專　論

複作灌溉管理

Irrigation Management for Diversified Cropping in Taiwan, ROC

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摘　　要

近一、二十年來，由於農業生產技術改進，經濟結構轉變，國人營養需求改變等，稻米生產過剩，農民需要轉作其他作物，以增加收入；另一方面，農村人口外移，勞力缺乏，生產成本增加，發生農業經營上種種困難，此種現象在東南亞開發中國家亦普遍發生。在這些地理氣候水土環境特殊之季節風農業（Monsoon Agriculture）國家，水田不失爲國寶，仍須以水田土地利用形態，繼續改良農地，以期轉作自如之高度多角經營，同時研究有關技術問題如(1)適地適作、作物改良、最適輪作制度、作物需水量、灌漑方法、農機改良、低成本栽培法等，以及研究經濟與社會問題如(1)作物價格穩定，(2)農產品產銷、(3)加强農民組織、(4)獎勵農民等。

INTRODUCTION

Irrigation has been essentially developed for rice cultivation in Taiwan. It began in the fourteenth century when immigrants came from mainland China. The early development was on a small scale. With a few exceptions, the irrigation systems were built and managed by the farmers themselves without any control or assistance from the government. By 1895, a total area of over 200,000 hectares had been developed for rice cultivation, of which about 100,000 hectares were under irrigation.

During the period from 1896 to 1945, the existing systems were remodelled, consolidated, and enlarged, and a number of new systems were constructed. In this period, the irrigation area was increased to the highest record of 562,000 hectares producing 1,400,000 metric tons of brown rice in 1938.

Since 1945, both irrigated rice crop area and production have been increased. The rice yield per unit area has been significantly increased. In 1945, the rice harvested area was 502,018 hectares with an annual brown rice production of 639,000 metric tons. It increased to 786,343 hectares with the highest production record of 2,712,985 metric tons in 1976. Needless to say, such progress can be attributed mostly to technology advancement, including the improvement of irrigation and drainage.[1,6]

For many years in the past, Taiwan not only enjoyed self-sufficiency in rice production, but also had surplus rice to export to other countries. However, this situation did not exist long as the rice demands both at home and abroad decreased. As a result, a diversified cropping program has to be enforced in order to release the pressure due to the over-production of rice.

Needless to say, technological innovation has also play an important role in the diversification of agriculture in Taiwan. The success of breeding early maturing varieties of crops, the practice of relay-interplanting, the effective plant protection measures, fertilization and densely spacing planting, the introduction of farm machineries, as well as the experiments and extension of dry farmed crop irrigation have resulted in an increase in the efficiency of water, land and labor use which in turn substantially increased the adaptability of diversified cropping, thus maximizing resources use.

NATURAL ENVIRONMENT

Geography

Taiwan, an island province of the Republic of China, is located in the subtropical zone. Its area is composed of Taiwan proper, the Penhu islands (the Pescadores) and other islets with a total coastline of over 1,600 kilometers and a total area of 36,006 square kilometers. The island of Taiwan proper is oblong in shape, about 394 kilometers in length from north to south and 144 kilometers at the widest. A central mountain range extends almost the entire length of the island from north to south, deviding the island into two parts. A number of the range peaks are over 3,800 meters above sea level. Two-thirds of the island are sloping and mountainous lands (Figure 1). The western part, with sizable plains is characterized by advanced agricultural, industrial and other economic activities.

The total cultivated land was 883,106 hectares in 1985, or about 25% of the total area. Paddy fields occupy 493,641 hectares and upland fields 389,465 hectares.[1, 12]

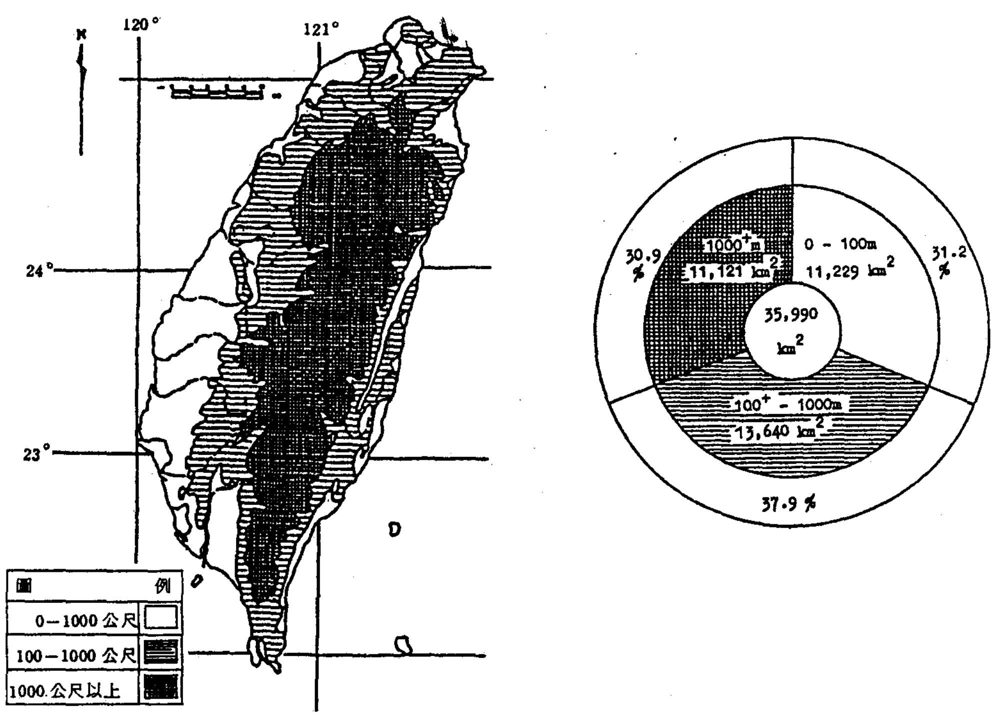


Figure 1. Topography and Broad Land Classification in Taiwan

The total irrigated area of the seventeen irrigation associations was 385,423 hectares in 1985, of which the double rice-crop area occupied 257,177 hectares; the single rice-crop area 27,036 hectares; the rotation cropping area (including two and three year rotations), 84,115 hectares; and upland crop area, 17,095 hectares. Besides, there are many scattered areas beyond the jurisdiction of the irrigation associations, totalling about 31,500 hectares.[1]

Climate

The climate of Taiwan is characterized by warm temperature and abundant rainfall. The mostly subtropical climate conduces to agricultural production, especially the year-round mild temperature permits diversified cropping. The average monthly temperature and rainfall in the main production areas of the coastal plains are given respectively in Figure 2 and Figure 3[2].

Generally speaking, the average temperature is 18°C in the winter months and 28°C in the summer months in the coastal plain areas. Topographically, the temperature lowers as the elevation goes up.

Rainfall in Taiwan is abundant but uneven in distribution. The average annual rainfall is 2,510 mm, of which about 78% occurs from May through October. The rainfall patterns in different parts of Taiwan are shown in Figure 4[3]. During the typhoon season, the rainfall occasionally exceeds 300–400 mm per day. The geographical and climatic factors necessitate not only flood control for the protection of lives and properties, but also irrigation purposes in the dry seasons.

INTENSIVE FARMING

Cropping Patterns

The agricultural development in Taiwan is characterized by intensive farming for multiple cropping, the success of which is attributed to many factors, the most important being the favorable climate, the supply of irrigation water, the development of early-maturing varieties, the improvement of cultural techniques, and the increasing demand for domestic consumption and for export especially in the early stage of development. The well-organized extension systems, the land reform, and the efforts of hard-working farmers have also contributed its success[4].

The intensity of farming varies throughout Taiwan. The paddy field ordinarily has three or four crops a year, with paddy rice as the main crop. The cropping systems and irrigation patterns used to be adopted in Taiwan may be classified into seven groups as shown in Figure 5[5,6]. A result of field tests reveals that the productivities of soils are at least not declining and may be increasing under the multiple cropping system[7].

Cropping Index

The basic motives for intensive farming on diversified cropping are mainly the limited land and water resources, and available labor in Taiwan. Owing to the relatively small size of private farm plots, farmers are naturally adopt intensive cropping to increase their incomes. This is true especially in the early stage of development when family labor is available. The utilization rate of the cultivated land or the multiple cropping index rose from 134.2 in 1939 to 189.7, the highest, in 1964 (Table 1)[1,14]. Later on, because

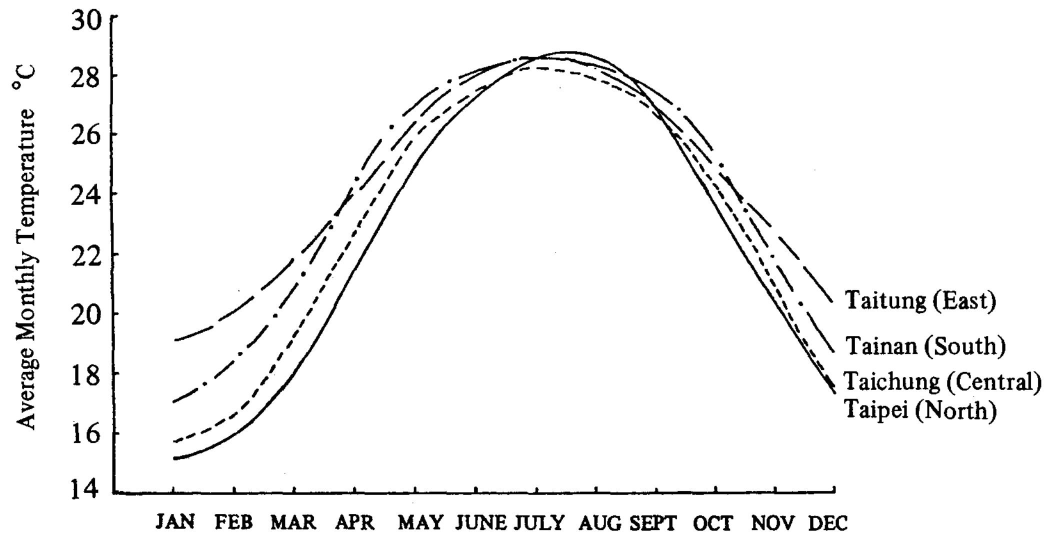


Figure 2. Average Temperature in Different Parts of Taiwan (1950-1969)

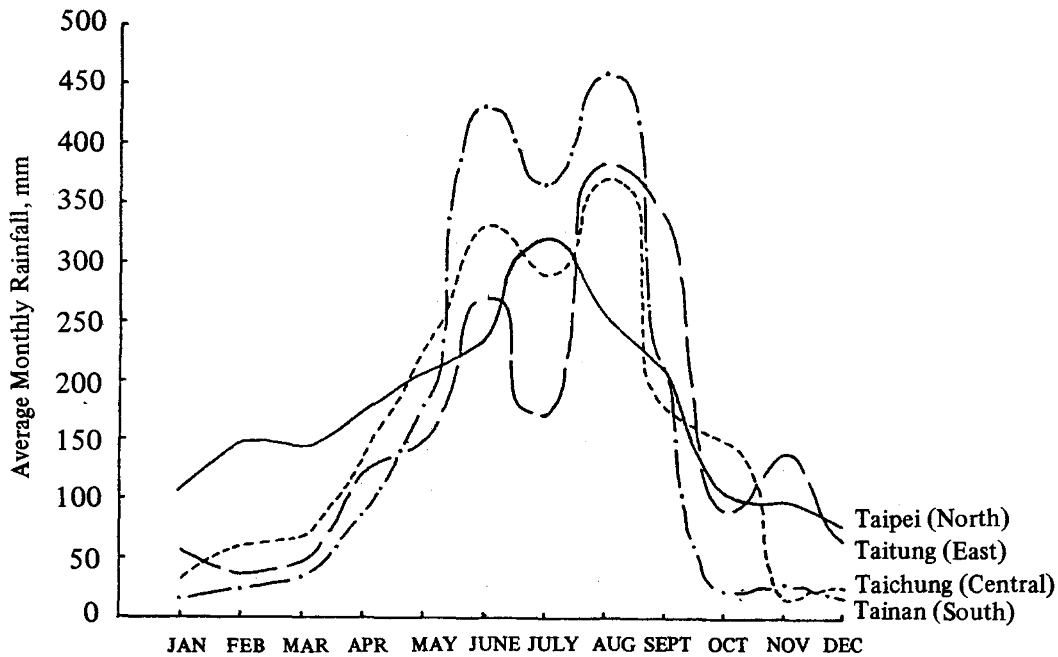


Figure 3. Average Monthly Rainfall in Different Parts of Taiwan (1950-1969)

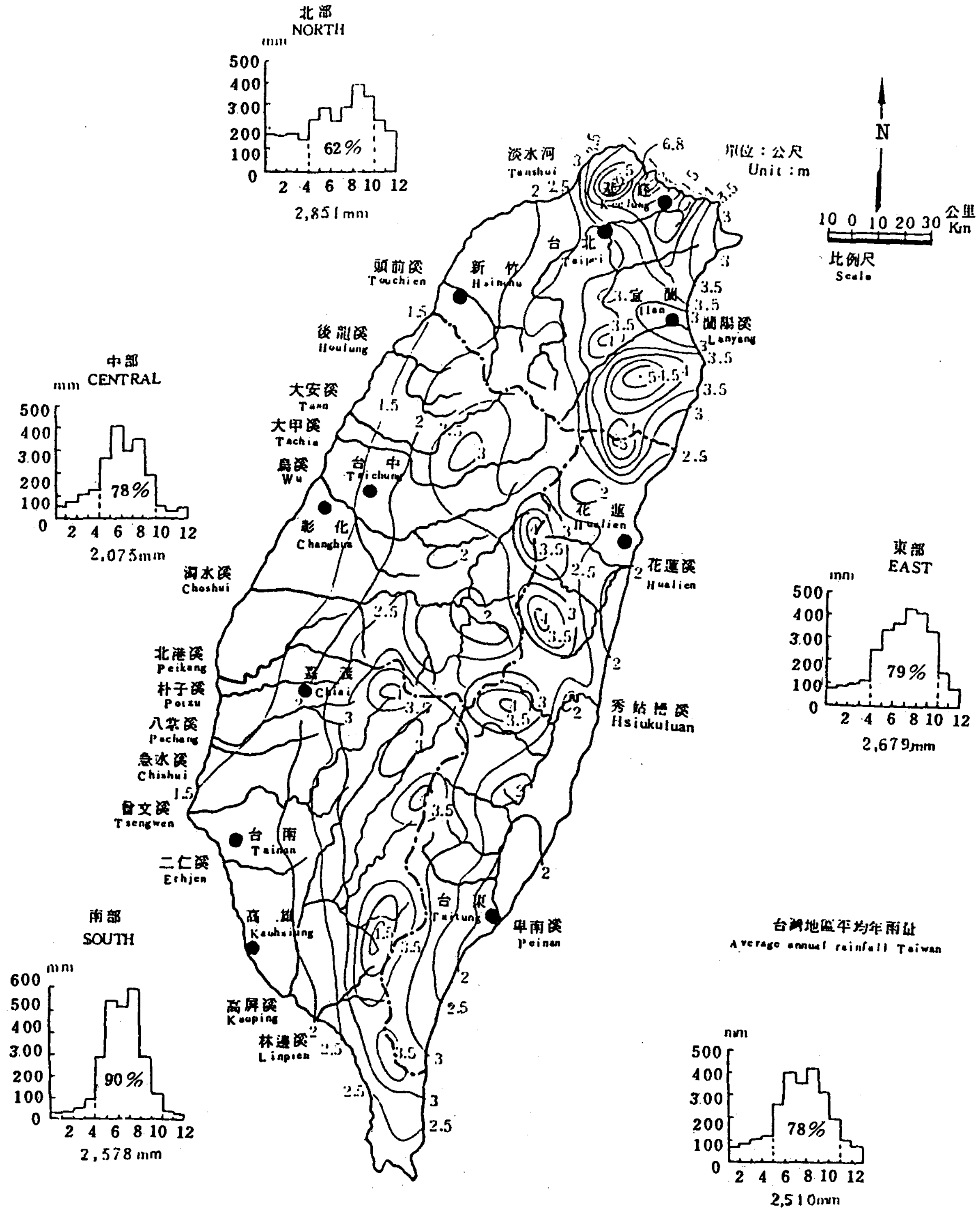
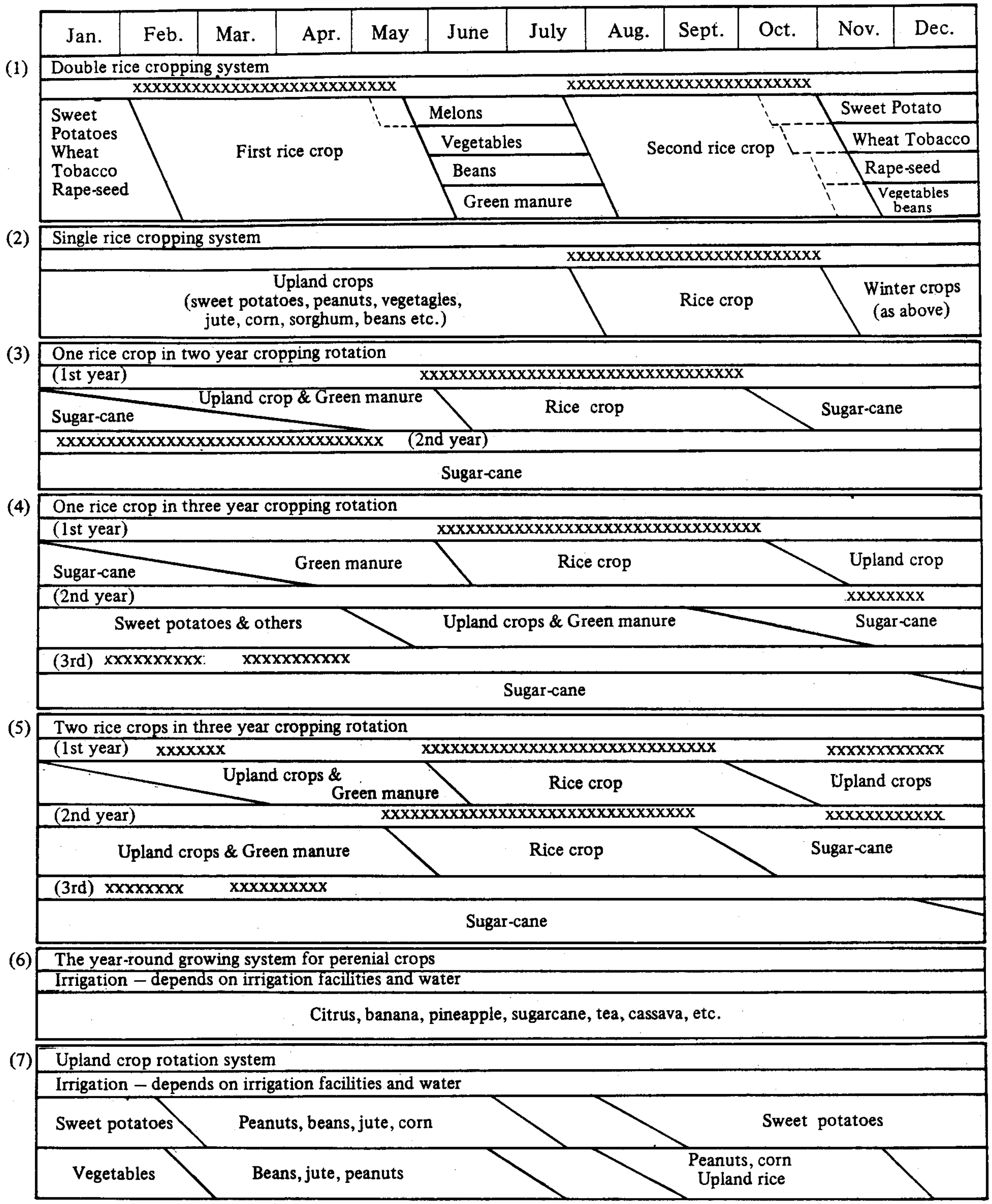


Figure 4. Annual Isohyetal Map and Rainfall Patterns in Taiwan (1949-1979)



Legend: xxxx indicates irrigation period

Figure 5. Various Cropping Patterns Adopted in Taiwan

Table 1. Multiple Cropping Index and Agricultural Employment

Area Unit: 1,000 ha

Year	Crop Area	Cultivated Land Area	Multiple Cropping Index	Agricultural Employment (1,000)	Agricultural Employment per ha of Cultivated Land
1939	1154	860	134.2		
1940	1162	861	135.0		
1941	1183	859	137.7		
1942	1155	854	135.2		
1943	1121	839	133.6		
1944	1077	808	133.3		
1945	833	816	102.1		
1946	975	832	117.2		
1947	1249	834	149.8		
1948	1383	863	160.3		
1949	1438	865	166.2		
1950	1435	871	164.8		
1951	1502	874	171.9		
1952	1521	876	173.6	1,642	1.89
1953	1488	873	170.4	1,647	1.89
1954	1501	874	171.7	1,657	1.89
1955	1508	873	172.7	1,667	1.92
1956	1544	876	176.3	1,675	1.92
1957	1566	873	179.4	1,689	1.92
1958	1588	884	179.6	1,707	1.92
1959	1590	878	181.1	1,722	1.96
1960	1600	869	184.1	1,742	2.00
1961	1613	872	185.0	1,747	2.00
1962	1618	872	185.6	1,760	2.00
1963	1613	872	185.0	1,775	2.04
1964	1673	882	189.7	1,810	2.04
1965	1680	890	188.8	1,748	1.96
1966	1686	896	188.2	1,735	1.92
1967	1696	902	188.0	1,723	1.92
1968	1692	900	188.0	1,725	1.92
1969	1679	915	183.5	1,726	1.89
1970	1656	905	183.0	1,680	1.85
1971	1620	903	179.4	1,665	1.85
1972	1586	899	176.4	1,632	1.82
1973	1567	896	174.9	1,624	1.82
1974	1644	917	179.3	1,697	1.85
1975	1659	917	180.9	1,681	1.82
1976	1606	920	174.6	1,641	1.79
1977	1566	923	169.7	1,597	1.72
1978	1549	918	168.7	1,553	1.69
1979	1494	915	163.3	1,380	1.52
1980	1400	907	154.4	1,277	1.41
1981	1398	900	155.3	1,257	1.39
1982	1380	891	154.9	1,284	1.45
1983	1334	894	149.2	1,317	1.47
1984	1285	892	144.1	1,286	1.45
1985	1257	883	142.4	1,297	1.47

Sources: 1) Taiwan Agricultural Yearbook, 1986
2) Taiwan Statistical Data Book, 1986

of rapid industrialization which caused considerable migration of rural labor to urban-industrial areas, farm labor became short, resulting in the high cost of crop production. On the other hand, owing to the rapid growth of Taiwan's economy, increasing demands for high protein food items and fruits have encouraged the farmers to grow more perennial crops.[8] Consequently, the multiple cropping index gradually decreased from 189.7 in 1964 to 142.4 in 1985[1].

ADJUSTMENT OF FARMING SYSTEMS

Group Farming

The trend of labor shortage by migration of rural labor to urban-industry sectors has induced changes in cropping systems, depending on farm size. Farmers of small farms (less than 0.5 ha) continue to intensify land use. Two to three harvests of fruit, or seven to eight vegetable crops in a year are practiced extensively on such farms. Small farms of around 1 ha or larger cannot be managed with family labor alone. Owners have to cut down on crop acreage which requires much labor input. Group farming operations as a means of accelerating farm mechanization have gradually been adopted. Thus, diversified multiple cropping systems tend to change to monoculture and multiple cropping index declines as more farmers join group farming.[9]

There are two common types of group farming activities in Taiwan. They are joint operations and entrusted farming. Both of these two types of group farming are based on voluntary cooperation in cultivation and management activities without any change in land ownership within the family farm systems. The first trial on joint operation was started in 1963. Farmers organized themselves into a group of 20 to 30 members with a total area of 20–30 hectares to jointly carry out farming operations including field preparation, planting, weeding, fertilizer application, irrigation and drainage, pest and disease control, harvesting etc.

Entrusted farming is also popular in Taiwan. It has two types: entrusted cultivation and entrusted management. The former is that a farmer entrusts another farmer to carry out a part or all of farming operations by paying an agreed amount of wages. The latter is to carry out all of farming operations and managements by the entrusted farmer, who acts as an owner-operater-manager and pays the return of land investment in lieu of land rent.

Change in Crop Production

In Taiwan, farmers grow rice, common crops (sweet potato, barley, wheat, millet, corn, sorghum, soybean, etc.), special crops (tea, sugarcane, tobacco, etc.) and horticultural crops (vegetables, banana, pineapple, citrous fruits). Among these crops, rice and sugarcane have been the two most important crops. Rice production enables self-sufficient supply of staple food and sugar is mainly for export.

With increasing per capita income, the structure of food consumption changed. Per capita consumption of rice dropped from 138 Kg in 1960 to 96 Kg in 1982. On the other hand, production of fruits, vegetables, hogs and chicken increased tremendously and per capita daily nutrient availability increased (Table 2). The local supply of corn, soybean and sorghum as feeds was far insufficient to meet the total demand. Consequently, the imports of

Table 2. Per Capita Daily Nutrient Availability

Year	Energy (Cal.)	Protein (Gm.)		
		Total	Animal Protein	Vegetable Protein
11952	2,078	49.04	11.73	37.31
1953	2,283	53.42	12.49	40.93
1954	2,176	51,88	12.74	39.14
1955	2,247	53.15	13.30	39.85
1956	2,262	53.93	13.50	40.43
1957	2,369	56.80	14.09	42.71
1958	2,359	56.89	14.60	42.29
1959	2,340	56.57	14.59	41.98
1960	2,339	57.13	13.91	43.22
1961	2,430	60.34	15.79	44.55
1962	2,317	57.83	16.18	41.65
1963	2,325	58.76	16.81	41.94
1964	2,364	59.51	17.47	42.04
1965	2,411	61.20	17.58	43.62
1966	2,433	62.26	19.28	42.98
1967	2,504	64.47	19.30	45.17
1968	2,545	64.85	20.52	44.33
1969	2,639	69.06	21.20	47.86
1970	2,662	72.17	23.32	48.85
1971	2,674	72.42	23.87	48.55
1972	2,737	74.61	24.79	49.82
1973	2,754	73.68	25.67	48.01
1974	2,780	74.24	24.73	49.51
1975	2,772	74.70	24.56	50.14
1976	2,771	75.90	26.70	49.20
1977	2,805	76.59	28.68	47.91
1978	2,822	76.95	29.75	47.20
1979	2,845	78.72	31.85	46.87
1980	2,850	79.36	33.24	46.12
1981	2,765	76.43	32.33	44.10
1982	2,802	78.19	33.57	44.62
1983	2,793	79.16	33.93	43.77
1984	2,811	80.22	37.07	43.15

Source: Taiwan Food Balance Sheet, Council of Agriculture, 1985

Table 3. Execution of Rice Crop Substitution Program in Taiwan (1984 & 1985)

Items	1984		1985	
	Substituted Area (ha)	Comparison with the original plan (%)	Substituted Area (ha)	Comparison with the original plan (%)
Corn. Sorghum	10,137	40.5	15,905	72.2
Vegetables, Fruits	23,104	888.6	24,017	128.6
Aquaculture	204	17.0	435	36.3
Miscellaneous crops & Fallow	30,359	204.0	55,758	272.1
Total	63,804	146.0	96,115	154.0

Source: Council of Agriculture, 1986

Table 4. Irrigated Area in Taiwan

Unit: ha

Year	Grand Total	Service Area of 17 Irrigation Associations						Private Irrigated Area				
		Total	Double-cropping Field	Single-cropping Field	Upland Field	Rotation Cropping Filed	Others	Total	Double-cropping Field	Single-cropping Field	Upland Field	Rotation Cropping Field
1965	494168	477726	299577	41045	15900	121204	–	16442	12255	1622	2324	241
1966	499703	482249	300073	45388	11614	125174	–	17454	12317	2971	2166	–
1967	505753	489509	307784	48751	13209	119765	–	16244	12794	2074	1376	–
1968	518915	499659	321053	43977	11987	122642	–	19256	15672	2315	1269	–
1969	484466	465270	284402	47227	3554	121366	12275	19196	15612	2315	1269	–
1970	500098	468040	283350	47196	3554	125844	8096	32058	29401	2181	246	230
1971	510460	453437	282514	45428	944	124551	–	57023	29907	16280	10021	815
1972	505744	448721	280448	44136	1083	123054	–	57023	29907	16280	10021	815
1973	452791	441256	274171	44965	879	121241	–	11535	3057	764	6798	916
1974	467868	441792	280841	42025	4407	114519	–	26076	13157	3160	8770	989
1975	456820	428305	281011	38496	5898	102900	–	28515	14900	3488	9257	870
1976	453197	427015	282018	38769	3651	102577	–	26182	11828	4069	9257	1028
1977	438618	420501	280426	36463	3654	99958	–	18117	7482	2262	7345	1028
1978	435176	417009	278414	34861	3546	10018[illegible]	–	18167	7468	2299	7484	916
1979	435951	411514	276800	31195	12602	90917	–	24437	11175	2735	9411	1116
1980	428133	403610	271139	29194	12803	90474	–	24523	11150	2836	9421	1116
1981	423385	398005	268663	27836	12163	89343	–	25380	9221	4107	11044	1008
1982	416415	393673	261955	28350	13415	89953	–	22742	8223	3817	9694	1008
1983	411256	388546	256711	28223	14480	89132	–	22710	8134	3817	9726	1033
1984	419676	388219	258777	26931	14853	87658	–	31457	8589	7015	14795	1058
1985	416880	385423	257177	27036	17095	84115	–	31457	8540	7064	14795	1058

Sources: 1) Taiwan Agricultural Yearbook, 1977-1986
2) Reconstruction Statistics of Taiwan Province, 1986

these crops increased, and the acreage of the same kinds of crops locally produced with high production costs decreased year after year.

There is a large rice surplus because of the very limited markets for rice domestic consumption and export. The best solution is to shift some rice acreage to cultivate corn, sorghum, soybean and other crops by an adjustment of farming systems.

Six-years Rice Crop Substitution Program

This program was initiated in 1984 for the purpose of releasing the pressure of the large rice surplus by shifting some rice acreage for cultivation of feed crops (corn, sorghum and soybean), vegetables, fruits or other miscellaneous crops, and even for fallow and aquaculture. The target of the program was to reduce the rice acreage from 645,855 hectares in 1983 to 515,500 hectares in 1989 for a decrease in rice production by 480,000 metric tons of brown rice within six years (from 2.48 million metric tons in 1983 to 2.0 million metric tons in 1989). In order to achieve this target, the following subsidy measures were adopted for trial in the first three years of the six-year program:

(1) A subsidy of 1.0 metric ton of paddy rice per hectare was provided to shift paddy rice fields to cultivate corn, sorghum, soybean or sugarcane.

(2) A subsidy of 1.5 metric ton of paddy rice per hectare was provided to shift paddy rice fields for cultivation of vegetables, fruits or miscellaneous crops or for fallow or aquaculture.

As the result of implementation in the first two years, the rice acreage decreased from 645,855 hectares in 1983 to 587,186 hectares in 1984 and to 564,392 hectares in 1985, and rice production decreased from 2,480,000 metric tons in 1983 to 2,240,000 metric tons in 1984 and to 2,170,000 metric tons in 1985. The result was favorable for releasing the rice production pressure. As to the breakdown of shifting the rice acreage, feed crops and aquaculture could not attain the targets but vegetables, fruits and other miscellaneous crops were well over the targets (Table 3).

PRESENT POTENTIAL AND PROBLEMS

Decreasing Irrigation Area

The total irrigated area in Taiwan decreased from 518,915 hectares in 1968 to 416,880 hectares in 1985 with a total decrease of 102,035 hectares in 18 years due to changes in land use for industrial and urban developments (Table 4).[1,11] The average annually decreased acreage is 5,669 hectares, which is not a small amount as far as the limited land resource in Taiwan is concerned. The decrease of the irrigated area should not be overlooked to predict rice production for self-sufficiency and to estimate acreage for diversified cropping in the future.

Maximum Imaginary Production Area

The maximum imaginary production area (MIPA) of imported crops may be calculated from the following assumption.

$$\text{MIPA} = \frac{\text{local crop production + imported crop quantity}}{\text{yield per hectare}}$$

The MIPAs of corn, sorghum, soybean and wheat in 1985 are too large to be met with the limited land in Taiwan

(Table 5)[1]. In other words, it is impossible to increase the production of corn, sorghum and soybean to the level of self-sufficiency for feed and edible oil requirements.

Regional Paddy Land Adaptability Survey

In order to map out a regional suitable crop system for reference in carrying out the rice crop substitution program in paddy fields, the Council of Agriculture initiated this survey project in 1984, in cooperation with the Provincial Department of Agriculture and Forestry, and District Agricultural Improvement Stations. The adaptability survey of major crops is based on data concerning water, soil, climate, and other natural factors related to crop production. The major crops includes corn, sorghum, sweet potatoes, peanuts, grapes, tomatoes and asparagus. By the end of 1985, the adaptability survey of corn and sorghum was preliminarily completed and that of other crops is in progress. Table 6 shows the preliminary result of the adaptability survey of corn in different counties in Taiwan[12].

Problems Encountered

1. Small farm size:

The average farm size in Taiwan is very small indeed. It decreased from 1.29 hectare in 1952 to 1.12 hectare in 1985[13]. The smaller the farming scale, the higher the farming cost is required, especially when farming labor is scarce, and proper machineries can hardly be employed. The small size of farms is one of the most crucial bottlenecks in increasing the operational efficiency of family farms in Taiwan[8].

2. Shortage of farm labor:

A high labor-land ratio is a favorable condition for the development of multiple cropping. Taiwan's experience indicates that the farm labor per hectare of cultivated land is positively correlated with the multiple cropping index[8,14]. The number of agricultural employment per hectare of cultivated land decreased from 1.89 in 1952 to 1.47 in 1985. Shortage of labor causes high wages thus resulting in high costs of crop production.

3. Market fluctuations:

The uncertainty of crop prices and changes of markets cannot be easily controlled, especially for production of crops other than rice in the areas of monsoon agriculture. Setting up processing facilities and marketing channels for the collection from numerous farmers scattered over large areas as suggested by Chen[15] is the only way for solution, but is complicated for management.

4. Competition with imported crops:

As shown in Table 5, large quantities of corn, sorghum and soybean were imported in 1985. The prices of these imported crops are much less than those of the locally porduced. The government is considering various means to increase crop yields, to development new suitable farm machines and to reduce production costs with the hope that the price difference will be minimum for the benefit of developing the small farm economy.

5. Income disparity between farm families and non-farm families

The widening income disparity between farm families and non-farm families has encouraged the rapid outflow of agricultural labor to the industrial and commercial sectors thus resulting in shortage farm labor in the rural area. The shortage of farm labor has resulted in high farm wages, which in turn has increased in the cost of production and depressed farm

Table 5. Maximum Imaginery Production Area (MIPA) of Imported Crops

Crop	(1) Cultivated Area (ha)	(2) Production (M.T.)	(3) Unit Production (M.T./ha)	(4) Imported Quantity (M.T.)	(2)+(4) Consumption (M.T.)	[(2)+(4)]÷(3) MIPA (ha)
Corn	61,636	226,010	3.67	3,016,822	3,242,832	833,605
Sorghum	19,023	86,729	4.56	564,410	651,139	142,794
Soybean	7,111	12,211	1.72	1,469,753	1,481,964	861,607
Wheat	1,053	2,125	2.02	754,657	756,782	374,645

Source: Taiwan Agricultural Yearbook, 1986

Table 6. Estimated Areas Adaptable for Regional Corn Cultivation in Different Counties in Taiwan

Unit: ha

Counties	Spring Crop				Autumn Crop			
	Adaptable	Relatively Adaptable	Subtotal	% of paddy field	Adaptable	Relatively Adaptable	Subtotal	% of Paddy field
Ilan	4,010	3,110	7,120	36	1,450	–	1,450	8
Taoyuan	1,310	5,510	6,820	17	11,320	1,450	12,770	33
Hsinchu	1,330	540	1,870	10	2,960	–	2,960	15
Miaoli	2,970	2,750	5,720	27	1,060	390	1,450	7
Taichung	1,390	2,540	3,930	11	1,820	4,640	6,460	18
Nantou	180	260	440	3	800	470	1,270	7
Changhua	3,650	11,680	15,330	28	890	24,040	24,930	46
Yunlin	–	–	–	–	6,360	21,120	27,480	44
Chiayi	14,580	580	15,160	73	12,950	22,870	35,820	78
Tainan	10,820	7,180	18,000	83	23,240	18,220	41,460	82
Kaohsiung	–	–	–	–	2,950	7,190	10,140	36
Pingtung	–	–	–	–	4,820	15,690	20,510	51
Taitung	4,340	1,660	6,000	52	5,470	360	5,830	49
Hualien	1,960	4,410	6,370	44	2,390	5,970	8,360	59
Total	46,540	40,220	86,760	–	78,480	122,410	200,890	–

Source: Annual Report of the Council of Agriculture, 1985.

income to a subsistence level. Consequently, the rate of return on agricultural investment has become low. All the factors are interacting and have sequential effects.

In recent years, the disparity of the two type-families was narrowed down to a certain level (about 30%) with the efforts of the government.

6. Some technical problems:

The mechanization for production of corn, sorghum, soybean, peanuts etc. is far behind that for rice production. The problem is lacking the adequate machines for harvesting the diversified crops. Through the cooperative efforts of the government research institutes and farm machine companies, new types of sorghum combines and corn ear-harvesters have been developed. On the other hand, the varieties and cultural techniques of diversified crops should be improved to adapt to the new conditions, especially in the rainy season.

Improvement Measures

1. For feed crops:

(1) To guide farmers to establish entrusted machine farming centers for production of feed crops.

(1) To promote labor-saving cultivation methods without land preparation for planting other crops after harvesting rice.

(3) To guide farmers to adopt group farming without any change in land ownership within the family farming system.

(4) To guarantee the prices of locally produced corn, sorghum and soybean.

2. For horticultural and special crops:

(1) To improve varieties for development of new heat and pest resistance crops.

(2) To strengthen research and experiment activities for improvement of cultivation techniques.

(3) To promote the extension of adjusting the harvest season or increasing the output of fruits.

(4) To promote research development on protective horticultural cultivation.

(5) To establish vegetalbe-specialized areas with emphasis on vegetable production in summer.

IMPROVEMENT OF IRRIGATION SYSTEMS

General Description

In the past twenty years, development and economical utilization of water resources were conducted in relation to agricultural production. The development covered large-scale irrigation, multi-purpose reservoirs, ground water development, tidal land reclamation, and waste land reclamation. For the efficient utilization of existing water resources, rotational irrigation practice, canal lining and land consolidation projects were implemented. Automatic remote control systems were installed and tested on several major canals for release, rating and recording of irrigation water. Computer programming was applied to plan water distribution in irrigation operation. Mechanized transplanting of paddy was possible with better coordinated water distribution to meet the peak of water supply as transplanting period is shortened. Installation of water measurement and recording facilities at major headworks and canals were nearly completed. On the other hand, experiments and extension of dry farmed crop irrigation were undertaken. Drainage improvement was also conducted to reduce damages caused by inundation.

At present, there are 18 reservoirs and 1,912 leading and main canals taking water from rivers for irrigation. The total length of the main and lateral and sub-lateral canals is 15,811 kilometers. The average length of supply ditches per hectare is about 57 meters. In addition to the irrigation systems utilizing surface water sources, there are 10,370 wells including 1,869 deep wells, most of which are used for supplementary irrigation[6].

Rotational Irrigation

A rotational system of water issue to farmers in appropriate quantity of water at the right time and in proper order is adopted for rice cultivation. It is also applicable to other crops, but is different in quantity, time and method of field irrigation. In order to facilitate this method of irrigation, the irrigation system is so improved that irrigation water can be simultaneously delivered into each individual "rotation area" of about 50 hectares. Each "rotation area" is sub-divided into four or five "rotation units", about 10 hectares each in size. Every "rotation area" is provided with one turnout gate, one measuring device, and several division boxes. Water flowing through the turnout is measured and rotated among the "rotation units" with the amount of water and interval of irrigation adjusted according to the actual rotation unit size, soil and crop conditions, effective rainfall and conveyance losses[6,16].

Continuous irrigation may be applied to rice cultivation, but it will cause water-logging which is unfavorable for the plant growth of other crops. On the contrary, rotational irrigation is in favor of plant growth, saves fertilizer, eliminates water disputes and saves labor especially in drought seasons. Since the rotational irrigation practice was initiated in 1956, more than 126,000 hectares of paddy fields have been improved. A layout of a rotational irrigation system is shown in Figure 6.

Land Consolidation

Since a land consolidation program was initiated in Taiwan in 1961, about 350,000 hectares of farm lands (of which about 80 percent is paddy fields) have been consolidated. Paddy fields were readjusted into rectangular blocks surrounded by farm roads three or five meters wide, to facilitate transportation. Each block is about 500–600 meters long and 200–240 meters wide. In a typical layout of farm-level irrigation systems, each farm supply ditch runs in the middle parallel to the long edge of the block and delivers water to the both side plots, each in a rectangular shape of 100–120 meters long and 20–40 meters wide depending on local conditions such as soil, topography, size of land holding, and farm mechanization. Farm drainage ditches are usually built on the both sides of the farm road. In case the topography does not permit a desirable layout, the drainage ditch may be located in the middle of the block and the supply ditch on the both sides of the farm road so that the drainage ditch runs along the lower place and the supply ditch along the high place in order to minimize the land leveling cost. As a rule, supply and drainage ditches are disposed in right-angle to contours in order to reduce the cross-sectional area of water flow, hence to minimize construction costs. On the other hand, the short edge of each plot is

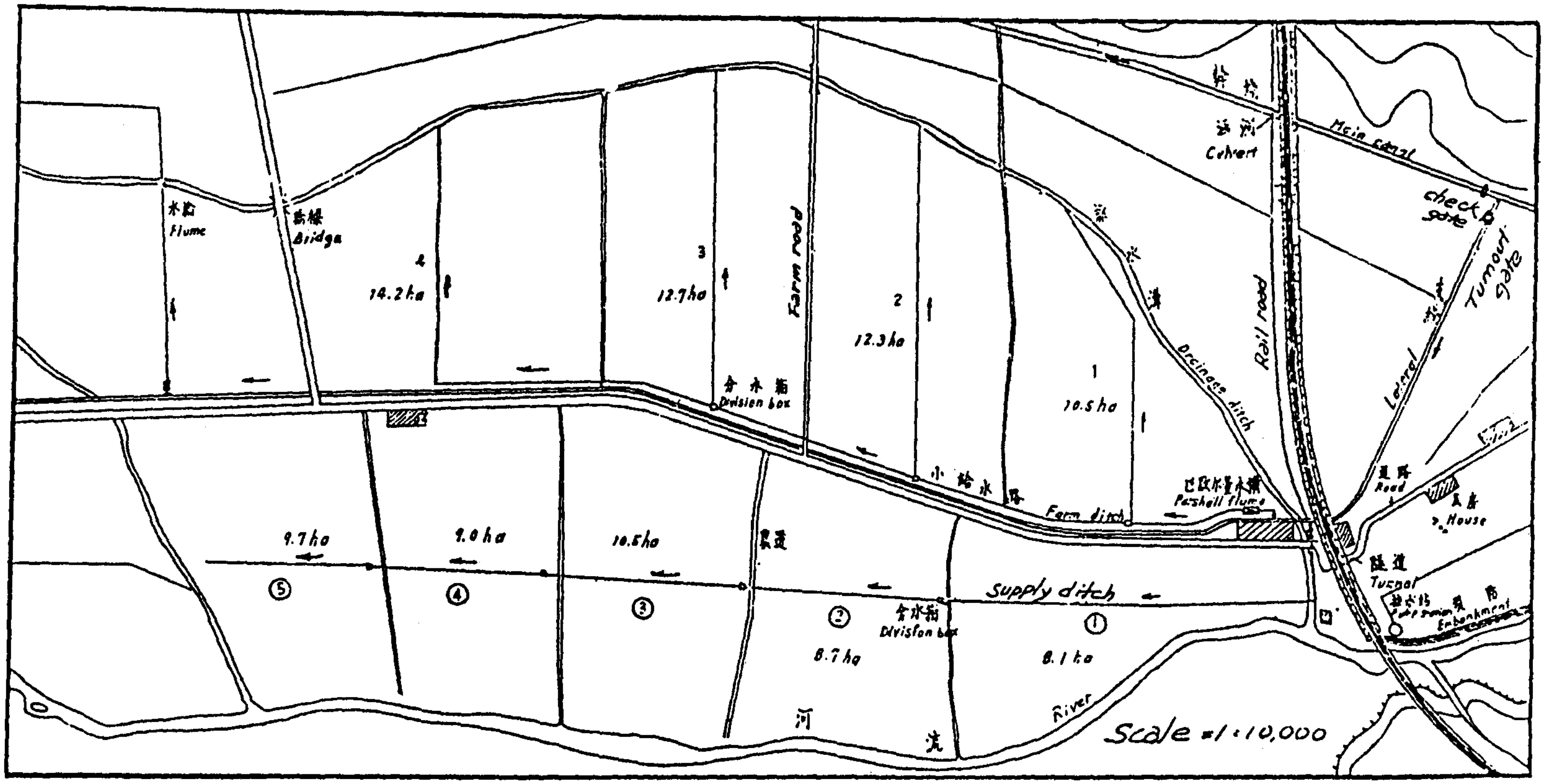


Figure 6. A Typical Layout of Rotational Irrigation System

in right angle to contours, in order to minimize the cost of land leveling. Consequently, supply and drainage ditches are arranged along the short edge of each plot and the main supply ditches run along the long edge of the plot to connect the lateral or sub-lateral and supply ditches. A typical layout of land consolidation is illustrated in Figure 7 [6,16].

In land consolidation, consideration is also given to perfect separation of supply ditches from drainage ditches; direct irrigation for free water management; easy access to each plot; suitability of water resue; minimum space for farm roads, canals, ditches and earth dikes in paddy fields; minimum earth work for leveling by adjusting the alignments and elevations of supply and drainage ditches; and conditions of the downstream drainage channels.

As to the water management on paddy fields, irrigation water can be freely delivered into each plot directly from the supply ditch without passing from field to field, and the controlled border or furrow irrigation method can easily be practiced in the fields for diversified cropping practices. For rotational irrigation practices, each block of about 10–14 hectares may be regarded as a rotation unit, and four or five units along a main supply ditch form a rotation area. Water flowing continuously through the turnout gate into the rotation area is properly rotated among the rotation units. In case when water supply is further limited, especially in time of drought, emergent intermitent irrigation may be adopted by rotating water delivery among rotation areas.

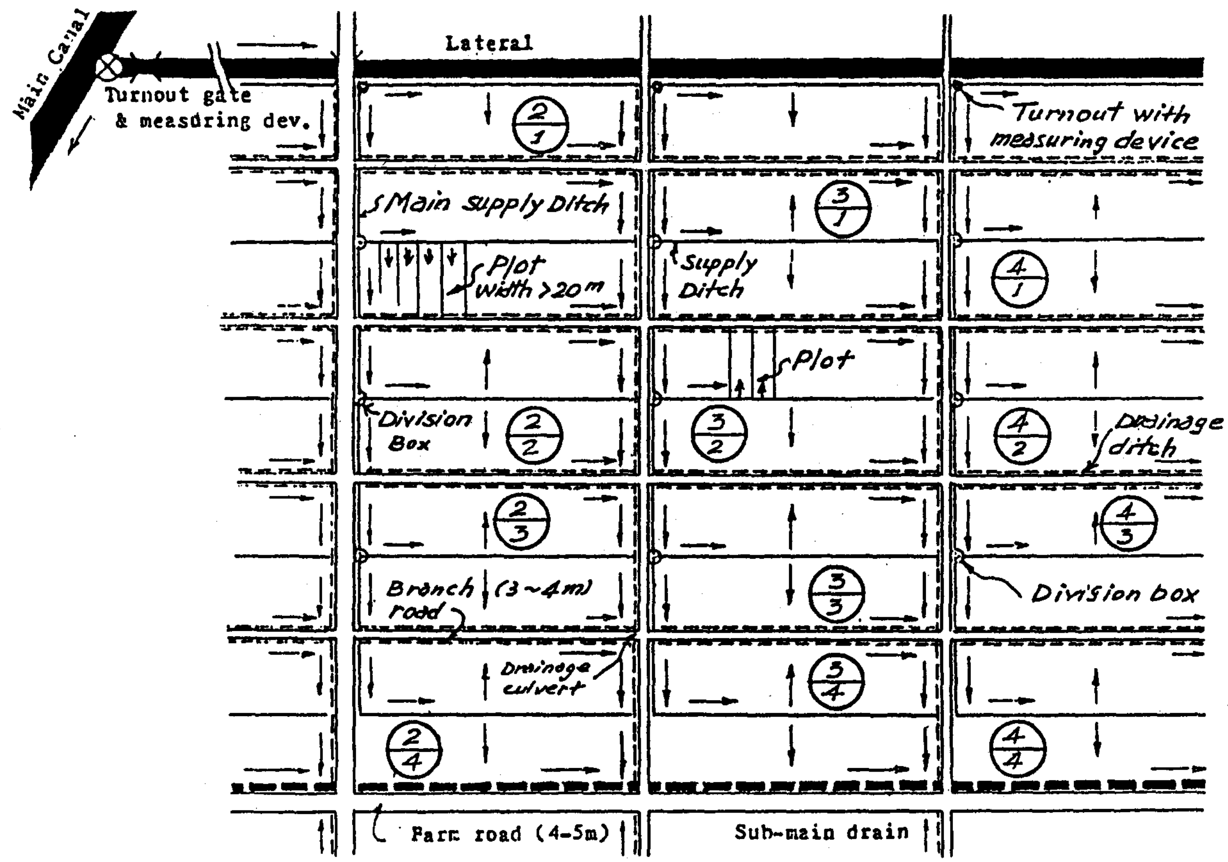
After the improvement with land consolidation, the farm land will be in good irrigation and drainage conditions not only for rice cultivation but for diversified cropping.

CROP IRRIGATION EXPERIMENTS

Historical Review

The actual irrigation requirements of various upland crops in Taiwan were not quite know to most irrigation and agricultural people in Taiwan before 1961. From 1961 to 1963, the first irrigation experimental project under the technical and financial support of the Joint Commission on Rural Reconstruction (JCRR)* was carried out at Hsuechia of the Chianan Irrigation Association in southern Taiwan. In 1963, the islandwide irrigation experiment and demonstration project on trial basis was started by the Taiwan Provincial Water Conservancy Bureau (PWCB) with assistance of JCRR, the Provincial Department of Agriculture and Forestry, Agricultural Engineering Research Center, the National Taiwan University, local irrigation associations and district agricultural improvement Stations. In the meantime, the Agricultural Research Institute, Sugarcane Research Institute, and district agricultural improvement stations were also continuously conducting researches and experiments on crop improvement and cropping systems as well as irrigation. The basic studies on irrigation may be grouped into three categories: (1) Experiments on water requirements, (2) Adaptation tests on cropping patterns, and (3) Experiments on irrigation methods.

*JCRR was reorganized as the Council for Agricultural Planning and Development (CAPD) in March 1969, and was reorganized again as the Council of Agriculture (COA) in September 1985.



Remarks: Upper number in the circle – "Rotation Area"
Lower number in the circle – "Rotation Unit"
Scale – 1 : 10,000

Figure 7. Typical Layout of Water Distribution System for Land Consolidation in Taiwan

Experiments on Water Requirements

Through constant observation on the depletion of the available moisture storage capacity in the soil, the seasonal (spring, summer and winter) water requirements, average and maximum daily water requirements, evapotranspiration / evaporation ratios, variation of daily water requirments and Blaney – Criddles's K values for various crops at different localities in Taiwan were evaluated respectively as shown in Table 7, Table 8 and Table 9[17,18,19]. The daily water requirement variations of some selected crops for three seasons at different places in Taiwan are shown in Figure 8[17,18]. As to water requirements of sugarcane, experiments were conducted in the sugarcane experimental farm of the Sugarcane Research Institute. Table 10 and Table 11[9,10] respectively show the evapotranspiration/ evaporation ratios, and monthly water requirements and Blaney – Criddle's K values of sugarcane in southern Taiwan.

Adaptation Tests on Cropping Patterns

Through rather precise soil, water, plant and fertilizer managements jointly made by the irrigation and agricultural people at the standard plots of each station, various requirement, yeild and cost figures of different crops were closely recorded for overall evaluation of the recommended crop rotation systems.

Some experiment results revealed that an increase of production by irrigation might exceed 500% (Table 12)[12]. As far as the total net income is concerned, it

Table 7. Seasonal Water Requirements of Selected Crops in Taiwan

Unit: mm

Items	Spring	Summer	Autumn
Soybean	200-440	130-310	150
Corn	160-300	250	170-350
Sorghum	200-350	250-370	
Peanut	170-410	160-300	440
Sweetpotato		210-380	150-400
Watermelon		180-200	
Edible rape			150-400
Wheat			160-170
Watermelon seeds		150	
Pea			150-250
Radish			70-200
Carrot			170-200
Multiflora bean	130		170-180
Sesame			280-320
Broad bean			200-230
Scallion			160-230
Average	160-410	160-380	150-400

Source: 1) Taiwan Water Conservancy Bureau,
2) Pipeline Irrigation Methods and Techniques, JCRR, 1974

Table 8. Average and Maximum Daily Water Requirements of Selected Crops in Taiwan (1964-1970)

Location	Crop	Max. Daily W. R.	Average Daily W. R.
Northern Taiwan		(mm)	(mm)
Shihmen	Spring corn	5.3	2.8
	Spring peanut	4.6	2.6
	Spring sorghum	5.4	2.9
	Summer rotooned sorghum	4.6	3.0
	Summer soybean	4.7	3.2
	Summer sweet potato	5.9	3.0
	Autumn broad bean	2.9	2.0
Miaoli	Spring corn	2.6	1.9
	Spring peanut	3.6	1.9
	Spring sorghum	5.0	2.0
	Summer rotooned sorghum	3.9	2.2
	Summer watermelon	3.8	2.3
	Autumn sweet potato	4.2	2.0
	Autumn scallion	3.0	1.8
Central Taiwan			
Changhua	Spring corn	5.5	2.2
	Spring peanut	3.6	2.2
	Spring sorghum	3.5	2.3
	Spring soybean	3.0	2.0
	Summer soybean	4.9	2.8
	Summer sweet potato	4.8	2.5
	Autumn sweet potato	4.2	1.8
	Autumn wheat	1.8	1.6
Southern Taiwan			
Kangshan	Spring corn	3.4	2.5
	Spring peanut	5.7	3.1
	Spring sorghum	3.7	2.6
	Spring soybean	6.0	3.0
	Autumn corn	3.1	2.3
	Autumn soybean	3.0	2.3
	Autumn sweet potato	3.3	2.4
Eastern Taiwan			
Juishui	Spring peanut	3.3	2.0
	Spring sorghum	3.1	2.0
	Summer peanut	3.7	2.5
	Summer soybean	4.1	2.6
	Autumn sweet potato	4.3	1.6
	Autumn spring pea	2.6	1.7
	Autumn corn	2.8	2.9

Sources: 1) Taiwan Water Conservancy Bureau.
2) Pipeline Irrigation Methods and Techniques JCRR, 1974.

Table 9. Daily Water Requirements, Evapotranspiration-Evaporation Ratios and Blany-Criddle's K values of Different Months in Taiwan (1964-1970)

Location	Crop	Value	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Planted Period
Central Taiwan (Shihmen)	Corn	U				2.12	4.03	3.93	3.08						Early Apr.-Mid. July
		C				0.72	1.22	1.47	0.71						
		K				1.15	0.69	0.64	0.41						
	Peanut	U			2.05	3.44	2.38	3.11	1.81						Mid. Mar.-Late July
		C			1.47	1.18	0.76	0.82	0.54						
		K			0.60	0.68	0.41	0.54	0.38						
	Sorghum	U				1.53	4.02	4.21	2.95						Early Apr.-Late July
		C				0.81	1.22	1.33	0.67						
		K				0.30	~~0.69~~	0.68	0.46						
	Ratooned Sorghum	U								2.17	3.47	4.10	1.72		Early Aug.-Mid. Nov.
		C								0.63	0.90	1.39	0.72		
		K								0.35	0.63	0.72	0.45		
	Soybean	U			0.90	3.13	1.67	1.81		2.74	3.84	4.01	2.11		Early Mar.-Late June Early Aug.-Mid. Nov.
		C			0.19	0.60	1.06	0.29		0.45	0.70	0.84	0.47		
		K			0.19	0.60	1.06	0.29		0.45	0.70	0.84	0.46		
	Sweet-potato	U						2.06	3.63	4.15	4.10	2.81	1.83		Early June-Early Nov.
		C						0.49	0.56	0.70	0.79	0.62	0.41		
		K						0.49	0.56	0.70	0.79	0.61	0.40		
	Broad-bean	U	2.89	2.35	1.28								1,25	2.52	Early Nov.-Early Mar.
		C	0.75	0.64	0.46								0.87	0.64	
		K	0.75	0.64	0.46								0.87	0.64	
Northern Taiwan (Miaoli)	Corn	U			0.67	1.42	2.55	1.67							Mid. Mar.-Late June
		C			0.18	0.45	0.48	0.23							
		K			0.15	0.28	0.43	0.17							
	Peanut	U			0.99	2.45	2.84	1.96	1.62	2.48	2.48	1.27	0.75		Early Mar.-Mid. July Late July-Late Nov.
		C			0.39	0.70	0.60	0.47	0.16	0.34	0.57	0.25	0.09		
		K			0.23	0.49	0.50	0.33	0.08	0.25	0.42	0.17	0.07		
	Sorghum	U				0.78	2.78	3.88	2.66	0.74					Early Apr.-Mid. Aug.
		C				0.29	0.53	0.70	0.40	0.24					
		K				0.20	0.42	0.49	0.42	0.16					
	Ratooned Sorghum	U								1.85	3.97	2.84	1.73		Mid. Aug.-Late Nov.
		C								0.48	0.66	0.52	0.54		
		K								0.38	0.75	0.65	0.35		
	Soybean	U			1.00	1.99	3.14	2.30	1.90	1.37	2.77	1.78	1.21		Mid. Mar.-Early July
		C			0.48	0.60	0.59	0.57	0.53	0.34	0.69	0.61	0.50		
		K			0.08	0.38	0.56	0.38	0.06	0.18	0.54	0.42	0.13		
	Sweet-potato	U	1.12	0.95							2.71	2.93	2.85	1.54	Mid. Sept.-Mid. Feb.
		C	0.46	0.28							0.50	0.62	0.81	0.76	
		K	0.29	0.32							0.50	0.73	0.66	0.45	
	Water-melon	U							3.58	2.71	1.51				Early July-Early Sept.
		C							0.32	0.54	0.52				
		K							0.40	0.45	0.38				
	Scallion	U	1.20	1.37	2.53	0.80								0.27	Late Dec.-Early Apr.
		C	1.22	0.71	0.86	0.25								1.18	
		K	0.35	0.40	0.60	0.17								0.08	

Table 9. Continued

Central Taiwan (Changhua)	Corn	U			1.73	2.52	3.72	1.84							Early Mar.-Mid. June
		C			0.50	0.69	0.82	0.43							
		K			0.36	0.49	0.56	0.32							
	Peanut	U			1.57	2.24	2.96	2.07							Early Mar.-Late June
		C			0.47	0.60	0.75	0.58							
		K			0.38	0.53	0.49	0.32							
	Sorghum	U			1.64	2.55	3.45	1.59							Late Mar.-Late June
		C			0.41	0.70	0.75	0.59							
		K			0.57	0.58	0.71	0.35							
	Soybean	U	1.47		1.46	1.31	2.47	1.33	2.08	3.17	2.96	1.51	1.84	1.66	Early Mar.-Mid. June
		C	0.36		0.51	0.49	0.65	0.48	0.42	0.59	0.60	0.32	0.46	0.65	Early July-Late Sept.
		K	0.36		0.79	0.38	0.50	0.39	0.29	0.48	0.35	0.31	0.47	0.65	Early Oct.-Mid. Jan.
	Sweet-potato	U	1.33	1.05				1.52	3.48	3.27	3.10	2.24	2.11	1.68	Mid. June-Early Oct.
		C	0.58	0.59				0.25	0.70	0.70	0.48	0.46	0.59	0.62	Mid. Oct.-Late Feb.
		K	0.72	0.63				0.27	0.61	0.57	0.48	0.37	0.45	0.59	
	Wheat	U	1.38	0.97								1.32	1.66	1.58	Late Oct.-Early Feb.
		C	0.48	0.32								0.35	0.51	0.61	
		K	0.43	0.34								0.24	0.39	0.52	
	Radish	U	2.19	1.45										1.20	Early Dec.-Mid. Feb.
		C	0.95	0.81										0.65	
		K	0.63	0.66											
Southern Taiwan (Kangshan)	Corn	U	2.17	1.35	1.51	1.71	1.58					1.82	2.34	2.98	Early Feb.-Mid. May
		C	0.75	0.76	0.61	0.89	0.31					0.35	0.77	0.97	Mid. Oct.-Early Feb.
		K	0.75	0.46	0.53	0.63	0.26					0.37	0.60	0.80	
	Peanut	U		2.27	2.62	4.75	5.01	4.45							Mid. Feb.-Mid. June
		C		1.32	0.91	1.18	1.23	1.33							
		K		0.53	0.56	0.91	0.89	0.60							
	Sorghum	U		1.81	2.33	3.00	1.73								Mid. Feb.-Late May
		C		0.36	0.51	0.80	0.46								
		K		0.29	0.50	0.60	0.39					1.82	2.35	2.98	
	Soybean	U	1.62	2.58	3.17	3.89	2.74					0.29	0.54	0.68	Mid. Feb.-Late May
		C	0.84	0.60	0.56	0.74	0.75					0.36	0.81	0.95	Early Oct.-Mid. Jan.
		K	0.54	0.35	0.46	0.63	0.37								
	Sweet-potato	U	2.41	1.77								2.23	2.64	2.50	Mid. Oct.-Mid. Feb.
		C	0.93	0.82								0.49	0.74	1.02	
		K	0.66	0.50								0.45	0.56	0.75	
Eastern Taiwan (Juishui)	Peanut	U		1.05	2.56	2.66	2.02	0.93	2.67	3.72	1.57	1.04			Mid. Feb.-Mid. June
		C		0.51	0.64	0.73	0.78	0.50	0.52	0.69	0.72	0.40			Mid. July-Mid. Oct.
		K		0.20	0.55	0.42	0.34	0.16	0.39	0.51	0.41	0.20			
	Sorghum	U			1.20	1.90	2.77	1.57							Mid. Mar.-Mid. June
		C			0.51	0.65	0.92	0.56							
		K			0.26	0.36	0.48	0.27							
	Soybean	U						1.88	3.02	3.47	2.51				Early June-Late Sept.
		C						0.16	0.47	0.74	0.68	0.85			
		K						0.22	0.53	0.58	0.36				
	Sweet-potato	U	1.52	1.11								1.09	1.87	2.06	Late Oct.-Mid. Feb.
		C	0.78	0.62								0.58	0.82	1.04	
		K	0.41	0.20								0.23	0.39	0.44	
	Pea	U	2.24	1.58									1.56	1.76	Early Nov.-Late Feb.
		C	1.06	0.64									0.73	1.11	
		K	0.52	0.32									0.38	0.46	
	Corn	U	1.35	0.98	1.35	2.40	2.66	1.52				1.54	1.79	1.92	Early Mar.-Late June
		C	0.85	0.56	0.44	0.71	0.77	0.61					0.80	0.82	Mid. Oct.-Late Feb.
		K	0.33	0.26	0.31	0.37	0.39	0.15				0.29	0.40	0.37	

Remarks: U= Daily water requirement (mm)
C= Evapotranspiration - evaporation ratio
K= Blany - Criddle K value

Sources: 1) Taiwan Water Conservancy Bureau 2) Pipeline Irrigation Methods and Techniques JCRR, 1974

Table 10. Evapotranspiration/Evaporation Ratios (PR) of Sugarcane in Taiwan (1963-1966)

Items			Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Average
Raised A pan Evaporation		mm	107.0	131.4	135.1	182.3	136.4	148.7	158.3	134.5	121.7	91.2	70.6	1417.2	4.24
		%	7.5	9.3	9.5	12.9	9.6	10.5	11.2	9.5	8.6	6.4	5.0	100.0	
Transpiration	Clay loam	mm	42.1	42.9	49.3	104.6	139.5	148.2	150.4	152.8	144.0	126.0	74.8	1174.6	3.52
		%	3.6	3.6	4.2	8.9	11.9	12.6	12.8	13.0	12.3	10.7	6.4	100.0	
		PR	0.39	0.33	0.37	0.57	1.02	1.00	0.95	1.14	1.18	1.38	1.06	0.83	0.83
	Sandy soil	mm	112.7	80.4	80.1	135.8	155.5	162.6	172.2	168.1	147.2	144.0	78.1	1436.7	4.30
		%	7.8	5.6	5.6	9.5	10.8	11.3	12.0	11.7	10.3	10.0	5.4	100.0	
		PR	1.05	0.61	0.59	0.75	1.14	1.09	1.09	1.25	1.21	1.58	1.11	1.01	1.01
Evapotranspiration	Clay loam	mm	50.3	56.0	57.6	158.0	222.1	207.0	169.7	180.1	134.2	112.9	68.8	1416.7	4.24
		%	3.5	3.9	4.1	11.1	15.7	14.6	12.0	12.7	9.5	8.0	4.9	100.0	
		PR	0.47	0.43	0.43	0.87	1.63	1.39	1.07	1.34	1.10	1.24	0.98	1.00	1.00
	Sandy soil	mm	112.0	82.6	80.2	187.6	242.6	245.1	200.6	195.7	161.6	180.8	98.7	1787.5	5.36
		%	6.3	4.6	4.5	10.5	13.6	13.7	11.2	11.0	9.0	10.1	5.5	100.0	
		PR	1.05	0.63	0.59	1.03	1.78	1.65	1.27	1.46	1.33	1.98	1.40	1.26	1.26

Source: Evapotranspiration and Water Requirements of Sugarcane in Taiwan, Taiwan Sugarcane Research Institute, TSC, 1968.

Table 11. Monthly Water Requirements (Evapotranspiration) and Blany-Criddle's K values of Sugarcane in Taiwan (clay loam in Taiwan)

Month	Monthly mean temperature °C(t)	% of Day time hours %(p)	Factor (f)	Water requirements mm(u)	K value (k)
Feb.	18.2	7.18	118.1	50.3	0.43
Mar.	20.7	8.40	147.8	56.0	0.38
Apr.	24.6	8.57	166.0	57.6	0.35
May	26.5	9.22	186.6	158.0	0.85
June	27.0	9.13	186.9	222.1	1.19
July	27.7	9.35	194.4	207.0	1.06
Aug.	27.8	9.03	188.1	169.7	0.90
Sept	26.6	8.31	168.6	180.1	1.07
Oct.	24.8	8.13	158.2	134.2	0.85
Nov.	22.2	7.48	136.7	112.9	0.83
Dec.	19.0	7.52	126.4	68.8	0.54
Total			1,777.8(F)	1,416.7(U)	0.80($\bar{k}$)

Source: JCRR "Water Requirements of Irrigated Sugarcane" (unpublished)

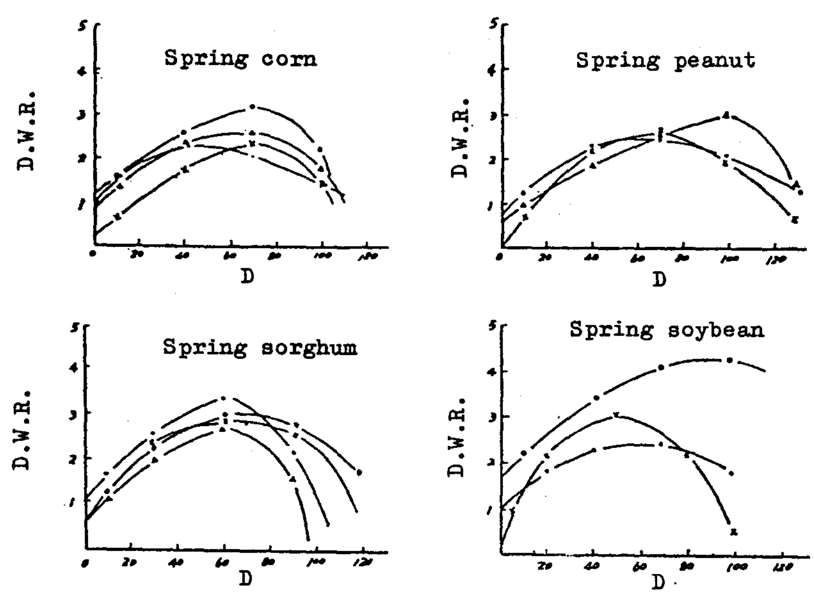


Figure 8-a. Daily Water Requirements of Spring Crops

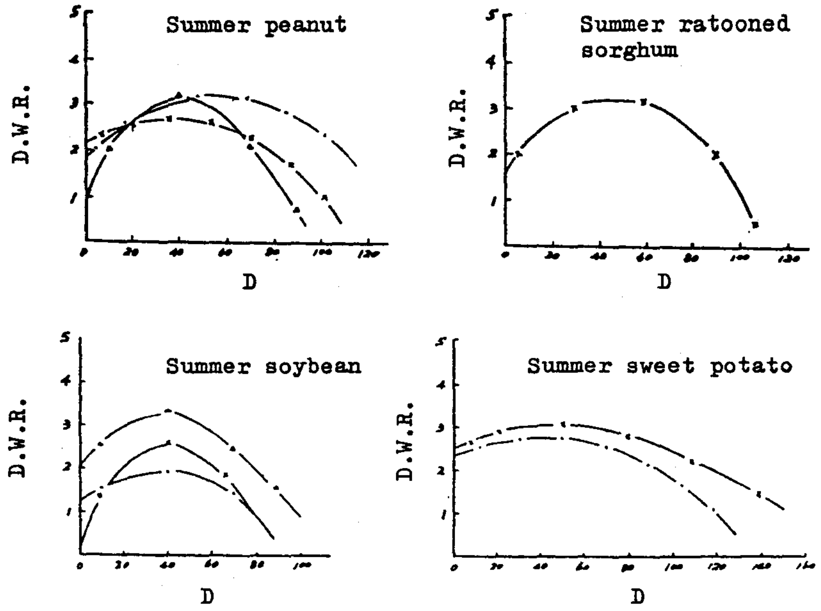


Figure 8-b. Daily Water Requirements of Summer Crops

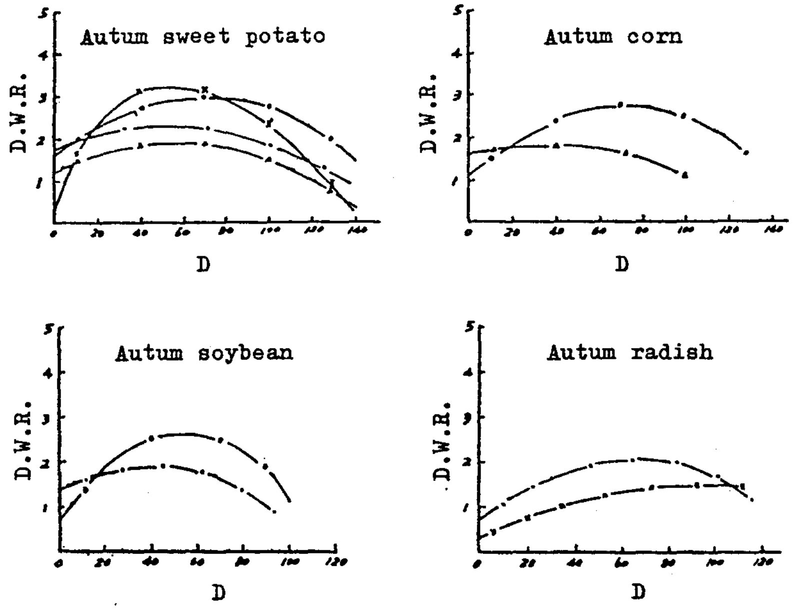


Figure 8-c. Daily Water Requirements of Autumn Crops.

Legends:
D.W.R.: Daily water requirements of crops in mm/day
D : Accumulated number of days for plant growth
– x –: Miaoli, northern Taiwan
– · –: Changhua, central Taiwan
– o –: Kangshan, southern Taiwan
– –: Juishui, eastern Taiwan

Figure 8. Daily Water Requirements of Crops in Taiwan

Table 12. Production Increase by Irrigation for Various Crops in Taiwan

Crop	Place	Soil type	Season	Production of non-irrigated crops(kg/ha)	Production of irrigated crops (kg/ha)	Increase of production (%)
Corn	N. Taiwan					
	Shihmen	Silty clay	Spring	4,381	4,762	9
	Miaoli	Sandy soil	Spring	3,823	4,397	15
	C. Taiwan					
	Taichung	Sandy loam	Autumn	2,316-3,660	3,052-6,909	32-89
	Changhua	Loamy sand	Spring	4,873	5,758	18
	S. Taiwan					
	Tainan	Loam	Autumn	3,889	7,628	96
	Tainan	Sandy loam	Autumn	1,936-3,400	5,400-6,929	33-254
	Tainan	Sandy loam	Winter	2,007	6,343	216
	Hsuechia	Silty loam	Spring	1,000-4,000	4,000-6,800	15-573
	Hsuechia	Silty loam	Autumn	3,000-6,000	5,000-9,000	31-71
	Kangshan	Silty loam	Spring	4,364	7,116	63
	Kangshan	Silty loam	Autumn	4,109	5,949	45
	E. Taiwan					
	Juishui	Loam	Spring	2,854	3,567	25
	Juishui	Loam	Autumn	1,597	2,605	37
Sorghum	N. Taiwan					
	Shihmen	Silty clay	Spring	5,000	6,334	26
	Shihmen	Silty clay	Summer	4,178	5,056	21
	Miaoli	Sandy soil	Summer	2,777	3,638	31
	C. Taiwan					
	Changhua	Loamy sand	Spring	3,586	4,336	21
	Changhua	Loamy sand	Summer	2,606	3,183	22
	S. Taiwan					
	Hsuechia	Sandy loam	Spring	2,959-3,596	3,369-3,955	10-14
	Kangshan	Silty loam	Spring	4,643	4,793	3
Sweetpotato	N. Taiwan					
	Shihmen	Silty clay	Summer	12,136	14,321	18
	C. Taiwan					
	Taichung	Sandy soil	Autumn	8,465	14,432	70
	Changhua	Loamy sand	Summer	17,818	19,566	10
	Changhua	Loamy sand	Autumn	21,630	26,395	22
	S. Taiwan					
	Tainan	Sandy loam	Autumn	7,084	21,109	205
	Hsuechia	Silty loam	Autumn	10,000-29,000	16,000-33,000	5-64
	Kangshan	Silty loam	Autumn	21,630	26,395	22
Multiflora	E. Taiwan					
bean Pea	Juishui	Loam	Spring	512	1,310	156
	Hualien	Sandy loam	Spring	140	640	357
	N. Taiwan					
	Taoyuan	Silty clay loam	Autumn	119	227	87
Wheat	C. Taiwan					
	Taichung	Sandy soil	Autumn	789-870	1,095-1,444	26-83
	Changhua	Loam sand	Autumn	2,090	2,880	37
	S. Taiwan					
	Tainan	Sandy soil	Autumn	738-1,493	3,806-4,431	188-464
	C. Taiwan					
	Changhua	Loam sand	Autumn	48	135	182
Mung bean	S. Taiwan					
	Hsuechia	Silty loam	Spring	1,093	1,336	22
	Kanshen	Silty loam	Spring	700	1,300	85
Broad bean	N. Taiwan					
	Shihmen	Silty clay	Autumn	1,600	2,321	45

Table 12. Continued

Crop	Place	Soil type	Season	Production of non-irrigated crops(kg/ha)	Production of irrigated crops (kg/ha)	Increase of production (%)
Sorghum	Kanshan	Silty loam	Spring	5,411	6,789	25
	E. Taiwan					
	Juishui	Loam	Spring	2,833	3,683	30
Peanut	N. Taiwan					
	Shihmen	Silty clay	Spring	2,679	3,285	23
	C. Taiwan					
	Changhua	Loamy sand	Spring	2,481	2,561	5
	Changhua	Loamy sand	Summer	2,400	2,808	16
	S. Taiwan					
	Tainan	Sandy loam	Autumn	762,-2,596	1,160-3,433	37-163
	Hsuechia	Silty loam	Spring	1,200-2,200	2,300-2,500	5-99
	Hsuechia	Silty loam	Autumn	1,599	1,884	18
	Kangshan	Silty loam	Spring	2,067	2,179	6
	E. Taiwan					
	Juishui	Loam	Spring	1,262	1,615	28
	Juishui	Loam	Summer	1,658	2,105	27
Soybean	C. Taiwan					
	Changhua	Loamy sand	Summer	1,688	2,106	25
	S. Taiwan					
	Tainan	Sandy loam	Spring	476-1,831	1,849-2,834	46-437
	Tainan	Sandy loam	Autumn	238-1,351	657-1,810	34-176
	Tainan	Loam	Autumn	451	668	48
	Hsuechia	Silty loam	Spring	2,563	2,762	8
	Hsuechia	Silty loam	Autumn	1,221	1,529	25
	Kanshan	Silty loam	Spring	2,704	3,163	17
	E. Taiwan					
	Juishui	Loam	Summer	1,403	2,113	51
Sugarcane	S. Taiwan					
	Tainan	Sandy loam	–	132,550	163,900	24
Tobacco	C. Taiwan					
	Taichung	–	–	1,494	2,022	35
Jute	S. Taiwan					
	Hsuechia	Silty loam	Spring	700-2,100	2,200-2,700	12-245
	Tainan	Sandy loam	Spring	1,105	1,580	83
	N. Taiwan					
	Shihmen	Silty clay	Autumn	573	762	33
	C. Taiwan					
	Taichung	Sandy loam	Autumn	1,775	2,091	18
	Changhua	Loamy sand	Autumn	372	1,028	176
	Changhua	Silty clay	Autumn	1,930	2,531	31
Sesame	S. Taiwan					
	Tainan	Sandy loam	Spring	829	950	15
Watermelon seeds	C. Taiwan					
	Changhua	Loamy sandy	Summer	278	336	19
Watermelon	N. Taiwan					
	Shihmen	Silty clay	Summer	5,619	12,738	126
Scallion	N. Taiwan					
	Miaoli	Sandy soil	Autumn	16,944	17,668	4
Radish	C. Taiwan					
	Changhua	Loamy sand	Autumn	20,204	21,903	8
Garlic	S. Taiwan					
	Hsuechia	Silty loam	–	7,600	8,500	11

Source: Irrigation and Drainage, Chinese Institute of Civil and Hydraulic Engineering, 1985 may not be profitable to irrigate the field frequently. Some tests on the frequency of irrigation were also conducted in Taiwan in 1963–1964. The experiment results of one application of irrigation at the critical stage of plant growth for some selected crops at different localities showed that there was an increase of production ranging from 21% to 228% (Table 13)[21].

As to cropping system, the total net incomes of different cropping patterns tested in recent years in the irrigated double-rice field in southern Taiwan are shown as an example in Table 14[22], from which one can see that vegetables are more profitable than other crops. In substitution for double rice cropping, the patterns of corn-rice, peanuts-rice, sorghum-rice and rice-peanuts are suitable in northern and eastern Taiwan. In consideration of the high unit yield of the first rice crop in central and southern Taiwan, the feasible alternative cropping patterns for these areas will be rice-short duration crops-corn, rice-short duration crops-garlic etc. The short duration crops include green manure crops, vegetables, melons, mung bean, vegetable soybean and early maturing soybean[22].

Experiments on Irrigation Methods

Observations on the advancement and penetration behaviors of irrigation water over the fields were made on furrow,

Table 13. Experiments on One Application of Irrigation at the Critical Stages of Plant Growth in Taiwan (1963-1964)

Crop	Critical Stage	Season	Time and Quantity of Irrigation	Production increase (%)
Sweetpotato	Rapid root expansion stage	Autumn	60 days after planting 60 mm one application	21
Peanut	Flowering Stage to pod expansion stage	Spring	50 days after seeding 50 mm one application	68
		Autumn	75 days after seeding 50 mm one application	32
Soybean	Flowering stage to initial pod growth stage	Spring	60 days after seeding 50 mm one application	114
		Autumn	55 days after seeding 50 mm one application	26
Corn	Silking stage to filling stage	Spring	60 days after seeding 50 mm one application	228
		Autumn	60 days after seeding 50 mm one application	52
Wheat	Young panicle stage to heading stage	Autumn	45 days after seeding 50 mm one application	48

Source: Irrigation and Drainage, Chinese Institute of Civil and Hydraulic Engineering, 1985.

Table 14. Total net income of different cropping patterns tested in irrigated single-rice field at Mei-nung, Kaoshiung, Taiwan, 1984

No	Cropping pattern			Total net income (US$/ha)	Index
	1st crop	2nd crop	3rd crop		
1	Rice (5.92)*	Vegetables (22.00)	Corn (5.57)	9,020	298
2	Rice (6.22)	Soybean (2.96)	Corn (5.69)	2,980	98
3	Soybean (1.91)	Rice (4.74)	Same red bean (2.83)	1,374	45
4	Rice (6.38)	Rice (4.83)	Same red bean (2.95)	3,027	100

*Figures in parenthese are unit yield (mt/ha) of different crops.

Source: Progress Report on Cropping Pattern Testing in Taiwan, Council of Agriculture, 1985.

border, and corrugation methods respectively. The converted depth of water required for different irrigation streams to cover different length of field up to 100 meters were found still higher than needed. Nomographs for determining the stream sizes, length of run and cutback time of border and furrow irrigation methods for various crops and different soil properties have been developed for application in Taiwan[23,24]. Some data on irrigation depths and stream sizes of border and furrow irrigation for corn, sorghum, peanuts and sweet potatoes on different soils of farms with and without machine plowing are shown respectively in Table 15 and Table 16[25]. Some data on irrigation efficiency of border and furrow irrigation for some crops in the Wushantou reservoir irrigation area in southern Taiwan are listed in Table 17[24] for reference.

On the other hand, experiments on different methods of sprinkler irrigation and drip irrigation have also been carried out. A simple low cost venyl-perforated-pipe sprinkler irrigation method was recommended for practical application[26].

For drainage especially in the rainy season, a method of crop production on raised beds with furrows has been developed for actual farming practices.

IRRIGATION ORGANIZATION

Irrigation Associations

Irrigation associations in Taiwan are corporate bodies organized by farmers to improve irrigation facilities, construct new irrigation works and supply irrigation water to farm lands in their individual designated service areas. They also assist the government in the planning and development of new large irrigation projects.

At present, there are 17 irrigation associations of which the largest is the Chianan Irrigation Association covering an

Table 15. Related Factors of Border Irrigation in Animal & Machine Plowing Fields

Soil types	Plowing Method	Crops	Application water depth (mm)	Unit Discharge (1/s/m/10m)	Cutback %
Sandy loam	Animal plowing	Peanut	80	0.30	80
Silty loam	〃	〃	85	0.35	80
Sandy loam	〃	Corn Sorghum	75	0.30	80
Silty loam	〃	〃	80	0.33	80
Loam	〃	〃	78	0.32	80
Sandy loam	〃	Prepared land	100	0.40	90
Silty loam	〃	〃	90	0.35	90
Loam	Tractor	Corn Sorghum	90	0.42	90
Loam	Power tiller	〃	81	0.40	90
Loam	Tractor	Prepared land	110	0.60	90
Loam	Power tiller	〃	105	0.50	90

Source: "Comparison on Surface Irrigation in Animal Plowing and Machine Plowing Field", NTU, NSC & JCRR, 1976

Table 16. Related Factors of Furrow Irrigation in Animal & Machine Plowing Fields

Soil types	Plowing Method	Crops	Application water depth (mm)	Unit Discharge (1/s/m/10m)	Cutback %
Sandy loam	Animal plowing	Sweetpotato	60	3	80
Silty loam	〃	〃	60	3.5	80
Silty clay	〃	〃	60	4.0	80
Sandy loam	Machine plowing	〃	80	7.0	80
〃	Semi-machine plowing	〃	70	6.0	80

Remarks: *plowed by a powertiller with furrows made by animal power.

Source: Comparison on Surface Irrigation in Animal Plowing and Machine Plowing Field, NTU, NSC & JCRR, 1976

Table 17. Experiment Data of Irrigation Application Efficiency in Wushantou Irrigated Area; Southern Taiwan

Crops	Irrigation Methods	Land prepatation	Length of farm (m)	Planned irrigation water depth (mm)	Actual water depth (mm)	Irrig. application efficiency (%)
Garlic	Border irrigation	Excellent	116.0m	34	62.9	54.1
"	"	good	117.5	34	62.9	54.3
"	"	"	136.5	34	43.9	77.4
"	"	Excellent	114.0	34	54.4	62.5
Sugarcane	Furrow irrigation	Inferior	97.0	51	63.9	79.8
"	"	Excellent	70.0	51	29.0	100.0
Corn	Corrugation irrigation	Good	70.5	45	58.5	76.9
"	Border Irrigation	Excellent	100.0	45	82.0	54.9
Barley	"	Inferior	143.0	45	91.8	49.0
Sweetpotato	Furrow irrigation	"	71	45	81.2	55.4
"	"	"	71	45	81.2	55.4
"	"	"	26	45	52.1	86.4
"	"	"	26	45	52.1	86.4
"	"	"	26	45	52.1	86.4
"	"	"	117	45	49.2	91.5
"	"	Excellent	90	45	31.4	100.0
"	"	Inferior	97	45	63.9	70.4
"	"	"	100	45	77.6	58.0
"	"	good	120	45	96.6	46.6
"	"	"	90	45	58.9	76.4
"	"	"	100.8	43	77.0	58.4
"	"	Inferior	100.8	45	56.4	79.8
"	"	good	88	45	59.8	75.3
"	"	"	100.8	45	49.5	90.9
"	"	"	100.8	45	51.7	87.0
"	"	Excellent	145.0	45	30.4	100.0
"	"	"	158.0	45	49.5	90.9
"	"	"	51.0	45	24.2	100.0
"	"	"	51	45	37.9	100.0
"	"	Inferior	114.5	42	96.3	46.7
"	"	good	100.0	45	79.8	56.4
"	"	Excellent	160.0	45	45.6	98.7

Source: Final Report of Upland Crop Irrigation Experiments at Hsue-chia Station, 1976 area of about 82,000 hectares in the southern part of the island, and the smallest is the Liukung Irrigation Association covering an area of only 279 hectares in Taipei. The total service area of the 17 irrigation associations in 1985 was about 390,000 hectares as shown in Table 18[1]. The organizational setup of a typical irrigation associations is shown in Figure 9.

Management System

The irrigation association has a management division at its head office to handle irrigation management policy, water planning, and statistical studies on water sources and irrigation requirements. In a typical irrigation association, the management division has local water source and regional irrigation management offices. The former may have some water source and main canal working stations for water control and supply; the latter has a number of irrigation working stations to operate and maintain the irrigation system. The water management system of a typical irrigation association is shown in Figure 10.

Field water distribution planning and execution are the main responsibilities of an irrigation working station which has three to five irrigation supervisors or attendants to take care of 800 to 1,500 hectares of irrigated areas. The station supervises and assists five to ten irrigation groups to carry out the water distribution and maintenance work of irrigation systems at the terminal level.

Irrigation Group

The irrigation groups are organized by association members themselves on the basis of farm-level irrigation systems. A group covers an area of 50 to 150 hectares. It consists of several teams, each with ten to fifteen members, to maintain irrigation and drainage ditches, to distribute irrigation water, to establish common seed-beds for group members, and to help the working station collect membership fees. The irrigation group has a chief and the team has a leader through election. They receive no salary from their irrigation association. Group meetings are held to discuss irrigation plans at least twice a year with participation of the farmers' association and the district agricultural improvement station for technical guidance.

IRRIGATION OPERATION AND MAINTENANCE

Irrigation Operation

Prior to the irrigation season every year, an irrigation guideline is worked out by the management division at the head office according to the government policy, production targets, the existing reservoir storage and water release, water flows at diversion weirs and other available water sources, past records of irrigation requirements, canal conveyance losses, rotational irrigation intervals, and time of irrigation etc. This irrigation guideline is distributed through regional management offices to irrigation working stations for further study and discussions with irrigation groups so as to work out detailed irrigation plans. The detailed plans so prepared by working stations shall be submitted to the head office for review and for compilation of an annual overall irrigation plan.

The approved water distribution plan is to be strictly carried out by the working stations. The canal operators of stations are in charge of the regulating and con-

Table 18. Service Area of Irrigation Associations (1985)

Irrigation Association	Irrigation Area (ha.)				
	Total	Double Rice crop annually	Single rice crop annually	Cropping rotation	Dryland
Total	385,423	164,852	19,944	79,088	12,318
Taiwan Province	383,908	255,831	27,036	84,115	16,926
Ilan	19,399	18,608	462	–	329
Peichi	5,457	4,498	959	–	–
Taoyuan	27,756	27,756	–	–	–
Shihmen	13,164	13,164	–	–	–
Hsinchu	7,086	7,086	–	–	–
Miaoli	10,007	9,870	–	–	137
Taichung	33,816	32,757	–	–	1,059
Nantou	12,688	11,509	1,179	–	–
Changhua	47,179	43,776	1,050	2,353	–
Yunlin	62,043	15,016	6,435	40,592	–
Chianan	81,523	24,666	9,867	38,496	8,494
Kaohsiung	19,470	11,938	3,927	2,674	931
Pingtung	21,880	14,257	2,238	–	5,385
Taitung	10,851	9,726	919	–	206
Haulien	11,589	11,204	–	–	385
Taipei City	1,515	1,346	–	–	169
Chihsin	1,236	1,236	–	–	–
Liukung	279	110	–	–	169

Remarks: The above figures do not include about 31,500 ha. of private canal systems and about 43,000ha. of the Taiwan Sugar Corporation's farmers.
Source: Taiwan Agricultural Yearbook, 1986.

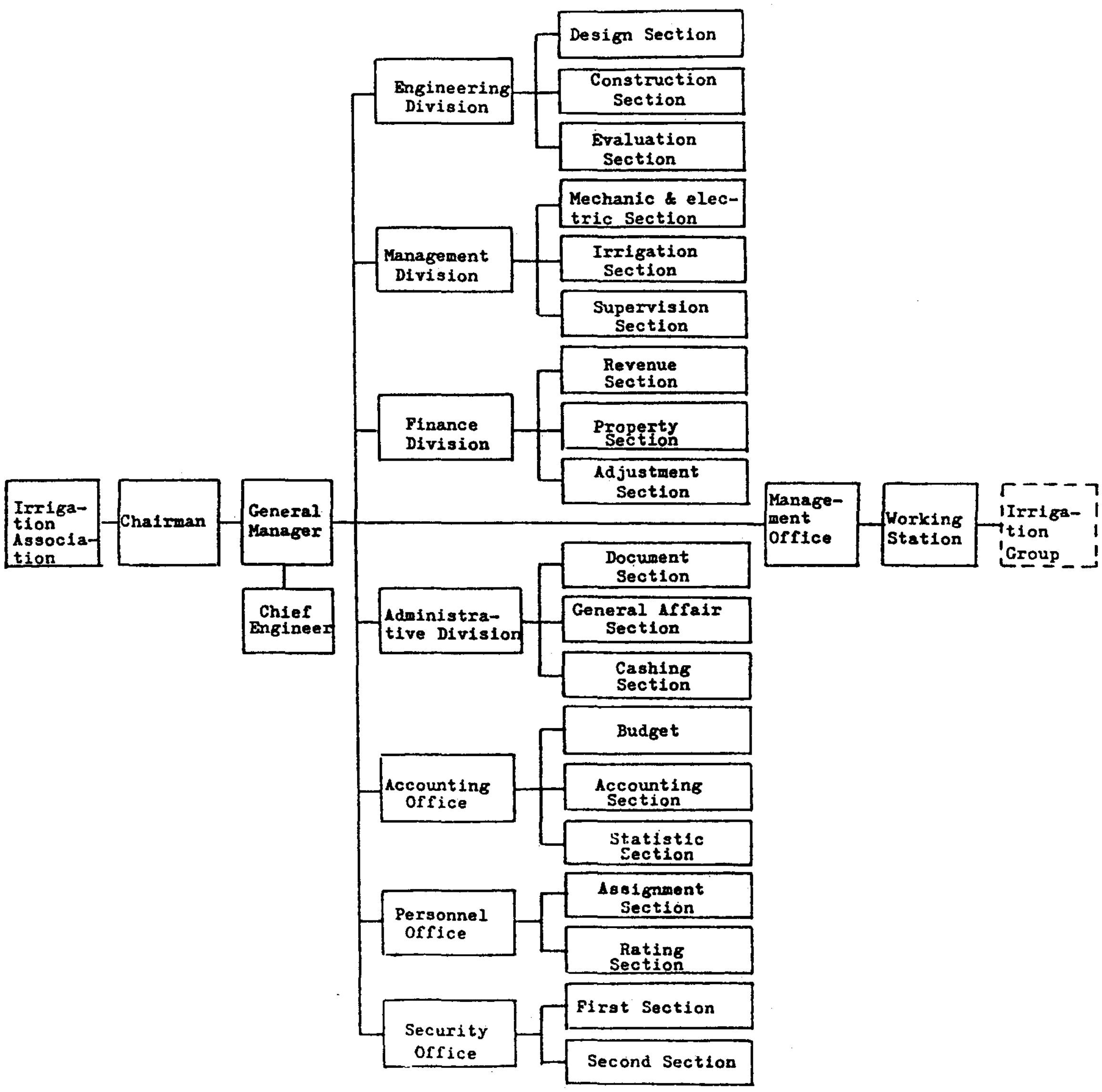
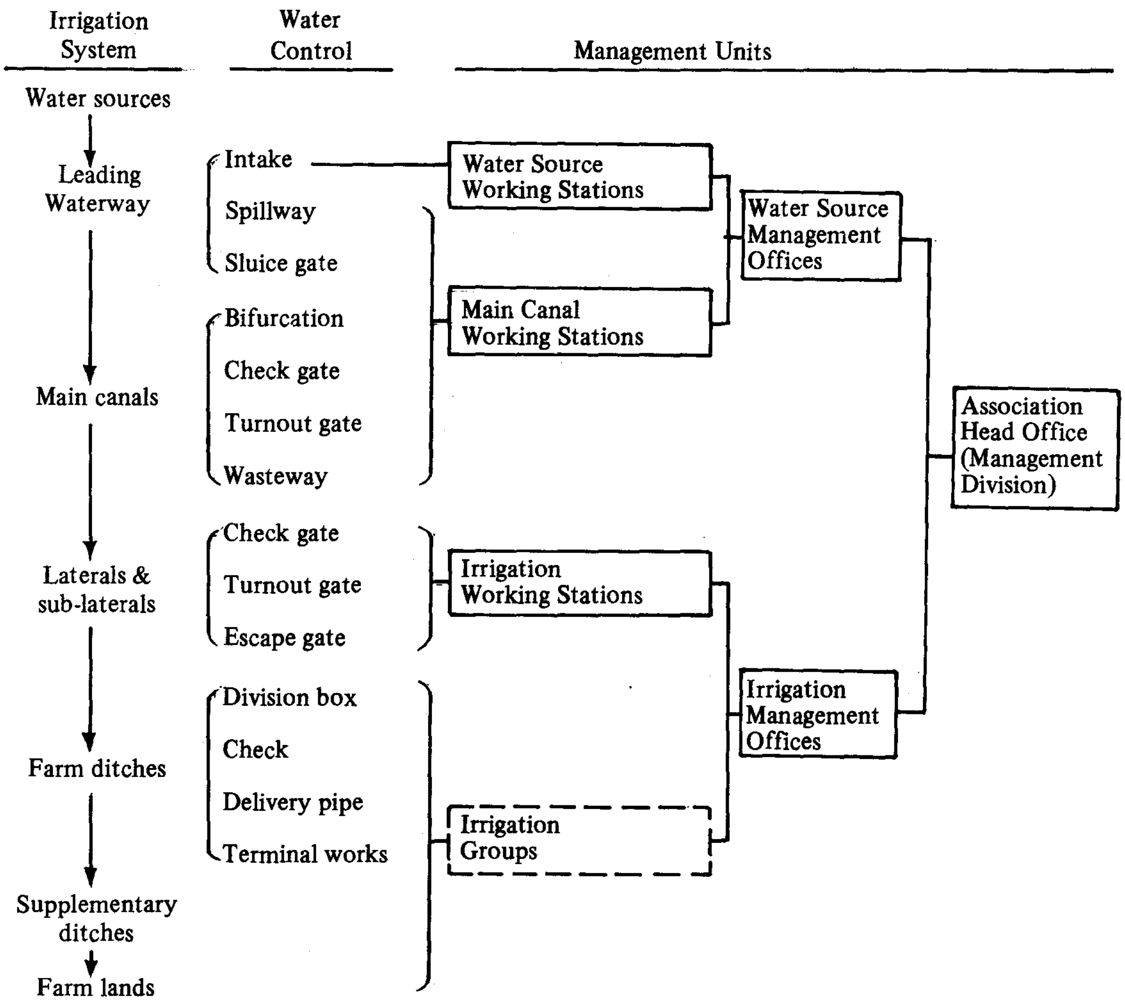


Figure 9. Organization Chart of Typical Irrigation Association



Remarks: In a small irrigation association, there may be no water source management offices, and the irrigation working stations may take the responsibilities of the water source and main canal working stations.

Figure 10. Management System of Irrigation Association

trolling water flows along main canal, laterals, and sub-laterals. The irrigation supervisors are in charge of water control and measurement at turnout gates on laterals or sub-laterals, and of inspections on farm-level water distribution which are undertaken by irrigation groups in their individual irrigation districts. One irrigation supervisor usually takes care of 300 hectares to 500 hectares covering six to ten rotation areas. Within a rotational area, one or two common irrigators may be hired by the irrigation group for the water distribution and maintenance of farm ditches.

Measurements of water actually used along the irrigation system from the water sources to the individual farm turnouts must be made in order to take advantage of each year's experience in planning and carrying on the following year's work.

Maintenance and Repair

In order to ensure adequate service to farmers, the irrigation and drainage systems must be maintained in good operating conditions. In general, damages of irrigation facilities are mainly due to flood and human destruction. The irrigation association pays more attention to maintenance than construction, and prevention than repair. Therefore, routine patrolling and inspections are important. For instance, the canal operators frequently make inspections on headworks, main canals, laterals, sub-laterals and related structures; and irrigation supervisors inspect turnout gates, farm ditches, checks, division boxes, etc. which were originally built by the association.

Maintenance and repair work may be classified as routine maintenance, annual maintenance and emergency repairs. The routine maintenance covers minor repairs discovered by irrigation supervisors or group members during their routine work. Annual maintenance check up is usually carried out during the non-irrigation season. Emergency repairs are mainly for damage cuased by floods during typhoon seasons.

IRRIGATION FINANCING

The collection of membership fees, the financing of projects, the setup of the Joint Irrigation Fund and other revenues are important financing features of an irrigation association. The annual budget of an irrigation association is drawn up to meet the need of irrigation administrative expenses, engineering construction, maintenance and damage repairs. The revenue comes from membership fees, construction fees for particular engineering projects, and government subsidies as the main financial sources.

Membership Fees

The annual revenue of an irrigation association mainly comes from membership fees which are collected from the direct beneficiaries to take care of the operation and maintenance costs. The fees are all to be collected in cash. The Government has set up a maximum limit of monetary value equivalent to 300 Kg and a minimum limit of 20 Kg of paddy grains per hectare per year.

Construction Fees

Construction fees are collected according to the capital cost and interest of each particular loan project as well as the benefits obtained by and the repayment ability of the farmers.

For improvement or new irrigation projects, the cost is financed partly by a grant and partly by a loan, either from the governmental or monetary agencies. The proportion of grant and loan on the total cost has had many changes depending on the financial conditions of the association and the source of funds. The grant portion was from 60–90 percent of the total cost. The term of the loan repayment varies from three to ten years and the interest is from 6–12 percent per annum. Collection of the loan repayment starts from the second year after the land is benefited.

Joint Irrigation Fund

A Joint Irrigation Fund was established for mutual cooperation among associations. Its main financial source is the associations' yearly contribution. The goal of 500 million New Taiwan Dollars (approximately equivalent to 11 million

US Dollars) has been achieved. It is deposited into a special bank account and is used as a revolving loan at six percent interest per annum for emergency projects, damage restoration projects, new projects, and other improvement projects.

Other Revenues

An association may also collect fees for leasing structures and the supply of surplus water. New members in a new project area or in an irrigation extension area as a result of improvement also have to pay for the engineering cost by proportion.

The budget for revenue and expenditure of the 17 associations in 1985 is shown in Table 19[27].

CONCLUSION AND RECOMMENDATION

In monsoon Asia, geographical and climatic conditions profoundly influence agriculture in which rice fields have been developed as the national treasures which may be described as follows:

1. Rice fields are equipped with irrigation systems which usually have a long history of improvements with enormous investments[28,29].

2. Since paddy rice survives from inundation for a period as long as three days, paddy fields have the function of regulating flood peaks of rivers with quite a large flood detention capacity which may be several times more than the total

Table 19. Total Income and Expenditure of Seventeen Irrigation Associations in FY 1984

Item	Amount	%
(1) Total Income	NT$3,841,472,251.13	100
Membership fee	NT$1,806,269,675.00	47.02
Property income (use of structures and surplus water)	NT$ 295,051,171.30	7.68
Interest and rental	NT$ 555,228,864.64	14.45
Property sale	NT$ 750,182,965.02	19.53
Fines and compensation	NT$ 4,407,238.20	0.12
Government subsidies, loan repayments and others	NT$ 430,332,436.97	11.20
(2) Total Expenditure	NT$2,899,593,648.27	100
Engineering construction	NT$ 763,135,484.07	26.32
Irrigation O & M	NT$ 531,842,062.44	18.34
Salary and administrative expenses	NT$1,427,105,726.90	49.22
Interest	NT$ 743,409.00	0.03
Property sale	NT$ 51,369,253.20	1.77
Contribution	NT$ 7,605,729.50	0.26
Others	NT$ 117,791,983.16	4.06

Remark: US$1 = NT$36.6

Source: FY1985 Data Book of Irrigation Associations,Taiwan Joint Irrigation Association, 1985 flood storage capacity of the existing reservoirs[28,29,30,31].

3. Paddy fields have the function of groundwater recharge which is very important especially in the coastal areas where land subsidence is caused by the withdrawal of groundwater.[29,30]

4. Paddy fields have the function of environment protection. They physically conserve soil and water, and chemically maintain the productivity of land.[29,30]

In order to preserve the aforementioned national treasures, paddy fields as well as irrigation water must be protected for continued development even for diversified cropping in monsoon agriculture.

As the result of increasing in both the unit yield and cultivated acreage of rice, and decreasing in the consumption of rice due to significant changes in the market demands for various farm products both at home and abroad, a number of countries have surplus in rice production, which in turn affects the farmers' income because of a declining price of rice. Consequently farmers have to seek ways of diversifing their production and income sources, but may face some problems in growing non-rice crops on irrigated paddy fields that were essentially used for rice production.

First of all, farm improvement has to be continuously carried out for production of diversified crops in paddy fields. It includes not only irrigation and drainage engineering works but soil and water management. The modernized farm improvement work has the following prerequisites:[31]

1. Farm land with high productivity for growing rice and other crops: – The land with high productivity or high yield per unit area must be in good condition for plant growth. It must be favorable for the development of plant root systems and functioning of photosynthesis with the following conditions:

(1) To be guaranteed with irrigation in appropriate amount of water and in right time, and be easy in water management: – Rice cultivation permits continuous irrigation with water flowing from parcel to parcel in paddy fields. This method of irrigation is not applicable to diversified cropping. The density of farm irrigation supply ditches must be increased to a certain extent. Pipe irrigation may be ideal but are expensive both in initial and operational costs. It is suggested that irrigation systems at farm level be improved with the method of rotational irrigation in corporated with land consolidation.

(2) Soil management and improvement: – Soil physical properties such as depth of soil layers, texture, permeability, porosity and water holding capacity, and chemical properties such as pH values and fertilities are closely related. For instance, soils may be improved by mixing rice husks or chemical compounds or others for different purposes.

(3) Good surface and subsurface drainage for free conversion from rice to other crops and vice versa: – Drainage is even more important than irrigation for diversified cropping in paddy fields, especially in low land areas and in wet seasons. Drainage systems must be separated from irrigation ones. Since subsurface drainage with tile drains is expensive, surface drainage with open ditches must be tried out first, in corporation with cultural practices such as raised beds with furrows. If subsurface drainage is required, rice husks may be used as materials for tile drains. This

method is inexpensive and applicable in many places.

2. To be easy for farm operations: – Farm operations including field water applications and cultural practices for diversified cropping need more labor than rice farming. High working efficiency of mechanized group farming is required for production of crops other than rice in order to reduce farming costs, especially in case when labor is in short. Paddy fields are to be improved for better workability and operations of farm machines such as tractors, power tillers, high pressure sprayers, harvesters, portable irrigation pump units and equiment etc., with the following considerations:

(1) Land readjustments may be required to get farm parcels as large as possible for joint farming operation. If necessary, irregular foot paths among the small parcels may be removed.

(2) Farm roads, supply ditches and drainage ditches are to be properly located in the field in order that high efficiency of mechanized farming and water management can be achieved.

(3) Farm roads must be sufficient in width and good in fundation for transportation of farm products, machines and other materials.

(4) The length and the width of each farm parcel must be suitable not only for irrigation application but for machine operations.

(5) Soils have sufficient depths in good drainage condition for plant growth and machine operations.

(6) Land and farm road slopes must be improved to fit the transportation of farm machines, which is especially important in hill-side farming.

3. To be stable in maintaining high productivity:

(1) Flood control and soil erosion prevention: – River levees, seadikes and regional drainage systems should be properly improved and maintained to protect farmlands.

(2) Wind erosion control: – Windbreaks are necessary especially in coastal areas where monsoon winds are strong.

(3) Prevention of land subsidence: – Strict control on withdrawal of groundwater is necessary to prevent the farmland from subsidence which is especially important in coastal areas.

(4) Prevention of landsliding: – Watershed management and soil conservation are also important in protecting farmlands from being eroded or buried.

(5) Pollution control: – Strict control on air and water pollution is necessary to secure crop production. To protect precious soils and irrigation water from water pollution is specially important.

In addition to the aforementioned farm improvement, researches and experiments on adaptability of crops, crop improvement, optimal cropping patterns, crop water requirements, irrigationmethods, improvement of farm machines as well as low-cost farming practices have to be conducted.

Parallel efforts must be made on studies of stabilizing the prices of crops, production and marketing plans, strengthening of farmers' organization, and farmer incentives which are a pre-requisite to increase production[32].

In concluding this report, the writer cites some research suggestions of Lee[33], which are still applicable to Asian countries in despite of being given in 1975. Lee's suggestions are:

1. To understand the differences between the types of products and between

technological characteristics in the land use of crops, a farm economy survey and research should be made on climate and soil requirements and on the input-output relationship of the grain and nongrain crops and livestock.

2. A long-term projection for national food consumption is a necessary step to understand the variety and future pattern of crops and livestock required by the people. This study will throw light on the economic considerations of an efficient cropping system.

3. The farmers′ response to price changes affecting crops other than grain should be surveyed. This will clarify the feasible solution for resource allocation.

4. Research on the domestic and regional production of crops and livestock should be undertaken from the viewpoint of economic comparative advantage.

5. Farmers′ organizations for the extension of new technology, the breeding of new varieties, and the protection from natural risks will be an important condition for promoting agricultural diversification. Sociological analysis on the impact of farmers′ organization will also be useful.

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Remarks:

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