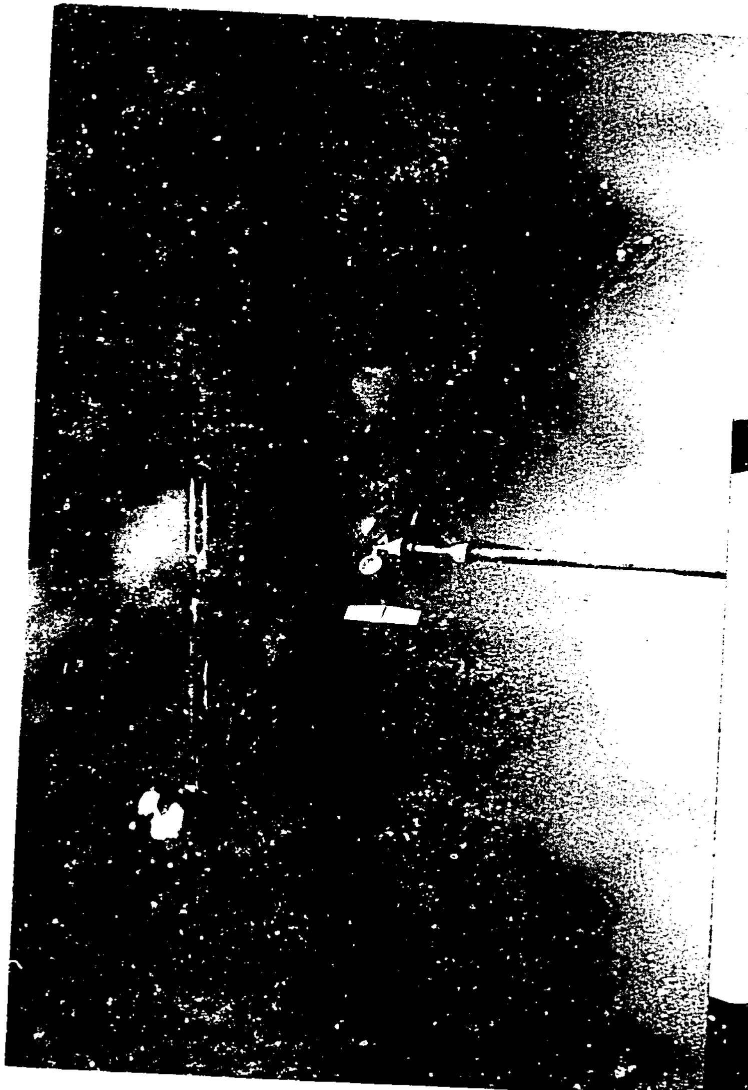
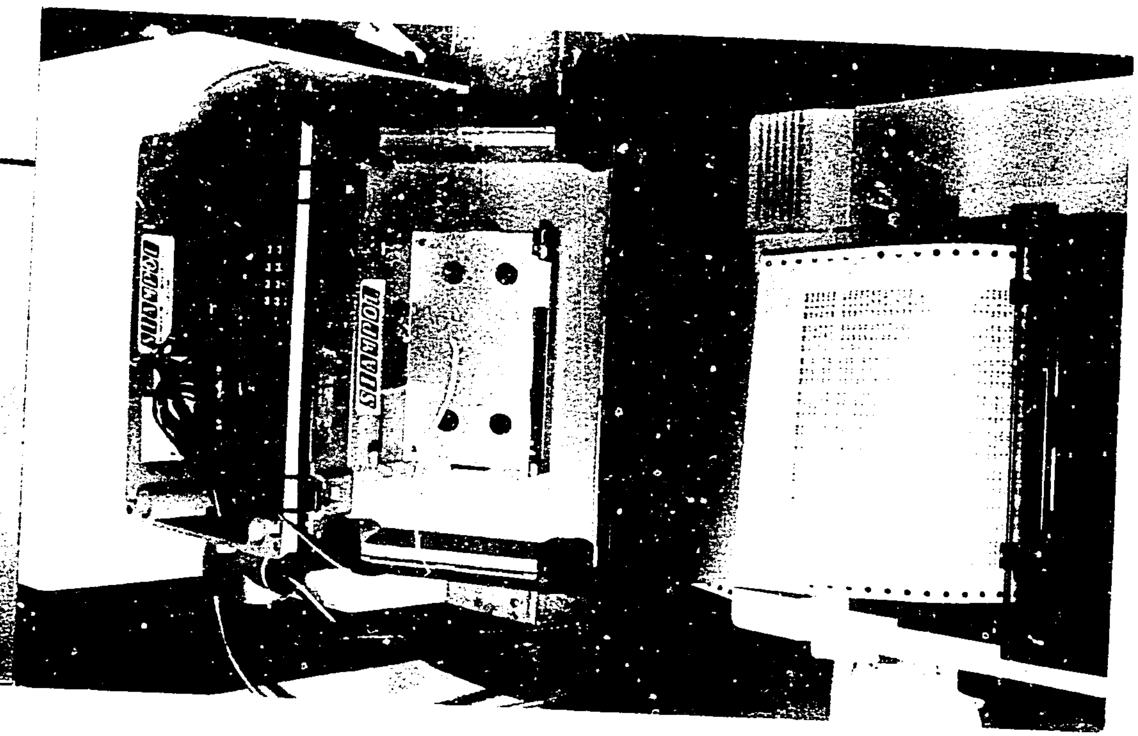


Figure 7.9 : Cross - correlation of wind speed averages versus separation distance between stations.



<u>Figure 7.10</u> : The cup-anemometer.



<u>Figure 7.11</u> : Micrologger assembly.

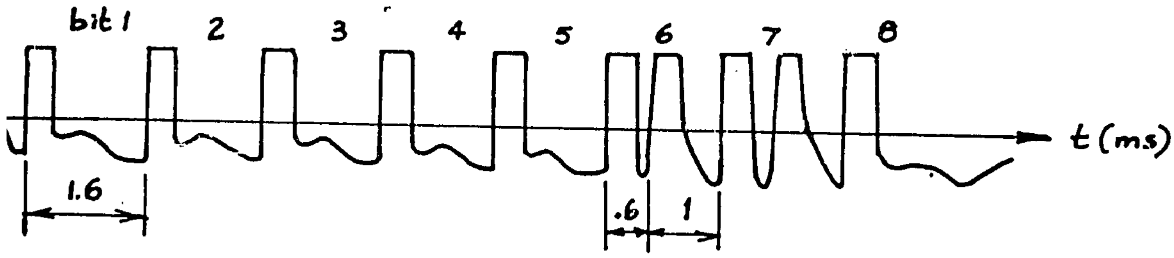


Fig.7.12 : (a) Cassette tape outout signal

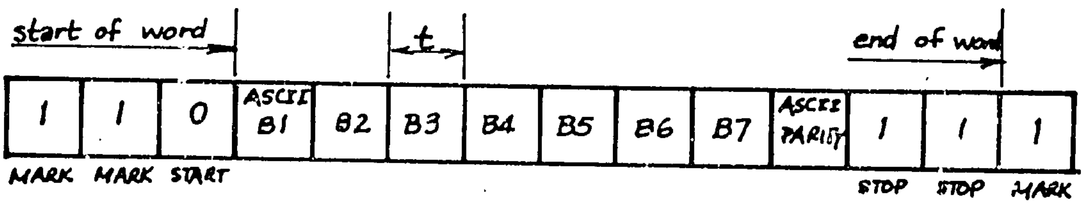


Fig.7.12 : (b) ASCII Character format

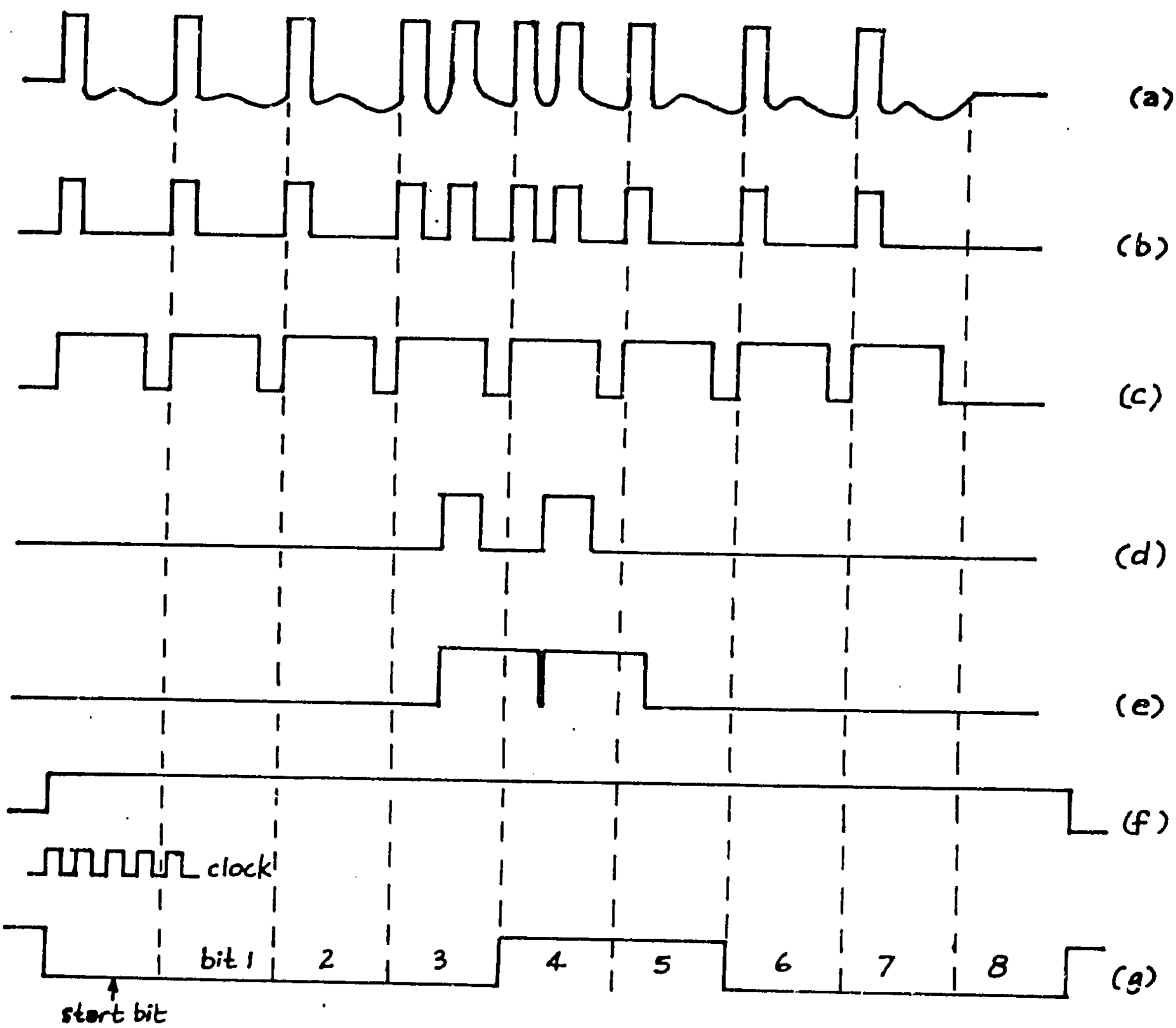


Fig.7.13 : Timing diagra... signal demodulation.

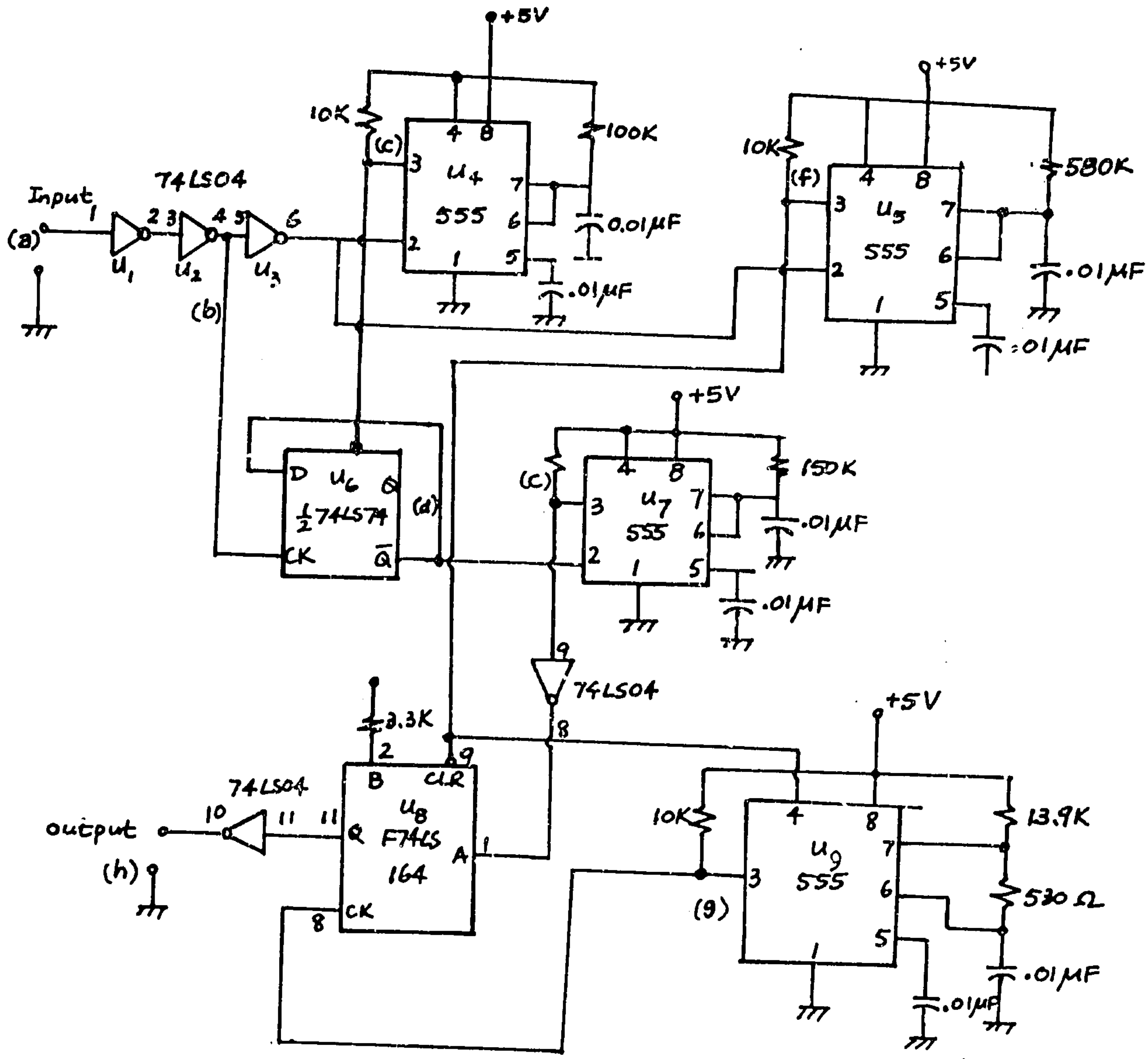


Fig.7.14 : The demodulator circuit

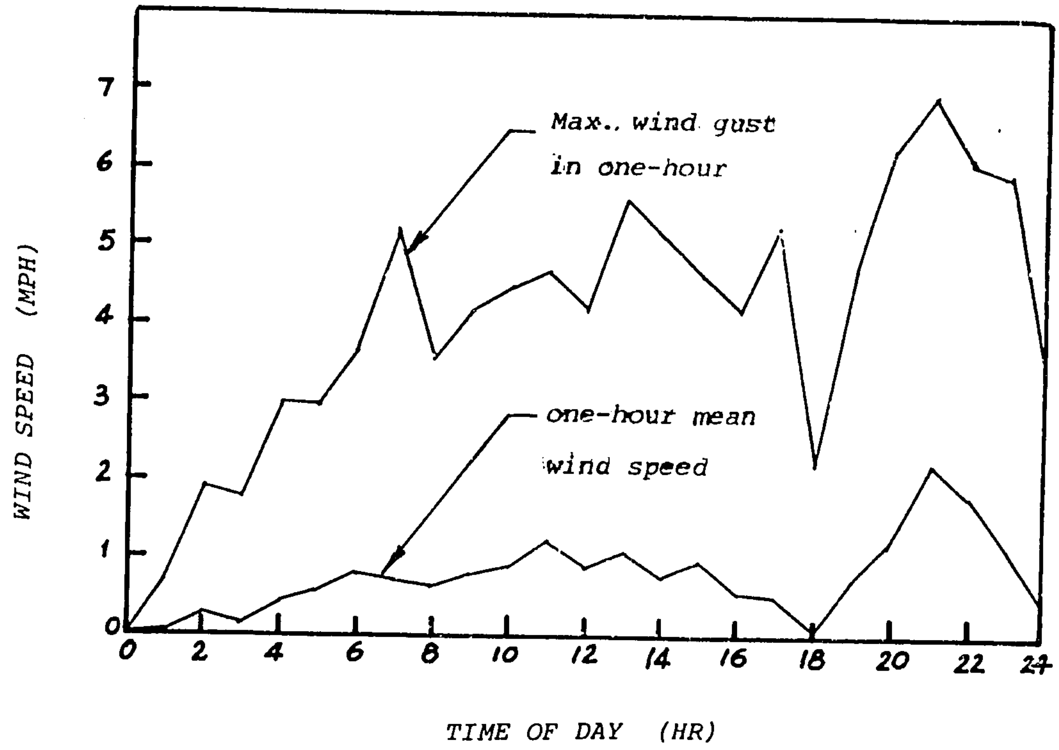


Fig.7.15 : Typical wind speed variations on a winter day.

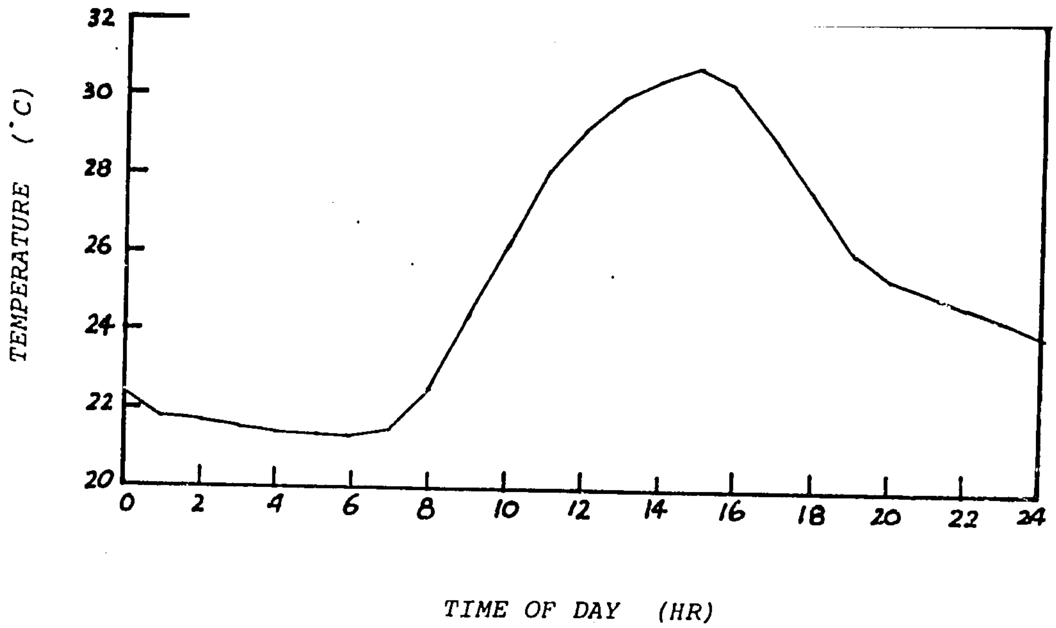


Fig.7.16 : Typical temperature variations on a winter day.

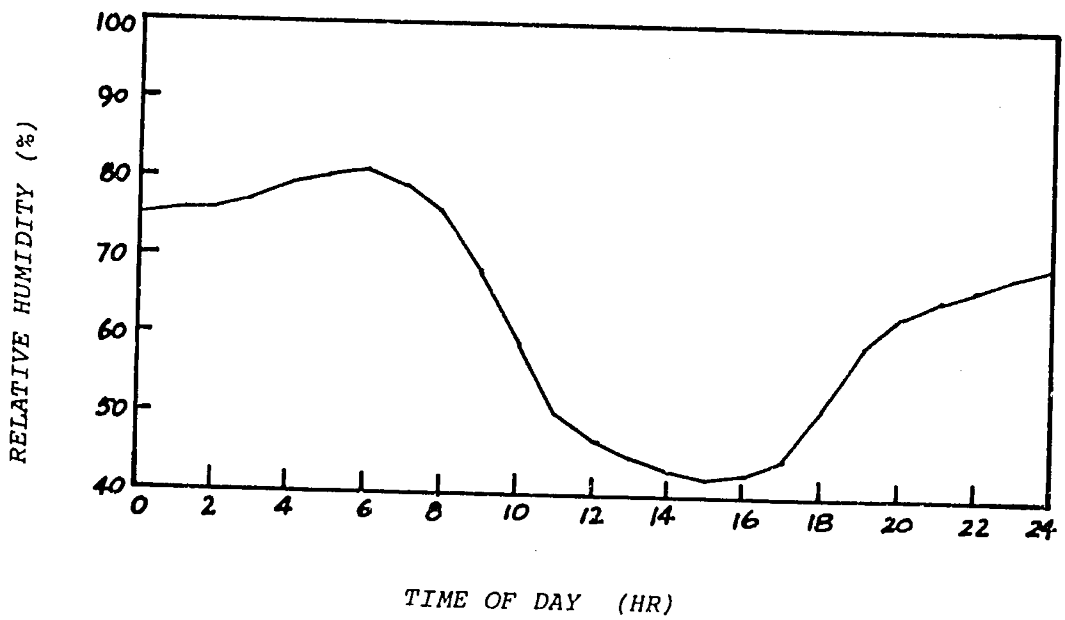
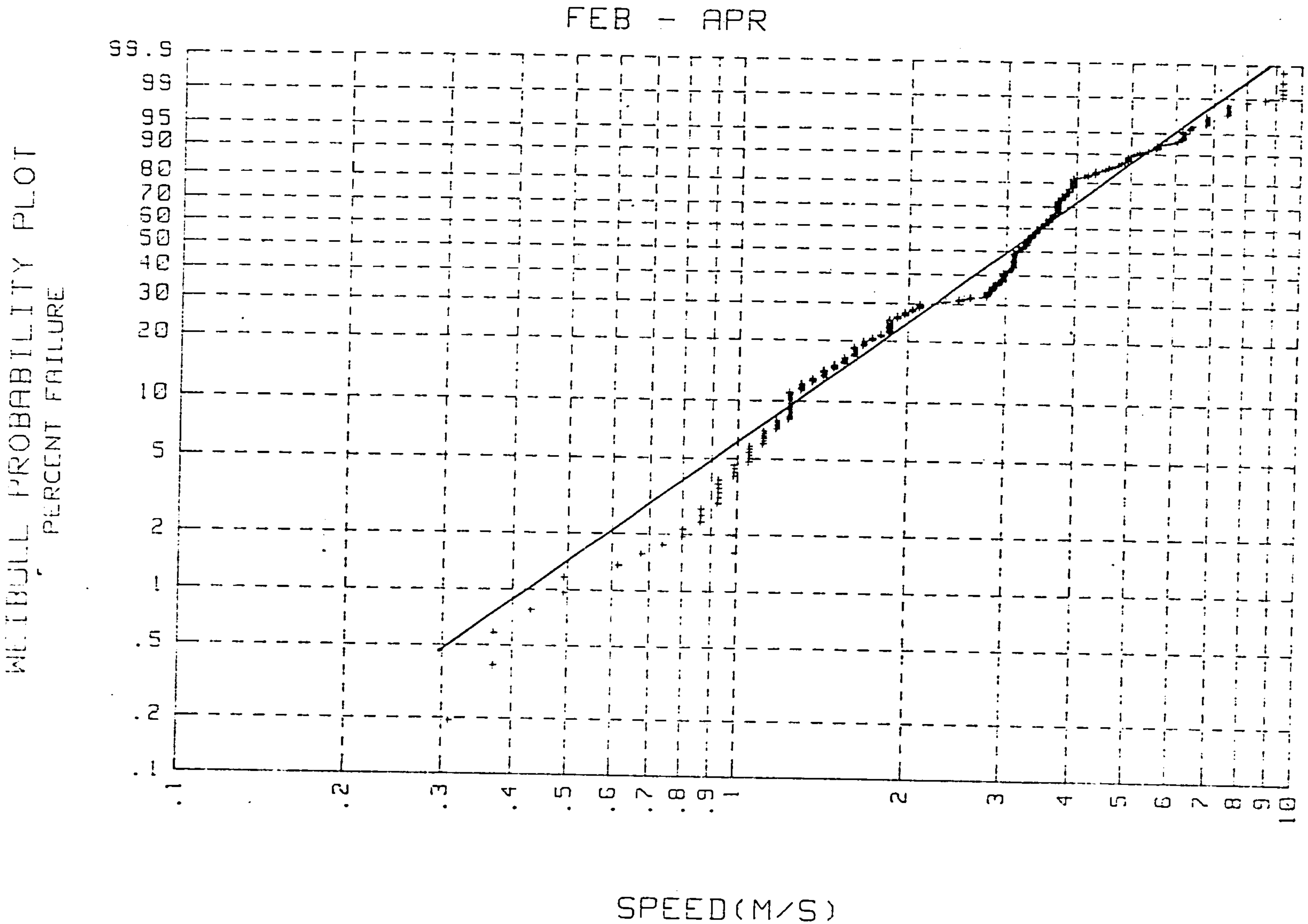


Fig.7.17 : Typical humidity variation



<u>Figure 7.18</u> : Weibull probability plot for Feb - Apr.

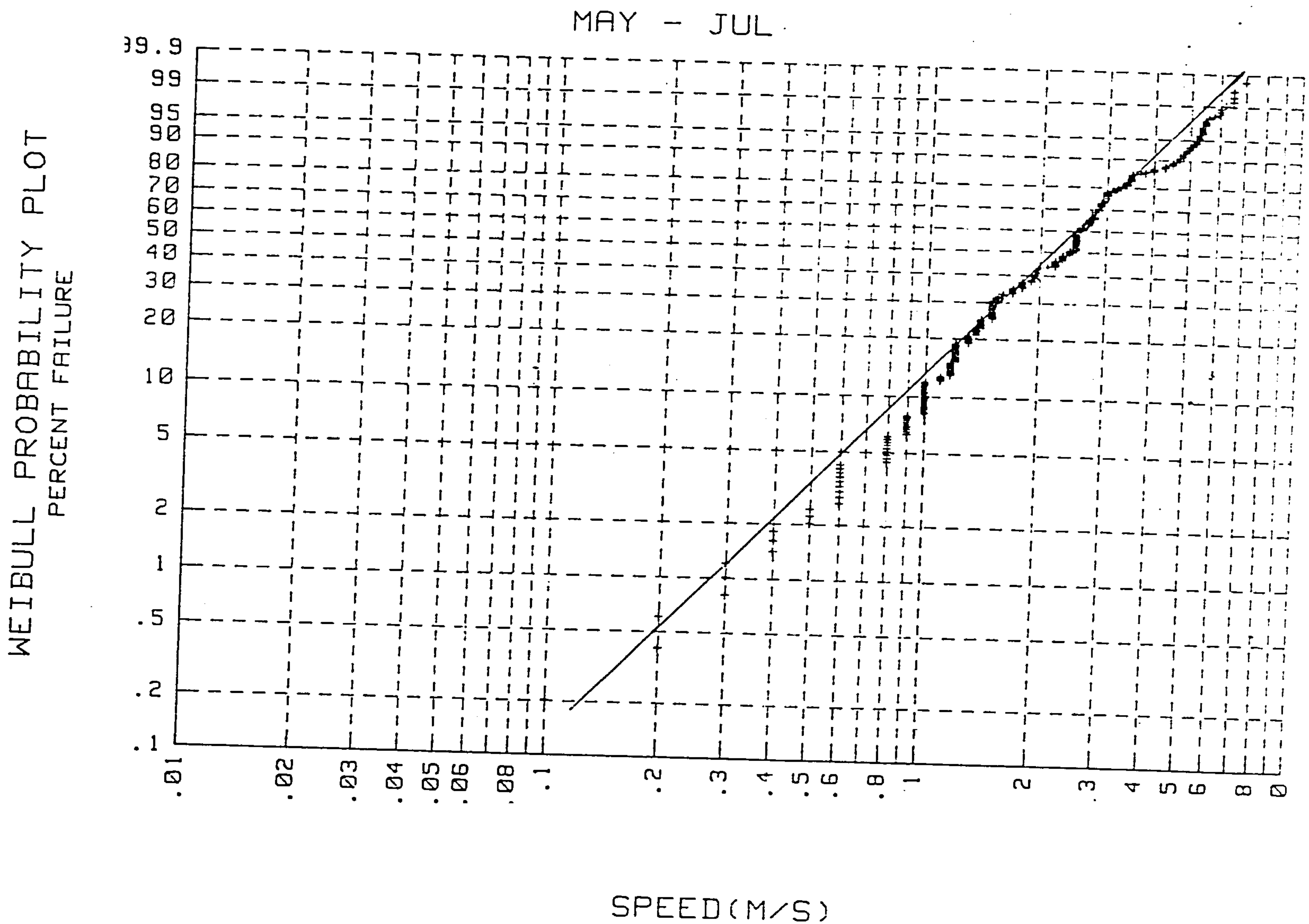


Figure 7.19 : *Weibull probability plot for May - Jul.*

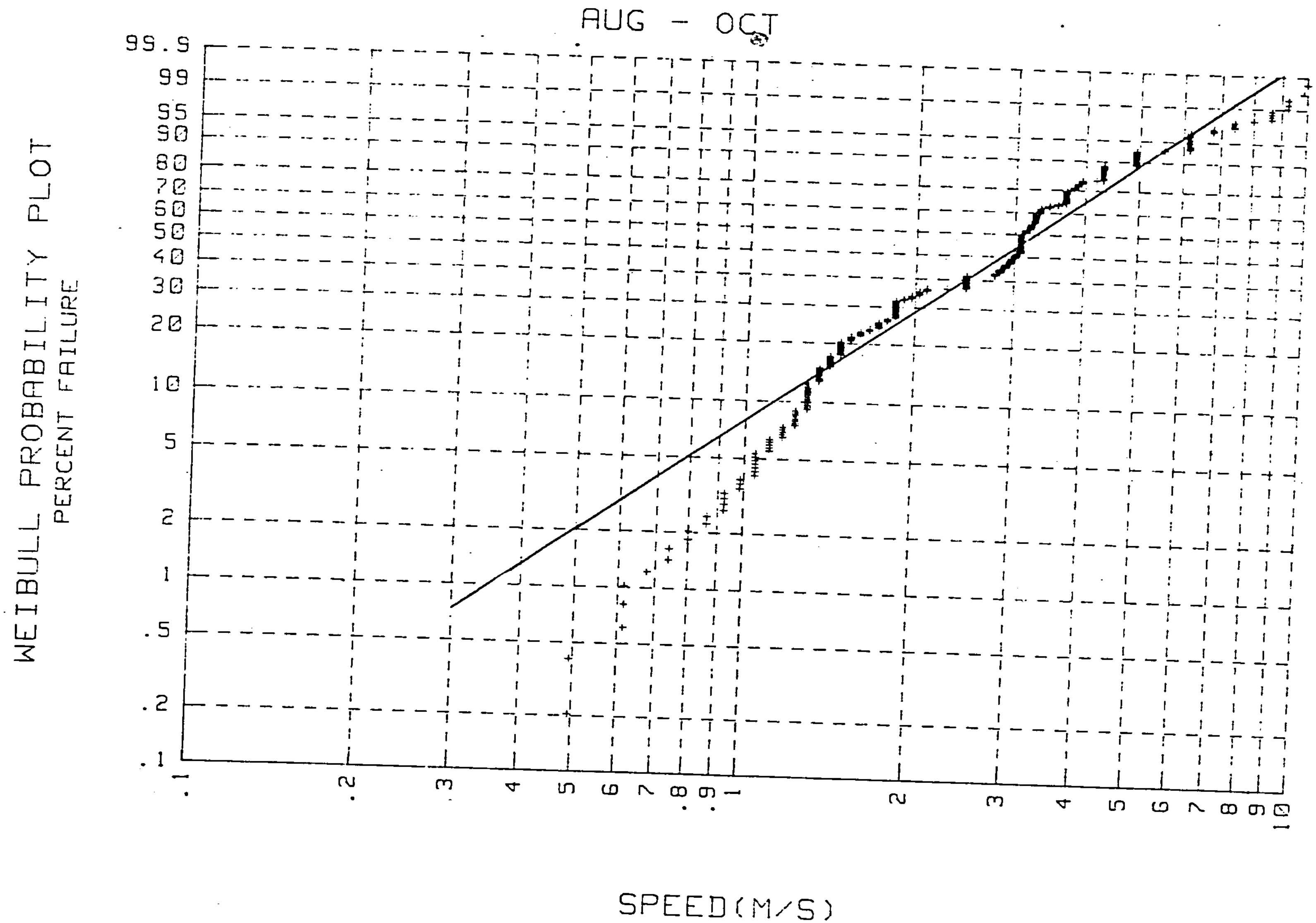
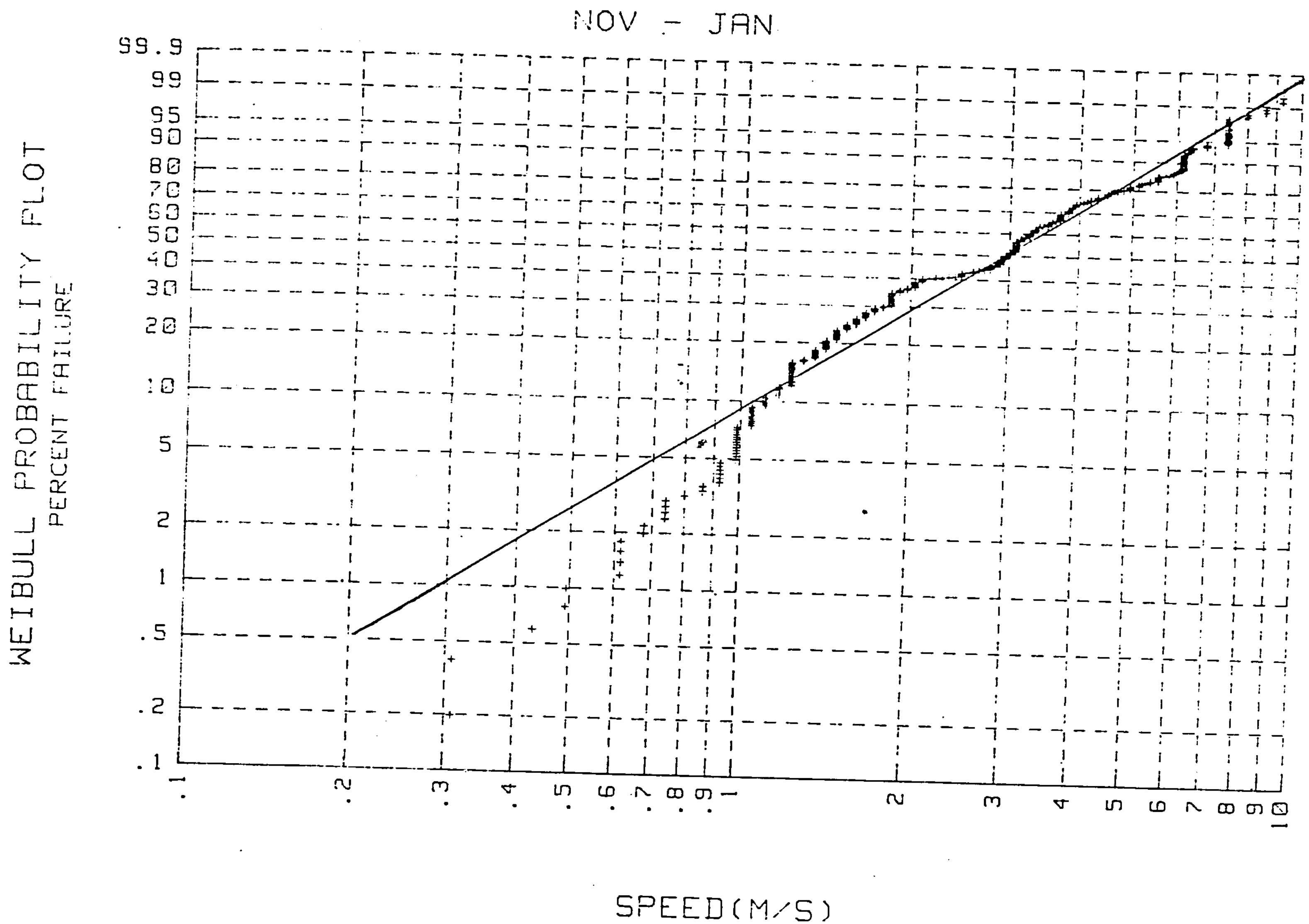


Figure 7.20 : *Weibull probability plot for Aug - Oct.*



<u>Figure 7.21</u> : Weibull probability plot for Nov - Jan.

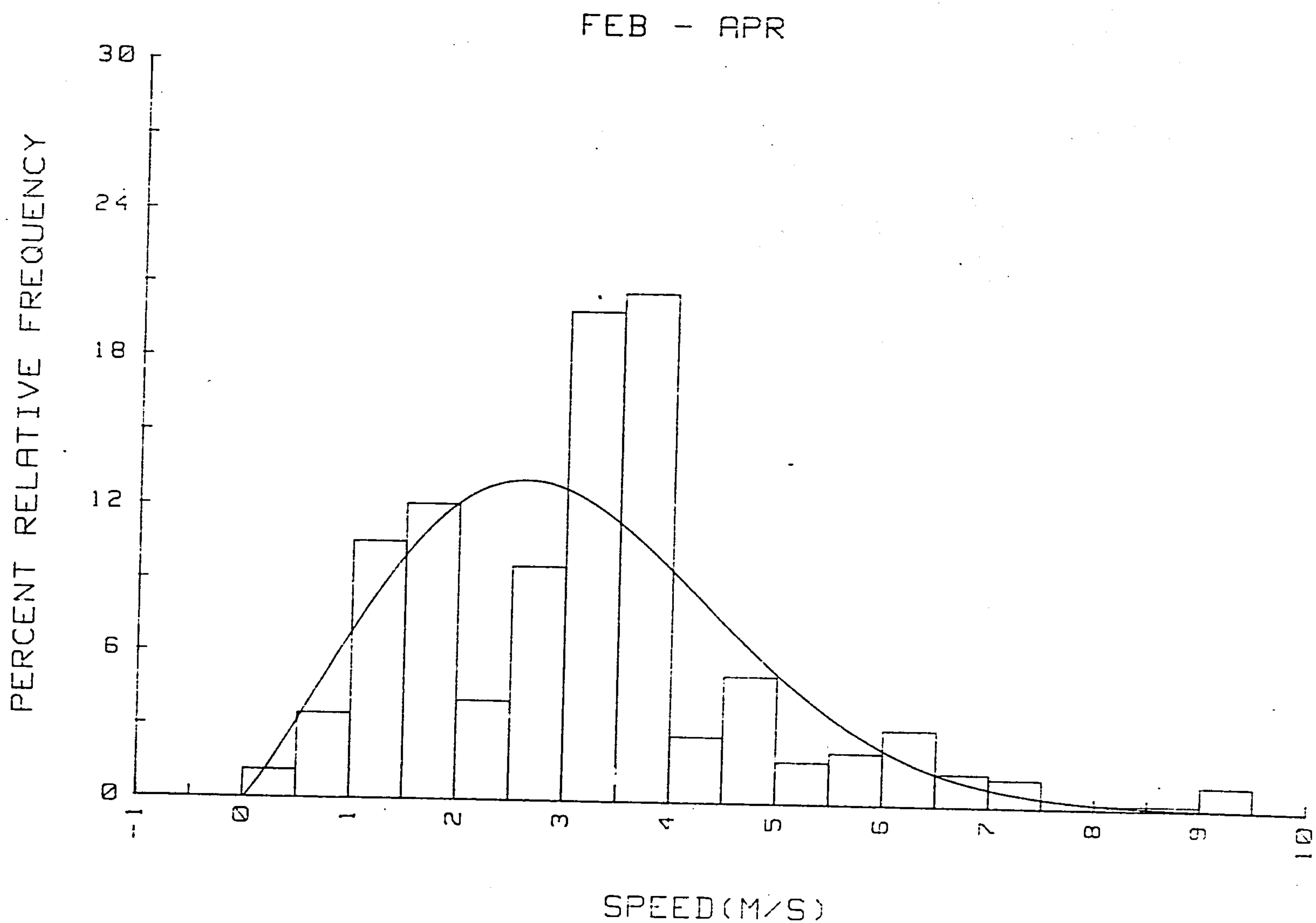


Figure 7.22 : *Histogram and Weibull distribution function for Feb - Apr.*

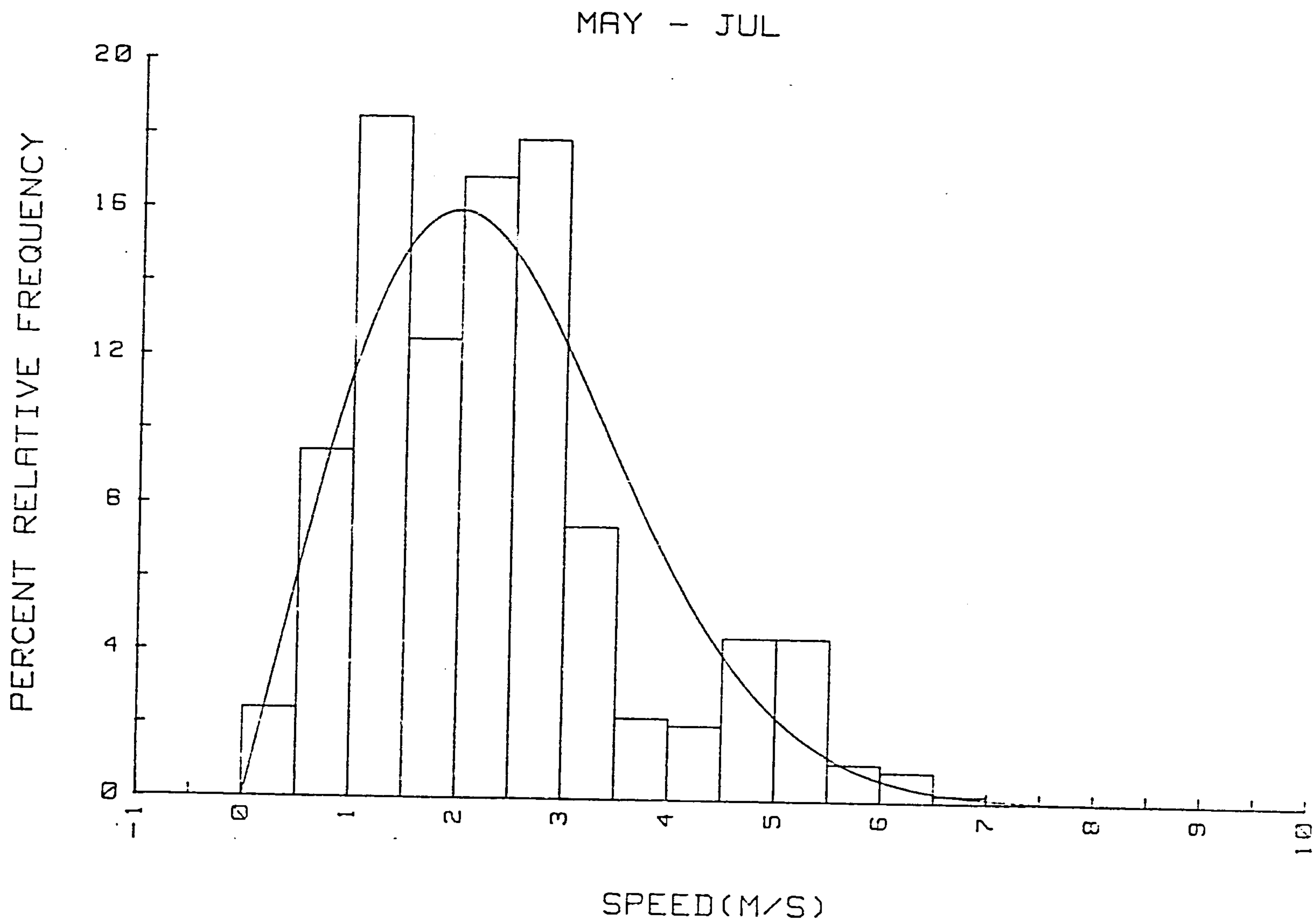


Figure 7.23 : *Histogram and Weibull distribution function for May - Jul.*

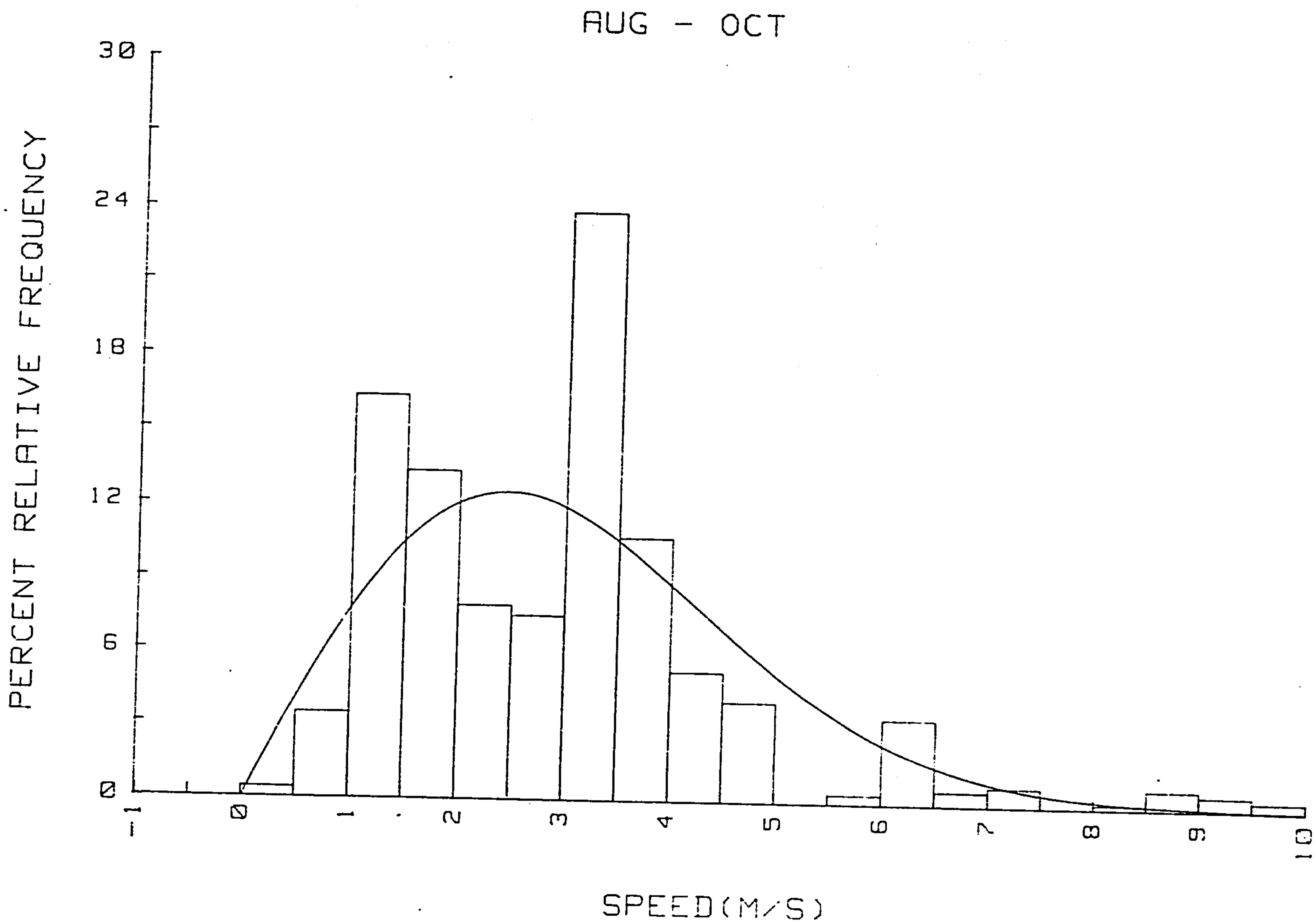


Figure 7.24 : *Histogram and Weibull distribution function for Aug - Oct.*

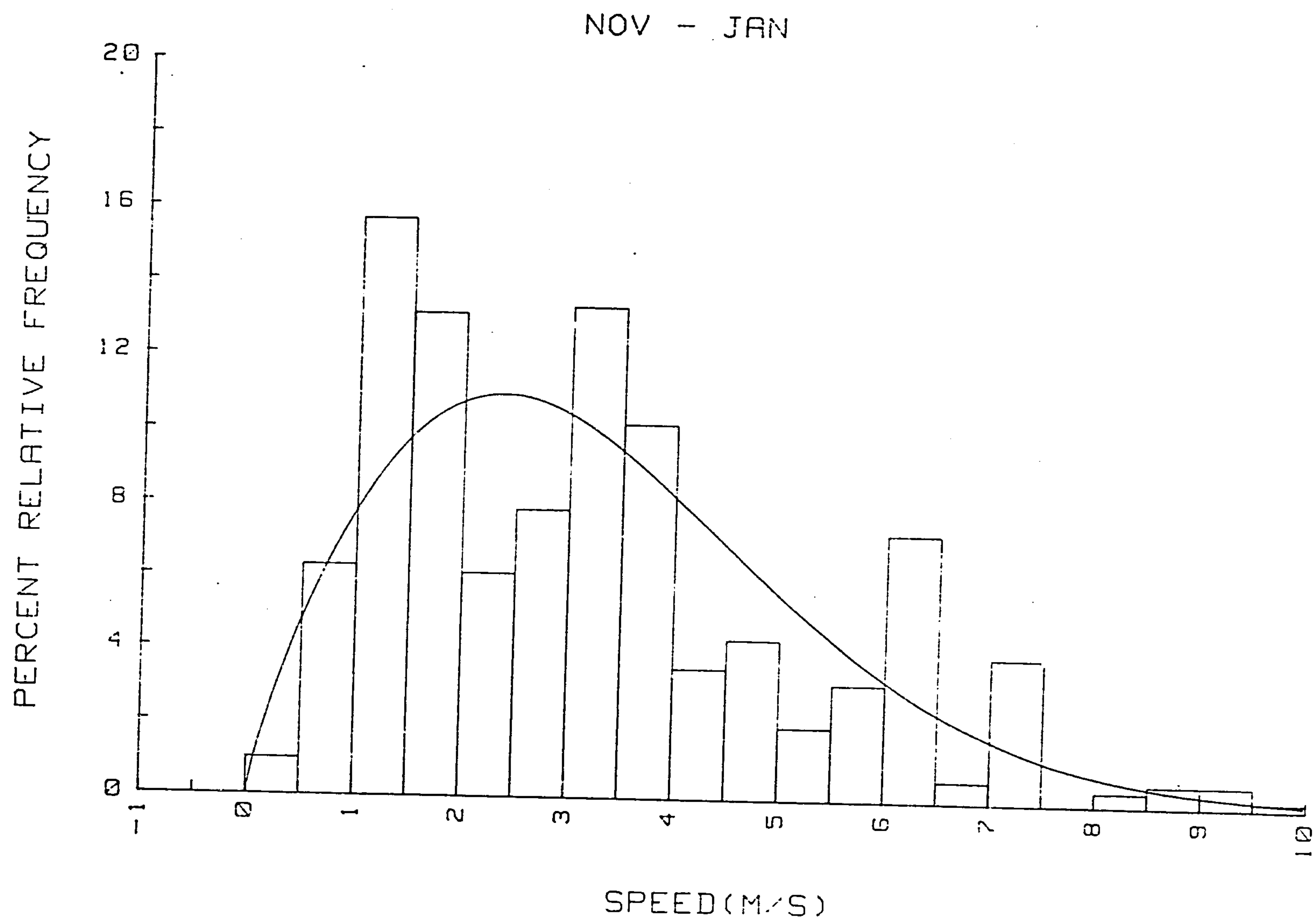


Figure 7.25 : *Histogram and Weibull distribution function for Nov - Jan.*

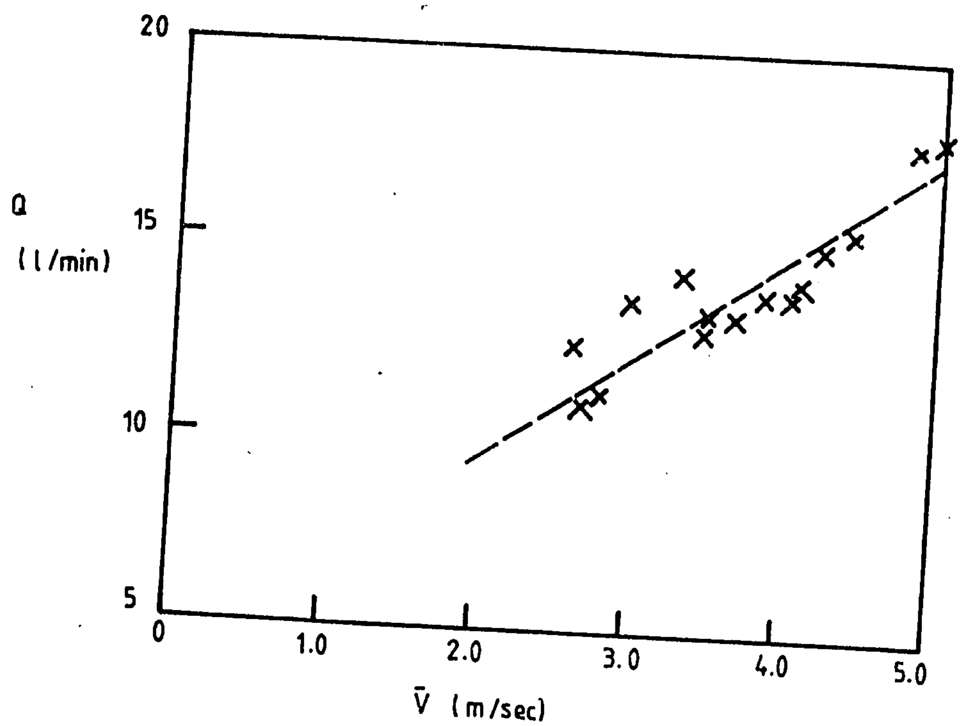


Figure 7.27 : Pump discharge as a function of wind speed.

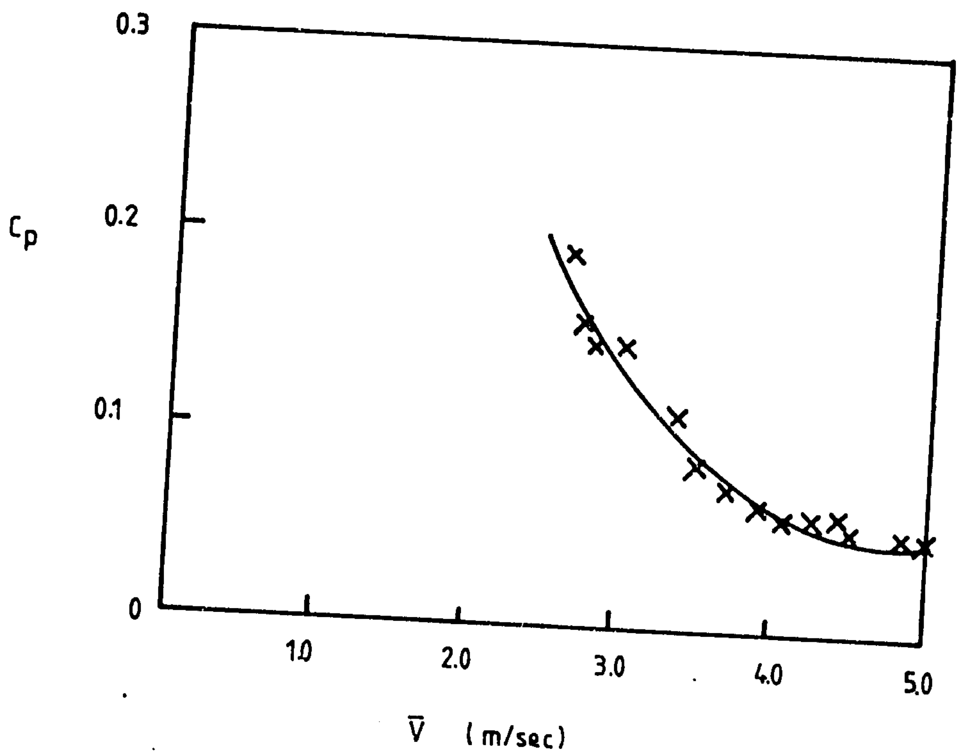


Figure 7.28 : Overall efficiency of the wind-pump system as a function of wind speed.

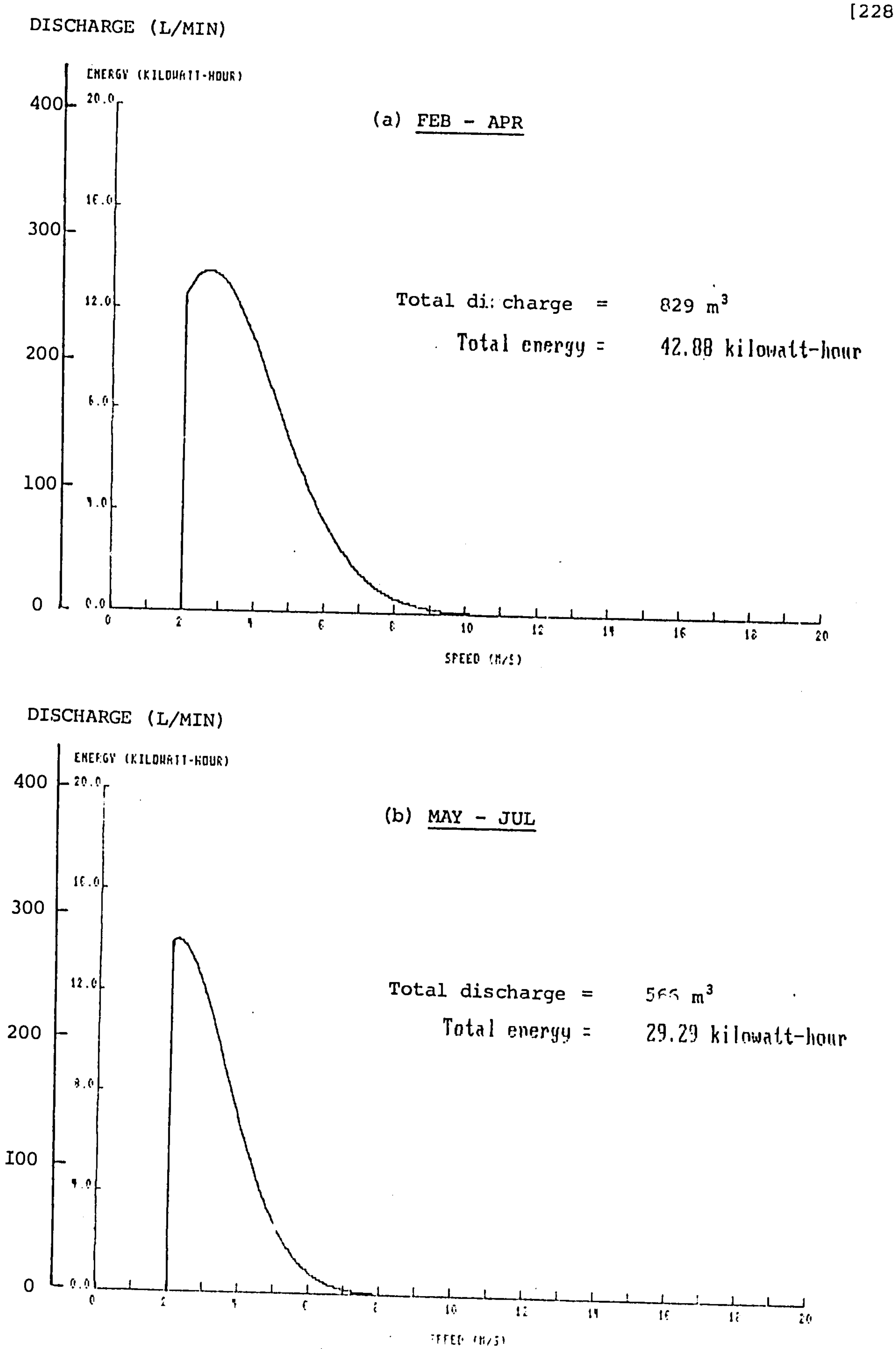
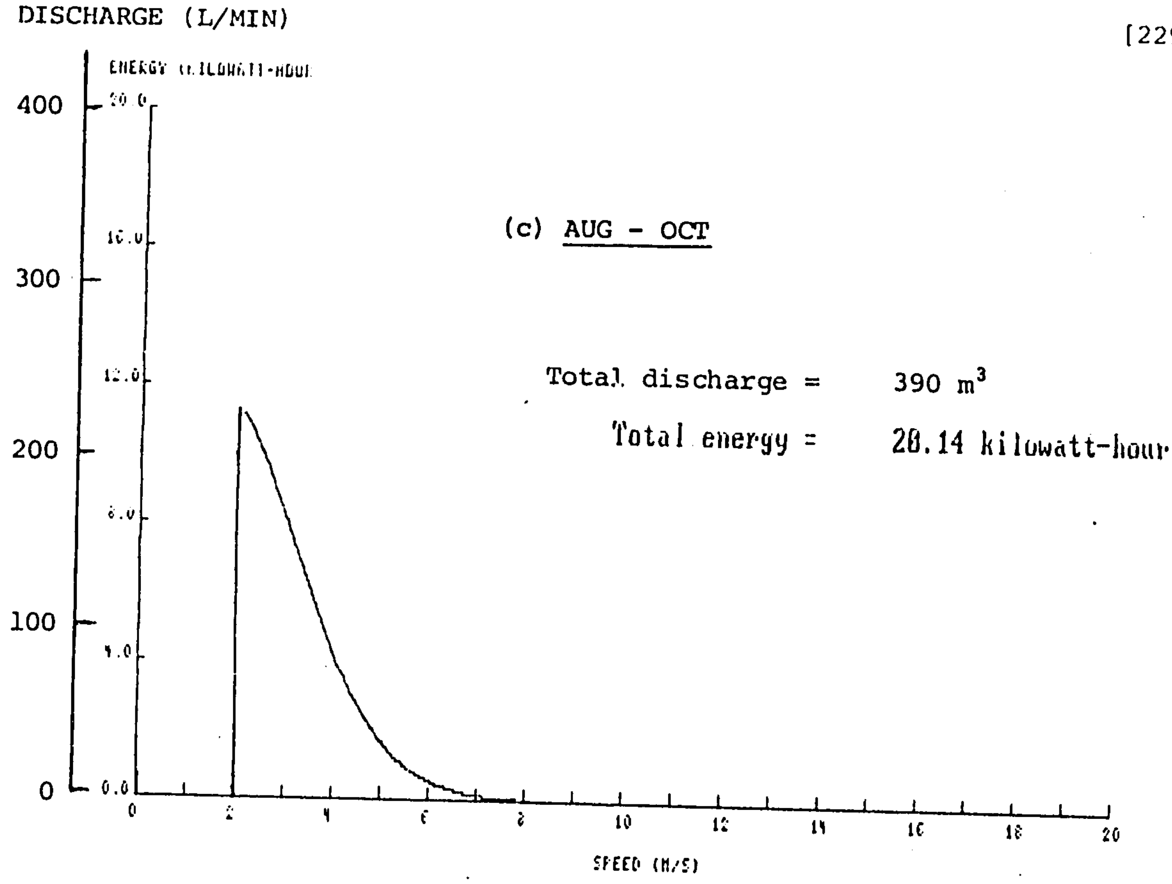


Figure 7.29 : Simulated seasonal pump discharge as a Function of wind speed



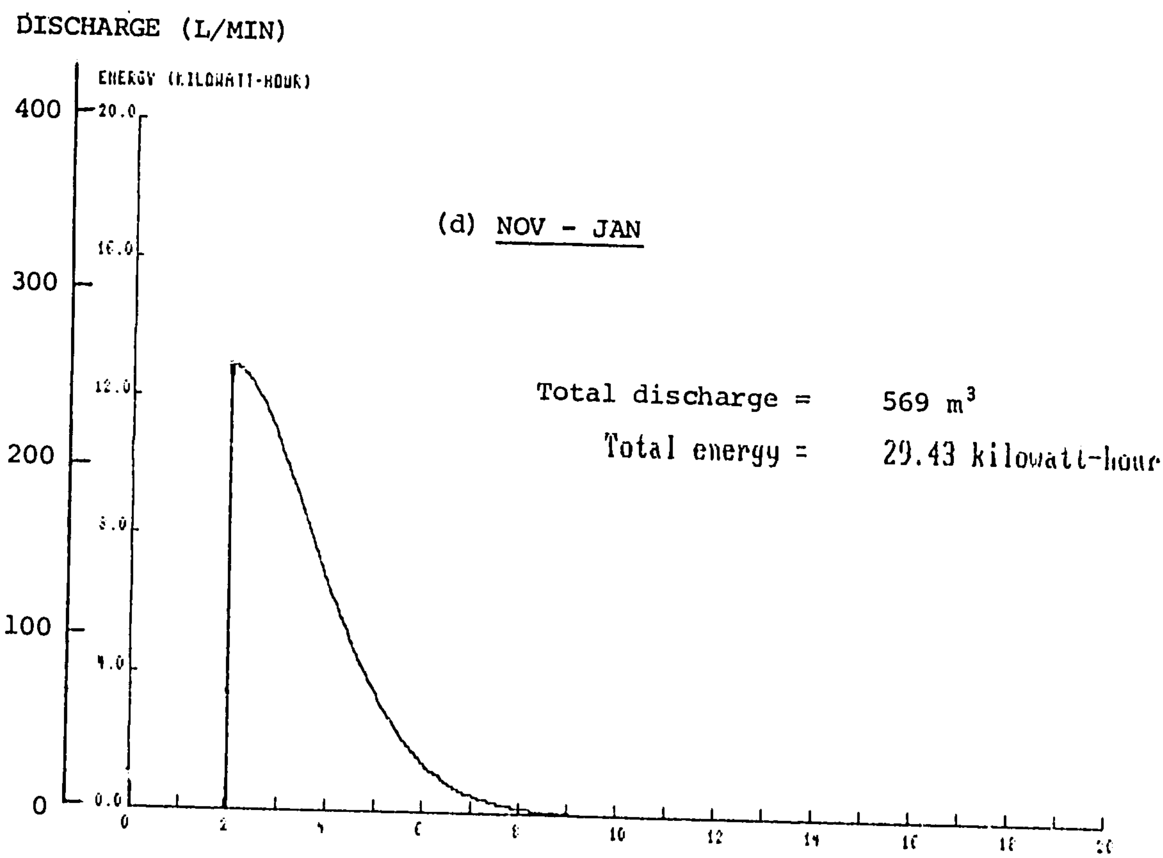


Figure 7.29 : (continued)

VIII. OVERALL CONCLUSIONS

A. Conclusions

This research project was conducted to investigate the possibility of creating a "buffer" area between salt-farms and cropland in the coastal provinces as a tool for protecting the procuctive soil from the proliferation of salinization. The study involved both greenhouse and field experiments with the specific objective of determining a viable means to reduce soil salinity in the buffer area down to a level preferable to the growth of physic-nut trees-a salt-loterant plant which can serve as an energy source. While there are shortcomings in this endeavour, there are successes which may be put on record as follows :

1. It has been demonstrated that through soil reclamation, physic-nut trees can indeed be grown on seemingly intractable former salt-farm soils of the southern coast along the Gulf of Siam near Bangkok.
2. Results from these experimental studies indicate that soil of this area can be reclaimed adequately for physic-nut growth by leaching alone. Alternatively, they can be reclaimed by addition of large quantities of organic material (e.g., 3% rice husks) and large amounts of gypsum (e.g., 6%), followed by leaching. Additions of lesser amounts of organic material (e.g., rice husks or composted manure) and/or gypsum actually worsened ability to reclaim these soils by subsequent leaching, in a greenhouse study. This was likely due to physical blockage of small pores in the soil by the finely -

ground organic materials. Use of coarse organic fragments would probably be better from the standpoint of improving soil physical characteristics including water permeability. [Optimum yields with maximum oil content has still been unanswered from the research results, however, unless change in product yields in the following harvests are studied with respects to properties of the field soils]

3. The results of engine performance studies under various load conditions further confirmed the technical feasibility of using physic-nut oil to power small diesel-fuel engines without appreciable modification. However, with the softening of oil prices, the economics of using physic-nut oil as an alternate energy may not be favourable for a long time, to come.

4. The compilation and testing of auto-and cross-correlations for a large number of long-term weather data at 15 sites in 3 physiographic provinces of Thailand has provided insights into the nature of wind speed fluctuations, and their inter-provincial dependencies. This then serves as an aid to further evaluation of the feasibility of using wind power to pump water necessary to recldaim saline and then maintain (irrigate) plantations on that soil.

5. The statistical analysis of on-site wind measurements and the field testing of wind-pump performance have enabled the simulation of the total seasonal wind-pump discharge, providing a more direct basis for the evaluation of the feasibility of using wind-powered water-pumping systems. The computer program package developed for

for this project can also be readily used for the feasibility study of other wind system.

6. Overall cost-benefit analysis of the project suggests that such a land-reclamation project may indeed be economically feasible, subject to the confirmation of the extent of area affected by salinization. At any rate, the initial outlay appears to be too high for a cropland owner.

B. Recommendations for further study

In dealing with a complex, multidisciplinary project such as the present one, there are bound to be problems and obstacles. In retrospect, there are lessons to be learned as a result of only-partial successes. The major ones include :

1. Incovenience caused by distance between the Institute and the research site. Because of the long distance involved, complex programs needing daily supervision by skilled scientists such as the greenhouse study, should have been performed in closs proximity to Bangkok, rather than at the experimental site. (The idea of building an on-campus greenhouse was comptemplated in the early stage of the project, but permission from the Institute was not forthcoming due to complicated official procedures). It would have proved much simpler, in retrospect, to transport the necessary quantities of experimental site soil to Bangkok, on a one-time basis, than to continually transport project personnel 120 km to the experimental site twice a week and/or to rely on less-skilled

or less-reliable on-site workers for sensitive tasks. The same is true of initial testing of the windmill units. Initial testing in Bangkok should have disclosed the gearbox problems that led to dysfunction of one or both windmill units. Once functional, however, the units would still need to be dissembled into subsections and reassembled on-site for the pumping tests and to ensure that additional factors including continuous contact with salt spray would not seriously impair their operation. Furthermore, other unforseen circumstances could also have been avoided had the experiment been carried out on-campus. A case in point is the unexpected, prolonged heavy rainfall from early July 1983 to mid January 1984 which inundated the site soil, thereby hindering the construction of essential facilities in the initial phase of the project.

2. Personnel administration. Qualified individuals, including responsible students, need to be located and adequately remunerated for windmill construction and installation, and for other sustained work on-site such as weather monitoring as necessary. A responsible student could have provided the necessary link between the project manager on-site and the project's principal investigators in Bangkok. It is also necessary, for a multi-location project such as this, that the investigators incorporate sufficient cross-checks of preformance by project personnel to insure that unsatisfactory performance do not occur.

3. Coordination and communication. Many parties are involved in a

large project such as this. Better coordination and more effective communication could have been maintained among the parties concerned, namely the principal investigators, the collaborators, the colleagues, the Institute administration as well as the grant donor, while recognizing the sensitivities of each. This applies from planning through to the final stages of the project.

4. When using drip emitters in fairly irregular patterns, and periodic portable overhead sprinklers to leach salt-spray from foliage and augment the amount of leaching, it is virtually impossible to predict the distribution of salinity across the plot area. Hence it is important that a regular sampling program across the traditional rooting area of selected well-growing and poorly-growing plants be conducted, and that physic-nut trees be grown in soils or sand culture of varying salinity levels to enable correlation of root - zone salinity levels with likely tree yields.

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APPENDIX

A. Water supply system

Referring to figure A.1, water is pumped up from the well (1) by two piston pumps (2), each driven by a wind turbine (3), and fed through a totalizing turbine meter (4), a check valve (5), and then recombines in the common supply line to the storage tank at 3.72 m from the ground. To control the water level in the storage tank, a float valve (7) was installed at the discharge point of the supply line. And to prevent unnecessary loss of ground water when the supply to the tank is shut off by the float valve, a relieve valve (8) was installed in the supply line of each pump. Thus, when the pressure builds up in the supply line, the water supply is discharged back into the pump suction line.

For the air-lift system, compressed air from the engine-driven air compressor (9) is injected into the same well-shaft as that used for the wind-pump system. The water supply is routed either to the storage tank or directly to field (for higher flow rates).

A ball valve (10) was installed to control the water supply from the tank to the field. At the supply point on site, the water passes through totalizing turbine meters (11) and gate valves (12) before being discharged to the field (13).

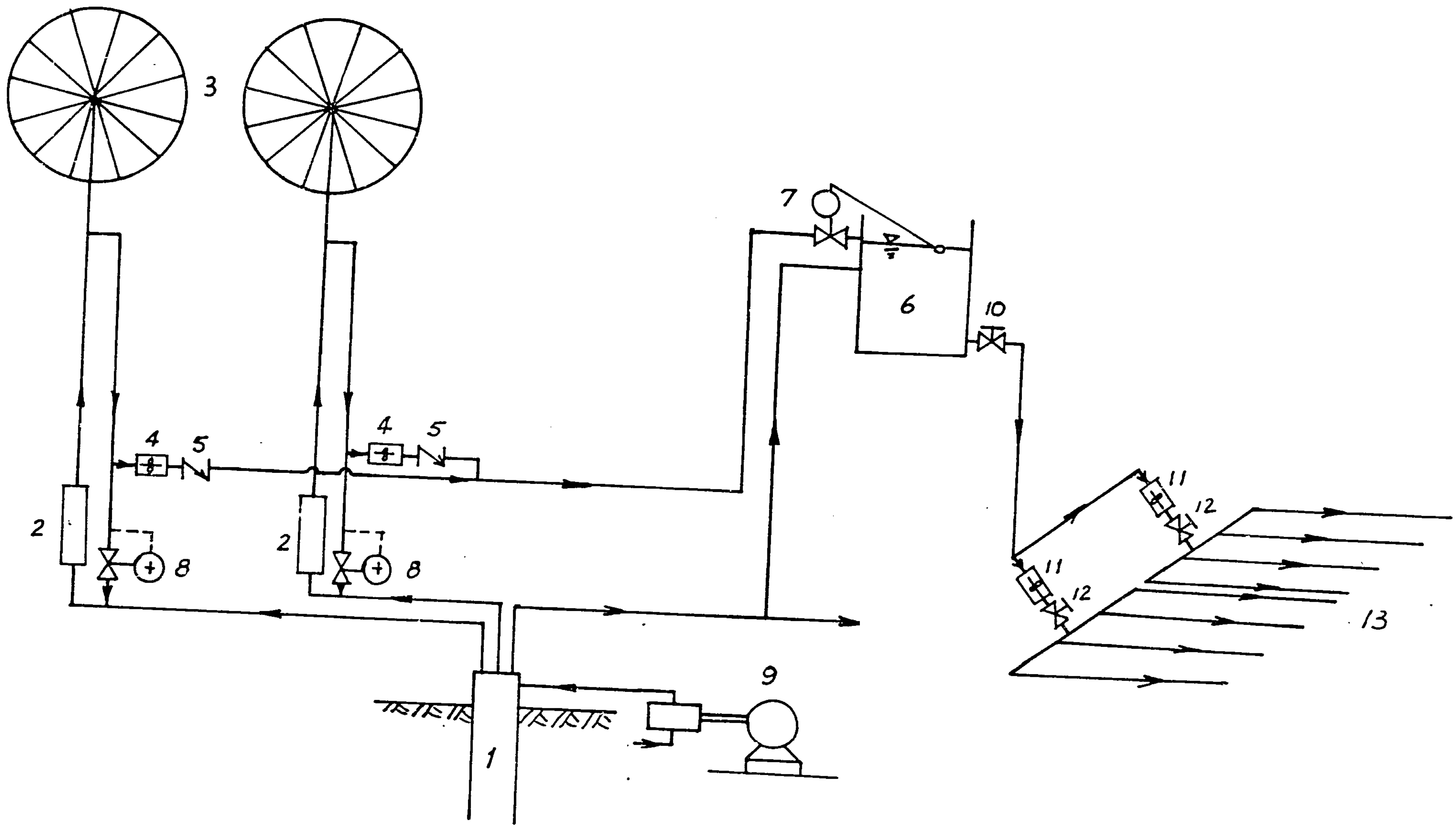

Figure A.1 . Schematic diagram of the water supply system