

**INTEGRATED WEED MANAGEMENT FOR PREVENTION  
OF THE EVOLUTION AND SPREAD OF HERBICIDE  
RESISTANT WEEDS IN SRI LANKA**

Projektförderung  
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**FINAL REPORT**  
**TO**  
**THE EISELEN FOUNDATION, ULM, GERMANY**

**A JOINT PROJECT OF**  
**THE UNIVERSITY OF PERADENIYA, SRI LANKA**  
**THE UNIVERSITY OF HOHENHEIM, GERMANY**  
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# **1. INTRODUCTION**

## **1.1 Weed and weed management in Asian rice systems**

Weed control is a significant challenge to rice farmers, especially in the developing world. This is due to the adverse impacts that weeds have in reducing yields and quality of rice, in situations where smallholders strive to increase yields on progressively limiting land. The weeds are also considered the most important biological factor limiting yields in Asian rice production enterprises. The losses of yields range from 30% to 75%; depending on the culture, cropping season, spacing, fertilization, ecological and climatic conditions and duration, time and amount of weed infestation.

The replacement of traditional tall varieties of rice with the semi and dwarf varieties in the 1970's with the onset of the green revolution has led to the increased growth of weeds, especially annual grasses. These compete directly with weeds and reduce yields to greater extents than the sedges and broadleaved species. The changes from transplanting to broadcasting systems adopted for planting has also aggravated the problem further, as germination of direct seeded rice requires non flooded conditions, which are also conducive for weed germination. The morphological similarities between rice and weeds at early growth stages make it difficult for farmers to differentiate one from the other, and hence the infestation of weeds increases, resulting in crop losses. The increased use of fertilizers through the green revolution has also enhanced weed infestation and studies do report the increased competitiveness of weeds than rice when grown with fertilizers. Thus, weed management is a critical factor in rice culture of Asia and also Sri Lanka, as all projects on pest management, including integrated systems and biotechnology have concentrated on insects and diseases rather than on weeds. Traditionally, weeding in Asian rice has been carried out by manual labor, where large supplies of rural unskilled workers made labor intensive methods profitable for farmers. However, economic growth in the last few decades in most nations caused a shift in labor, and manual weeding became a very expensive mechanism of weed management. Hence most rice farming systems in Asia are now using herbicides, especially in intensive culture, for weed management.

## **1.2 Weeds in rice systems of Sri Lanka.**

In Sri Lanka, rice is the most important food crop, occupying approximately 770,000 ha in 21 of the 24 agro ecological zones of the nation. The crop is cultivated in two seasons of the year, the major rainfed season (Maha) corresponding to the Northeast monsoon (October – February) occupying some 550,000 ha and the minor rainfed/irrigated season (Yala) corresponding to the Southwest monsoon (Late April – August) when some 300,000 ha are cultivated.

Weeds are a major problem in rice culture in Sri Lanka, and if not managed, could account for over 80% yield reductions. In addition, weeds reduce crop quality, interfere with harvesting and could

harbor insect pests and disease causing organisms. The costs of weed control, including land preparation, water management, herbicides and family labor, along with the impact of phytotoxic effects could cause a heavy burden on the smallholder rice farming families.

The weed flora of rice varies from location to location, on the basis of rice culture, soil type, hydrology, tillage and cultural practices. However, the Food and Agriculture Organization of the United Nations, have identified 10 important weeds in rice culture of Asia, namely *Echinochloa crus-galli*, *Cynodon dactylon*, *Digitaria spp*, *Cyperus spp*; *Fimbristylis miliacea*, *Eclipta alba*, *Sagittaria spp*, *Scirpus spp*, *Monochoria vaginalis* and *Masilea quadrifolia* . In Sri Lanka, the Department of Agriculture states that grasses are dominant in irrigated systems found principally in the dry and intermediate zones of Sri Lanka, while sedges are predominant in the rainfed systems in the wet zone. Furthermore, weeds are a very serious problem in the irrigated rice fields, which are generally found in the major rice growing regions of the country. This is attributed to the rotational methods of water use, which cause alternating dry and wet regimes, and could favor the germination and survival of weeds. There are approximately 135 spp of weeds in rice fields of Sri Lanka, belonging to 32 taxonomic families. Of these, over 70 spp are grasses, 50 spp are sedges and 20 are broadleaved spp. However, 23 spp are considered economically important in rice culture of Sri Lanka and grasses are identified as the major category of weeds in rice fields.

Table 1. Major weeds in rice fields of Sri Lanka.

Grasses	Sedges	Broadleaves	Ferns
Echinochloa colonum	Cyperus aria	Commelina diffusa	Marsilea quadrifolia
Echinochloa crus-galli	Cyperus difformis	Eclipta alba	Salvinia molesta
Panicum repens	Cyperus rotundus	Eichornia crassipes	
Ischaemum rugosum	Fimbristylis miliacea Fimbristylis dichotoma	Monochoria vaginalis	
Isachne globosa	Lindernia spp. Scirpus supinus	Murdannia nudiflora Sphenoclea zeylanica	
Paspalum distichum		Ludwigia perennis Haeranthus africanus	

Of the above, *E. crus-galli* is considered the most important weed, which is identified to be resistant to Propanil, while *Ischaemum rugosum* and *Leptochloa chinensis*, although not listed above are becoming important weeds due to continued application of herbicides.

### **1.3 Herbicide use in rice culture of Sri Lanka**

Herbicides account for over 60% of all pesticides used in Sri Lanka. Of this quantum the highest use is in rice culture, especially farmers in the dry regions, which is the major rice producing area of the island, both under rainfed and irrigated systems.

There are many different categories of herbicides sold in Sri Lanka. In rice culture, the herbicides are categorized as total herbicides and those used for grasses and for sedges and broadleaved species, and there are over 25 different products registered as effective herbicides for rice in Sri Lanka.

### **1.4 Herbicide resistance in rice.**

Herbicide use in Sri Lanka is increasing due to the increasing incidence of weeds, the availability of chemicals and marketing strategies. It is widely used in rice both under rainfed and irrigated conditions. With increasing use of herbicides, the existence of resistance has been identified in selected populations of *Echinochloa crus-galli* to Propanil in 1997. Hence the recommended method to overcome the presence of this weed is to use mixtures of Propanil and Organophosphate herbicides.

In the recent past, due to widespread use of herbicides in rice, other species have been identified as persistent weeds in rice fields, especially in the principal rice growing regions. Hence the presence of resistance in these species warrants investigation.

### **1.5 The Eiselen Project**

The problem of weeds in Sri Lankan agriculture has been addressed by many researchers at different times. The problem was identified and some remedial measures developed. However, in 1992, Dr Sangakkara developed a project on weeds in food legumes, in conjunction with the University of Gent, in Belgium. Funds for this project was obtained from the Overseas Development Aid program of the Belgian Government, and research and training was carried out both in Sri Lanka and Belgium, where one doctoral student and one Masters student completed their degrees, equipment purchased and training for technical staff provided. In 1996, at the Plant Protection Conference in Gent, Dr Sangakkara met Professor Dr B Rubin of the Hebrew University of Jerusalem, Rehovot, Israel, and discussed possibilities of collaborating in research on herbicides and herbicide resistant weeds. It was at this time that the first report on herbicide resistance was published in Sri Lanka, where *Echinochloa crus-galli* was reported to be resistant to propanil. This attracted the attention of Professor Rubin and Dr Sangakkara, who discussed possibilities of furthering this aspect which was a current theme of research and also of national importance, especially to the resource poor rice farmers.

Professor Dr Rubin held discussions with Professor Dr K Hurle, of the University of Hohenheim, Stuttgart, Germany, who in turn developed a proposal for submission to the Eiselen Foundation in

Ulm. The Eiselen Foundation kindly granted the sum of D Marks 100,000 in late 1998 to undertake a project on Weeds, Herbicide use and herbicide Resistance in food crops of Sri Lanka, emphasizing that the outcome must benefit the farming community of Sri Lanka.

The specific title provided was **INTEGRATED WEED MANAGEMENT FOR PREVENTION OF THE EVOLUTION AND SPREAD OF HERBICIDE RESISTANT WEEDS IN SRI LANKA**

The project, which was initiated in 1999, paid emphasis to the most important food crop in Sri Lanka, rice and possibly other crops, and had the broad mandate to identify prominent weeds in rice, herbicide use patterns by rice farmers and ascertain the possible existence of herbicide resistance. It was also anticipated to develop a brochure that could be used for training farmers on weed management in rice culture, a feature emphasized by the Eiselen Foundation.

### **1.6 Objectives**

The overall objectives of the project were mandate to identify prominent weeds in rice, herbicide use patterns by rice farmers and ascertain the possible existence of herbicide resistance. It was also anticipated to develop a brochure that could be used for training farmers on weed management in rice.

The specific objectives of the project were as follows:

- a. Document herbicide use patterns in the rice fields and their weeds in selected major rice growing regions of Sri Lanka during the major and minor seasons (Wet and Dry) that correspond to the Northeast and Southwest monsoons**
- b. Evaluate the weeds in selected highland crops and herbicide use patterns**
- c. Identify prominent weed species in rice farming systems**
- d. Ascertain the possible existence of resistance in the most prominent weeds to the most common herbicides used in rice culture**
- e. Train staff at the University of Peradeniya on identifying herbicide resistance in weeds**
- f. Develop a brochure for use in extension work for the farming community on weed management in rice**
- g. Publish research on the study for the scientific community**

An additional objective of determining weed seed banks in selected rice fields was also added to the project in 2001.

## **2. THE PROGRAM OF STUDY**

The program of research study undertaken by the project had three major components. These were as follows:

- A: Identify herbicide use patterns and prominent weeds in rice culture of Sri Lanka using selected locations**
- B: Evaluate weeds and herbicide use in selected crops (Sugar cane and carrots)**
- C: Study the possible existence of herbicide resistance in the most prominent weeds to the common herbicides used**
- D: Determine weed seed banks in rice soils, using selected locations**

## **2.1 Herbicide use patterns in selected rice growing regions of Sri Lanka**

### **2.1.1 Background**

Herbicide use is fast becoming a common phenomenon in rice fields of Sri Lanka. Due to the lack of sufficient labor and the rising costs of manual weeding. However, the herbicide use patterns in Sri Lanka, especially in the major rice producing regions have not been well documented, although herbicide resistance has been reported, which arises due to the haphazard use of these chemicals. Hence, as the first step in the development of an integrated management program on weeds in the documentation of herbicide user by farmers and also the weed populations, this project began with a survey. The objective of the survey was to ascertain herbicide use patterns, the popular herbicides applied for rice, identify weed populations and the most prominent species in the rice fields of major rice growing regions of Sri Lanka.

### **2.1.2 Methodology**

The first survey of this project was undertaken in May, 1999, corresponding to the minor (Yala) season, using two sites in the dry zone of Sri Lanka, where rice is extensively grown. The sites were Rajangana in Kurunegala, Pulathisigama in Polonnaruwa.

The survey was planned to identify herbicide use patterns and also weeds in rice. Thus the services of the offices of the Department of Agrarian Services in the two regions were utilized to locate farmers cultivating rice continuously for over 5 years.

In this season, 40 farmers in Kurunegala and 50 farmers in Polonnaruwa were surveyed, using a structured questionnaire.

In the next season in October, 1999, the survey was repeated in the two locations to correspond to the wet season, and another location in the wet zone (Uduwela) was identified. In this location, 40 farmers were surveyed using the same questionnaire.

The final survey was carried out at the location of the wet zone in April, 2000. The questions that arose in relation to the survey were verified in the seasons of 2001.

The weed populations in all fields were also determined using 1 m x 1 m quadrates and the most prominent weeds identified.

### 2.1.3 Results

In all locations, there were farmers not using herbicides (Table 1). These farmers either could not afford the costs and/or had family members that helped out with manual weeding. A few were concerned about the hazards of using herbicides. Hence weeding in these was carried out either manually or by water management. The location in Kandy in the wet zone had the highest number of non users, especially as the fields and extents were small and hence, weeds could be managed manually.

Table 1. Numbers of rice farmers of each category surveyed in the three regions of Sri Lanka

Region	Farmer Category*			
	NU	SO	O	E
Kurunegala	2	5	6	4
Polonnaruwa	5	5	6	5
Kandy	4	7	4	2

\* NU, SO, O and E refer to Non, Suboptimal, Optimal and Excess users of herbicides, respectively.

The highest numbers of suboptimal users were also in the same location. These smallholders could not afford the purchase of recommended amounts and all were part time farmers who grew rice for consumption, and did not own the land. The suboptimal users in the other regions owned the lands, but could not afford the full compliment of recommended rates. The highest numbers of optimal and excessive users of herbicides were in the dry regions of Sri Lanka (Polonnaruwa), where the extents were large (1.5-2.0 ha) and yields were high, which enabled farmers purchase the herbicides. The farmers using excessive quantities stated the lack of adequate control with recommended rates of herbicides, and hence applied higher rates especially to control grass weeds.

Table. 2: Common herbicides used by different categories of rice farmers in the selected regions of Sri Lanka

	Farmer Category*			
	NU	SO	O	E
Kurunegala	-	3-4 DPA MCPA	Gramoxone 3-4 DPA Facet MCPA Nominee	3-4 DPA MCPA Nominee
Polonnaruwa	-	Gramoxone 3-4 DPA Whipsuper Nominee	Gramoxone Whipsuper Nominee Facet MCPA	3-4 DPA Whipsuper Facet Nominee MCPA
Kandy	-	Gramoxone 3-4 DPA MCPA	3-4 DPA Whipsuper MCPA	Gramoxone 3-4 DPA Whipsuper MCPA

\* NU, SO, O and E refer to Non, Suboptimal, Optimal and Excess users of herbicides, respectively.

Common names of used herbicides:

Gramoxone - Paraquat; 3-4 DPA - Propane; Facet - Quinclorac; Nominee - Bispyribac sodium; Whipsuper - Fenoxaprop-ethyl; MCPA - MCPA 40 EC K salt

The common herbicides used were primarily for grasses and broadleaved species (Table 2), Gramoxone and 3-4 DPA were the most common, followed by Whipsuper. However, a recent introduction to overcome the problems of persistence of *Echinochloa* species, namely Nominee was also a very popular herbicide. The suboptimal users purchased a smaller range of products while other categories utilized a wide range. The rates used by the excessive users were in most instances higher than recommendations of all herbicides.

The numbers of weeds in the wet season were lower in all regions due to the availability of adequate moisture through rainfall (Table 3). However, Polonnaruwa in the dry zone had higher numbers of weeds in both seasons, due to erratic rainfall even in the wet season and the lack of sufficient irrigation water in the dry season. Hence, farmers in this region used a greater range of herbicides (Table 2), and numbers of excessive users were also greater. The differences between weed populations in the fields



of suboptimal and optimal users of herbicides were greater in the dry season, due to the absence of rainfall, which increased the efficacy of the applied herbicides. In the wet season, rainfall reduced the effects of applied herbicides even at optimal levels. Hence, farmers need to apply the herbicides during dry weather even in the wet season to optimize the efficacy of the chemicals.

Table. 3: Weed densities (number of weeds/10m<sup>2</sup>) of rice fields in the wet and dry seasons in the selected regions of Sri Lanka

Region	Season	Farmer Category*			
		NU	SO	O	E
Kurunegala	Wet	91±5.3	34±6.1	32±4.7	18±2.3
	Dry	160±14.9	63±3.8	53±2.0	45±4.1
Polonnaruwa	Wet	115±11.4	56±4.0	44±1.9	25±5.0
	Dry	180±18.6	95±5.1	56±2.8	42±3.5
Kandy	Wet	89±14.9	45±6.8	39±3.7	15±2.6
	Dry	138±21.9	72±9.1	56±3.6	39±2.1

\* NU, SO, O and E refer to Non, Suboptimal, Optimal and Excess users of herbicides, respectively.

The decline in weed density due to different rates of application was greater in the dry season, irrespective of the location. This again is due to the dry weather in this season which increases the efficacy of the herbicides. The most significant decline in weed infestations with herbicides was observed in Polonnaruwa, the driest region studied. The lowest impact was in the wet region (Kandy), which receives a high quantum of rainfall, facilitating rainfed culture, even in the relatively dry season. In the wet season too, the greatest impact was in the dry regions (Polonnaruwa and Kurunegala), while Kandy again recorded the lowest impact of herbicide applications. This could also be a factor that discourages farmers to use pesticides in this region.

Generally, all three locations had a similar diversity of weed species (Table 4). In the two dry regions, grasses and sedges were more prominent than broadleaved species. In contrast, the wet region (Kandy) had similar numbers of grasses and broadleaved species, with the lowest numbers of sedges. As the causal factors for these observations were not determined in this study, further investigations are required for ascertaining the reasons for these variations in diversity of weeds in the three regions.

Table. 4: Common weeds found in rice fields of the selected regions of Sri Lanka

Region	Grasses	Sedges	Broadleaves
Kurunegala	<i>Echinochloa colonum</i> * <i>Echinochloa crus-galli</i> ** <i>Panicum repens</i> <i>Ischaemum rugosum</i> ** <i>Leptochloa chinensis</i>	<i>Cyperus iria</i> * <i>Cyperus rotundus</i>	<i>Commelina diffusa</i> <i>Ludwigia perennis</i> <i>Monochoria vaginalis</i> *
Polonnaruwa	<i>Echinochloa colonum</i> * <i>Echinochloa crus-galli</i> ** <i>Ischaemum rugosum</i> ** <i>Leptochloa chinensis</i>	<i>Cyperus iria</i> * *	<i>Commelina diffusa</i> <i>Monochoria vaginalis</i> * <i>Fimbristylis miliacea</i>
Kandy	<i>Echinochloa colonum</i> * <i>Echinochloa crus-galli</i> * <i>Panicum repens</i> ** <i>Leptochloa chinensis</i>	<i>Cyperus iria</i> * <i>Cyperus rotundus</i> *	<i>Commelina diffusa</i> * <i>Ludwigia perennis</i> * <i>Limncharis flava</i> * <i>Sphenoclea zeylancia</i>

\*Dominant weed species in rice fields in the selected regions of Sri Lanka. The numbers of stars indicate greater prominence of the particular species.

The most common species observed were *E. crus-galli*, *E. colonum* and *I. rugosum* in the dry regions. This could be attributed to the resistance of the *Echinochloa* spp. to 3-4 DPA (Propanil) in Sri Lanka. The significant increase in populations of *I. rugosum*, especially in field applied with Nominee (Bispyribac sodium) to control *Echinochloa* spp. requires further study. *I. rugosum* was however not a prominent weed in the wet region, which had greater populations of *P. repens*. In the highland crops, the most prominent weeds were *Echinochloa colonum*, *Panicum repens*, *Cyperus rotundus*, *Imperata cylindrica* and *Amaranthus* spp.

## **2.2. Herbicide use in selected highland crops**

### **2.2.1 Background**

Sri Lanka grows many highland crops for procuring food and other commodities. These range from perennial species such as tea to exotic temperate vegetables such as carrots. Due to the diversity of species and locations, the project selected two species randomly. These were sugar cane, a very important smallholder crop in the south eastern region of Sri Lanka and carrots in the wet zone. Carrots were selected as it is one of the most popular exotic vegetable crops grown in the country.

## **2.2.2. Methodology**

### **2.2.2.1 Sugarcane**

#### **2.2.2.1.1 Methodology**

The survey was carried out in conjunction with the Sugar Research Institute of Sri Lanka, located at Udawalawe in south eastern Sri Lanka. Over the period May – November, 1999. The survey included 40 farmers, all of whom grow sugar cane on outreach programs for a factory. As all farmers use herbicides, there were no non users and suboptimal users. All were either optimal or excessive users of herbicides.

A structured questionnaire was used again in this survey and several visits were made to obtain information and identify weeds in the fields.

#### **2.2.2.1.2 Results**

The survey identified 33 excessive users of herbicides, and 6 optimal users. The excessive users clearly stated that using recommended rates do not kill the weeds. The most prominent weeds were *Imperata cylindrica* and *Panicum maximum* (grasses) *Cyperus rotundus* (sedge) and *Ageratum conyzoides* and range of *Ipomoea* species with a predominance of *I obscura*, and *Mimosa pudica* (broadleaved species).

The herbicides used were Paraquat, Glyphosate and MCPA. Most farmers also identified the presence of *Imperata cylindrica* and *Ipomoea obscura* even after spraying excessive rates of herbicides.

### **2.2.2.2 Carrots**

#### **2.2.2.2.1 Methodology**

The survey carried out in the central hills of the wet zone of Sri Lanka was located at Hanguranketa. The survey included 25 farmers, all growing carrots on a commercial scale. The season of study was from October 1999 – February 2000.

The structured questionnaire was used again in this survey and several visits were made to obtain information and identify weeds in the fields.

#### **2.2.2.2.2 Results**

The survey identified the four categories of farmers, namely non users, suboptimal, optimal and excessive users. The most common herbicide used was Sencor(metribuzin), due to its extensive use in vegetable culture and all farmers using chemicals applied this product. Only one farmer was an excessive user, while 6 were optimal users, 11 suboptimal and the balance non users. The most prominent weeds were as follows:

Grasses: *E crus-galli*, *Elusine indica*, *I. rugosum*, *I chinensis* and *Panicum repens*

Sedges: *Cyperus rotundus*, *C difformis*

Broadleaved spp: *Commelina*, *Euphorbia heterophylla*, *Limnocharis flava*, *Erigeron* spp.

The study also highlighted that farmers cultivating this crop intensively did not use excessive quantities of herbicides as they were aware of the toxicity and health hazards.

## **2.3 Herbicide resistance in selected weed species**

### **2.3.1 Background**

The survey carried out over many seasons highlighted that the most prominent weeds in the dry regions, where rice is extensively cultivated for production of nearly 70% of the country's requirements were *Echinochloa crus-galli*, *E. colonum* and *Ischaemum rugosum*, while the most common herbicides were Propanil and Nominee. As herbicide resistance in *E crus-galli* to Propanil was already recorded in 1997, this program of experiments envisaged to confirm this while evaluating the existence of herbicide resistance in *E colonum* to Propanil and *I rugosum* to Nominee. The selection of *I rugosum* and Nominee was based on the farmer response that *I rugosum* appeared with the use of Nominee to control *Echinochloa* spp.

### **2.3.2 Methodology**

The survey identified most common weeds especially in the dry region to be *Echinochloa crus-galli*, *E. colonum* and *Ischaemum rugosum*. Seeds of populations of these species were collected from different fields in 2001. The seeds were air dried, and transported to the University of Peradeniya, Sri Lanka, to determine the possible presence of resistance of these grass weeds to the most common herbicides used, Propanil and Nominee (Bis pyribac Sodium). The concentrations used were 0 – 40,000 µg/ml of Propanil, when the recommended rate was 6750 µg/ml, and 0 – 5000 in Nominee, when the recommended rate was 625 µg/ml. Propanil was used for the two *Echinochloa* species while Nominee was used for *I rugosum*.

### **Experiment 1**

Petri dishes (90 mm diameter) were lined with filter paper (90 mm) and soaked with one of the concentrations of Propanil or Nominee. The seeds of the different populations of *E. crus-galli*, *E. colonum* and *I. rugosum* were soaked in distilled water for 24 hours and 30 seeds placed in each Petri dish, covered, and kept under dark conditions at room temperature ( $27.5\text{ }^{\circ}\text{C} \pm 2.4\text{ }^{\circ}\text{C}$ ). The 10

treatments for each population were replicated 10 times. Germination of seeds was determined 14 days after sowing.

## Experiment 2

Based on germination patterns observed in Experiment 1, populations showing a high degree of germination under high concentrations of the herbicide were selected along with two populations which were considered sensitive populations in Experiment 1. From each seed lot of these populations, 10 seeds were soaked in water as in Experiment 1, and planted in black polythene bags (gauge 300, 40 cm diameter and 50 cm high), containing 4 kg of a potting mixture made up of 75 % sand and 25 % top soil, and kept in a plant house (mean temperature,  $29.4^{\circ}\text{C} \pm 2.7^{\circ}\text{C}$ ,  $84\% \text{ RH} \pm 3.7\%$ , 30 % shade and 11-12 h mean day length). The bags were watered daily to provide a conducive environment for germination. All treatments were replicated 6 times. At the three leaf stage, plants were thinned to 5-7 plants per bag and the 10 herbicide concentrations used in Experiment 1 were sprayed uniformly using a pressurized hand held nozzle sprayer. At 21 days after spraying, the numbers of surviving and dead seedlings were counted in each treatment. Thereafter, the potting mixture of bags containing the highest numbers of surviving seedlings was carefully washed, seedlings removed, rinsed and dried at  $80^{\circ}\text{C}$  for 48 h and dry weights of shoots and roots determined.

The ED50 values (the concentration showing 50% response) and resistance ratios ( $\text{ED}_{50}\text{R}/\text{ED}_{50}\text{S}$ ) were calculated.

### 2.3.3 Results

#### A. Experiment 1

##### Seed germination

Germination tests carried out with *E crus-galli* populations in different concentrations of Propanil identified 18 to have high ED50 values and high Resistant ratios (i.e. Over 3.0). In *E colonum*, there were 8 populations with high ED50 values and Resistant ratios when germinated with different concentrations of propanil. There were 14 populations with high ED50 values and resistant ratios in *I rugosum*, when germinated with different concentrations. All of these populations were obtained from the dry zone, where greater amounts of herbicides are used more frequently.

## Experiment 2

### a. Seedling mortality

The dose responses, and the ED50 values of all species differed significantly in terms of seedling mortality. In *E crus-galli*, from the 30 seedling populations tested, 10 (33%) had relatively high ED50

values over the recommended rates of 6750 µg/ml, the recommended rate for this herbicide. (Table 5). The resistance ratios calculated on the basis of the ED50 values of the two populations (G10 and G16) had values ranging from 2.24 to 8.27, and 10 populations had values over 3.0. The highest resistance ratio values were in populations G15, G16, G22, and G31. These populations of *E crus-galli* seem resistant to Propanil based on seedling mortality, confirming earlier reports) of the resistance of this species to Propanil. However further studies will be required to confirm the process and identify causal factors.

Table 5. ED50 values for seedling mortality of selected populations of *Echinochloa crus-galli* and the resistance ratios in relation to two susceptible populations to Propanil

Population	ED50 (µg/ml)	Resistance Ratio
G13	15950 ± 422.2	3.86
G14	22540 ± 220.6	5.45
G15	31250 ± 264.8	7.56
G16	29830 ± 521.6	7.22
G22	34160 ± 169.5	8.27
G24	28220 ± 380.4	6.83
G26	18010 ± 90.5	4.36
G31	31590 ± 504.3	7.64
G35	20110 ± 299.4	4.86
G41	15990 ± 105.4	3.87

The mean ED50 value of the susceptible populations (G10 and G14) was 4130 µg/ml, and the recommended rate of application was 6750 µg/ml.

Table 6. ED50 values for seedling mortality of selected populations of *Echinochloa colonum* and the resistance ratios in relation to susceptible populations to Propanil.

Population	ED50 (µg/ml)	Resistance Ratio
C10	14530 ± 54.9	2.78
C32	18030 ± 104.6	3.45

The mean ED50 value of the susceptible populations (C01 and C15) was 5220 µg/ml, and the recommended rate of application was 6750 µg/ml.

From the populations of *E colonum* tested, for possible resistance to Propanil, only 32 had relatively high ED50 values and resistance ratios (Table 6). In addition, the values obtained were very low in

comparison to those of *E crus-galli*. Hence, the populations of *E colonum* tested do not seem to have resistance to Propanil at this stage.

Table 7. ED50 values for seedling mortality of selected populations of *Ischaemum rugosum* and the resistance ratios in relation to susceptible populations to Nominee

Population	ED50 (µg/ml)	Resistance Ratio
IR 20	2855 ± 86.5	6.51
IR 28	3542 ± 54.9	8.08
IR 31	4265 ± 107.6	9.73
IR 32	4052 ± 59.3	9.25
IR 42	4342 ± 120.7	9.91
IR 45	3655 ± 98.4	8.34
IR 52	3599 ± 40.7	8.21
IR 55	4642 ± 74.9	10.59
IR 59	3484 ± 113.6	7.95

The mean ED50 value of the susceptible populations (IR 01 and IR 02) was 438 µg/ml, and the recommended rate of application was 625 µg/ml

In *I rugosum*, among the 25 populations tested for seedling mortality by Nominee, 9 (36%) had high values of ED50 and also resistance ratios (Table 7). The resistance ratios ranged from 6.51 to 10.59, and 5 populations (IR 28, IR 31, IR32, IR42 and IR%%) had values over 9.0. These suggest the possible existence of resistance in this species to Nominee, as reported in Malaysia (Heap, 2003). The existence in Sri Lanka needs further confirmatory studies.

**b. Plant dry weights**

From the *E. crus-galli* populations selected from germination studies, only 4 had high ED50 and resistant ratios in terms of plant dry weights (Table 8). This suggests the possible existence of resistance of these four populations to Propanil. All of these populations were obtained from Polonnaurwa, where the herbicides are used extensively.

Table 8. ED50 values based on plant dry weights of selected populations of *Echinochloa crus-galli* and the resistance ratios in relation to two susceptible populations to Propanil

Population	ED50 (µg/ml)	Resistance Ratio
G16	12530 ± 125.3	3.97
G22	9560 ± 89.8	3.03

G31	20155 $\pm$ 225.8	6.39
G35	10380 $\pm$ 301.4	3.29

The mean ED50 value of the susceptible populations (G10 and G14) was 3150  $\mu$ g/ml, and the recommended rate of application was 6750  $\mu$ g/ml.

From the populations of *E colonum* tested, for possible resistance to Propanil, none had high ED50 values nor Resistance ratios, in comparison to those of *E crus-galli*. Hence, the populations of *E colonum* tested do not seem to have resistance to Propanil at this stage.

Table 9. ED50 values for seedling mortality of selected populations of *Ischaemum rugosum* and the resistance ratios in relation to susceptible populations to Nominee

Population	ED50 ( $\mu$ g/ml)	Resistance Ratio
IR 28	1655 $\pm$ 30.4	4.18
IR 31	2235 $\pm$ 55.6	5.65
IR 42	1960 $\pm$ 101.4	4.96

The mean ED50 value of the susceptible populations (IR 01 and IR 02) was 395  $\mu$ g/ml, and the recommended rate of application was 625  $\mu$ g/ml

In *I rugosum*, among the populations tested for plant dry weights, by Nominee, 3 had high values of ED50 and also resistance ratios (Table 9). These again suggest the possible existence of resistance in this species to Nominee, as reported in Malaysia (Heap, 2003)., which needs further confirmatory studies.

## **2.4 Seed banks**

### **2.4.1 Background**

A project on the development of integrated management of weeds requires the identification of sources of weeds. While the influx of weed seeds from external sources such as rice seeds can be minimized, the evaluation of the seed bank is of vital importance. Thus this experiment addressed the objective of determining the seed bank in selected rice fields in the dry region of Sri Lanka, where the survey was undertaken.

### **2.4.2 Methodology**

Among the farmer fields with high populations of weeds, soil samples were taken in February 2003. The depths to which the soils were sampled were 0 – 20 cm, 20 – 40 cm, 40 – 60 and 60 – 100 cm,



using a soil auger. From each field, 15 samples at each depth were removed to the University laboratory. The soil was air dried, spread on newspapers and left at ambient conditions ( 25.5 °C, 75%RH and a 11 – 12 hour day length). Water was sprayed daily to avoid desiccation. The germinating species were counted and separated into grasses, sedges and broadleaved species.

### **2.4.3 Results**

Evaluation of seed banks in 10 rice fields (on the basis of germination counts) in the region of study highlighted the presence of large numbers of graminaceous weeds, especially in the top 0 – 20 cm and 20. 40 cm layers of soil. The weed seed numbers declined rapidly after 40 cm soil depth. The numbers of seedlings emerging per square meter were  $12566 \pm 2355$  in the top 20 cm, of which 67% ( $\pm 4.4\%$ ) were grasses. In the 20 – 40 cm layer, the seeds (based on germination) per square meter were  $7545 \pm 314$  of which 51% ( $\pm 5.3\%$ ) were grasses. The numbers declined to  $2501 \pm 198$  per sq meter in the 40 – 60 layer, of which  $34\% \pm 4.6\%$  were grasses. The seeds in the 60 – 100 cm layer were  $1667 \pm 204$ , of which  $27\% \pm 1.7\%$  were grasses. This suggested the existence of a large viable seed bank of grasses in the top layers of the soil which is within the plough pan. These germinate easily when the conditions become favorable, with the lack of standing water in the fields, especially in the dry season, when irrigation water is supplied on a rotational basis, thus making it impossible to have flooded conditions in the critical weed free periods.

### **2.5 Conclusions from the research studies**

The series of studies over the four years presented valuable information that could be utilized by the agricultural sector of Sri Lanka in formulating weed management strategies in rice culture. These can best be summarized as follows:

**A . Not all farmers do use herbicides for rice culture. There are farmers who do not use herbicides at all, while another category uses suboptimal rates. Another group uses the recommended rates, and a few use excessive quantities, anticipating total weed control.**

**B. Farmers in the major rice producing regions use more herbicides than those in the wet regions. This is due to the higher incidence weeds in rice fields of the dry regions. Furthermore, the weed populations are greater in the dry season due to the lack of sufficient water, which stimulates weed growth.**

C. The most common weeds in the dry regions, where the study placed emphasis, due to its importance in rice production of Sri Lanka were grasses. The most common were *Echinochloa crus-galli*, *E. colonum* and *Ischaemum rugosum*. While a range of herbicides were used by farmers the study showed that Propanil and Nominee were used much more widely than other herbicides.

D. All farmers cultivating sugar cane used herbicides, either at optimal or excessive rates. However weeds were still present in these fields, which call for further studies on seed banks and the possibility of resistance in the weeds.

E. Herbicide use patterns of vegetable farmers (Carrots) use herbicides in a similar manner to that of rice farmers. All four categories of farmers classified on the basis of herbicide use in rice were found within the population of carrot growers. Weeds, especially grasses were the prominent species in this crop, and were persistent even with herbicides. This again requires further study.

F. Selected populations of *E. crus-galli* and *I. rugosum* showed resistance to Propanil and Nominee respectively. However, the existence of resistance in *E. colonum* to Propanil could not be determined. Seeds of populations of all species were affected by the selected herbicides to a greater extent than seedlings. Hence studies on seedlings need to be carried out to confirm herbicide resistance. However, these observations do require confirmation by detailed analysis.

G. There is a large bank of weed seeds in rice soils. The highest numbers, as expected, are in the top 0 – 20 layer followed by the 20 – 40 cm layers. This bank could bring in a significant population of weeds into rice systems and management strategies need to address this factor, a phenomenon not recorded in Sri Lanka earlier.

### **3. TRAINING PROGRAMMES**

The program carried out under the sponsorship of the Eiselen Foundation envisaged training of scientists and technical offers of the Department of Crop Science, University of Peradeniya, Sri Lanka, where weed science is being taught at undergraduate and post graduate levels. The project also supports a research program of a student from Hohenheim University, specializing in Weed Science in 2004.

Thus four short term training fellowships were built into the project, and were awarded to two members of the academic staff and two technical offers of the Department of Crop Science, in 2001 and 2002. In addition a student from Hohenheim was supported to visit Sri Lanka to undertake studies on weeds in rice.

### **Training of Academic staff:**

The members of the academic staff who were awarded the fellowships were Dr P Weerakkody (B Sc Sri Lanka, M Sc Obhiro, Japan, Ph D Sri Lanka), Senior Lecturer in Crop Science and Dr S P Nissanka (B Sc Sri Lanka, M S, Ph D Guelph).

Dr Weerakkody spent 6 weeks in the laboratory of Professor Dr K Hurle in Hohenheim. During this period, he observed the research projects on herbicide resistance being carried out and read papers pertaining to techniques used in these studies. The objective of this was to enable him work on weeds in tropical vegetables, and possibly develop projects for evaluating herbicide resistance in upland weeds.

Dr Nissanka spent 6 weeks at the Laboratory of Professor Dr Rubin in Rehovot, Israel. During this period, he worked with scientists in the laboratory studying techniques of assessing herbicide resistance. In addition, he observed possible techniques to determine antioxidants in plants, a field of growing importance in agricultural and nutritional research projects.

### **Training of Technical staff**

The technical staff selected for training was Mr. P R S D Bandaranayake and Ms U Dissanayake, of the Department of Crop Science. Both spent 8 weeks each at the Laboratory of Professor Dr K Hurle in Hohenheim, in 2001 and 2002 respectively.

Mr. Bandaranayake worked on techniques of herbicide application for measuring resistance and evaluating the presence of herbicide resistance. This was very valuable as there was no one trained in this area in Sri Lanka and his input to the project on return was very useful.

Ms Dissanayake was trained in molecular techniques of determining herbicide resistance. As Ms Dissanayake is attached to plant propagation and biotechnology laboratory of the department, this training was again valuable, for teaching purposes.

### **Training of the student**

Sonja Hähnke, a Bachelor student travelled to Sri Lanka in November 2003 for three months. She has undertaken a survey on rice weeds in farms situated in the project area. The objectives of the project were to determine weed populations in rice in the wet season, identify differences in weeds in broadcast and transplanted rice and document cultural practices in rice with emphasis on weeds.

This study will add valuable inputs to the overall goal of this project and the report will be submitted on completion of the research project in Sri Lanka.

**The reports of the four trainees are attached as appendices to this report.**

## **4. Scientific visits**

The principal collaborators of the project – Professors Dr K Hurle and B Rubin and Dr Sangakkara travelled to the respective countries for discussions and evaluations. The details of these are presented below.

### **4.1 Dr Ravi Sangakkara**

Dr Sangakkara visited the University of Hohenheim in 1999 while being at the ETH, Zurich as a guest professor. During this time, the modalities of the experiment were discussed and the activities were finalized. At this time, Dr Sangakkara accompanied Professor Dr Hurle to Ulm and met with Dr Hermann Eiselen at the Foundation. The project was discussed in detail at this meeting.

Dr Sangakkara visited Hohenheim in 2000 August, on his way back from the International Crop Science Congress in Hamburg, where he was the only invited keynote speaker from Asia. This meeting with Professor Dr K Hurle was to discuss the current status of the project and also the training of academic staff.

**These two visits were not supported by the Eiselen Foundation.**

Dr Sangakkara traveled to Thailand in January 2002 on partial support from the foundation to attend the Conference titled Sustaining Food Security and Managing natural Resources in Southeast Asia – Challenges for the 21<sup>st</sup> Century, at Chiang Mai, Thailand, from 8-11 January, 2002. This conference was sponsored by the Eiselen Foundation. Dr Sangakkara presented a poster titled **Herbicide Resistance and Sustaining Food Security in South Asian Rice Culture – A Case Study**, based on the work of the project. In addition he met with Dr Eiselen and Dr Fadani, and discussed the work of the project.

Dr. Sangakkara has attended the German Conference on Weed Biology and Control, University of Hohenheim from 2-4 March 2004 on a sponsorship from the project. He has presented two posters titled **Herbicide use patterns and weed populations in rice fields of Sri Lanka** and ***Ischaemum rugosum* – Is there herbicide resistance?** based on research of this project.

## **4.2 Professor Dr K Hurle**

Professor Dr Hurle, visited Dr Sangakkara in December, 2002 and November 2003 while the latter was at the Institute of Plant Science, ETH Zurich as a guest professor. These visits were made to discuss the activities of the project. In 2002, the research program and data analysis were discussed, while in November 2003, the visit of the student from Hohenheim to Sri Lanka and the final reports of the project were discussed

### **Report**

on a visit of the project in Sri Lanka by Prof. K. Hurle and Prof. B. Rubin

27 July to 08 August 2001

### **Aims**

Initially the visit was planned for the third year of the project, however, the three partners agreed on to do it during the second year in order to

- a) provide the visitors detailed on spot information about the status and development of the project and
- b) make them familiar with the Sri Lankan agriculture especially the weed situation in the crops included in the project.

### **Climate and agriculture**

The climate of Sri Lanka is tropical in the lowlands and somewhat cooler in the central hills/mountains. Annual precipitation depends on the region and varies from < 600 mm - > 1500 mm. The southwest monsoon brings rain to the western, southern and central regions from May to July, while the northeastern monsoon occurs in the north and east in December. The dry season is bridged by irrigation in most parts of the country.

Sri Lanka's agriculture is dominated by small scale farms. Weed problems are severe in all crops due to favourable growing conditions during the rainy season and under irrigation. Although farming is small scale and family based, weed control is done with herbicides to a considerable extent, and the use of herbicides is increasing.

### **Outcome**

The visit was excellently organized by Prof. Sangakkara. He made it possible that Hurle and Rubin got to see a great part of the country's agriculture.

We obtained an overview on Sri Lanka's agriculture in the typical climatic zones of the country, on the major crops and the respective weed problems.

We visited almost all areas where the weed surveys of the project had been made during the first and second year. The fields where the surveys took place are appropriate and representative for Sri Lankan agriculture.

The persons involved in the field part of the surveys are enough familiar with the crops, the weed species and weed control practices in the respective crops.

The scientific and technical staff of the Crop Science Department of the University of Peradeniya involved in the project are experienced in weed science and did already own investigations on herbicide resistance before our project was started. However, some members of the department have left Peradeniya. Sangakkara is now trying to strengthen the weed activities of the group with Dr. Nissanka and Dr. Weerakkody, young scientists who got their PhD in Canada and Japan respectively. The equipment of the laboratories in the department is rather basic and the weed group has no own laboratory. This is also true for greenhouses. Laboratories and greenhouses are shared with others. Although the possibilities to do experiments is limited, the investigations involved in the project can be carried out. In rice, the main staple food, the one-sided use of propanil created already resistance in *Echinochloa crus-galli*, and now the one-sided use of a sulfonyl urea herbicide leads to a rapid increase of *Leptochloa* sp.

In tea *Crassocephalus crepioides* is not controlled with the presently used chemicals. It therefore may increase and cause problems in the near future.

In sugarcane there is an intensive use of herbicides in the year of planting, and potential for the build-up of diuron resistance since this compound is used already since decades.

In vegetables chemical control is based mainly on paraquat and to a certain extent on glyphosate in combination with hand weeding.

In coconut, another major crop of Sri Lanka (not included in the surveys), *Eupatorium odorata* is a problem species which is not adequately tackled by the present control methods.

Except for tea, there was evidence that chemical weed control is not practiced to a great extent on a knowledge based strategy. In addition the spectrum of compounds used is rather narrow, and there is a great potential for the build-up of herbicide resistance and unfavourable shifts in the weed flora, creating new problems.

From our experience made during the visit we can conclude that there is a need for an integrated approach in weed control and hence the project is justified.

### **Status of the project and future activities**

The project is behind schedule but it is believed that it can be terminated in 2003 without further funding.

Since Mr. Bandaranayake and Dr. Weerakkody were trained in practical and theoretical aspects of herbicide resistance at Hohenheim and Dr. Nissanka at Rehovot, they now are able to continue the project work. The immediate next steps will be the testing of weed species from rice fields on herbicide sensitivity *via* dose-response experiments.

It was of great value to get to know each other, and this will facilitate the cooperation.

Sangakkara will visit Hurler in October 2001 while he is staying at ETH, Zurich, and discuss the ongoing activities especially the dose-response experiments.

Sangakkara will attend the conference at the Chiang Mai University, Thailand, in January 2002 and contribute with a paper on "Herbicide resistance and sustaining food security in South Asian rice culture – A case study." The paper is based on results of the project.

Another technical officer Sangakkara's group will go for training to Rehovot and Hohenheim in 2002.

In order to support the project we discussed to do a master thesis on *Leptochloa* in rice. Hurle will look for a student and ask the Eiselen Foundation for financial support *via* the Hohenheim Centre for Tropics and Subtropics. The University of Peradeniya will provide accomodation at a reasonable price (room including three meals for about 200 € per month).

Another future activity is the cooperation with the Coconut Research Institute. The institute is very much interested in gaining more expertise in weeds and weed control in coconut plantations.

It has been discussed with Dr. Gunathilake, head of the agronomy department of the institute, to start a PhD project on “Population dynamics and control of *Eupatorium odorata* in coconut plantations in Sri Lanka.” Mr. Senarathne, member of the department, was proposed by Prof. Sangakkara and Dr. Gunathilake as the right person. He got his Master Degree at Peradeniya and is very much interested to do it. Both, Hurle and Rubin discussed with him the idea and found him competent to do such a PhD project.

The concept would be that the candidate would do the field investigations in Sri Lanka and spend some months at Hohenheim and Rehovot respectively for laboratory experiments in order to supplement the field results and gain international experience.

Mr. Senarathne will apply for acceptance as a PhD candidate at the University of Hohenheim. If he is accepted, K. Hurle will act as his supervisor in cooperation with Sangakkara and Rubin.

Mr. Senarathna will get his salary during his PhD period from the Coconut Research Institute. For his stay in Germany and Israel, however, he needs additional financial support. Provided he will be accepted by the Hohenheim Faculty of Agriculture, we would develop a detailed work plan and, if any possible, ask the Eiselen Foundation for funds.

For a detailed information about the visit see “Notes” taken by Hurle

## 5. OUTCOMES

A research and development and its outcomes need to be evaluated on two fronts, namely the achievements of the project objectives and secondly the multiplier effects

Thus the outcomes of this project will also be analysed from these two aspects



## 5.1 Achievements of objectives

The objectives of the project were cited as follows:

- a. **Document herbicide use patterns in the rice fields and their weeds in selected major rice rowing regions of Sri Lanka during the major and minor seasons (Wet and Dry) that correspond to the Northeast and Southwest monsoons**
- b. **Evaluate the weeds in selected highland crops and herbicide use patterns**
- c. **Identify prominent weed species in rice farming systems**
- d. **Ascertain the possible existence of resistance in the most prominent weeds to the most common herbicides used in rice culture**
- e. **Train staff at the University of Peradeniya on identifying herbicide resistance in weeds**
- f. **Develop a brochure for use in extension work for the farming community on weed management in rice**
- g. **Publish research on the study for the scientific community**

In terms of the first objective, this was achieved very successfully. The herbicide use patterns of rice farmers were ascertained in three regions of Sri Lanka, which consisted of two prominent and one minor region. This was done in the two agricultural seasons that correspond to the two monsoons. Although the data found does not cover the entire country, the study presents some of the major aspects of herbicide use in rice culture of Sri Lanka. The weed populations were also ascertained and the presence of greater numbers of weeds in the dry season was clearly identified, a feature that people believed in but without numbers under Sri Lanka conditions.

The second objective of this study was to diversify the emphasis on rice by looking at weeds and herbicide use in other crops. The crops elected were sugarcane in the dry regions and carrots, a popular exotic vegetable in the wet region. In sugarcane, all farmers within the population used herbicides in excessive or optimal rates. However weeds, especially broadleaved species such as *Ipomoea* still persisted, a feature not reported earlier for this crop.

In carrots all four categories of farmers found in rice systems were noted within the population. Most farmers either used optimal or suboptimal rates, or interestingly most noted the hazards of using pesticides on this crop, which is consumed directly in fresh forms by people. However, there were weeds, especially grasses in this crop even with the application of pesticides.

The third objective was to identify prominent weeds. This too was achieved in the selected regions, and the presence of *Echinochloa* species and *Ischaemum rugosum*, especially in the dry regions of Sri Lanka, where rice cultivated in the major season with rainfall and with irrigation in the minor season. The presence of other species was also noted although not as prominent as these species.

The presence of herbicide resistance in *E. crus-galli* to Propanil had been recorded earlier, and this phenomenon was confirmed by this study in several populations. While the resistance to Propanil was not observed in *E. colonum*, *Ischaemum rugosum* recorded some degree of resistance to Nominee, a popular herbicide that is being used to destroy *Echinochloa* species. This was the first systematic study done in Sri Lanka and hence warrants confirmatory work.

Training of staff was a very important feature in the project. The faculty of Agriculture of the University of Peradeniya, Sri Lanka, established in 1948, is the oldest faculty in the island. This has the biggest intake of students. However, Sri Lanka being a developing country does not provide resources for training university staff during their careers. The training is provided only at the inception that too principally through programs found by the respective persons. Technical staff is not provided any formal training and learn with time.

This project fulfilled a major vacuum in the training offered to students. Weed science is taught in the first semester and again in the 5<sup>th</sup> semester to all students and thereafter to the students specializing in crop science in the 8<sup>th</sup> semester. At all stages weeds in rice, herbicide use and resistance is discussed, and practicals are conducted. The academic and technical staff is involved in this process and after training; the technical staff have been really motivated to improve the standards of the lessons and practicals. The academic staff trained have also gained experience in new research techniques, not carried out earlier in the University.

A principal objective of this project, as instructed by the Foundation and Dr Hermann Eiselen several times, was that it must have an impact on the farming community. Most rice farmers in Sri Lanka depend on their experiences to carry out certain cultural practices as extension services do not provide required information at the present time. Thus as advocated the project envisaged the development of a brochure for extension services, schools, farmer societies and officers of the Department of Agrarian Services. This brochure, developed by the project, will be distributed to all the mentioned communities as well as the university students. The printing of this in both English and Sinhalese will be an added bonus as farmers and farmer societies are more fluent in the local language than English. Thus, the development of the brochure could be considered a major outcome of this project.

## **5.2 Multiplier effects**

A success of a research project is judged by the dissemination of information to scientific bodies and the public through presentations and publications. This too was achieved in this project.

The project produced three publications, based on the research, and one more has been submitted. The three publications printed are based on presentations made at the following conferences with the following titles:

Conference on Sustaining Food Security and Managing natural Resources in Southeast Asia – Challenges for the 21<sup>st</sup> Century, at Chiang Mai, Thailand, from 8-11 January, 2002.

This conference was sponsored by the Eiselen Foundation.

Dr Sangakkara presented a poster titled **Herbicide Resistance and Sustaining Food Security in South Asian Rice Culture – A Case Study** which was published in the Proceedings of the conference and is on the website.

German Conference on Weed Biology and Control, University of Hohenheim from 2-4 March 2004 on a sponsorship from the project. Dr Sangakkara has presented two posters titled **Herbicide use patterns and weed populations in rice fields of Sri Lanka** and ***Ischaemum rugosum* – Is there herbicide resistance?** The papers were published in the Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz (Journal of Plant Diseases and Protection), which is cited in the Web of Science and Science Citation Index.

The fourth paper titled **Weeds, Herbicide Use and Resistance in Rice Fields of Sri Lanka** will be submitted to the International Crop Science Congress to be held in Australia in September, 2004. Hence the results of the project have been and will be given publicity and further papers will be developed for publication in journals related to weed science.

The second multiplier effect that the project has generated is the training of a German student in Sri Lanka. This too will have a very significant impact on the knowledge base on Sri Lanka and on tropical weeds. The success of this project may induce others in Germany to travel, and obtain practical experiences in the developing world that would help in their future careers in Germany and internationally.

Sri Lanka is a developing country. A project of this nature, which evaluated a significant factor constraining rice yields, was known to many. Several discussions were held with farmers involved in the survey. The visits made by the scientists from the principal counterparts from Germany and Israel gave them an insight into the problems faced by the developing nations in achieving success in agriculture, and more importantly on their staple diet, Rice. The reciprocal visit by Dr Sangakkara brought him into contact with international scientists. The academics and technical staff of the University were encouraged and obtained new ideas, which were passed onto students.

The above stated outcomes cannot be quantified – however they do form a significant part of the success of this project.

## 6. CONCLUSIONS

The project on **INTEGRATED WEED MANAGEMENT FOR PREVENTION OF THE EVOLUTION AND SPREAD OF HERBICIDE RESISTANT WEEDS IN SRI LANKA**, INITIATED with the support of the Eiselen Foundation in Ulm, Germany, in 1999, had 7 objectives at its inception. The project started a few months late due to administrative problems, but the work was carried out successful over a period of 4 years and 6 months.

The project is the first of its kind, where some systematic studies were carried out to identify the problems of weed principally in rice culture, the most important food crop in Sri Lanka, and possible other crops. This was the principal objective of the project, as weeds are the most significant biological (non human) constraint to rice production in Sri Lanka. Herbicide use is increasing at alarming rates, they are available island wide and haphazard use is becoming a common phenomenon. This needed documentation and the possible development of herbicide resistance required attention.

The project fulfilled this task – and it can be stated that rice farmers do use herbicides, especially in the dry regions, where rice is the most important commodity. The herbicides are used to control the greater population of weeds found in this region.

Resistance to two of the most popular herbicides was noted in two common weeds and hence precautionary measures need to be recommended after further studies on integrated systems of management. This would help rice farmers of Sri Lanka significantly to improve their yields and thus incomes, creating a better livelihood.

The development of a brochure on weeds in rice, resistance and possible methods of management developed by the project would thus be of immense benefit. This would have a multiplier effect to the farming community and students studying agriculture, researchers, extension agents and the public at large.

The identification of weeds in two other crops, despite using herbicides, is of also of interest. Herbicide resistance in weeds of these species has never been evaluated. Neither have the impacts of weeds ascertained on exotic vegetables. Studies leading to ascertain data on these aspects would be of value.

The project also trained staff and a student. It published papers and contacts were made with many reputed scientists and a close collaboration was built between the three counterparts from Hohenheim, Rehovot and Peradeniya. This was a significant achievement and the multiplier effects of this link are immeasurable.

At the end of this project, one need to ask - Is this end, or a beginning of another journey. The farmers of developing countries and students of agriculture in these nations need help. The economies of the countries do not offer much support due to the lack of resources. Thus, projects of this nature, although modest in money (approximately €50,000 over four years) could achieve significant strides and have a lasting impact on the farming community and students of agriculture, the future farmers and leaders of the farming communities.