Multiple cropping in paddy fields of Taiwan

Shan-Ney Huang
Taiwan Banana Research Institute
PO Box 18 Chiuju, Pingtung, 904 Taiwan, Republic of China
tbri@mail.banana.org.tw

Abstract: Taiwan is an island located in tropical and subtropical monsoon area of Asia. There are intense sunshine, abundant rainfall and high temperature on the island; these climatic conditions are in favor of the growth of many crops year round. The natural environment and irrigation systems are suitable to grow two to three crops of rice. Rice is an important cereal crop in Taiwan. Paddy field is a place for multiple cropping in combination with short-term crops such as corn and vegetables and long-term crops such as sugarcane.

Key words: Multiple Cropping System, Paddy Field, Rice

I. Background

Taiwan is an island situated about 160 Km of south-eastern coast of China, lying between latitude 21^{o} 53’ N and 25^{o} 18’ N. It is in shape like a sweet potato being approximately 383 Km long and 142 Km at its greatest width. Under a subtropical climate where the temperature are warm and water are abundant , it is suitable for growing crops the whole year round. On paddy fields, farmers generally grow two crops of rice and two to three upland crops or vegetables, this system is very popular in an area with a good irrigation facilities. This type of cropping has been established by technicians and farmers during the past several hundreds years under the suitable climates.

A. **Temperature.** Characterized with oceanic subtropical and tropical climates, summer is long and hot, and winter is short and mild. The monthly average temperature (Table 1) during the period from June to August ranges from 26^{o}C to 28^{o}C, while in January and February, the coldest month (Table 2) of the year from 15 ^{o}C (north head) to 20^{o}C (south end). Killing frosts rarely occur in Taiwan and have been recorded only 2 or 3 times in 10 years and only in a few places. We can see that temperatures are suitable for growing a variety of crops throughout the year.

B. **Rainfall and water.** Being influenced by the monsoon winds and the altitude of the total area and its adjacent mountains, the rainfall in Taiwan (Table 3) is abundant. Most of rainfall comes in summer (from June to August) as thunderstorm or typhoon. However, there are distinct wet and dry seasons in the central and southern parts especially along western sea coast of Taiwan, where evaporation rates are higher than the rainfall. The relative humidity averages between 75% and 80%. The supplementary irrigation is needed in many areas for growing short-season crops. Although Taiwan has 19 main rivers and many streams, due to the high mountains and steep lands, all of these are short and rapid-flowing during the rainy seasons. In view of the fact that the rainfall distribution does not always coincide with crop requirements, many dikes and reservoirs have had to be constructed for irrigation purposes.

C. **Length of sunshine.** The length of sunshine is another factor affecting the multiple cropping systems. As seen in Table 4, sunshine hour in northern Taiwan is much less than that in central and southern parts, especially during the winter season.

D. **Soils.** The capacity of soils is to supply higher plants with mechanical support, provide air, water and nutrients. With high temperature and precipitation, there are many physical-chemical reactions proceeding in soils including heavy leaching. In general, soils of Taiwan are low in fertility, also under the different pattern of climate, relief and parent materials, soils of Taiwan are diversified considerably. Latosols and alluvials of different parent materials are the main agricultural soils in Taiwan. Medium coarse (sandy loam) and medium (loam, silt and silt loam) textured soils constitute 80% of the total agriculture land. Two third of the total agricultural soils have pH values varying from 4.0 to 6.5. Liming has been proved beneficial on slightly to strongly acidic soils, particularly for vegetables and legumes. Organic matter content is low ranging from 1% to 3%. Soil phosphate and potassium content are classified as the levels from medium to low. Thirty percent agricultural land have soil test values of 4 to 10 ppm and 32% of 10 to 20 ppm Bray's P, while 37% of 15 to 35 ppm and 43% between 35 and 80 ppm Melich's K. Along the sea coast of the western parts of Taiwan, the agricultural irrigation water are not enough. In addition, over pumping of underground water and the evaporation rate higher than precipitation are disadvantages to the agriculture of the areas. There are about 30 thousand hectares salt-affected soils. Reclamation of saline and alkali soils is needed to grow row crops normally.

II. Rice is the basic crop grown on paddy field in Taiwan

A. **Importance of rice production.** On a global basis, rice ranks second to wheat in terms of the total harvested acreage. In terms of importance as a food crop, rice provides more calories per hectare than any other cereal crop. At the average world yield, a hectare of rice could sustain 5.7 persons per year compared to 5.3 for maize and 4.1 for wheat. It is estimated that 40% of the world population uses rice as a major source of calories. Rice provides more than half of the food for 1.3 billion people and 25~50% of the food for 400 million people. Rice is the only major food crop which grows primarily on the vast areas of flat, low-lying river basins and delta areas in Asia that are flooded to various depths during the monsoonal season. The significance of rice production is further emphasized by the fact that its successful production has often been linked with the stability of the world.

B. **Wetland rice culture and its association with soil environments.** Rice produces greater yields when it is grown in flooded soil. Submergence results in greater suppression of weed growth, higher efficiency in the utilization of added NH^{4+}-nitrogen, higher soil phosphate availability, active N_2-fixation and better pests and weeds control with granular chemicals. In Taiwan, 99 percent of cultivated rice areas are in wetland rice culture. The general operations involved in submerged rice cultivation are:

(1) Submergence of the soil with or without puddling.

(2) For the duration of the crop growth with or without soil drying in midseason.

(3) Draining and drying the soils before harvest.

These wetland practices result in greater than 90% of rice growth cycle being completed while it is submerged.

C. **Characteristics of submerged soil.** Since oxygen diffuses 10,000 times slower through water than through a gas phase, oxygen availability in submerged soil layer is very low. Oxygen that is trapped or diffuses into soil is rapidly consumed by microbial respiration. Under the resultant anaerobiosis, facultative and strict anaerobes predominate the microbial community in submerged soils (Table 6). Functions of submerged soils include:

(1) N_2-fixation by algae and bacteria, and nitrification in the flood water.
(2) Fe^{3+}, Mn^{4+}, and NO_3^- reduction in the reduced soil layer.
(3) pH increase in acidic soils and decrease in calcareous soils.
(4) Increase in soil available phosphate after Fe-P reduced and organic acids released.
(5) Increase in soil organic matter content by slow decomposing under anaerobic soil layer.
(6) Suppression or control of several soil borne plant diseases and weeds.

The above mentioned soil anaerobsis processes in paddy field are in favor of the developing multiple cropping systems and growing various crops after harvest of rice.

D. Paddy rice playing as a key role for multiple cropping in Taiwan.

According to “Tung-fan chi” (1602), the aborigines of Taiwan were already growing rice, soybeans, phaseolus, sesame, Job’s tears, sweet potatoes, onions, ginger, sugarcane, etc. Rice was planted on the hills by using direct-seeded method. At the beginning of the Chin Dynast (1684), farmers started to organize themselves to develop irrigation schemes, which enabled the planting of two crops of rice a year. From 1895 to 1945, Taiwan was controlled by the Japanese. The most outstanding achievement in agricultural development by the Japanese was the construction and repair of irrigation facilities. In 1921, irrigation associations were organized to accelerate irrigation and drainage operation. The peak record of cultivated land reached 860,436 ha, of which 529,600 ha were registered as paddy fields (324,202 ha of double rice and 205,407 ha of single rice) and 330,829 ha as upland fields.

Acreage of rice cultivation reached its peak around 1975. After 1975, the acreage of rice cultivation decreased rapidly due to the change of food consumption habit from starch to animal protein, the emigration of farm labor from villages to factories in urban areas, and the rice price was fixed and controlled by the government. Increasingly high rates of wages have also created a problem. However, rice is still an important cereal crop in Taiwan. Advantages of rice cultivation can be summarized as follows:

(1) Productivity of rice is higher than other food crops.
(2) Under the area of abundant water or rain, rice can produce the most yield of grain in all staple food crops. There is lower yield production risk than other crops especially in monsoonal Taiwan where rainstorm and typhoon hit frequently during June to August. Farmers are willing to grow rice with less investment.
(3) Rice can get part of nutrients from its irrigated water. Availability of soil phosphate and silica are increasing during the paddy fields are submerged.
(4) Rice cultivation has its ecological functions of soil and water conservation. High ridge of field operation are in favor of pond water, reducing run-off and supplying underground water.
(5) Soil borne diseases and weeds are suppressed during paddy rice growing period when the soils are flooded.

III. Leading multiple cropping systems in Taiwan

Natural climatic conditions such as temperature, water, sunshine and cultivation techniques allowed farmers to grow many crops in the early 1960 in Taiwan. Multiple cropping systems are developed from the joint endeavor between agricultural scientists and farmers. The pattern of farming is the result of the integration of breeding, soil management and the improvement of techniques, including fertilizer application and plant protection. Intensive research has been systematically carried out by the District Agricultural Research and Extension Station with technical and financial support from the government.

A. **Rice and crops with a short growth period**

This pattern was developed to include four crops in a cycle. An early ripening rice variety was selected for the first crop of rice combined with the relay interplanting of oriental pickling melons or green manure crop sesbania, to be followed by a second crop rice combined with sweet potatoes, wheat, tobacco, peas, sweet corn or a number of vegetables (Fig.1).

B. Rice and sugarcane

When the cropping pattern involves rice and sugarcane, special arrangements are necessary, because of the extremely long growing period of sugarcane (16~19 months). Usually the first crop of rice is planted in late February and harvested in late June. From the middle of June until late July, a summer crop is inserted. The second rice will then take up from late July to early November. Sugarcane is relay-planted in September alongside the rows of the second rice and harvested in February of the third calendar year. After the second rice is harvested in November, an additional winter crops may be raised between the rows of sugarcane seedlings. This crop can be flax, buckwheat, potatoes, garlic or brassica. This pattern may be practiced with five crops in 25 months (Fig. 2).

C. Rice and sugarcane when irrigation available in only one of every three years.

The sequence of crops is first crop of rice, a summer crop , second crop of rice, relay-planted sugarcane (September of the first year to February of the third year), ratooned sugarcane (February of the third year to February of the fourth year). In the early stages of each of the two crops of sugarcane, one more crop may be grown between the rows of sugarcane. This pattern may be practiced with seven crops in 36 months (Fig. 3).

IV. Needed in promoting multiple cropping

The success of multiple cropping in Taiwan is really a joint endeavor between agricultural scientists and farmers. However, social and economic background and economic analysis of multiple cropping are very important.

A. For the technical background, we should be concerned about

(1) The development of new crops or varieties for the multiple cropping pattern, through breeding and introductions from other countries.

(2) The improvements in irrigation methods.

(3) The improvements in fertilizer use, weighing crop characteristics, soil fertility status, and types of fertilizer to adapt the proper way of soil management and fertilizer application for grown crops.

(4) The improvement of cultivation methods for follow-up crops, relay-interplanting, or with no-tillage before the previous crop harvested.

(5) The plant protection by using physical and biological controlled methods. Researches are needed to look at the related pest occurrence between the previous and follow-up crops.

(6) The development of farm machines to uphold efficiency and save labor.

B. **Economic analysis of production costs, gross returns and net returns considering for the moment the two crop combinations.** From competitive, complementary and supplementary points of view for each crop grown in the multiple cropping systems and to find out the optimum combination which can be practiced in the area.

C. **Social and economic background**. We should look at the availability of farm labor, demand on local and export markets, farm credit and subsidy programs for farmers. Government policies such as land reform, improvement and expansion of irrigation facilities, improved marketing of farm products are also important.

Conclusion

Multiple cropping systems are designed for efficient use of natural resources such as sunshine, temperature, water and soils. Geographically, Taiwan is located in the tropical and subtropical monsoonal Asia. With advanced technical background, irrigation facilities, fertilizer allocation and high price marketing, several multiple cropping systems were developed and practiced. We believe that the systems will be further developed and adapted in the near future when the land is limited and natural resources are depleted gradually.

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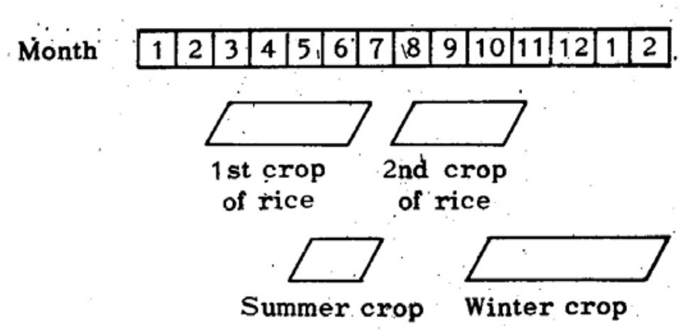

Fig.1. Multiple cropping pattern-rice and crops with a short growth period.

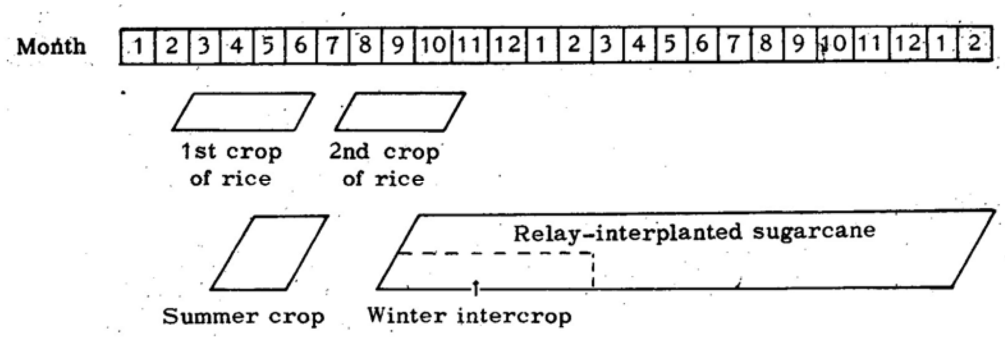

Fig. 2. Multiple cropping pattern-rice and sugarcane under normal conditions.

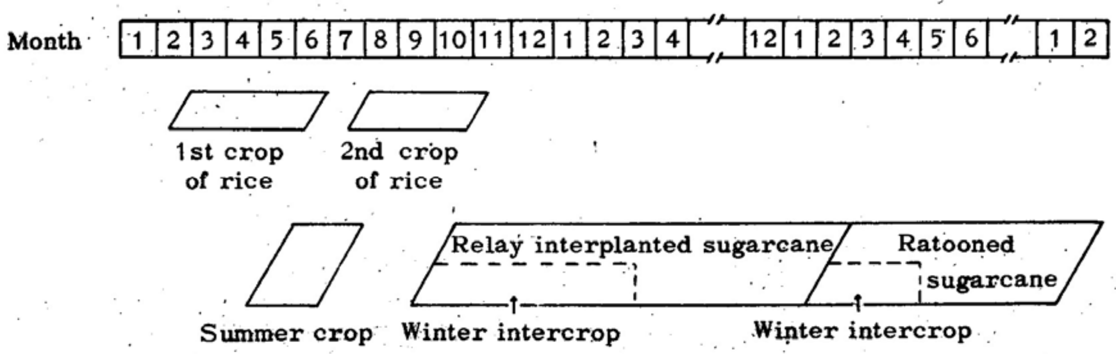

Fig. 3. Multiple cropping pattern-rice and sugarcane when irrigation available in only one of every three years.

Table 1. Average monthly temperatures in Taiwan.

Station[(1)]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average	Recorded years
								(°C)						
Keelung	15.6	15.3	16.8	20.2	23.7	26.5	28.2	28	26.6	23.5	20.4	17.3	21.8	1903~1955
Hsinchu	15.1	15	17.1	20.5	24.5	26.7	28.1	28	26.8	23.5	20.5	16.9	21.9	1938~1955
Taichung	15.8	15.9	18.4	22	25.4	26.9	27.8	27.6	26.7	23.5	20.7	17.4	22.4	1897~1955
Tainan	17.1	17.3	20	23.4	26.4	27.4	27.9	27.6	27.3	25	21.8	18.6	23.3	1897~1955
Taitung	19	19.2	20.9	23.2	25.4	27	27.6	27.4	26.6	24.5	22.3	20	23.6	1901~1955
Hengchun	20.4	20.7	22.4	24.6	26.7	27.4	27.6	27.3	26.9	25.4	23.5	21.4	24.5	1897~1955

(1) In order of decreasing latitude

Table 2. .Average monthly maximum and minimum temperatures in Taiwan.

Station[(1)]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average	Recorded years
								(°C)							
Keelung	Max	18.2	18.1	19.8	23.5	27.2	30.4	32.2	32.1	30.2	26.2	22.2	19.9	25.1	1903~1955
	Mim	13	12.9	14.1	17.3	20.7	23.4	24.9	24.8	23.8	21.1	17.9	15	19.1	1903~1955
Hsinchu	Max	18.8	18.6	20.8	24.3	28.5	30.5	32.3	32.5	31.3	27.6	24.4	20.6	25.8	1938~1955
	Mim	12	12.1	14.1	17.4	21.2	23.7	24.8	24.6	23.4	20.4	17.5	13.7	18.8	1938~1955
Taichung	Max	21.9	21.5	23.8	27.1	30.2	31.6	32.6	32.3	31.9	29.8	26.8	23.4	27.7	1897~1955
	Mim	11.7	12	14.6	18.3	21.7	23.3	24.1	24	22.9	19.8	16.5	13.2	18.5	1897~1955
Tainan	Max	24	24.2	26.5	29.2	31.5	31.8	32.4	32.1	32.4	31	28.3	25.1	29.1	1897~1955
	Mim	12.7	12.7	15.3	19	22.4	24	24.4	24.3	23.5	20.6	17.3	14.2	19.2	1897~1955
Taitung	Max	23.3	23.5	26.1	27.4	29.6	31.1	31.7	31.5	30.8	28.7	26.4	24.1	27.8	1901~1955
	Mim	15.6	15.7	17.4	19.7	22	23.4	24	23.8	23.2	21.3	19.1	16.8	20.2	1901~1955
Hengchun	Max	24.2	24.9	26.8	29.1	30.9	31	31.1	30.8	30.7	29	26.8	24.7	28.3	1897~1955
	Mim	17.6	17.6	19.3	21.5	23.5	24.7	24.8	24.6	24	22.9	21.1	18.9	21.7	1897~1955

(1) In order of decreasing latitude

Table 3. Monthly distribution of precipitation and evaporation in Taiwan.

Station (1)		Total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Number month <100mm"dry"	Number month >200mm"wet"	Average. rainy days of a year	Rainfall classification (2)
								mm										
Keelung	P	3038	306	293	298	217	261	287	137	167	250	247	269	306	0	10	214.6	I
	E	1423	67	61	80	96	116	143	204 (3)	198	160	127	97	74				
Hsinchu	P	1845	66	162	193	198	282	368	173	221	91	23	25	43	5	3	141.5	II
	E	1389	69	61	74	96	124	145	165	172	155	147	102	79				
Taichung	P	1782	33	68	114	130	228	371	295	338	139	22	16	28	5	4	126.2	II
	E	1538	94	88	102	120	143	148	167	156	153	152	118	97				
Tainan	P	1839	19	33	47	70	185	390	438	422	167	3.5	17	19	7	3	109.6	III
	E	1586	97	101	132	150	167	146	154	144	148	142	111	94				
Taitung	P	1815	36	46	66	71	173	201	353	305	292	175	61	36	6	4	153.1	II
	E	1731	118	112	127	137	150	167	183	173	157	157	132	118				
Hengchun	P	2513	15	21	43	79	194	500	654	592	303	74	21	17	7	4	152	III
	E	2026	154	150	190	199	199	159	160	148	154	183	171	159				

(1) In order of decreasing latitude
(2) I-continuously wet; II-dry season; III-very dry season.
(3) months in which evaporation exceeds precipitation.

Table 4. Length of sunshine by month in Taiwan.

Station[(1)]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total	Recorded years
								hours						
Keelung	43.5	48	62.9	81.2	100.3	133.2	209.1	206.2	158.4	90.5	61.2	46.8	1241.3	1917~1955
Hsinchu	112.6	94.2	95.3	116.6	165.1	175.8	236.7	244.1	219.9	211	150.9	126.4	1948.6	1938~1955
Taichung	186.4	157.5	164.1	171.7	203.3	204.1	245.2	233	245	247.7	209.7	194.6	2462.2	1898~1955
Tainan	198.7	184.6	203.4	209.6	235.9	221.9	239.6	223.4	241.8	248.5	212.2	198.3	2617.9	1898~1955
Taitung	109	99	104.7	126.6	160.3	209.5	244	224.3	193.1	165.5	133	112.5	1881.5	1901~1955
Hengchun	180.2	177	204.6	209.4	226.1	208.6	225	199.4	205.6	212.9	187.4	168.8	2405	1898~1955

(1) In order of decreasing latitude

Table 5. Changing planted acreage of several cereal crops in Taiwan (1000 ha).

Year	Rice	Sweet potato	Corn	Sorghum	Soybean
1952	778.4	237.7	5.5	2.4	27.1
1960	776.4	235.4	13.8	3.2	59.1
1965	775.9	234.1	18.7	4.1	53.2
1970	776.1	228.7	21.2	4	42.7
1975	790.2	156.7	49.6	7.2	41.4
1980	63.8	62.5	40.3	2.8	15.3
1985	564.4	23.2	62.5	23.3	7.1
1990	455.4	11.8	81.7	26.4	4.2
1995	363.5	10.9	72.8	22.9	3.8
2000	339.9	9.3	30.4	5.4	0.2
2005	269.1	10.2	21	2.1	0.1

Table 6. Anaerobic microbial processes and their reaction products (Tiedje et al. 1984).

Process	Reaction[1]
Fe^{3+}, Mn^{4+} reduction	OM[2] + Fe^{3+}, Mn^{4+}?Fe^{2+}, Mn^{2+}
Denitrification	OM + NO_3^- ? N_2O, N_2
Fermentation	OM ? organic acids, principally acetate and butyrate
Nitrate respiration	OM + NO_3^- ? NO_2
Dissimilatory NO_3^- reduction to NH_4^+	OM + NO_3^- ? NH_4^+
Sulfate reduction	OM or H_2 + SO_4^{2-} ? S^{2-}
Carbon dioxide reduction	H2 + CO_2 ? CH_4, acetate
Acetate splitting	Acetate ? CO_2 + CH_4
Protein reduction	Fatty acids and alcohols + H+ ? H_2 + acetate + CO_2

[1] Major reduction products are shown. Oxidized products are also produced, usually CO_2 if the electron donor is an organic compound.

[2] OM = organic matter