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Relay-Intercropping of *Stylosanthes guianensis* in Rainfed Lowland Rice Ecosystem in Northeast Thailand

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Abstract : We evaluated the usefulness of the *Stylosanthes guianensis* (stylo)- rice relay-intercropping system for increasing agricultural productivity in Northeast Thailand. Although large production variability was observed, the relay-intercropping system produced an average of 350 g m^{-2} stylo dry matter during the dry season under non-irrigated and non-fertilized conditions in the experimental fields at the Ubon Rice Research Center. Utilization of the stylo production as green manure increased rice yield, but only slightly. The relay-intercropping also slightly improved soil chemical properties, but not significantly. The trial of the relay-intercropping in farmer's fields produced a maximum of 367 g m^{-2} stylo dry matter. Since the stylo production did not decrease the subsequent rice production, the rice-stylo relay-intercropping system is worth considering as one way to utilize the paddy fields during the dry season in Northeast Thailand.

Key words : Dry season, Forage production, Green manure, Nutrient deficit, Rainfed rice.

Rainfed agricultural regions without large-scale irrigation facilities are generally characterized by low productivity. In order to alleviate poverty, many organizations have invested considerably in attempts to increase the productivity in these regions. Northeast Thailand is such a rainfed agricultural region, in which the irrigation area occupies less than 5% of agricultural land, and agricultural productivity is much lower than in other regions in Thailand (Office of Agricultural Economics, Thailand, 2004). Constraints on agricultural production in Northeast Thailand are summarized by two factors. One is low yield of rainy season rice and the other is a lack of dry season crops.

Rainy-season rice in Northeast Thailand occupies 70% of the agricultural land, most of which is classified as rainfed fields. The average yield is 2.0 t ha^{-1}, which is about 60% of average yield in the central plain. Although water shortage caused by erratic rainfall is one of the major constraints (Fukai et al., 1998), low soil fertility also strongly restricts rice productivity, even with sufficient water supply (Homma et al., 2001). The low soil fertility is often caused by low clay and organic matter contents in the soil (Willet, 1995). Organic matter content seems to be the best indicator of soil fertility (Homma et al., 2003). Therefore, many investigators have incorporated organic materials, such as farmyard manure, compost, and green manure, into soil and concluded that organic materials were effective for increasing soil fertility and rice productivity (Supapoj et al., 1998; Whitbread et al., 1999). Since the availability of farmyard manure and compost is often limited, green manure is recognized as a promising application (Garity and Becker, 1994). However, green manure practices such as crop establishment and residual incorporation (Palaniappan and Budhar, 1994) need to be established, as this technology has not been commonly used by farmers in Northeast Thailand.

The dry season in Northeast Thailand is from November to May. Low precipitation and lack of large-scale irrigation facilities restrict the area and the kind of dry season cropping. For example, rice production in the dry season in Northeast Thailand was only 0.4 million tons in 2003, 5% of that in the rainy season. Rice production in the dry season in the central plain was 3.7 million tons, which was 75% of that produced in the rainy season (Office of Agricultural Economics, Thailand, 2004). Although small-scale irrigation, including the use of tube wells and pumps, allows for cultivation of some vegetables during the dry season, the cultivation is limited by the small market in the area. In order to increase agricultural production in the dry season, new crops or new agricultural systems adapted to large-scale cultivation without irrigation are needed.

Water buffalos were traditionally kept for agricultural management, such as plowing and puddling. Rapid expansion of small tractors beginning in the 1990s dramatically decreased their agricultural use, and consequently, the number of buffalos decreased from 4.0 million head in 1993 to 1.5 million head in 2003 (National Statistical Office, Thailand, 1995, 2005). However, the buffalo was

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still important for meat production (Simaraks et al., 2003). Recently, farmers in Northeast Thailand began raising cattle as an economic option (Simaraks et al., 2003; Phaowphaisal et al., 2005). Recent increases in consumption of meat and dairy products expanded the demand for cattle (Ohmomo et al., 2002; Simaraks et al., 2003), and the number of cattle increased from 3.3 million to 4.2 million in Northeast Thailand (National Statistical Office, Thailand, 1995; 2005). In the traditional methods of cattle raising, rice straw and grasses on non-agricultural fields were used for forage (Fukui, 1993). However, the amount of such forage is limited, and this constrains increases in the number of livestock, especially cattle (Fukui, 1993; Kawashima et al., 1998; Suzuki et al., 2006). In order for a small rice farmer to develop a stock-raising system, it is important to secure adequate feed.

The facts that huge areas of paddy fields are not utilized during the dry season, and that potential demand for cattle feed is quite large, suggest that farmers will produce forage crops if a system for production during the dry season is developed. Although the socioeconomic situation at present restricts the amount of input to dry season production, one method to overcome this restriction may be a relay-intercropping system. In such a system, residual water and nutrients from rice culture can be utilized for subsequent forage crops (Guldan et al., 1998; Caviglia et al., 2004). If the forage crops are not harvested, they may be grazed or used as green manure to the subsequent rice crop. Since farmers commonly leave livestock to graze residual rice straw, of which biomass and nutrients are low, in the fields during the dry season (Kawashima et al., 1998; Suzuki et al., 2006), forages may improve the nutrient status of livestock.

This study aimed to develop a forage production system by relay-intercropping on rainfed paddy fields in Northeast Thailand. Since a feasibility study showed that *Stylosanthes guianensis* (stylo) produced the most dry matter of several leguminous crops tested (*Vigna unguiculata,* cowpea; *Macroptilium atropurpureum*, siratoro and *Centrosema pascuorum,* centro; Watatsu, 2002), thus, only stylo was tested as a forage crop for this system. We tested the system not only in experimental fields in the Ubon Rice Research Center (URRC; Ubon Ratchathani, Thailand), but also in farmer's fields at three locations in Northeast Thailand. In the URRC, the biomass of stylo was tested as green manure as one of possible uses.

Materials and Methods

1. Experiment 1: Field experiment at the Ubon Rice Research Center

The experiment was conducted in rainfed paddy fields of the URRC (15°20'N and 104°41'E, 123 m in altitude). Since soil fertility and water availability are greatly different at different toposequential positions in a mini-watershed in Northeast Thailand (Homma et al., 2003; 2004), two types of fields along a toposequence in a mini-watershed in the URRC were selected for the experiment: one was located in the upper toposequence (upper field), and the other in the lower toposequence (lower field). The lower field was classified as rainfed shallow, favorable subecosystem, and the upper field as rainfed shallow, drought-prone subecosystem. The difference in altitude between the upper and lower fields was 1.1 m. Soil properties of the fields before the experiment are shown in Table 1. Soil organic carbon (SOC) and clay contents in the lower field were slightly higher than those in the upper field. The upper field scarcely had standing water, while the lower field was submerged for most of the rainy season. Each field was divided into six plots, 10×10 m each. Three types of cropping systems were tested at each field in two replications from 2000 to 2003 (four seasons of rice and three seasons of stylo): Rice-*Stylosanthes guianensis* (stylo) relay-intercropping with chemical fertilizer (relay-intercropping), rice mono-cropping with chemical fertilizer (mono-fertilized) and rice mono-cropping without chemical fertilizer (mono-unfertilized). The effect of stylo can by examined by comparing relay-intercropping and mono-fertilized as the two were

Table 1. Soil properties of the experimental field at Ubon Rice Research Center, measured prior to the experiment in June 2000.

	Position	
	Upper	Lower
pH	5.0	5.0
SOC[1)] (g kg^{-1})	3.3	4.4
Texture (kg kg^{-1})		
Sand	0.95	0.84
Silt	0.01	0.11
Clay	0.04	0.06

[1)] SOC: soil organic carbon.

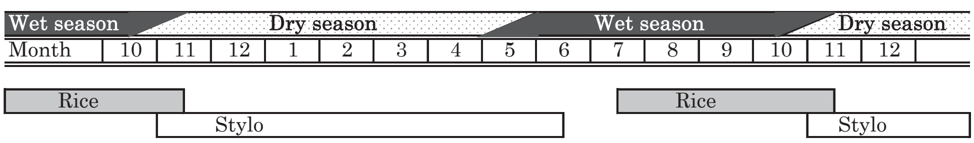

Fig. 1. Cropping calendar of rice-*Stylosanthes guianensis* (stylo) relay-intercropping system.

fertilized in the same way, while the mono-unfertilized treatment will provide the base rice productivity with no nutrient inputs to the crops.

A rice-stylo relay-intercropping system was designed as shown in Fig. 1. Seedlings of rice cultivar KDML105, about 35 days old, were transplanted in mid-July each year, and grown in rainfed conditions. Planting density was 16 hills per square meter (0.25 m × 0.25 m) and two plants per hill. Fertilizer, at a rate of 2.5-2.5-1.25 g m^{-2} (N-P_2O_5-K_2O) was applied in the relay-intercropping and mono-fertilized plots. The rate was a representative application rate for rainfed rice farmers in Northeast Thailand (Miyagawa et al., 1999). Half this amount of chemical fertilizer was applied as top dressing in late-July and the remaining half in mid-September every year. Rice plants were harvested in late-November. The seed of stylo cultivar CIAT-185 was soaked in water at 60ºC for 1 minute so that it would germinate uniformly. It was broadcast before rice harvesting, in early-November in the upper field, and immediately after standing water disappeared (around mid-November) in the lower field. Stylo survived during the dry season under non-irrigation and non-fertilized conditions, utilizing residual soil moisture and nutrients after the rice crop. At the end of the dry season, stylo started to grow rapidly as precipitation increased. In mid-June, one month before rice transplanting, the above-ground biomass was harvested and incorporated into the soil as green manure. The relay-intercropping experiment was started in mid-July 2000, when rice was transplanted, and ended in late-November 2003, when rice was harvested.

The aboveground biomass and paddy yields of rice were measured for two 1-m^2 areas in each plot at maturity. The aboveground biomass of stylo was measured for two 0.5-m^2 areas in each plot just before incorporation into soil. Additional plant materials were also collected from each plot to determine the nitrogen (N) content. The N content of these materials was measured by the Kjeldahl method after drying for 72-h in an oven.

Soil in each plot was sampled from the plow layer (0–15 cm) before and after rice cropping, and before incorporation of the above ground biomass of stylo every year. Soil organic carbon (SOC) content was measured for all the soils, and ammonium-nitrogen (NH_3-N) and extractable phosphorus (P) contents were measured for the soils sampled in December 2001 and June 2002. SOC content of soil was determined by the Walkeley method (Walkeley, 1947). NH_3-N was determined by the indophenol method after extracted by potassium chloride (Dorich and Nelson, 1983). Extractable P was measured by the Bray 2 method (Bray and Kurtz, 1945).

2. Experiment 2: Application of the relay-intercropping to farmer's fields

The rice-stylo intercropping system was tested at farmer's fields in three locations in Northeast Thailand: Udon Thani (17º15'N, 102º31'E), Chum Phae (16º39'N, 102º00'E) and Buri Rum (14º58'N, 103º12'E). In each location, two types of field were selected for the test along a toposequence in a mini-watershed: one was located in the upper and another in the lower toposequnce. The selection was in accordance with Exp. 1: the lower field was classified as rainfed shallow, favorable subecosystem, and the upper field as rainfed shallow, drought-prone subecosystem. Each field was divided into four experimental plots

Table 2. Farmer's management for the rice-stylo relay-intercropping system. Management of rice was the same as they customarily used.

Site	Management			
	Rice			Stylo
		Upper	Lower	
Udon Thani	TP:	late-June	late-June	BC: early-Nov.
	HV:	late-Nov.	late-Nov.	UT: harvested to feed cattle
	CF:	2.6-1.3-1.3	1.5-0.8-0.8	
		(splited into 2 applications)		
Chum Pae	TP:	mid-Aug.	mid-July	BC: early-Nov.
	HV:	late-Nov.	late-Nov.	UT: green manure
	CF:	3.1-3.9-0.0	0.6-0.7-0.0	
		(one application)		
Buri Ram	TP:	early-Aug.	early-Aug.	BC: early-Nov.
	HV:	late-Nov.	late-Nov.	UT: grazed water buffalo
	CF:	1.5-1.5-0.8	1.8-1.8-0.9	
		(splited into 3 applications)		

TP: transplanting; HV: harvesting; CF: application rate of chemical fertilizer (N-P_2O_5-K_2O g m^{-2}); BC: broadcasting; UT: utilization of stylo biomass.

and each plot was about 10×10 m in area. We used two treatments: rice mono-cropping (mono-fertilized) and rice-stylo relay-intercropping (relay-intercropping), with two replications, from transplanting of rice in mid-Juy 2002 to harvesting of rice in late-November 2004. The aboveground biomass and paddy yield of rice and aboveground biomass of stylo were measured by the same protocol as in Exp. 1.

Rice cropping both in mono-fertilized and relay-intercropping fields was managed by farmers according to their usual practices. The management is summarized in Table 2.

3. Weather data and statistical analysis

Precipitation was measured at the URRC, the Udon Thani Rice Experiment Station, the Chum Pae Rice Experiment Station, and the Buri Rum Meteorological Station. Table 3 shows the precipitation during the experiment. Seasons are divided into the wet season (June to October) and the dry season (November to May).

The experimental data were subjected to analysis of variance with least significant difference (LSD) and test of residuals using IRRISTAT 5.0 (IRRI).

Results

1. Experiment 1: field experiment at the Ubon Rice Research Center

(1) Dry matter production of *Stylosanthes guianensis* (stylo)

The maximum dry matter production of stylo was recorded in the first season in the field experiment at the URRC (Table 4). In particular, the production in the field located in the lower toposequence (lower field) was 950 g m^{-2} under non-fertilized and non-irrigated conditions during stylo production in the dry season. Stylo produced less dry matter in the second and the third seasons, but, with the exception of the upper field in the second season, more than 200 g m^{-2} of dry matter was produced. No significant relationship was observed between stylo production and precipitation in the dry season.

(2) Effects of relay-intercropping on rice paddy yield

More precipitation during the wet season in 2002 increased rice yield in the upper field, but it did not increase rice yield in the lower field (Table 5). Although rice yield was not significantly different between the relay-intercropping and mono-fertilized treatments, relay-intercropping fields tended to produce more rice yield and more biomass than mono-fertilized fields for three continuous years. The relay-intercropping caused greater N uptake by the subsequent rice crop. Without fertilizer application, rice biomass production was lowest, and the yield was only about 70% of that in the relay-intercropping treatment where fertilizer and green manured stylo was applied.

Table 3. Precipitation (mm) during the experiment. The wet season is the period from June to October, and the dry season from November to May.

Year	Season	Precipitation (mm)			
		Ubon	Udon Thani	Chum Pae	Buri Ram
2000	Wet season	1325			
2001	Dry season	209			
	Wet season	1324			
2002	Dry season	338			
	Wet season	1882	1336	756	1199
2003	Dry season	666	458	354	542
	Wet season	1009	949	733	1103
2004	Dry season		454	439	300
	Wet season		1057	1555	1086

Table 4. Production of stylo (g m^{-2}) in three cropping seasons at different toposequential positions (upper and lower).

Position	2000–2001	2001–2002	2002–2003
Upper	415±192	77±21	211±19
Lower	950±479	229±19	236±13

Mean±standard deviation (n=2).

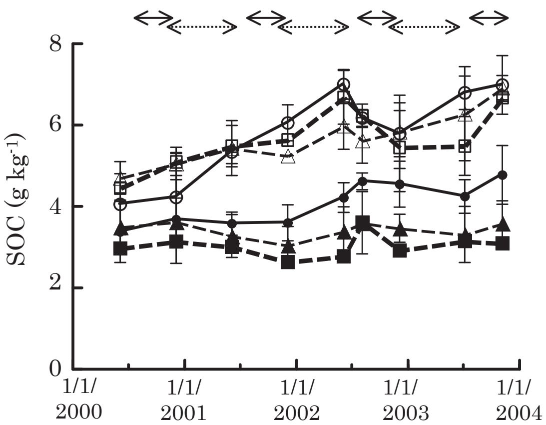

Fig. 2. Change in soil organic carbon (SOC) content in relay-intercropping (○ ●), mono-fertilized (□ ■) and mono-unfertilized (△ ▲) in the upper field (solid) and the lower field (open). Arrows shows cropping duration of rice (solid) and stylo (dotted). Error bars indicate standard error (n=2).

(3) Effect of the relay-intercropping on chemical properties of soil

Soil organic carbon (SOC) content increased with time in the relay-intercropping system (Fig.2). In the lower field, it also increased in the mono-cropping systems and hence the advantage of relay-intercropping was not clear. However, in the upper field, the SOC content after 3 years of relay-intercropping was significantly higher than that after the 3 years of mono-cropping, where the SOC content of soil was almost constant for three years.

Table 5. Grain yield, aboveground biomass and nitrogen (N) uptake by rice in four cropping seasons in a relay-intercropping system, rice monoculture (mono-fertilized) and rice monoculture without chemical fertilizer (mono-unfertilized).

	Position	Treatment	2000	2001	2002	2003	Average
Grain	Upper	Relay-intercropping	214 ns	204	320	43	189 a
($g\ m^{-2}$)		Mono-fertilizerd	233	222	274	35	177 ab
		Mono-unfertilized	167	160	212	45	139 b
	Lower	Relay-intercropping	372 ns	330	237	354	307 a
		Mono-fertilizerd	353	218	235	332	262 ab
		Mono-unfertilized	295	181	174	333	229 b
Biomass	Upper	Relay-intercropping	583 ns	383	828	321	510 a
($g\ m^{-2}$)		Mono-fertilizerd	579	427	755	235	473 a
		Mono-unfertilized	364	387	560	163	370 b
	Lower	Relay-intercropping	1066 ns	845	826	927	866 a
		Mono-fertilizerd	1021	648	785	828	754 b
		Mono-unfertilized	781	530	611	783	641 c
N uptake	Upper	Relay-intercropping	3.3 a	4.2	5.9	2.2	4.1 a
($g\ m^{-2}$)		Mono-fertilizerd	3.5 a	3.0	4.4	1.6	3.0 b
		Mono-unfertilized	1.1 b	2.2	3.0	1.3	2.2 b
	Lower	Relay-intercropping	6.1 ns	6.7	5.7	7.4	6.6 a
		Mono-fertilizerd	6.1	3.8	5.5	6.4	5.2 b
		Mono-unfertilized	5.1	3.1	5.2	5.8	4.7 b

Since relay-intercropping (cultivation of *Stylosanthes guianensis*) was started after heading of rice in the 2000 cropping season, statistical analysis was conducted separately for 2000 and for the period from 2001 to 2003. Numerals followed by a common letter are not significantly different a 5% level. ns denotes not significantly different at 5% level.

Table 6. Ammonium nitrogen (NH_3-N) and extractable phosphorus (P) content of soil at the early stage (Dec. 2001) and at the end (June 2002) of the second cropping season of stylo in relay-intercropping, mono-fertilized and mono-unfertilized plots.

Position	Treatment	NH_3-N ($mg\ kg^{-1}$)			Extractable P ($mg\ kg^{-1}$)		
		Dec-01	Jun-02	Increase	Dec-01	Jun-02	Increase
Upper	Relay-intercropping	2.8	3.9	1.0 ns	43	41	−2 ns
	Mono-fertilized	1.8	2.7	0.9	38	39	1
	Mono-unfertilized	2.2	2.7	0.5	26	26	1
Lower	Relay-intercropping	2.9	7.9	5.0 ns	39	32	−7 ns
	Mono-fertilized	4.0	5.8	1.8	44	44	0
	Mono-unfertilized	3.3	4.6	1.3	22	26	4

ns denotes not significantly different at 5% level.

Ammonium nitrogen (NH_3-N) and extractable phosphorus (P) contents of soil in the relay-intercropping tended to be higher in the early stage and at the end of the second cropping season of stylo than they were in the mono cropping (Table 6). The stylo in relay-intercropping tended to increase soil NH_3-N, but to decrease extractable P. However, these values had large deviations and the differences were not statistically significant.

2. Experiment 2: Application of the relay-intercropping to farmer's fields

In the first cropping season, 2002–2003, we obtained little biomass of stylo at the beginning of June because of submergence in the lower field in Chum Pae and grazing by water buffalo in the upper and lower fields in Buri Rum. However, the standing biomass exceeded 150 $g\ m^{-2}$ in the other three fields and the maximum was 367 $g\ m^{-2}$ in the upper field in Udon Thani (Table 7). In the second cropping season, 2003–2004, the standing biomass of stylo hardly exceeded 100 $g\ m^{-2}$. Since we left management of stylo to farmers, they used the stylo biomass for themselves. The farmer in Udon Thani harvested the aboveground biomass to raise cattle. The farmer in Chum Pae plowed the stylo into the soil as green manure. In Buri Rum water buffalo grazed it.

The relay-intercropping system tended to increase the grain yield of rice more than the mono-fertilized cropping (Table 8). However, the difference was not significant because of the relatively large variability. The percentage of the increase of grain yield in the relay-intercropping system compared to that in the mono-fertilized cropping was approximately 20, 10, and 0% in Chum Pae, Buri Rum, and Udon Thani, respectively, with an average of 10%.

Table 7. Dry matter production of stylo (g m^{-2}) at the beginning of June in 2 cropping seasons at different toposequential positions (upper and lower) in Udon Thani, Chum Pae and Bri Rum experimental sites.

Site	Position	2002–2003	2003–2004
Udon Thani	Upper	367±27	103±27
	Lower	176±21	90±11
Chum Pae	Upper	322±103	92±44
	Lower	2±1[1)]	20±11
Buri Ram	Upper	7±1[2)]	41±4
	Lower	1±0[2)]	57±20

[1)] Stylo was extremely damaged by submergence.
[2)] Water buffalos grazed.

Discussion

Stylosanthes guianensis were proposed as leguminous pasture crops in Thailand (Guodao et al., 1997) and as fallow crops in Lao PDR (Roder and Maniphone, 1995; Saito et al., 2006). The present results show that stylo can be produced in paddy fields during the dry season in Northeast Thailand in rice-stylo relay-intercropping. The relay-intercropping did not need irrigation or fertilization during the stylo cropping, which utilized residual water and nutrients from the rice cropping. Under such conditions, the maximum stylo production was 950 g m^{-2} on the experimental field at URRC and 367 g m^{-2} at the farmer's field in Udon Thani. However, the stylo production showed a large variability. In order to introduce the relay-intercropping system to farmer's fields, the production variability must be decreased.

The largest difference in the stylo production was observed between the first and the second cropping seasons. The production decreased in the second cropping season in both the experimental fields and the farmer's fields. In order to reveal the production constraints, we conducted a pot experiment. The decrease in the production may be caused in part by sulfur deficiency, but the details will be published elsewhere. Craswell and Karjalainen (1990) also stated a risk of sulfur deficiency in paddy field in Thailand. In spite of sulfur deficiency, the relay-intercropping still produced more than 200 g m^{-2} dry matter in the

Table 8. Grain yield of rice (g m^{-2}) for 3 cropping seasons in the relay-intercropping system and rice monoculture (mono-fertilized).

Site	Position	Treatment	2002	2003	2004	Average
Udon Thani	Upper	Relay-intercropping	225	67	166	117
		Mono-fertilized	231	54	178	116
	Lower	Relay-intercropping	220	123	217	170
		Mono-fertilized	241	112	211	162
Chum Pae	Upper	Relay-intercropping	375	320	444	382
		Mono-fertilized	366	231	408	320
	Lower	Relay-intercropping	333	258	301	280
		Mono-fertilized	337	201	284	243
Buri Ram	Upper	Relay-intercropping	255	154	224	189
		Mono-fertilized	259	142	178	160
	Lower	Relay-intercropping	293	160	206	183
		Mono-fertilized	313	148	195	172
Average	Upper	Relay-intercropping	285 ns	180	278	229 ns
		Mono-fertilized	285	142	255	199
	Lower	Relay-intercropping	282 ns	80	242	211 ns
		Mono-fertilized	297	154	230	192

Since relay-intercropping (cultivation of *Stylosanthes guianensis*) started after heading of rice in the 2002 cropping season, statistical analysis was conducted separately for 2002 and for the period from 2003 to 2004. ns denotes not significantly different at 5% level.

third cropping season at the experimental fields. Since urea is commonly used as nitrogen fertilizer for rice cropping in Northeast Thailand (Author's observation; also see Craswell and Karjalainen, 1990), a change to ammonium sulfate may increase the stylo production.

Another factor affecting the production variability seems to be water conditions. The production decrease of stylo in the upper field in the second cropping season may have been caused by drought. The lower production in the lower fields than in the upper fields in Udon Thani and Chum Pae may be associated with excessive soil moisture. Such constraints can be avoided to some extent by changing the broadcast time of stylo seed. Earlier sowing benefits from more available water, while later sowing alleviates injuries from excessively wet conditions. In order to determine the optimum time of sowing, more trials are necessary.

In the experimental field, we used the stylo biomass as green manure. The green manure tended to increase rice yield and to improve the soil chemical properties. The relay-intercropping system may cause sulfur deficiency, although it seems not to affect rice yield. Significant effect of fertilizer on green manure biomass has been reported (Arunin et al., 1994; Herrera et al., 1997). Accordingly, the stylo crop which received only residual nutrient of rice cropping may not be suitable for green manure production. In Udon Thani and Buri Rum, the farmers fed the stylo biomass to livestock. The feeding did not decrease rice yield, suggesting that stylo biomass produced in relay-intercropping can be utilized for livestock production without affecting subsequent rice production.

In order to introduce the relay-intercropping system to farmer's fields, many problems remain to be solved, such as low seed supply and high cost. If the stylo production is used for cattle raising, a stable supply of seed is required. However, the increased amounts of agricultural products on the many paddy fields not currently used during the dry season, would be of value. The products, forage in this case, can increase livestock production and be converted to barnyard manure. The manure contributes to improved soil fertility and agricultural productivity.

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References

Arunin, S., Pongwichian, P. and Aragon, E.L. 1994. Integrated nutrient management strategies : the INSURF experience in Northeast Thailand. In J.K. Ladha and D.P. Garity eds., Green Manure Production Systems for Asian Ricelands. Selected Papers from the International Rice Research Conference. IRRI, Manila. 155-171.

Bray, R.H. and Kurtz, L.T. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59 : 39-45.

Caviglia, O.P., Sadras, V.O. and Andrade, F.H. 2004. Intensification of agriculture in the south-eastern Pampas. I. Capture and efficiency in the use of water and radiation in double-cropped wheat-soybean. Field Crops Res. 87 : 117-129.

Craswell, E.T. and Karjalainen, U. 1990. Recent research on fertilizer problems in Asian agriculture. Fert. Res. 26 : 243-248.

Dorich, R.A. and Nelson, D.W. 1983. Direct colorimetric measurement of ammonium in potassium chloride extracts of soils. Soil Soc. Am. J. 44 : 833-836.

Fukai, S., Sittisuang, P. and Chanphengsay, M. 1998. Increasing production of rainfed lowland rice in drought prone environment. Plant Prod. Sci. 1 : 75-82.

Fukui, H. 1993. Food and Population in a Northeast Thai Village. University of Hawaii Press, Honolulu. 1-421.

Garity, D.P. and Becker, M. 1994. Where do green manures fit in Asian rice farming systems. In J.K. Ladha, and D.P. Garity eds., Green Manure Production Systems for Asian Ricelands : Selected Papers from the International Rice Research Conference. IRRI, Manila. 1-10.

Guldan, S.J., Martin, C.A. and Daniel, D.L. 1998. Interseeding forage brassicas into sweet corn : forage productivity and effect on sweet corn yield. J. Sustainable Agric. 11 : 51-58.

Guodao, L., Phaikaew, C. and Stür, W.W. 1997. Status of *Stylosanthes* development in other countries. II. *Stylosanthes* development and utilization in China and south-east Asia. Trop. Grassl. 31 : 460-466.

Herrera, W.T., Garrity, D.P. and Vejpas, C. 1997. Management of *Sesbania rostrata* green manure crops grown prior to rainfed lowland rice on sandy soils. Field Crops Res. 49 : 259-268.

Homma, K., Horie, T., Ohnishi, M., Shiraiwa, T., Supapoj, N., Matsumoto, N. and Kabaki, N. 2001. Quantifying the toposequential distribution of environmental resources and its relationship with rice productivity. In S. Fukai, J. Basnayake eds., Increased Lowland Rice Production in the Mekong Region. ACIAR proceedings, No. 101. ACIAR, Canberra. 281-291.

Homma, K., Horie, T., Shiraiwa, T., Supapoj, N., Matsumoto, N. and Kabaki, N. 2003. Toposequential variation in soil fertility and rice productivity of rainfed lowland paddy fields in mini-watershed (*Nong*) in Northeast Thailand. Plant Prod. Sci. 6 : 147-153.

Homma, K., Horie, T., Shiraiwa, T., Sripodok, S. and Supapoj, N. 2004. Delay of heading date as an index of water stress in rainfed rice in mini-watersheds in Northeast Thailand. Field Crops Res. 88 : 11-19.

Kawashima, T., Pholpark, S., Boonpakdee, W. and Srihakim, S. 1998. Mineral status of diary cattle and available mineral sources in Northeast Thailand. In T. Kawashima and P. Vijchulata eds. Status and Requirement of Minerals in Ruminants in Thailand. –Current Knowledge and Future Research– JIRCAS Working Report No. 10. JIRCAS, Ibaraki. 63-73.

Miyagawa, S., Kono, Y., Nagata, Y. and Nawata, E. 1999. Technical changes in rainfed rice cultivation in Northeast Thailand. In T. Horie, S. Geng, T. Amano, T. Inamura and T. Shiraiwa eds., World Food Security and Crop Production Technologies for Tomorrow. Kyoto Univ., Kyoto. 169-172.

National Statistical Office, Thailand. 1995. 1993 Agricultural Census Northeastern Region. Ministry of Information and Communication Technology, Bangkok, Thailand. 1-130.

National Statistical Office, Thailand. 2005. 2003 Agricultural Census Northeastern Region. Ministry of Information and Communication Technology, Bangkok, Thailand. 1-131.

Office of Agricultural Economics, Thailand. 2004. Agricultural Statistics of Thailand Crop Year 2002/03. Ministry of Agriculture and Cooperatives, Bangkok. 1-258.

Ohmomo, S., Nitisinprasart, S. and Hiranpradit, S. 2002. Silage-making and recent trend of dairy farming in Thailand. JARQ 36 : 227-234.

Palaniappan, S.P. and Budhar, M.N. 1994. Seed production, crop establishment, and incorporation practices as agronomic constraints in green manure production systems. In J.K. Ladha and D.P. Garity eds., Green Manure Production Systems for Asian Ricelands : Selected Papers from the International Rice Research Conference. IRRI, Manila. 83-97.

Phaowphaisal, I., Suzuki, T., Indramanee, S. and Oshio, S. 2005. Cattle feeding is now popular in village. In M. Oda, O. Ito and J.S. Caldwell eds., Increasing Economic Options in Rainfed Agriculture in Indochina through Efficient Use of Water Resources. JIRCAS, Khon Kaen, Thailand. 54-66.

Roder, W. and Maniphone, S. 1995. Forage legume establishment in rice slash-and-burn systems, Trop. Grassl. 29 : 81-87.

Saito, K., Linquist, B., Keobualapha, B., Phanthaboon, K., Shiraiwa, T. and Horie, T. 2006. *Stylosanthes guianensis* as a short-term fallow crop for improving upland rice productivity in northern Laos. Field Crops Res. 96 : 438-447.

Simaraks, S., Subhadhira, S. and Srila, S. 2003. The shifting role of large livestock in Northeast Thailand. Southeast As. Stud. 41 : 316-329.

Supapoj, N., Naklang, K. and Konboon, Y. 1998. Using organic material to improve soil productivity in rainfed lowland rice in Northeast Thailand. In J.K. Ladha, L.J. Wade, A. Dobermann, W. Reichardt, G.J.D. Kirk and C. Piggin eds., Rainfed Lowland Rice : Advances in Nutrient Management Research. IRRI, Manila. 161-168.

Suzuki, T., Phaophaisal, I., Kawashima, T., Pholsen, P., Narmsilee, R., Indramanee, S. and Oshio, S. 2006. Nutritional status of cattle on dairy farms and in mixed agriculture farms raising beef cattle. In O. Ito, J.S. Caldwell, M. Oda, Y. Yamamoto, H. Hamada and T. Nishida eds. Increasing Economic Options in Rainfed Agriculture in Indochina through Efficient Use of Water Resources. JIRCAS Working Report No. 47. JIRCAS, Ibaraki. 121-123.

Walkeley, A. 1947. A critical examination of a rapid method for determination of organic carbon in soils : Effect of variation in digestion conditions and of inorganic soil constituents. Soil Sci. 63 : 251-257.

Watatsu, E. 2002. Improvement of soil fertility and productivity by introduction of green manure crops to rainfed rice fields in Northeast Thailand. MS thesis, Kyoto University, Kyoto. 1-21.

Whitbread, A., Blair, G., Naklang, K., Lefroy, R., Wonprasaid, S., Konboon, Y. and Suriya-arunroj, D. 1999. The management of rice straw, fertilises and leaf litters in rice cropping systems in Northeast Thailand. 2. Rice yields and nutrient balances. Plant Soil 209 : 29-36.

Willet, I.R. 1995. Role of organic matter in controlling chemical properties and fertility of sandy soils used for lowland rice in Northeast Thailand. In R.D.B. Lefroy, G.J. Blair and E.T. Craswell eds., Soil Organic Matter Management for Sustainable Agriculture. ACIAR Proceedings, No. 56. ACIAR, Canberra. 109-114.