Potential for Zero-Tillage Technique in Rice and Other Field Crop Cultivation in Rice-Based Cropping Systems in the Dry and Intermediate Zones of Sri Lanka

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Abstract

The high production cost and scarcity of water for crop cultivation are some of the major problems faced by farmers in many rice-based cropping systems in the country. In many crop production systems, around 15-20 % of the total cost of production accounts for tillage/land preparation, such activities also consume around 15 % of the total water requirement. Hence, it is important to adopt technologies that would save water and reduce the cost of cultivation without sacrificing the yield. This paper discusses the adoption of zero-tillage crop establishments in rice and other field crop cultivation in paddy fields in the dry and intermediate zones. Zero-tillage conditions were created by applying the total weed killer, 'Glyphosate' after the fields were drained and subsequently establishing crops without tillage.

Results of six seasons on rice cultivation show that the rice crop could be established under zero-tillage conditions (without tillage) without significantly affecting the yield. This practice helps to cut down the total cost of cultivation by around 15 %, and save water at least for a period of 1-2 weeks, and shorten considerably, the time taken for land preparation. Similarly, many crops such as green gram, cowpea, black gram and maize could be cultivated under zero-tillage conditions. Experiences show that zero-tillage technology has many advantages over conventional tillage. Hence, more attention needs to be given to develop the appropriate machinery to suit zero-tillage conditions and at the same time, to fine-tune technologies to suit the different cropping systems as well.

Introduction

Tillage is one of the most important field operations in the production of rice and other field crops. The primary objective of tillage is to control the weeds and have a good 'seed bed' for the establishmenmt of a better crop. In addition, it helps to reduce soil compaction. Zero-tillage or no-till farming systems have been developed and applied around the world over several decades. The benefits of zero-tillage in economic, production and the environmental aspects of farming have been recognized. The high cost of production is one of the major constraints in the cultivation of rice and the production of other field crops (OFC) in Sri Lanka. Tillage and other field preparations required to prepare the fields for planting various types of irrigated OFC and rice cultivation, account for around 20 % of the total cost on average (DOA 2008). Therefore, finding ways and means to cut down the tillage cost is important to further reduce the cost of production. In addition to the cost factor, farmers also face other problems in preparing the land, such as the difficulty of finding tractors on time, labor scarcity during the land preparation and establishment period and inadequate time for land preparation. The inadequacy of tractors for land preparation has particularly, resulted in delays in rice crop cultivation in Sri Lanka (Tilakaratne and Tilakeratne 2003).

Crop establishment with zero-tillage is used widely for many crops around the world. It has the potential to save time, energy, water and labor during crop establishment (Piggin et al. 2001). However, little research has been conducted on zero-tillage establishments in rice cultivation (Hood 1961; Boevema 1965; Castin and Moody 1985; Smith 1992; Diop and Moody 1989). Russell and Keen (1941) concluded that the primary function of ploughing is to control weeds, because the omission of ploughing in a weed-free situation did not result in any reductions in the yield. In Sri Lanka, attempts have been made to explore the potential for adopting the zero-tillage technique in rice and other crop cultivation (Abeyratne 1956; Fernando 1981; Jayawardena et al. 2006). However, no priority has been given to this area of research due to various reasons. Research on this issue is important to Sri Lanka now more than ever before, given that lack of labor, the high cost of tractors for tillage and water shortages are known as major constraints in rice and OFC cultivation. This paper reports the results of the experiments conducted during 1995-2008 at the Field Crops Research and Development Institute (FCRDI) and the Rice Research and Development Institute (RRDI), relating to zero-tillage cultivation in other field crop (OFC) and rice.

Zero-tillage Rice Cultivation

Field experiments using the two methods of land preparation, those being conventional tillage and zero-tillage, were carried out in a replicated trial for six seasons from *yala* 2006 to *maha* 2008, in imperfectly drained soils at the Rice Research and Development Institute, Batalagoda, Ibbagamuwa, in the IL1a agro-climatic zone of the low country intermediate zone of Sri Lanka. Initial weed and rice stubble and voluntary seedlings counts in the plots were recorded before the tillage operation using two random 1.0m x 1.0m quadrants per plot and their relative abundance was calculated as a percentage. Soil at the study site was sandy clay loam, with pH 4.9, EC 27.6 (ms/cm) with nutrient contents of, 23.50 mg/kg of K, and 4.50 mg/kg (olsen) of P. The organic matter content was 2.87 % and the bulk density was 1.4 mg m-^{3}. Conventional tillage plots were prepared by ploughing to a depth of 15-20 cm using a mold board plough, followed by harrowing and leveling before crop establishment. Zero-tillage plots were sprayed with Glyphoshate (N-[phosphonomethyl] glycine) at the rate of 4 liters ha-1 3 weeks before the crop establishment. Five to seven days after the spraying and after the weeds turned in to yellow, the field plots were inundated for about one week. Before the crop establishment, rice stubbles and the dead weeds debris in zero-tillage plots were flattened to the ground by pulling a banana log over the field after the field was drained. Pre-germinated seeds of Bg 403 (4-month age) were broadcasted at the rate of 100 kg/ha. Fertilizer was applied at the rate of 150 kg ha-1 of N, 75 kg ha-1 of P2O5, 40 kg ha-1of K2O and 5 kg ha-1 of Zn. Nitrogen fertilizer was split-applied at 0, 2, 5 and 8 weeks after crop establishment at the rate of 5, 25, 30 and 30 kg ha-1, respectively. Phosphorous fertilizer was applied in a single application during the crop establishment, while K was applied at two equal splits at 0 and 8 weeks after the crop establishment. Post emergence weedicide, Nomine (Bispyribac sodium) was sprayed at the rate of 250ml ha-1 week after the establishment of the crop to control weeds. Rice crop establishment counts at 3 WAE (weeks after establishment) were taken using in two random quadrants (0.5m x 0.5m) per plot. Weed biomass was recorded at panicle initiation (PI) stage. Biomass production, yield and yield components were recorded at the harvest. Grain yield was determined from a sample area of 20 m^2 per plot. Yield components were determined from 10 hills selected at random per plot. SAS package was used to analyze the data. Partial budgeting was used to compare the economic advantage of the system.

Crop Establishment

In all six seasons the crop establishment in zero-tillage was comparatively lower than that of conventional tillage plots. The average numbers of seedlings were 321 and 297 m^{-2}, respectively, for conventional and zero-tillage plots. Retaining broadcasted rice seeds on rice stubbles and weed debris without touching the field is the major reason for low establishment in zero-tillage plots. Increasing the seed rate could be the solution for this problem (Table 1).

Table 1. Effect of method of land preparation on the rice crop establishment, grain yield and weed dry weight at RRDI.

Season	Rice crop establishment seedlings m-2 at 3 WAS		Grain Yield t ha-1		Weed dry weight (gm-2) at 5 WAE	
	Conventional tillage	Zero-tillage	Conventional tillage	Zero-tillage	Conventional tillage	Zero-tillage
Yala 2006	310 a	278 b	5.27 a	4.94 b	50.4 a	34.4 b
Maha 2006/07	314 a	276 b	5.46 a	5.15 b	53.6 a	41.6 b
Yala 2007	356 a	333 a	4.43 b	5.30 a	33.6 b	46.0 a
Maha 2007/08	338 b	311 a	5.38 a	5.51 a	41.2 a	48.4 a
Yala 2008	298 a	264 b	4.99 a	4.62 a	39.2 b	59.6 a
Maha 2008/09	311 a	298 a	4.87 a	4.34 b	48.4 b	69.2 a
Mean	321	297	5.06	4.97	44.4	49.8

Source: Batalagoda (2006-2008)

Weed Dry Weight and Composition

Murdannia nudiflora, Cyperus iria, Ludwigia octavalvis, Echinachloa spp.and Isachne globosa were identified as weeds that were in abundance at the beginning. However, in the latter stages of crop growth this composition has changed. The populations of Murdannia nudiflora Isachne globosa, Leftocloa chinensis and Echinochloa colona have increased gradually over time. Piggin et al. (2001) found that it is difficult to control Murdannia nudiflora and Isachne globosa in zero-tillage plots completely with' Glyphosate, Echinochloa colona and Ludwigia octavalvis in wet-seeded paddy and Fimbristylis dichotma in zero-tillage plots. The dry weight of weed in different seasons varied a lot in the two treatments. Perhaps this could be due to the weather conditions and the variation in the management conditions prevailing at the time. Weed dry weight in zero-tillage plots was significantly lower in the first two seasons and thereafter, showed an increasing trend. This is mainly due to the increase in the population of Murdannia nudiflora, Leftocloa chinensis, and Ludwigia octavalvis in the last few seasons (Table 1).

Effects on Grain Yield

Rice yield ranged from 4.34- 5.51 t ha-1 and varied across the seasons. The results were not consistent over the seasons. This inconsistency could be due to the seasonal variation in weather conditions. The overall yield difference between conventional tillage and zero-tillage plots was (0.09 t ha-1) more or less similar. Out of the six seasons that were tested, three seasons (*yala* 2006 and *maha* 2006/07 and *maha* 2008/09) have produced a comparable yield to that of conventional tillage plots. Poor crop establishment due to heavy rains prevailing at the establishment time in *yala* 2006 and *maha* 2007/07 seasons, was the major reason for the low yield (Table 1).

Water Saving

Water requirement for a 3.5 month rice crop is around 1,300 mm and, of which, 300 mm (23 %) accounts for land preparation (IRRI 2005). In the conventional cultivation system, the paddy field is irrigated for about 3 weeks before the establishment of the crop, where at least six irrigations are needed be given. However, in zero-tillage practice the field is inundated only for one week and only two irrigations are required. Hence, at least four irrigations or 60 % of the water required for land preparation could be saved.

Economic Advantages

A partial budget was performed to compare the economic advantages of the systems. The total cost of tillage (first, second ploughing and the final leveling) with a tractor was Rs.10,600 ha-1 while it was only Rs. 4,125 ha-1 for zero-tillage (Table 2). The yield obtained under zero-tillage and conventional tillage was more or less the same. However, net benefit has been increased in zero-tillage plots by Rs.695 ha-1 due to the omitting of the tillage operation. In this calculation, labor cost for pre-weedicide spraying, weedicide cost and labor cost for irrigation until broadcasting has not been accounted. If accounted, the benefit would be much higher than the Rs.695 ha-1. Other than the economic benefits, zero-tillage requires less labor units for the cultivation of a unit of land and also helps to cut down the water requirement for land preparation. Michel et al. (2001) reported that other than the economic advantage, zero-tillage helps to minimize the delivery of soils, nutrients and pesticide pollutants from place to place.

These results suggest that it is possible to establish a good rice crop and obtain a satisfactory yield in a lowland paddy field under zero-tillage conditions. Initial weeds in the zero-tillage plots should be killed and controlled completely and the field should be drained completely before the application of Glyposhate'. The rice crop should be broadcasted as soon as the weeds are killed to avoid germination of weed seeds before the establishment of the crop.

Table 2. Partial budget per hectare for the conventional and zero-tillage establishment methods (1997-2008).

Descriptions	Method of land preparation	
	Conventional tillage	Zero-tillage
Variable cost		
Cost of ploughing (first and second ploughing+leveling) at	10,600	
Rs. 10,600		
ha-1		
Cost of Glyphosate for 4 l h at Rs. 900/liter		3,100
Application cost for Glyphosate 1 man-day at Rs. 525/day		525
Total variable cost	10,600	4,125
Income		
Average yield (t ha-1)	5.06	4.93
Gross benefit(at Rs. 30/kg)	151,880	146,100
Net benefit	141,280	141,975
Net benefit from zero-tillage	695	

Other Field Crop Cultivation under Zero-tillage Conditions

The low economic return due to the high cost of production is one of the constraints to increasing production in rice and many other field crops. Therefore, it is important to introduce technology to lower the cost of production. As an average, around 15-20 % of the total cost of cultivation in other field crops accounts for land preparation, weeding and irrigation.

Effect of Tillage and Mulching on the Growth and Yield of Chilies and Weed

Results from this experiment can be compared with the results from experiments conducted at the Field Crops Research and Development Institute (FCRDI) and by Maha Illuppallama during the late 1990s. The latter mentioned experiments were conducted using field crops other than rice usually referred to as OFCs. Results of an experiment conducted by the principal author of this paper in 1997 to evaluate the effect of tillage methods and mulching on the growth and yield performances of chilli grown in paddy fields (after the *maha* rice harvest) under irrigated conditions, is informative. Four treatments including a combination of mulching (rice straw at 8 t ha-1 on dry basis applied immediately after transplanting of chilli) and ploughing as: a) ploughing with mulching; b) ploughing only; c) no ploughing with mulch; and d) no ploughing and no mulching, were tested in a replicated trial. Soils of the ploughing plots were turned up to 20 cm with a mammoty. Four-week old seedlings of chili (cv. MI-2) were transplanted at 60 x 45 cm spacing with two plants per hill. The recommended dosage of fertilizer was applied. Mammoty-weeedng was done at each weeding and the dry weight of weeds was recorded. Soil moisture at 5, 15 and 30 cm depth was determined gravimetrically. Plant height and canopy cover for five plants selected randomly, were recorded at regular intervals. The harvest yield components for 10 randomly selected plants were recorded. The yield also was recorded separately.

The study revealed that the pod number, 100 pod weight of chilli, dry weights of chilli, and weeds, plant height and final plant stand were not affected significantly by ploughing. Also, 5 days after irrigation the total soil moisture and total root length density were not affected significantly. This shows that chilli could be established in paddy fields after the rice crop without ploughing, thereby eliminating the cost of ploughing. In contrast, mulching had a significant effect on yield components and the dry chilli yield except for 100 pod weight, plant height and final plant stand at harvest. The highest dry chilli yield (1,478 kgha-1) and the highest pod number per plant were recorded from the treatment with ploughing and mulching. The increases in yield and pod number were 13 % and 17 %, respectively, over the conventional ploughing treatment. The lowest weed dry weight (124 gm-2) was observed from the same treatment (Table 3).

Table 3. Yield, yield component of chilli and weed dry weight as affected by tillage and mulching at FCRDI, Maha Illuppallama - *yala* 1997.

Treatment	Pods plant-1	100 pod weight (g)	Dry chill yield Kg ha-1	Weed dry weight g m-1	Plant height at harvest (cm)	Plant stand at harvest (cm)
Ploughing						
+tillage	52	200	1,303	170	29.4	20
-tillage	50	194	1,238	193	27.6	21
LSD (0.05)	4.4	21.8	336.8	63.6	1.7	1.2
Mulch						
+mulch	61	208	1,478	124	30.6	20
-mulch	41	186	1,064	239	25.6	21
LSD (0.05)	8.3	28.4	225.9	42.3	2.1	1.3

Source: Annual reports—FCRDI, Maha Illuppallama

Sandwich Crop Cultivation After *Maha* Rice Crop

Due to the high cost of production and comparatively low returns, farmers are not interested in cultivating legumes in paddy fields under irrigation during the *yala* season. Instead, they prefer to cultivate high-value crops in paddy fields. Therefore, two simple and cost-effective crop establishment techniques were introduced i.e., black gram and green gram, two of the most commonly grown legumes in the country. In the first system, legume seeds are broadcasted into the standing rice crop about 5-7 days before harvesting the rice crop. Here, land preparation or weeding is not practiced. However, in case there is a possibility of poor growth of crops, a few kilograms of urea is applied while broadcasting the seeds. In the second system, seeds of legumes are row-planted using a mammoty or wooden stick on the rice stubble immediately after the *maha* rice is harvested. These zero-tillage applications require adequate levels of soil moisture to facilitate the germination of seeds. Immediately after seeding, Paraguat or Glyphosate is sprayed to kill the existing weed flora. Ploughing is not necessary, while weeding is done whenever necessary. Crops can be irrigated if water is available, otherwise the crop growth is dependent on incidental rains and residual soil moisture. In these systems the land perpetration could be omitted and the considerable amount of money spent on labor for planting could also be saved. Results show that around 300-500 kg of seed yield could be obtained with little inputs (Table 4).

Table 4. Effect of establishment methods on the yield of legumes 1985-1999 at FCRDI, Maha Illuppallama.

Year	Crop	Yield kg ha-1		
		Broadcasted into standing rice crop	Row-planted under conventional tillage	Row-planted under zero-tillage conditions
1985	Black gram	354	551	432
	Green gram	400	521	661
1997	Green gram	520	835	854
1999	Green gram	305	489	503
Mean legume yield		394	599	612

Source: Annual Reports, FCRDI, Maha Illuppallama

The cost and return analysis showed that any of the methods of crop establishment could be adopted to cultivate legumes in paddy fields. As far as income is concerned, among the three methods, row-planting under zero-tillage conditions and row-planting under the conventional tillage system have performed equally in comparison to each other, and better than the income generated when broadcasting seeds into standing rice crop. However, as far as the concern of curtailing the cost of cultivation, broadcasting seeds into standing rice crop is also a good method (Table 5).

Table 5. Estimated cost and returns (Rs. ha-1) of legumes under different establishment methods.

Operation	Broadcasted into standing rice crop	Row-planted under conventional tillage	Row-planted under zero-tillage conditions
Seeds	2,700	2,250	2,250
Land preparation	-	5,477	-
Weeding/weedcide	-	6,623	6,233
Insecticide	3,045	3,045	3,045
Harvesting and processing	6,480	6,480	6,480
Total cost	12,225	23,875	18,008
Yield	394	599	612
Gross return	29,250	46,722	47,736
Income	17,025	22,847	30,728

Source: Annual Reports, FCRDI, Mahailluppallama

Effect of Weed Management and Nitrogen Fertilizer Application on the Weed Growth and Yield of Green Gram Grown under Zero-tillage Conditions in Fallow Paddy Lands

Around 50 % of the paddy lands (0.3 million ha) of the country are not cultivated during the *yala* season due to the inadequacy of water. It has been found recently that the there is a possibility of cultivating green gram under zero-tillage conditions successfully in these uncultivated paddy lands, utilizing the limited *yala* rains. However, weeds are a major problem in green gram cultivation. This study was conducted to find cost-effective weed control methods and to determine whether nitrogen fertilizer application is necessary for green gram grown in these lands. In this study, the effect of five weed control treatments — 1) Paraguat only (4l ha-1 at sowing; 2) Paraguat (4l ha-1) followed by Alachlor (2.5l ha-1); 3) mammoty weeding at 3 weeks after seeding (WAS); 4) mammoty weeding at 3 and 5 WAS; and 5) no weeding and two nitrogen levels (0 and 30 N kg ha-1) were tested on the yield of green gram grown in these lands.

The major weeds at the establishment were rice ratoon, rice seedlings and many spices of grass, sedges and broad leaves. The degree of control ranged from 63-76 % over the control of weeds. The effects of different weed control methods on broad leaves were similar. All weeding treatments have controlled grass weeds significantly (Table 6). However, a higher degree of control was observed from both treatments of Paraguat (>70%) over the mammoty weeding treatment (>40%). Both mammoty weeding treatments have effectively controlled the grass (>53%) over both weedicide treatments (>36%). There was no significant effect from the application of Lasso in controlling weeds. Mammoty weeding at 2 and 5 WAS gave the highest yields of 677 kg ha-1, which is an increase compared to the 73-82 % increase of the other three treatments (Table 7). The application of nitrogen fertilizer increased the yield of green gram significantly and no interaction was observed between weeding methods and fertilizer levels. The overall yield that was increased due to nitrogen fertilizer application was 24 %.

Table 6. Effect of different weed control methods on weeds, rice stubbles and rice seedlings at 4 WAS of green gram grown in fallow paddy lands, at FCRDI, Maha Illuppallama, during *yala* 1998.

Treatment	Weed count/m^2					
	Broad leaves	Grass	Sedges	Rice seedlings	Rice ratoon	Total weeds
Paraguat only	61	21	120	22	187	431
Paraquat followed by Lasso	45	18	132	23	169	377
Mammoty weeding (2 WAS [a])	65	35	94	32	68	294
Mammoty weeding (2 and 5 WAS)	53	38	89	35	67	122
Control (No weeding)	115	62	190	93	192	652
LSD (0.05%)	27.8	12.1	34.9	20.2	24.4	102
CV (%)	26.3	23.3	18.5	31.9	11.6	18.7

Note: [a] WAS refers to weeks after sowing

Table 7. Effect of different weed control methods and nitrogen fertilizer application on the yield of green gram grown under zero-tillage conditions in fallow paddy lands, at FCRDI, Mahailluppallama, during *yala* 1998.

Treatment	Yield (Kg ha -1)
Weeding Methods	
Paraguat only	483
Paraguat fb Lasso	463
Mammoty weeding (2 WAS [a])	459
Mammoty weeding (2 and 5 WAS[a])	677
Control (no weeding)	266
LSD (0.05)	78.8
CV (%)	11.2
Nitrogen levels (Kg ha-1)	
0 N Kg ha-1	419
30 N Kg ha-1	520
LSD (0.05)	
CV (%)	11.2

Note: [a] WAS refers to weeks after sowing

It can be concluded from the results that any of the weed control methods used in these experiments can be adopted to control weeds in green gram grown under zero-tillage conditions in fallow paddy lands. Considering the investment, time, possibility of soil moisture stress due to weeding and risk factors, it is appropriate to control weeds by Paraguat application alone. Application of nitrogen fertilizer at the rate of 30 kg ha-1 is economical.

Conclusions

These results suggest that the potential to establish rice and other field crops to obtain a satisfactory yield and income is there. The zero-tillage technique would help to lower the labor requirement and water requirement for land preparation while saving the time taken for land preparation. There are many aspects, such as development of suitable seeders, better pre-weed control methods, fertilizer and crop management, long-term impact on environment etc., that need to be adopted to support the zero-tillage technique.

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