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Multiple Cropping as a Strategy in Sustainable Soil Management

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Introduction

Farm land sustainable management are processes to grow crop aiming at the use of renewable nature resources to provide food, income and livehood for the need of mankind not in current society but also in coming generations. The system concern the maintainence of ecosystem and the maximum Agricultural economic productivity (Cohen et al., 1991). However, in commercial agriculture management, a stable production and high productivity cropping system are adapted in farm land and natural resources using. Those systems always impact farmland ecosystem adversely. In modern agriculture practice, monoculture without rotation induce soil degradation severely. How to maintain the productivity and vitality of farm soil becoming an important issue in sustainable agriculture management. According to Damask et al (1991), the following goals are searching for agricultural production and sustainable management. There are a). maintain or enhance production/service, Productivity, b).reduce the level of production risk, Security, c).preserve the productive potential of natural resources and prevent degradation of soil and water qualities, Protection and d).be economically viable, viability and be socially acceptable, Acceptability.

Cropping pattern is the yearly sequence and spatial arrangement of crops, or of crops and fallow on a given farm. And cropping system is the cropping patterns used on a farm their interactions with farm resources, other farm enterprises, and available technology that determine their make up. There are many cropping system practice in the world including swidden cultivation, monocropping, multiple cropping and fallow or setaside. Monoculture is the repetitive growing of the same crop on the same piece of land, while multiple cropping is the intensification of cropping in time and space dimensions, growing two or more crops on the same field in a year. The cropping patterns of multiple cropping can be intercropping such as mixed, row, strip or relay cropping, and sequential cropping such as double, triple, quadruple or ratoon cropping (Table 1). Strategies in multiple cropping emphasis on time and space arrangement to maximumize crop productivity, so, multiple cropping system provide high efficieny in farm land use (Howard and Lessman, 1991). In areas of the world where multiple cropping is a common aspect of agroecosystem

management, productivity generally is more stable and constant in the long term (Gliessman and Amador, 1979 and 1980).

In considering use multiple cropping as actual alternatives we need to understand thoroughly the biological and agronomic basis responsible for the observed response, as well as the advantages and disadvantages to their use.

The advantages of multiple cropping are summarized as follow: 1).reduce the risk of field losses to drought, insects and diseases, 2). obtain a better use of vertical space and time in limited farmland. 3).legumes (as well as a few other plant families) are able to fix and incorporate nitrogen into the system, 4).diversified products are produced to help balance diet for farmer, 5).higher planting density and heavier mulch cover aids in weed control, avoidance or reduction of surface erosion. 6).improved soil structure, avoiding the formation of a "hard pan" and promoting better aeration and filtration 7).better opportunities for biological control of insects and diseases.

The disadvantages of multiple cropping systems are 1).competition between plants for light, soil nutrients and water, 2).it is difficult to harvest one crop without damage the other, mechanize and incorporate a fallow period in or into the systems 3).possible over-extraction and loss of nutrients and allelopathic influence between different crop plants.

Change of soil fertility under cropping patterns

Soil is an essential part of the biosphere and the basis for crop cultivation. Soils as natural-historical body have two alternative ways of development, 1).natural or, 2).anthropogenic. For the natural development of soils a period of one hundred years is immaterial and may not cause radical changes of soils and soils cover. More important way of development is the anthropogenic one. And this way is negative and leads to the violation of natural processes, degradation and final destruction. An improper cultivation especially fertilization results in the influence of different extents on soils. Sustainable soil management is the fundamental basis for sustainable agriculture.

As world population has increased, increasing the need for agricultural production, continues to stimulate more intensive agricultural investigation in a search for more productive alternatives. By the types of genetic manipulation that gave us such rapid and impressive yield increases during the "Green revolution". However, the high yielding varieties required high levels of fertitizers, water use and pest control. In order to uphold crop yield and increase profit, a monocropping system with large scale cultivation, heavy chemical fertilizers and pesticides application and huge and heavy farm machinery field operation were developed. The system impact the agroecossystem diversely. chemical fertilizers, pesticides, herbicides and farm machinery become the main materials for agricultural production (Rappaport, 1971).

For the past 50 years, we learned that the producer selected their crops to grow and their cultivation practices by considering how much profit they can get and neglecting the influence of the cropping system in farm land ecosystem. The

farming practices are close related to types of farm land use. According to Salterm et al (1941), continuous corn or wheat had detrimental effects on soil organic and nitrogen content (Table 2). Farm land fallow in high cultivated frequency, high cropping index area may not be a good practices of sustainable soil management. For example, in rain-forest area or rain-season, the fallow land suffer from increasing soil loss and run-off due to exposed surface soil without any mulch (Table 3). So, in the crop growing processes, from the soil protection point of view, no matter which cropping pattern you have taken, the most important thing you must consider is to grow or leave crop covering on soil surface. Soil losses and run off problem were more seriously in continuous plot than rotation (multiple cropping) plot. Since the nutrient losses are close related to soil losses, the nutrient losses also more in continuous plot (Table 4).

In order to meet the market demand or to provide the agriculture commodity year around, the types of large scale continuous single crop cultivation in specific area were developed. However, one harvest always get limited yield. So, the farmer always grow many same crops in the same land per year. They applied heavy fertilizers, pesticides, used a lot of water and huge farm machinery. Soil degradation were found in those farm land. There are 5 to 7 millions farm desertification in the every year (FAO, 1995). Soil degradation of farm land had three major characters 1).degraded soil physical, chemical and biological properties by lowering down their productivity. 2).erosion reduce soil volume and mass, losing the physical size of soil ecosystem 3).accumulated specific chemicals in soil. For the first soil degradation process comes from a).excess or improper tillage induce soil compaction and humus shortage, b).improper crop grown or fertilizers and pesticides application make less soil microbial population and diversity. c).continuous corn and cassaw deplete soil nutrients in long time growing. The second process comes from a).continuous single crop growing in same piece of farm land, b).strip farming c).excess tillage or plowing, d).clearing tilled or crop residues removal, e).development of new land. While the third process comes from a).the move of soluble salts upward to the soil surface becoming soil salinization; b).nitrate leaching or crop or residues removal and excess fertilization, c).chemicals addition in growing period, those chemicals can not be absorbed or decomposed and then contaminated the soil. For the all above mentioned soil degradation processes are easily found in continuous single crop long term growing system. Currently, the development and use of continuous cropping system may resolve food shortage problem temporaily. But system impact farm land agroecosystem adversely. Eventually, a stable and sustainable agriculture production will be destoryed by inducing quantities and qualities of soil degradations.

Effect of multiple cropping on agricultural production and farmer's revenue

Current agricultural management in farm land and resources use take stable

and higher yield as goals for agriculture production. In general, two types (mono or multiple) of cropping system are seen. In many modern countries, the monoculture is more popular than the multiple cropping. However, in considering the sustainability, the multiple cropping is better than the mono. Because the multiple cropping need less inputs such as chemical fertilizers, pesticides and farm machinery. 1).higher crop diversity in cropping system reduce or avoid the occurrence of harmful. insects or diseases damaged(Hammod and Jeffers, 1990; martin et al., 1989), 2).by using the root characteristics such as shallow or deep root distribution in soil to absorb and use nutrients in soil lager. and water. incorporating legumes in cropping system increase N2-fixation and reduce the amount of nitrogenous fertilizer application. 3).multiple cropping emphasis rotation or intercropping, left more crop residues or roots on soil. and increase soil organic matter content indirectly. Reduce the frequency of tilth and prevent soil crust formation.

From the point view of producer, multiple cropping systems increase the value and income of agricultural production (Beuerlein, 2001; Craner and Cucero, 1992). According to Ohio State University the roots of wheat penetrating soil to the depth 35-47 inches, while soybean 23-35 inches in relay cropping experiment (Table 5) (Taylor, 1965; Hagan and Stewart, 1972). The two crops can be intercropping although the yield of wheat decreased and harvesting time prolonged slightly by the influence of soybean but the total yield of two crops were higher the crop grown as continuous cropping individually (Table 6). The intercropping also had better profit (Talbe 7). Indicating a proper combination crops growing could increase the values and profits in multiple cropping system.

Multiple cropping systems in Taiwan

Taiwan is situated in a subtropical and tropical climate where the warm temperature, high rainfall and abundant sunlight are suitable for growing crops the whole year around. During the past 300 years, an intensive farming system with rice crop as basis and four or five crops year was established. Three major multiple cropping patterns were popular on paddy fields in early 1960's, 1).rice and crops with a short growth period, thus, 1st crop of rice follow-up a summer crop, then 2nd crop of rice, and finally winter crop, 2).rice and sugarcane under normal conditions, thus, 1st crop of rice follwow-up by a summer crop then 2nd crop of rice, and finally winter intercrop and relay interplanted sugarcane 3). Rice and sugarcane when irrigation available in only one of three years, thus, 1st crop of rice followed by summer crop, then winter intercrop and relay interplanted sugarcane, and finally, ratooned sugarcane with winter intercrop. At the same time, an intensive farming systems in upland with various crops also developed. sweet potatoes, corn, vegetables and fruits were grown. During 1960s, multiple cropping index of Taiwan reached 1.90, one of the highest in the world.

In order to know the effect of different crops grown in multiple cropping on the production soil fertility and farmer's income, field experiments were carried out in Tainan and Hualein District Agricultural Improvement Station. Results of Tainan showed that the grain yield of rice were not affected (Table 8). While sorghum and corn had better yield in legume included systems. (Table 9 and 10). Soybean got more yield after rice (Table 11).

For the net income, the rice-soybean-corn got the best, then rice-sesbania-corn and soybean-rice-corn were followed (Table 12).

As for the changes of soil fertility, we found soil fertility in Tainan were getting better such as organic matter phospbrous, potassium content increased after the 10 years experiment.

Discussion and conclusion

Reducing the inputs of man-made materials and the operation frequency of heavy farm machinery in farm land are the final goals purchasing in using multiple cropping systems as a strategy in sustainable agricultural management. Multiple cropping can avoid the depletion of soil resources. By chosing suitable crop combinations. Growing period and types of cropping system increase soil productivity, water use efficieny, and insects and diseases controlling, we may bring down the processes of soil degradation which are accelerated by monocropping.

On the basis of crop cultivation, many selections may take several argicultural technologies or practices including 1).land preparations, crop residues management and tillage, 2).chosing crops and varieties. 3).growing period and types of planting 4).fertilizers and their application, 5).pest controlling. Although multiple cropping systems including intercropping or rotation are better than monocontinuous cropping in maintainence of farm land agroecosystem, recycling agricultural wasters and usage of natural resources. However, monocropping could better agricultural economic efficiency of the in short term.

Monocropping system are characteristic with single crop, large scale farming and year around continuous cultivation, simplify the crop planting and field operation, applying chemical fertilizers and pesticides to supply nutrients and controlling insects and diseases. It is also easy to use huge, high efficient farm machinery to substitute man power for reducing labor cost. Those methods are making monocropping system reach high yield production in short period. However, after several decades monocropping have degraded soil with low productive found in many farms. Among them, improper or excess pesticide application make the occurrence of insects and diseases more frequent and difficult to control. High rate chemical fertilizer application resulted in soluble salts accumulation which contaminatsed or toxificed the soil. The single continuous growing crop depleted plant nutrients in soil. In order to sustain farm land management in crop producing several strategies are suggested:

A better use of vertical space and time on farm land before crop cultivation, especially in soil mulch and cover to prevent surface soil erosion.
Maintain the field crops diversity highly. Consider the possibilities of mechanization in rotation or intercropping systems.
Recycle plant nutrients completely. Return plant residues to field for nutrients and soil surface protection.
Increase soil biological activities. Incorporate legumes in multiple cropping systems to increase nitrogen fixation.
Maintain and rebuild soil matter content.
Better combination of crops to be use in sequential. mixed or relay cropping.

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Table 1. Multiple cropping system definitions.

Multiple Cropping	Intensification of cropping in time and space dimensions. Growing two or more crops on the same field in a year.
1.Sequential Cropping	● Crop intensification is only in the time dimensions. ● Growing two or more crops in sequence on the same field per year. ● The succeeding crop is planted after the preceding crop has been harvested. ● No intercrop competition. ● Farmer manages only one crop at a time in the same field.
a) Double Cropping	Growing two crops a year in sequence.
b) Triple Cropping	Growing three crops a year in sequence.
c) Quadruple Cropping	Growing four crops a year in sequence.
d) Ratoon Cropping	Cultivation of crop *regrowth* after harvest, although not necessarily for grain; allows multiple, separate harvests.
2.Intercropping	● Crop intensification is in both time and space dimensions. ● Growing ywo or more crops *simultaneously* on the same field. ● There may be intercrop competition during all or part of crop growth. ● Farmer manages more than one crop at a time in the same field.
a) Mixed Intercropping	Growing two or more crops simultaneously with no distinct row arrangement.
b) Row Intercropping	Growing two or more crops simultaneously where one or more crops are planted in distinct rows.
c) Strip Cropping	Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation, but narrow enough for the crops to *interact* agronomically.
d) Relay Cropping	Growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage of growth but before it is ready for harvest.

Source: Papendick, *et. al.*, 1976

Table 2. Organic matter and nitrogen content of unfertilized plots at Wooster, Ohio.

Cropping-system	Begun Year	Analyzed Year	Organic matter (lb/acre)	Nitrogen (lb/acre)
1984		1894	35,050	2,176
Corn, oats, wheat, clover, timonthy	1984	1925	26,700	1,546
Continuous corn	1984	1925	12,730	840
Continuous oats	1984	1925	22,800	1,425
Continuous wheat	1984	1925	22,050	1,315
Corn, wheat, clover	1987	1925	29,500	1,780

Source: Salter, *et. al.*, 1941

Table 3. Average annual rainfall, runoff , and soil loss from crops

Cropping-system	Years of record	Rainfall (in.)	Runoff (in.)	Soil loss (t/acre)
Continuous fallow	1960-1966	48.53	11.84	5.14
Continuous peanuts	1951-1958	42.92	2.88	1.23
Continuous corn	1955-1966	47.05	1.24	0.77
Meadow (bermudfrass and clover)	1951-1954	43.66	0.35	0.34
Three-year rotation	1951-1966	46.20	1.83	0.98
Oats	1951-1966	46.20	1.20	0.51
Peanuts	1951-1966	46.20	1.83	1.32
Corn	1951-1966	46.20	2.47	1.12
Four-year rotation	1952-1966	46.09	1.96	0.71
1^{st} year meadow	1952-1966	46.09	3.11	0.92
2^{nd} year meadow	1953-1966	46.33	0.31	0.46
Corn	1952-1966	46.09	0.80	0.56
Peanuts	1952-1966	46.09	1.65	0.91

Source: Thomas, *et. al.*, 1969

Table 4. Average annual rainfall, runoff , and soil loss by cropping treatment.

Treatment No.[a]	Cropping treatment	Slope (%)	Row direction[b]	Rainfall (in.)	Runoff (in.)	Soil loss (t/acre)
1	Fallow	7	(C)[c]	55.71	18.35	60.43
2A	Cotton continuously	7	A	55.71	6.33	12.28
2B		7	W	55.71	9.84	21.86
3A	Corn continuously	7	A	55.71	4.54	4.02
3B		3	W	55.71	6.54	2.40
3B		7	W	55.71	7.03	12.11
3B		11	W	55.71	2.40	20.90
4A	3-year rotation of					
	1st costal bermudagrass	7	(C)	54.78	2.42	1.99
	2nd costal bermudagrass	7	(C)	54.78	1.78	0.16
	Corn	7	W	54.78	4.42	4.43
	Rotation average	7	W	54.78	2.87	2.19
4B	3-year rotation of					
	1st costal bermudagrass	7	(C)	54.78	2.25	2.26
	2nd costal bermudagrass	7	(C)	54.78	2.74	0.19
	Corn	7	A	54.78	2.99	1.08
	Rotation average	7	A	54.78	2.66	1.17
5	3-year rotation of					
	1st tall fescue	7	(C)	56.73	5.42	0.88
	2nd tall fescue	7	(C)	56.73	2.80	0.09
	Corn	7	A	56.73	4.56	1.97
	Rotation average	7	A	56.73	4.26	0.98
6	4-year rotation of					
	1st tall fescue	7	(C)	57.56	11.04	4.05
	2nd tall fescue	7	(C)	57.56	5.07	0.05
	Corn	7	A	57.56	6.04	2.93
	Cotton	7	A	57.56	7.23	6.25

[a] Years of record: treatment numbers 1 to 3, 1961-1967; treatment numbers 4, 1962-1967; treatment numbers 5 and 6, 1961-1965.
[b] A = rows on contour ascross slope; W= rors uphill and downhill with the slops.
[c] No rows.
Source: Carreker, *et. al.*, 1977

Table 5.

Crop	Depletion of Availiable Water (percent)	Root Zone Depth (deep soil irrigation) (inches)
Alfafa	30-50	47-70
Beans, dry	50-70	23-35
Corn	40-60	29-47
Cotton	50-65	35-47
Potatoes	25-50	23-35
Sugarbeet	30-60	35-47
Grain sorghum	50-70	35-47
Sobean	50-60	23-35
Wheat	50-70	35-47

Source: Taylor, 1965; Hagan and Stewart, 1972

Table 6. Three-Year Average Yield of Becker Wheat and Union, Regal, and Williams-82 Soybeans, Wooster, Ohio.

Row Arrangement	Wheat		Soybean	
	Bu/Ac	Percent	Bu/Ac	Percent
Monocrop*	71	100	48	100
14" rows, both crops	65	91	36	74
21" rows, both crops	60	84	38	79

* Wheat in 7" rows; soybean in 14" rows.
Source: Beuerlein, 2001.

Table 7. Comparison of the Production Budgets of Monocrop Wheat and Soybeans with a Relay Crop System.

Item	Unit Price	Monoculture		Intercrop	
		Wheat	Soybean	Wheat	Soybean
Crop Yields		75	50	68	35
Receipts	**$3.00-$6.25**	**$225**	**$312**	**$204**	**$219**
Variable costs					
Seed		20	24	10	20
Fertilizer		35	19	31	13
Herbicides		4	24	4	12
Trucking, Fuel		11	11	10	9
Lub., Repairs, Misc.		31	38	30	33
Interest on Operating $		7	8	6	6
Total Variable Costs		**108**	**124**	**91**	**93**
Fixed Costs					
Labor (3 hrs)	$8.00	24	24	24	24
Machinery & Equip.		48	48	24	24
Land Ownership/Rent		80	80	40	40
Management (5% of Gross)		11	15	10	11
Total Fixed Costs		**163**	**167**	**98**	**99**
Total Costs		**271**	**291**	**189**	**192**
Return Above Costs		**-46**	**21**	**15**	**27**
Net Return / 2 Acres			**($25)**	**$42 X 2 ac = $84**	
Advantage for Relay Cropping 2 Ac.				**$109.00**	

Source: Beuerlein, 2001.

Table 8. The grain yield of rice in different cropping systems. (Tainan DARES)

Unit : (kg／ha)

Cropping system	Crop season	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average	Index (%)
A. Rice—Rice	spring	6,264a	6,641a	6,024a	6,541a	5,298b	6,569a	6,330a	7,150a	5,907a	6,972a	6,370a	100
B. Rice—Soybean—Maize	spring	6,306a	6,341a	5,599a	6,346a	5,833a	6,084a	4,971b	5,897b	5,346b	5,597b	5,832b	92
C. Rice—Sesbania—Maize	spring	6,194a	6,751a	6,037a	6,376a	6,295a	6,333a	4,786b	6,347ab	6,242a	5,861b	6,122a	96
A. Rice—Rice	summer	3,095b	4,475a	5,809a	3,517a	5,508a	4,626a	4,860a	5,820a	3,736b	5,850a	4,730a	100
D. Soybean—Rice—Maize	summer	3,583a	4,329a	5,389a	3,460a	3,733b	4,479a	2,707b	5,902a	4,333a	4,983a	4,290a	91

Note : Values followed by the same letter do not significantly different (P = 0.05), according by Duncan's multiple range grouping test.

Table 9. The grain yield of maize in different cropping systems. (Tainan DARES)

Unit : (kg／ha)

Cropping system	Crop season	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average	Index (%)
D. Soybean—Rice—Maize	fall-winter	7,071b	3,223b	5,721b	5,394a	5,464c	5,336b	6,297ab	4,290b	4,985a	4,560bc	5,324c	100
B. Rice-Soybean-Maize	fall	7,956ab	3,686b	6,472b	4,620bc	6,010bc	6,041ab	5,360c	4,397b	4,944a	4,458c	5,394c	103
C. Rice-Sesbania-Maize	fall	8,483a	4,926a	9,025a	5,205ab	8,332a	6,074ab	6,485ab	4,760a	5,200a	6,415a	6,491a	124
E.Sorghum-Ratoon sorghum-Maize	fall	7,675a	4,921a	7,973a	4,310c	7,798a	5,660ab	6,064ab	4,243b	5,011a	5,271b	5,892b	113
F. Sorghum-Soybean-Maize	fall	7,522ab	3,062c	6,306b	5,400a	6,585b	6,386a	5,713bc	4,381b	4,792a	4,625bc	5,477bc	105

Note : Values followed by the same letter do not significantly different (P = 0.05), according by Duncan's multiple range grouping test.

Table 10. The grain yield of sorghum in different cropping systems. (Tainan DARES)

Unit : (kg／ha)

Cropping system	Crop season	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average	Index (%)
E.Sorghum–Ratoon sorghum–Maize	spring	5,490a	5,059a	3,939b	3,996b	3,372a	4,682a	3,156a	3,530a	3,972a	4,773a	4,197a	100
F. Sorghum–Soybean–Maize	spring	6,009a	5,944a	5,708a	5,195a	3,774a	5,227a	3,626a	3,589a	4,106a	4,874a	4,805a	114
E. Sorghum–Ratoon sorghum–Maize	fall	2,825	2,333	2,017	1,688	2,129	3,164	2,504	4,111	3,472	1,828	2,614	62

Note : Values followed by the same letter do not significantly different (P = 0.05), according by Duncan's multiple range grouping test.

Table 11. The grain yield of soybean in different cropping systems. (Tainan DARES)

Unit : (kg／ha)

Cropping system	Crop season	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average
D. Soybean—Rice—Maize	spring	2,365	3,523	2,638	1,747	996	2,477	2,508	960	2,383	2,479	2,207
B. Rice—Soybean—Maize	summer	1,833a	2,349a	2,314a	3,197a	1,237a	2,967a	1,533a	1,908a	850a	2,350a	1,964a
F. Sorghum—Soybean—Maize	summer	2,228a	2,985a	2,343a	2,521a	1,314a	988b	1,259a	2,474a	1,275a	2,810a	2,020a

Note : Values followed by the same letter do not significantly different (P = 0.05), according by Duncan's multiple range grouping test.