RELATIONSHIP BETWEEN WEED DENSITY AND YIELD LOSS IN SEMI-DRY RICE

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Relationship between weed density and yield loss in semi-dry rice"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Relationship between weed density and yield loss in semi-dry rice"** is a record of research work done independently by **Miss. C.P. Shiji**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship for her.

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INTRODUCTION

Plate 1. *Sacciolepis interrupta* (with long spikes) and *Isachne miliacea* (spreading) infestation in a paddy field.

A study of the extent of influence of *S. interrupta* and *I. miliacea* on the crop and the quantum of damage inflicted on the crop based on their differential densities will throw light on the control measures that are to be resorted to avoid crop losses. Such models on weed-crop competition based on field studies are therefore very helpful for any short or long term economic analysis of the weed management strategy.

The threshold density is defined as the density where the cost of control of the weed is equal to the net benefit derived from control. As it is practically impossible and uneconomical to maintain the field completely free of weeds, it will be very much useful if threshold levels of densities of major weeds are worked out to decide on the need of weed management operations.

In this thesis entitled "Relationship between weed density and yield loss in semi-dry rice", studies were conducted with the following objectives:

1. construction of response models to study the effect of the different densities of the weeds *S. interrupta* and *I. miliacea* on the yield of rice and
2. estimation of threshold weed densities of these two weeds beyond which control is necessary.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Weed problem is severe in direct-sown rice especially in semi-dry rice. Weed-crop competition may lead to losses as high as 80 % (Smith, 1988). Predicting crop losses due to weeds is an inseparable part of weed management. Since only single weed species competition has been studied extensively by many researchers, reports on multi-species competition are limited. Some of the important works by researchers have been reviewed in this chapter under the following headings.

2.1 Crop-weed competition studies

2.2 Weed density- crop loss modelling

2.1 Crop-weed competition studies

Cousens (1991) found that additive designs were well suited to agronomic objectives. He suggested that regression approaches to analysis were more relevant; many non-linear equations are now easy to fit to data and these can be used without the need for linearisation. He, however, warned of various pitfalls not adequately reported to date.

Connolly (1993) outlined a general and flexible conceptual approach to the study of crop weed systems. Such an approach allowed the assessment of weed effects on crop and crop effects on weeds over a wide range of densities. The implications for measuring the effect of weed infestation on crop yield and the use of crop density as a tool in weed control were also discussed.

Yang and Lu (1994) conducted field experiments to evaluate the effects of weed inflorescence and environmental conditions on the yield of corn under no-tillage conditions. Regression analysis revealed a linear relationship between weed dry weight and grain yield.

Zhou *et al.* (1994) calculated the relationship between weed density and crop yield loss of lucerne. Eco-economic thresholds were calculated for handweeding and chemical weed control and it was concluded that weed control measures should not be taken when weed density is below the economic threshold.

Zuza (1994a) studied the relative dynamics of a number of crops and their weeds. He reported that the competing ability of crop plants in relation to weeds depends on their rate of biomass accumulation; while the nature of the competitive interrelationships is determined chiefly by the species composition of the weeds. Further, Zuza (1994b) considered competitive interrelations of crops and weeds on the basis of the dynamics of the changes in the total biomass during the vegetative period. By comparing the rates of change thus obtained for crops on the one hand and for a particular weed or group of weeds on the other hand, coefficients of competitiveness were obtained, and a scale of such values was suggested. However, he suggested that other aspects must also be taken into account, such as the relative weights of weeds and crops at the commencement of competition and their life span.

Agrawal *et al.* (1995) conducted field trials to assess the effects of weeds on the performance of soyabeans. The correlation and multiple linear regression analysis indicated that crop yield was related to crop biomass and number of leaves. They found that crop performance was most affected by total weeds density. They also found that crop and total weed biomasses were inversely related and weed biomass was also inversely related to number of leaves of soyabean plants.

Crop yield loss due to weeds is mainly explained in terms of competition for light. Early prediction of yield loss and weed dynamics depends on the ability to measure and / or estimate partitioning of incoming light between species. Assemat *et al.* (1995) used a simple method for measuring interception efficiency within a weedy maize system. This hinted at further possibilities for modelling competition in crop weed system.

Bussler *et al.* (1995) suggested that volume based variables be used to develop competitive indices on physico-empirical based interference models.

Das and Yaduraju (1995) estimated weed dry matter accumulation, nutrient uptake and yield reduction to assess the weed competition on six crops under no weeding, weeding once at three weeks after sowing and weed-free condition. The total weed dry weight differed significantly amongst crops at all dates except at 20 days after sowing (DAS). At 60 DAS and at harvest, total weed dry weight in pearl millet was comparable with other crops.

Gonzalez *et al.* (1995) conducted greenhouse experiments and found that tomato was more competitive than the weed, which was more competitive than pepper. Crop yield was reduced whenever the weed reached a greater height than the crop plant, which occurred in tomato only in the case of simultaneous emergence of both species, and in pepper when the weed emerged even at the crop six-leaf stage.

Huh *et al.* (1995) found that the number of panicles per plant, spikelet per panicle, grain weight and yield of rice in dry sown rice showed highly negative correlations with the growth of *Echinochloa crus-galli, Ludwigia prostrata, Cyperus difformis, Bidens frondosa* and *Cyperus serotinus.*

Li *et al.* (1995) investigated the occurrence of weeds and the resultant yield loss in tobacco following rice. By investigation and determination of the number of weeds (fresh weight) as well as tobacco yield, a straight line regression on the relationship between weed parameters and yield loss of tobacco based on local production levels was established. It was found that tobacco yield decreased with an increase in the number of weeds and their fresh weight and yield loss rate also increased with increased number of weed plants and fresh weight.

Lutman *et al.* (1995) conducted experiments to investigate the relative competitive effects of 11 annual weeds in winter oilseed rape. They showed that it is possible to produce a tentative index of the competitive abilities of weeds by integrating infestation level with the reduction in crop growth.

Lutman and Cussans (1995) conducted experiments and found that assessments of relative weed vigour based on dry weight and leaf area achieved more reliable estimates of yield loss than predictions based on weed density.

Vitta and Fernandez (1995) studied the effectiveness of three methods namely visual observation, an optical measure and photographic techniques for estimating weed cover and their usefulness as predictors of yield production. They found that the best association between weed canopy and yield losses was obtained using visual observations.

Assemat *et al.* (1996) studied the growth and seed production in *Polygonum lapathifolium* to elucidate the relationship between biomass and seed production and to identify early growth factors which might be predictive of seed production. They concluded that weed growth under conditions of competition could be described by simple statistical measures using early vegetative measurements. They found that seed production was linearly related to ear length and seed number and shoot dry weight was a good early indicator of seed production.

Burhan *et al.* (1996) investigated the yield loss caused by *Ludwigia octovalvis, Cyperus iria, C. difformis, Monochoria vaginalis* and *Scirpus juncoides* in relation to their densities, time of introduction and fertilizer application rates based on regression equations.

Collet and Frochot (1996) assessed the importance of competition for water in the relationship between young sessile oaks, *Quercus petraea,* and two grass species *Agrostis stolonifera* and *Deschampsia cespitosa.* They found that competition had a marked effect on tree growth with trees grown in the absence of competition making up 1.5 times the height of those grown with either grass species.

Cousens and Griffith (1996) argued that each experimental design for the study of interference has both its merits and its realizations. So it was unreasonable to expect that any design will be universally applicable. Their conclusion was that a researcher must match the aim of the experiment with an appropriate design and method of analysis.

Canada thistle reduced spikes per plant and seeds per spike of wheat to varying extents over years, but Canada thistle had comparatively little effect on 1000-seed weight of wheat. Path coefficient analysis showed that Canada thistle reduced spring wheat yield chiefly by the indirect effects of decreasing wheat density, the earliest formed yield component (Donald *et al.*, 1996).

Drennan and Alshallash (1996) found that though weed growth reduced in high wheat density plots, there was still a large seed return even at the highest crop density and argued that crop density alone cannot suppress weeds below threshold levels.

Hamdane *et al.* (1996) conducted experiments to investigate the effect of red sprangletop density on grain yield and yield components of direct seeded rice. It was found that there was no effect of red sprangletop competition on the vegetative growth of rice plants. Height and tiller number of rice at 45 days after sowing were not affected by weed competition. However, the weight of 1000 filled grains was affected by competition and panicle number / m^2 showed a significant correlation with red sprangletop density. The results suggested that competition occurred between red sprangletop and rice from the middle stage of vegetative growth to the grain filling stage.

Hernandez *et al.* (1996) carried out studies to evaluate the competition of *Oschaemun rugosum* with rice. They determined the yield components which were affected directly or indirectly by the weed and the stage of rice plants mostly affected by the weed. The results showed that the competition period was from rice plant emergence until 45 days after emergence. They concluded that most damage to the crop occurred when weeds competed at crop emergence, because of competition for factors such as water, light and nutrients, which are essential for crop development.

Jain *et al.* (1996a) reported that densities of *Echinochloa crus-galli, Digitaria adscendens, Cyperus rotundus, Cyanotis axillaris* and *Phyllanthus* spp. had a significant and negative effect on seed yield and a linear decline in yield was predicted.

Jain *et al.* (1996b) studied the influence of weeds on the growth and yield of safflower. They found that weed population at the initial stage, weed population at harvest and weed biomass at harvest had inverse relationships with crop biomass. Weed biomass also showed a negative correlation with crop height, the number of filled capsules and of branches per plant. Regression analyses showed a linear increase in weed biomass in line with an increase in the weed population.

Lutman *et al.*(1996) carried out experiments to investigate alternative methods of predicting the competitive effects of a simulated weed (oats) on the yields of five crops. They found that weed density (plant m^{-2}) was a very variable prediction of yield loss. They also found that prediction based on the relative dry weight (dwt) of crop and oats (oat dwt / (oat dwt + crop dwt)) assessed while the plants were still small achieved more reliable predictions.

O'Donovan (1996) presented information on yield loss as a function of weed density; estimating single-season economic thresholds; difficulties associated with weed thresholds; including factors other than weed density that influence crop / weed interactions; and beyond the threshold concept.

Soroka *et al.* (1996) carried out a field study on the relationship between oat yield and annual dicotyledonous weed infestation. The results of small plot experiments showed that an increase in the number of weeds gave an increase in weed weight and a decrease in oat yields. They illustrated this with the help of regression equations. The biological threshold densities under which the reliable oat yield decreases were also found out.

Uygur and Mennan (1996) conducted field trials to determine the economic thresholds for *Galium aparine* and *Bifora radians* in wheat. The results indicated that both species caused a density-dependent yield loss. *G. aparine* was the more competitive of the two causing greater losses at all densities tested and significant yield losses even at low densities. They also calculated the economic thresholds for each species taking into account the cost of herbicides.

Wellmann and Marlander (1996) established different densities of *Chenopodium album* and introduced them progressively at different stages of sugarbeet development. They reported that as the period between emergence of crop and weed increased, less growth of *C. album* occurred. They concluded that yield loss could be described suitably by weed density, taking into account the time of weed emergence.

Dhaliwal *et al.* (1997) kept crop density constant while varying density from 0 to 500 plants / m^2. They reported that as the density of weed increased, wheat yield decreased exponentially. They attributed reduction in wheat yield mainly to reductions in the number of ears.

Doll (1997) found that a reduction in barley plant density from normal to half or quarter density resulted in a 2- to 5- fold increase in shoot dry matter at harvest. His experiments indicated that a negative relation existed between grain yield level and weed growth.

Hakansson (1997) reviewed his basic research on competitive effects in annual plant stands with particular emphasis on measurement methods. He also discussed plant density effects on biomass production with particular reference to crop weed stands and mixed stands of barley, spring wheat and *Sinapis alba.*

Ingle *et al.* (1997) conducted experiments to study the interference between winter wheat and three weed species namely *Stellaria media, Alopecurus myosuroides* and *Galium aparine.* Six target densities (including zero) of each weed were sown in 2 m^2 plots. The percentage yield loss was calculated, plotted against weed density and curves were fitted. It was concluded that the use of weed density alone to predict yield loss was unrealistic and other factors would need to be introduced.

Izquierdo *et al.* (1997) studied the competition between winter barley and ryegrass (*Lolium rigidum*) at different densities. Reductions of weed biomass (by 85 %), number of spikes / m^2 (by 78 %) number of seeds / spike (by 61 %) and 1000 seed weight (by 39 %) were found by increasing barley densities. They found that crop yields were reduced linearly with increasing weed densities. They reported that competition was mainly early in the growing season as the only yield component affected was the number of ears / m^2.

Mishra *et al.* (1997) conducted field trials to assess the effects of *Vicia sativa* planted at densities of 0 to 180 plants / m^2 on plant growth and crop parameters of lentil. Results indicated that plant dry weight and grain weight of *V. sativa* increased with density. They reported that lentil yield parameters such as pods / plant, grains / plant, 1000 grain weight, plant dry weight and grain yield reduced with increasing *V. sativa* densities.

O' Donovan and Blackshaw (1997) determined the relationships between volunteer barley plant density and both pea and volunteer barley yield. Non-linear regression analysis indicated that severe pea yield losses occurred due to volunteer barley. Based on certain assumptions, they calculated economic thresholds from the equations.

Paradkar *et al.* (1997) studied the competitive effects of four weed species (*Vicia sativa, Cichorium intybus, Phalaris minor* and *Chenopodium album*) at four densities (50, 100, 150 and 200 plants / m^2) on the growth and yield of gram (chickpeas). They concluded that the most competitive weed species was *Cichorium intybus* followed by *Phalaris minor.*

Petrulis (1997) investigated the relationship between winter and spring wheat yields and weed number and mass. A very strong relationship was established between grain yield, plant height and weed mass.

Pritts *et al.* (1997) identified critical periods when weed pressure was most detrimental to strawberry growth so that control efforts could be concentrated during these periods. They found that the longer the length of weed pressure, the greater the effect on runnering and yield. They concluded that weed control efforts should be concentrated early in the season because strawberries are most sensitive to competition at this time.

Qasen (1997) reported that redroot pigweed (*Amaranthus retroflexus*) and nettle-leaved goosefoot (*Chenopodium murale*) exhibited severe growth reductions in response to intraspecific competition with a greater reduction in *C.murale.* He found that *C. murale* was a better competitor in the spring and *A. retroflexus* in the summer. He reported that two weeks' delay in weed emergence after tomato reduced weed growth, more for *A. retroflexus.*

Sanchez and Torner (1997) carried out a field study to investigate the effects of different densities of *Solanum nigrum* (0 to 4.2 plants / m^2) in transplanted peppers (*Capsicum annuum*). Plots were kept weed free for 14, 25, 34, 42 and 52 days after transplanting after which weeds were allowed to grow until harvest. Total yield reductions of 75 % were observed with the highest weed density from 14 days onwards. No yield losses were observed with weed competition starting after 52 days.

Tanji *et al.* (1997) studied competition between wheat and rigid ryegrass and between wheat and cowcockle using additive series and growth analysis. They found that shoot dry weight was the easiest, fastest and least expensive component to measure competition. Growth analyses of individual plants showed that wheat had a greater leaf area, shoot and root dry weight and absolute growth rate than rigid ryegrass or cowcockle, particularly early in the season.

Wright *et al.* (1997) studied the interactive effects of multiple weed species competition in winter wheat. *Galium aparine, Matricaria perforata* and *Papaver rhoeas* were grown singly and as pairs of species in wheat. They found that *P. rhoeas* produced most biomass both singly and in mixture resulting in the greatest crop biomass and yield reductions. They concluded that the effects of weeds in mixture on crop biomass were additive in May, but at harvest, yield reductions from weed in mixture were only slightly greater than from single species.

Karim *et al.* (1998) studied the weed density effect of *Chenopodium album* on wheat at three densities of the weed and three densities of the crop. They found that dry matter of wheat / plant, grain yields / plant and weed dry matter / plant were reduced progressively with the increase in both weed and crop densities. The competitive ability of the weed as measured by aggressivity was significantly higher at low densities of the weed but it was unaffected by different crop densities.

Kim and Pyon (1998) reported that the greatest weed occurrence in terms of dry weight was found to be in dry direct sown rice followed by that sown on puddled soil than that sown on submerged soil, compared to low occurrence in plots sown with transplanted seedlings. They also found that yield loss of rice due to uncontrolled weeds was 96 % in dry direct sown rice as compared to 61 % in water-sown rice and 40 % in the machine-transplanted crop.

Moorthy and Das (1998) carried out a field experiment to find out the threshold density of umbrella sedge in rainfed direct seeded upland rice. Different densities of this weed from 40 to 400 plants / m^2 producing a dry matter of 0.3 – 2.34 t / ha reduced rice grain yield by 11.40 %. Thus a density of 40 plants of *Cyperus iris* / m^2 with a dry matter accumulation of 0.3 t / ha was considered as the threshold level in upland rice.

Premlal *et al.* (1998) determined the effect of root and shoot competition of *Echinochloa colonum* and *Euphorbia heterophylla* on bush bean and pole bean. Treatments included no competition, root competition, shoot competition and full competition. It was concluded that pole bean was more competitive than bush bean, while bush bean competed better with grass weeds (such as *Echinochloa colonum*).

Stanojevic *et al.* (1998) assessed the effects of maize density on *Convolvulus arvensis* and *Sorghum halepense* for two years. In both years and for both weed species, weed density was consistently lower in high density planted maize plots.

Correlation between canopy characteristics of rice under monoculture and competition indicated that leaf area index (LAI), specific leaf area (SLA) and tillering ability were predictive of competitiveness regardless of the competing species (Dingkuhn *et al.*, 1999). They found that competitiveness was negatively but weakly correlated with yield potential, and positively with crop duration. They concluded that SLA and tillering ability, which are major determinants of vegetative vigour, and crop duration, which affects the ability to recover from early competition, are useful traits in the selection of weed competitive rice.

Ngouajio *et al.* (1999a) developed and validated a powerful image analysis system for measuring leaf cover to compare the efficiency of weed relative leaf area and relative leaf cover in predicting maize yield loss using varying densities of common lambsquarters (*Chenopodium album*), barnyard grass (*Echinochloa crus-galli),* common lambsquarters plus barnyard grass, and a natural weed community. They found that relative leaf area of weeds was an adequate predictor of maize yield loss. In general smaller values of q (damage coefficient) of weeds and m (predicted maximum yield loss) were obtained as a consequence of using the relative leaf cover of weeds in model fitting. It was concluded that the development of weed control decision-making tools using relative leaf cover of weeds may require improvements prior to being used in weed management systems.

Ngouajio *et al.* (1999b) conducted field experiments to study the effects of crop growth stage and images recording height on the estimates of leaf cover obtained through digital image analysis techniques and to test the effectiveness of these data in maize yield prediction. They reported that maize yield prediction was slightly affected by the timing of leaf cover sampling. The results indicated that appropriate timing of leaf cover assessment might help improve the accuracy of crop yield prediction, and thereby, reduce the risk of making wrong weed control decisions.

Sowing different densities of *Echinochloa crus-galli* (15, 30, 45, 60, 75, 90, 105 and 120 m^{-2}) in drilled rice revealed that all densities of *E. crus-galli* adversely affected rice yield and yield attributes and the values decreased linearly as *E. crusgalli* density increased. A strong negative correlation of *E. crus-galli* density and biomass with all the yield attributes and grain yield was revealed. (Paradkar *et al.*, 1998).

Wellmann (1999) studied the influence of density and time of emergence of *Chenopodium album* and *Chamomilla recutita* on the competition between sugarbeet and weeds. Weed infestations of one species reaching the same dry matter caused almost the same shading and the same relative loss of sugarbeet dry matter, irrespective of the time of weed emergence.

Zhang *et al.* (1999) described the relationship between the density of *Euphorbia helioscopia* and wheat yield loss by straight line correlation. They also described spike number loss by straight line correlation. They also carried out investigations into the economic threshold for *E. helioscopia* which determined the weed densities at which herbicides should be applied.

2.2 Weed density – crop loss modelling

Cousens (1985) described a simple model using a rectangular hyperbola which has two meaningful parameters and found it to provide the best description of data. It was further substantiated by Zanin and Sattin (1988), Streibig *et al.* (1989), Caussanel *et al.* (1990), Wilson and Wright (1990), McLennan *et al.* (1991), Weaver (1991) and Norris (1992) among others.

Fredshavn *et al.* (1990) integrated a simple growth model based on an asymptotic sigmoid growth curve. They also examined the suitability of the model in analysing biomass production in relation to plant density and competition.

Lotz *et al.* (1990) used a dynamic model simulating the competition for light and water between broad leaved weeds and winter wheat to assess the observed small effects of weeds on yield in terms of the relative emergence time, physiological and morphological characteristics of weeds.

Kropff and Spitters (1991) introduced a new simple empirical model for early prediction of crop losses by weed competition. Their model related yield loss to relative leaf area of the weeds shortly after crop emergence using the relative damage coefficient q as the single model parameter. The model was derived from the hyperbolic yield density relationship and therefore accounts for the effects of weed density. It described a single relationship between crop yield over a wide range of weed densities and relative times of weed emergence.

Pantone and Baker (1991a) assessed the competitive ability of red rice, a weedy variety of rice and 'Mars' a cultivar of rice. Red rice was the dominant competitor and an average of one red rice plant reduced Mars grain yield per plant equal to the effect of four Mars plants. Using reciprocal yield model coefficients, grain yield losses of Mars, due to red rice densities of 4, 16, 25 and 300 plants m^{-2} were predicted to approximate 13, 37, 48 and 92 % respectively at a fixed cultivars density of 100 plants m^{-2}. Further, Pantone and Baker (1991b) fitted a response surface model consisting of non-linear yield density equations. Average yield / plant was taken as the dependent variable and the densities of competing plants were the independent variables.

Norris (1992) described the relationship between crop yield and *Echinochloa crus-galli* density by a rectangular hyperbolic function. The economic threshold density of *E. crus-galli* was also estimated .

Diaz *et al.* (1994) determined seed yield losses in dry peas caused by the effect of different plant densities of volunteer rape and tall oatgrass (*Arrhenatherum elatius* subsp *bulbosus*). A rectangular hyperbola was fitted to the relationships between seed yield losses and weed density. They also worked out the economic threshold densities of rape and tall oatgrass.

Leguizamon *et al.* (1994) studied the damage caused by the main weeds in soyabean. The damage functions presented correspond to a hyperbolic model adjusted to points obtained in different experiments, localities and years. The fits obtained clearly account for the variation in yield due to weed population in most cases. The intercept of the hyperbolic function allowed a tentative competitive hierarchy to be established among weed species. Restrictions on using weed density as an estimator of populations were examined.

Swinton *et al.* (1994a) expanded the original equation of Cousens (1985) hyperbolic crop yield model to account for multiple weed species. Further Swinton *et al.* (1994b) converted the densities of individual weed species to equivalent densities of the most competitive species. They then used the total competitive load which is the sum of individual density equivalents of all the weeds to fit the simple hyperbolic model thus reducing the dimensionality of the problem.

Aikman *et al.* (1995) developed a simple mechanistic model to simulate individual plant growth within monocultures. The model allowed for environmental factors and for competition for these factors with neighbouring plants. The model parameters could be determined easily by fitting the model to data from pure species stands. With no further adjustments the model gave good prediction of the growth of each of the component species in mixed-species stands. The model was used to evaluate the effects of different weed control strategies on crop and weed growth at different crop and weed densities, different relative seedling emergence times and in different environment.

Castro and Garcia (1995) developed an interactive microcomputer program named SEMAGI for sunflower (*Helianthus annuum*) to evaluate the potential yield reduction from multispecies weed infestation and from the parasitic weed broomrape *(Orobanche cernua / O. cumana*) and also to determine the appropriate selection of herbicides. The expert system related weed-infested crop yield, potential weed free yield, weed density and weed biomass. A relationship between weed density, weed size and equivalent biomass was established for any weed group.

Dieleman *et al.* (1995) used three empirical crop yield loss models to describe the interference of redroot pigweed (*Amaranthus retroflexus*) and

Powell amaranth (*A. powellii*) populations with soyabean. The model incorporating pigweed density and time of emergence gave the best description of soyabean yield loss in comparison with the two relative leaf area models. The relationship between relative leaf area and soyabean yield loss was best described by the one-parameter model estimating a relative damage coefficient 'q' rather than the two-parameter model that also estimated maximum expected yield loss. Empirical models that incorporate time of weed emergence represent a step towards improving predictions of yield loss. This was important for the selection of cost effective weed control strategies.

Kropff *et al.*(1995) introduced a two parameter model that accounted for a maximum crop yield loss by weed competition. The parameters were the relative damage coefficient (q) and a parameter that described the maximum yield loss caused by the weeds (m). The one and two parameter models were evaluated with data on the effects of weeds on rice (*Monochoria vaginalis* and *Echinochloa crus-galli*), sugarbeet (*Chenopodium album*, *Stellaria media* and *Polygonum persicaria*) and tomato (*Solanum ptycanthum*). Both models described the data on the effect of different weed densities and periods between crop and weed emergence fairly well.

Prasad *et al.*(1995) developed simple models to estimate the yield loss caused due to weed competition during initial as well as later stages of crop growth in sprouted rice under puddled conditions. These models were rectangular hyperbolic and were found to provide the best description of data. A close agreement between the expected and observed yield losses indicated a satisfactory performance of the models.

Scholes *et al.* (1995) conducted studies to measure the effect of velvetleaf on corn growth and yield. Velvetleaf was overseeded in corn rows and thinned to densities of 0, 1.3 ,4, 12 and 24 plants / m^2. Velvetleaf leaf area index and total biomass were positively correlated with velvetleaf density. Biomass per velvetleaf plant and corn biomass were correlated negatively with velvetleaf density. Maximum yield loss estimated by a hyperbolic yield reduction model was 37.2 % with a loss of 4.4 % per unit velvetleaf density.

Berti *et al.* (1996) presented a methodological approach to determine the optimum time to control weeds. A model was developed that accounted for the pattern of weed emergence and permitted the determination of timing of weed control that minimised economic loss due to weeds emerging both before and after treatments.

The influence of weeds on crop yield is not only dependent on weed-related factors such as density and time of emergence, but also on environmental and management factors that affect both the weed and crop through time. Chikoye *et al.* (1996) developed the first physiologically based dry bean (*Phaseolus vulgaris*) model that accounted for the influence of weed competition.

Debaeke (1996) discussed the potential applications of a general process-oriented model for two competing plant species, ALMANAC (Agricultural Land Management with Alternative Numerical Assessment Criteria) in decision making processes involved in weed management. It was designed to define integrated damage thresholds and management risks. Its use in a broad range of crops and varieties to assess the effects of crop and weed density, emergence data etc. were also explored.

Dunan *et al.* (1996) conducted weed removal experiments in northern Colorado during 1990-91 to assess the effect of duration of competition, weed density, weed competitiveness and crop density on irrigated seeded onions. A polynomial multiple regression model accounting for the duration of competition and weed load, explained 75 % of the variation in onion relative yield.

In a simple conceptual model of competition for resources, Goldberg and Griffith (1996) broke down the net interaction between plants into two distinct components; competitive effect on resources, or the rate at which resources are depleted by neighbouring plants and competitive response to resources, or the degree to which a target plant is limited by resource availability. This description suggested a number of ways in which predicting the impact of competition on individual plants could be simplified and made more general. They reported that the most important factor currently complicating general predictions about the outcome of competition was variation among sites.

Lindquist and Kropff (1996) used a simulation model for evaluating rapid leaf area expansion and leaf area index as potential indicators of improved rice competitiveness and tolerance to barnyard grass. Increasing early leaf area expansion rate reduced simulated barnyardgrass seed production and increased single year economic thresholds, suggesting that the use of competitive rice cultivars may reduce the need for chemical weed control. The model predicted that rice leaf area index at 70 to 75 days after planting was a good indicator of early leaf area expansion rate.

The crop weed interference relationship is a critical component of bio-economic weed management models. Lindquist *et al.* (1996) conducted experiments to determine the stability of corn velvetleaf interference relationships across year and locations. Two coefficients (I and A) of a hyperbolic equation were estimated for each data set using non-linear regression procedures. The I and A coefficients represent percentage corn yield loss as velvetleaf density approaches zero, and maximum percentage corn yield loss respectively. Results do not support the use of common coefficient estimates for all locations within a region.

Lotz *et al.* (1996) launched a large joint experimental programme within the European Weed Research Society to test simple yield loss models based on the relative leaf area of weeds and to compare these models with a hyperbolic density model. White mustard (*Sinapis alba*) was used as a model weed in plots of sugarbeet and spring wheat. They concluded that relative leaf area model gave a better description of yield losses by competition from weeds that emerge in flushes, than a model based on weed density. Their results strongly suggested that the predictive ability of the relative leaf area models needed to be improved before they can be applied in weed management.

Lotz *et al.* (1996) found that most data sets were better described by a model based on the relative leaf area of the weed than by a hyperbolic model based on weed density. The leaf area model accounted for part of the effect of different emerging times of the weed, whereas the density model did not. Their results strongly suggested that the predictive ability of the leaf area model needed to be improved before it can be applied in weed management system.

Parker and Murdoch (1996) carried out a field study on *Sinapis alba* and Avena sativa (oats) in a drilled crop of spring wheat . Five weed densities and all possible combinations were included. Ground cover, height and density were used to predict yield losses due to weed competition, using expanded versions of existing linear and non-linear models to accommodate two species. A linear model with relative cover and height of both species gave the best fit but the non-linear relative ground cover model contained fewer parameters and varied less over time, making it more suited to practical applications. Models with weed cover irrespective of species gave a poor description of the data. None of the models derived accounted for enough variance in yield losses to be used in a practical situation.

Swinton and Lyford (1996) introduced a test for evaluating hyperbolic yield response nested in a sigmoidal model. The test was used to discuss whether a flexible sigmoid provides a better fit to crop weed competition data than the hyperbolic alternative. They concluded that sample sizes larger than the one in weed science were required to reject the null hypothesis of hyperbolic response.

Toler *et al.* (1996) examined the competitive relationships between johnsongrass, smooth pigweed and soyabean and assessed the adequacy of an additive response model (ARM) and product response model (PRM) in predicting yield reduction due to multispecies weed populations. As monospecific johnsongrass density increased, reductions in soyabean seed yield were linear whereas experimental response patterns adequately characterised reductions in soyabean seed yield due to smooth pigweed interference. Based on calibrated monospecific response, the ARM and PRM generally projected higher soyabean seed yield reduction for multispecies weed population than that were observed. When crop production conditions were favourable and competitive effects of weeds were low, both models adequately predicted soyabean seed yield reduction. When dry condition unfavourable for crop production existed, the PRM best accomodated the interactive effects between johnsongrass, smooth pigweed and soyabean.

Vitta and Quintanilla (1996) compared simple regression models of crop yield losses based on weed density and weed leaf area using results obtained from field studies conducted in Spain during 1992-93 in fields of spring wheat with *Sinapis alba* as a model weed. Finally, three simple methods to assess weed cover were compared: visual, photographic and optic device assessment. Although all methods to assess weed cover correlated adequately with weed leaf area, visual estimates were the best to predict crop yield losses, perhaps because very low levels of weed leaf area could be distinguished visually better than by other methods.

Comprehensive, process-oriented simulation models which treat competition in a mechanistic rather than an empirical fashion can offer insight into relationships among competition, crop and weed density, relative time of emergence, various morphological and physiological traits and resource levels. They can also be used for prediction as part of a systems approach to weed management (Weaver, 1996). His paper reviewed the features of a number of recent simulation models of crop-weed competition, the species for which they have been parameterised and their applications. To date, these models have been used primarily to predict crop yield losses due to weed competition.

Acker *et al.* (1997) conducted experiments on linseed and autumn-sown field bean (*Vicia faba* (faba beans)) to test how well a relative leaf area-based yield loss prediction model estimated yield loss due to interference from *Stellaria media* or barley alone, or a combination of both *S. media* and barley. The model provided a better estimate of yield loss due to interference from barley than from *S. media* because of both the variability in crop yield response stemming from the plasticity of *S. media* and the generally minor crop yield response to *S. media* interference. It was shown that two weed species yield loss prediction models parameterised using data from single weed species experiments generally resulted in different estimates of yield loss in comparison with models parameterised using data from two weed species experiments.

Aibar and Zaragoza (1997) took data from a seven-year trial field and fitted it to several models. They concluded that logistic models were best adapted to the prevailing conditions, while simple models predicted satisfactorily only in particular infestation levels.

Bourdot *et al.* (1997) assessed the ability of a simple two parameter model based on the relative leaf area of weeds to describe grain yield losses in wheat. Wheat was sown at 100 and 300 plants / m^2 and oversown with *Brassica nigra* (0-1000 plants/ m^2). Results showed that the model could be simplified to a one-parameter model in this particular experiment. The rate at which crop yield declined with increasing relative weed leaf area did not vary between the times of leaf area determination or between wheat densities.

Debaeke *et al.* (1997) evaluated the ALMANAC model using data on wheat oat mixtures, differing in oat densities, the period of oat emergence, the data of suppression by herbicides and the wheat genotype. They also used additional data on rape and vetch (*Vicia sativa*) competition in spring wheat.

They correctly simulated the competitiveness of oats, oilseed rape and vetch. They suggested that the model was a reasonable tool for estimating damage thresholds in integrated weed control programmes.

Doyle (1997) made an examination of the role that mathematical modelling could have in developing integrated strategies involving reduced dependence on chemicals, for controlling weeds in crops. He concluded that given the complexity of the management system involved in integrated crop protection, mathematical modelling would seem to be a potentially valuable tool.

Guan *et al.* (1997) found a positive correlation between the rate of occurrence of *Alopecurus japonicus* and *Vicia sativa* and wheat yield. They presented a mathematical equation representing this relationship and established control targets for the two species.

Kropff *et al.* (1997) described different modelling approaches for crop weed interactions and weed population dynamics. They also discussed the opportunities to use these models for precision weed management, as well as the limitations due to insufficient insight in biological processes.

Lindquist and Mortensen (1997) calibrated and tested an ecophysiological model of interplant competition for light (INTERCOM) for maize-velvetleaf (*Abutilon theophrasti*) competition in Nebraska, USA. Results suggested that the ecophysiological models might be useful tools for exploring the causes and effects of crop weed competition.

Olesen *et al.* (1997) described a simulation model of the interactions between winter wheat and weeds. The model is based on the metabolic pool approach. They assessed the sensitivity of the crop model to different types of vertical distribution of leaf area. The results showed that the relative height of the weed canopy is more important than the vertical distribution function for the weed leaf area index.

Smith *et al.* (1997a) conducted field studies in which *Sinapis alba* and oats (*Avena sativa*) were broadcast as model weeds into a drilled crop of spring wheat. Ground cover, height, density and leaf area were used to predict yield loss due to weed competition, using expanded versions of existing hyperbolic models to accommodate both weed species. The practical use of such models was also discussed in relation to weed management decision models.

Smith *et al.* (1997b) constructed a Monte-Carlo simulation model to evaluate the practical use of the relative leaf area model as a method to predict consequent yield loss from weeds present at an early crop growth stage. The use of such models in a real life situation was discussed.

Economic assessment of weed management strategies in rice is dependent upon a quantitative estimate of the yield impact of a given weed population. To assist rice producers in making such assessments, VanDevender *et al.* (1997) developed a mathematical model to predict rice yield reduction as a function of weed density and duration of interference. The non-linear empirical model was a unique 3-dimensional adaptation of the Richards equation with four parameters. They concluded that predictions from the model would be useful and reliable in assessing the economic impact of weeds and in determining the feasibility of alternative weed control treatments for various field scenarios.

Yenish *et al.* (1997) measured yield loss of hard red spring wheat due to competition from common milkweed using the area of influence and additive competitive methods. The area of influence model had limited value. In an additive competition model, wheat yield was reduced by 47 % at the highest density of 12 common milkweed shoots m^{-2}. They reported that restrictions of common milkweed density due to factors other than competition limited yield loss response to the simple linear phase of both the non-linear rectangular hyperbolic and the linear square root function models.

Acker *et al.*(1998) used the graphical method of analysis designed to study the efficacy of herbicide mixtures, the additive dose model for analyzing the effect of two-weed species interference on crop yield.

Chen and Wang (1998) fitted equations for a model predicting yield losses in rape after weed infestation by *Sclerochloa kengiana, Polypogon frugax* and *Alopecurus aequalis.* The accuracy of the model for yield losses was 86.8 %. The economic threshold for weed control in rape fields was also calculated.

Garrett and Dixon (1998) modelled crop yield resulting from weed competition as a function of the economic threshold, the level of competition within the neighbourhood, neighbourhood size and the type and scale of weed pattern. They found that the systems most sensitive to weed spatial pattern were those with low economic thresholds, less competitive weeds, smaller neighbourhoods and aggregation at the neighbourhood scale.

Velu (1998) fitted three mathematical models (Gopertz, Richard's and Logistic) to values of the total biomass produced by three green gram (*Vigna radiata*) cultivars to determine the critical weed competition period and its impact on crop growth. The Gompertz model showed a high predictability for estimations of the total drymatter production of cultivars.

Weaver and Ivany (1998) modelled barley yield as a function of barley and weed density. Increasing densities of wild radish and wild oat reduced the number of barley heads primarily by interfering with tillering but wild oat also reduced barley 1000-kernel weight. Hemp-nettle and corn spurry had little effect on barley yield, except in a year of low barley yield potential.

Brain *et al.* (1999) developed a model of the interaction between crop : weed competition and herbicide dose using empirical models of the relationships between crop yield and weed biomass (related to weed density); weed competitiveness and weed biomass and weed biomass and herbicide dose. They suggested that the yield loss predictions be used to quantify the herbicide dose required to restrict yield loss to a given percentage.

Caton *et al.* (1999) developed the model DSRICE1 for analysing integrated weed management strategies for direct sown rice. The model was used to simulate competition for light between rice and two weeds, *Echinochloa oryzoides* (early watergrass) and *Ammania* spp. (redstem). Structural sensitivity analyses of rice in competition with the two weeds revealed that water depth effects and leaf area distributions strongly affected competition and shading by dead leaf and stem dry mass reduced total production.

A simulation model was built as a decisive aid for the management of five weed species in direct sown irrigated onion. (Dunan *et al.*, 1999). It predicted yield reduction caused by photosynthetically active radiation (PAR) according to the ratio of crop leaf area index (LAI) to weed LAI and respective light extinction coefficients (k). Input variables were plant density by species and average number of leaves by species. The model accurately described competitive interactions, taking into account respective plant densities, time of emergence and time of weed removal. The model can also be used to evaluate mechanisms of plant competition for sunlight.

Florez *et al.* (1999) developed an algorithm for predicting rice yield losses based on early assessments of multispecies weed infestations emerging in successive flushes within variable crop stands. Yield losses were predicted using hyperbolic models with independent variables describing the mixed-weed infestation in terms of density, leaf area index, dry matter m^{-2}, relative density (weed / (weed + rice)), relative leaf area (RLA), and a visual estimate of relative ground cover (RC).

Lindquist *et al.* (1999) estimated two coefficients (I and A) of a rectangular hyperbola equation using nonlinear regression procedures. The I and

A coefficients represented percentage maize yield loss as foxtail density approached zero and maximum percentage maize yield loss respectively. The results showed that the utility of using common coefficient estimates to predict future crop yield loss from foxtail interference between years or among locations within a region was limited.

McDonald and Riha (1999) modified ALMANAC to simulate maize-*Abutilon theophrasti* competition. The modified ALMANAC model was judged to be capable of distinguishing between environmental conditions that facilitate large yield losses and those that allow maize to outcompete *A. theophrasti.*

Ngouajio *et al.* (1999c) derived a flexible sigmoidal model relating crop yield to relative leaf cover of weeds. The model was shown to embody a hyperbolic, a symmetric sigmoidal and an asymmetric logistic model as special cases. A high accuracy was observed for yield description, and the four parameters of the model were estimated easily using a non-linear regression procedure. They found that the failure of the sigmoidal model to outperform the hyperbolic model was primarily due to the weak sigmoidal yield response and the relatively small sample sizes. The high flexibility of the model may allow the detection of special cases and thus minimize the risk of a wrong decision.

Stone *et al.* (1999) found that the most accurate equation describing the effect of Italian ryegrass interference was a simple linear regression: percentage wheat yield loss = 5.7 +(1.15 x percentage of ryegrass plant in the total plant population). Thus it may be possible to predict potential yield loss in wheat fields from Italian ryegrass interference by scouting.

Swanton *et al.* (1999) suggested mechanistic weed threshold crop competition models as a means of overcoming some of the limitations of empirically based threshold models. They suggested that a mechanistic approach to the development of weed threshold models was desirable since relative crop and weed responses to environmental factors, cultural practices and the dynamic nature of competition were considered.

Tu and Hu (1999) modelled the competitive effects of varying *Alopecurus aequalis* and wheat plant density. The models were capable of describing the competitive relationship between *A. aequalis* and wheat and predicting crop yield losses. These models were proposed to have applications in researching the economic thresholds for effective weed management and for the establishment of effective agro-ecosystems.

Vitta and Satorre (1999) validated a model of crop weed competition, based on parameters from the logistic biomass growth of both crop and weeds in monocultures under several sets of conditions. The model adequately described the dynamics of the competition between species when the relative yield total of the mixture was close to one, i.e. the slope and intercept of the regression between observed and simulated values were not significantly different from one and zero respectively. Sensitivity analyses indicated that final crop biomass was particularly affected by change in relative growth rate of the species. The simplicity of the model validated would allow its use as a tool to predict the outcome of competition and species relative importance, particularly when parameters needed to run more complex models are not available.

Werner (1999) tested the economic threshold model which has been developed at the University of Gottingen for weed control in winter oilseed rape in state wide trials. He calculated predicted losses and the relative weed coverage by the model.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The investigation "Relationship between weed density and yield loss in semi-dry rice" consisted of two field experiments laid out in the fields at the Agricultural Research Station, Mannuthy during the years 1999 and 2000.

3.1 General details

3.1.1 Experimental site and location

The experiments were conducted during the *Virippu* seasons (first crop season or early *Kharif*) of 1999 and 2000. Geographically, this area is situated at 10° 32' N latitude and 76° 10' E longitude and at an altitude of 22.5m above the mean sea level.

3.1.2 Soil and climatic conditions

The experimental site experienced typical humid tropical climate. The soil of the experimental site belongs to the laterite soil type (Order:Ultisols). These soils are of low to medium fertility. The soil was sandy clay loam in nature.

3.1.3 Cropping history of the fields

The experimental site was a double crop paddy wet land, where a semi-dry crop was taken during April-May to August-September and a transplanted crop during December to January every year. The land was usually left fallow during the summer season.

3.1.4 Rice variety used

The rice variety Kanchana (PTB 50) was used for the study. Kanchana is an early duration variety (105-110 days) suitable for all seasons. It is resistant to diseases such as blight and blast and pests like stem borer and gall midge.

Plate 2. A good crop of rice without weeds

Plates 3,4 & 5. A view of the effect of different densities of *Sacciolepis interrupta* and *Isachne miliacea* on rice

3.2 Experimental details

The experiments were laid out in a Randomised Complete Block Design (RCBD) as a 5^2 factorial experiment with the weeds *Sacciolepis interrupta* and *Isachne miliacea* as factors (Plates 2,3,4 & 5).

The levels of *S. interrupta* and *I. miliacea* were the densities 0, 2, 4, 16 and 32 plants per m^2 for each weed.

3.2.1 Experimental layout

Fig. 1. Layout of the experiment "Relationship between weed density and yield loss in semi-dry rice" in 1999

N

R_1	$S_{32}I_{16}$	S_0I_0	$S_{16}I_{32}$	S_0I_{16}	S_4I_{32}	S_2I_0	S_0I_2
	$S_{16}I_2$	$S_{32}I_4$	S_2I_{16}	$S_{32}I_2$	$S_{16}I_{16}$	S_4I_2	
	S_4I_{16}	S_2I_4	$S_{32}I_0$	$S_{16}I_4$	S_0I_{32}	S_0I_4	
	$S_{32}I_{32}$	$S_{16}I_0$	S_2I_{32}	S_4I_4	S_4I_0	S_2I_2	
R_2	$S_{32}I_0$	$S_{32}I_{16}$	$S_{16}I_4$	S_4I_2	S_2I_2	S_4I_2	
	$S_{16}I_0$	S_2I_4	$S_{32}I_2$	S_2I_0	S_4I_0	S_0I_2	
	$S_{32}I_{32}$	S_4I_{16}	$S_{16}I_2$	S_2I_{16}	S_0I_{32}	S_4I_{32}	
	$S_{16}I_{16}$	$S_{32}I_4$	S_0I_0	$S_{16}I_{32}$	S_4I_4	S_0I_{16}	S_0I_4
	Main		irrigation		channel		

S = *Sacciolepis interrupta*
I = *Isachne miliacea*

Fig. 2. Layout of the experiment "Relationship between weed density and yield loss in semi-dry rice" in 2000

N

R_1

$S_{16}I_{32}$	S_4I_2	$S_{32}I_2$	S_0I_4	$S_{32}I_{32}$	S_2I_{32}	S_2I_0	S_4I_{16}	S_0I_{32}	S_2I_2
$S_{32}I_0$	S_0I_{16}	$S_{16}I_4$	S_4I_0	$S_{32}I_4$	$S_{16}I_{16}$	$S_{16}I_0$	S_0I_0	S_4I_{32}	S_0I_2
S_4I_4	$S_{32}I_{16}$	S_2I_{16}	$S_{16}I_2$	S_2I_4	$S_{32}I_2$	$S_{16}I_{32}$	S_2I_4	S_0I_0	S_2I_0

$S_{32}I_{32}$	$S_{16}I_{16}$	$S_{32}I_{16}$	S_0I_{32}	$S_{32}I_0$	S_4I_0	S_4I_{32}	$S_{16}I_0$	S_2I_{32}	S_4I_2
$S_{16}I_4$	S_4I_{160}	$S_{32}I_4$	S_2I_{16}	S_0I_4	$S_{16}I_2$	S_0I_2	S_2I_2	S_4I_4	S_0I_{16}

Main irrigation channel

R_2

S = *Sacciolepis interrupta*
I = *Isachne miliacea*

Number of treatments = 25

Design = RCBD

Replications = 2

Total number of plots = 50

Gross plot size = 2×2 m^2

Net plot size = 1.6 ×1.4 m^2

Rice variety = Kanchana

Spacing = 15 cm ×10 cm

3.2.2 Field operations

Field operations were done as per the package of practices recommendation of Kerala Agricultural University (KAU, 1996).

3.2.3 Land preparation

The experimental area was well ploughed and levelled. Plots of 2×2 m^2 size were prepared by constructing bunds of 30 cm width and 30 cm height. Irrigation and drainage channels were provided at suitable intervals.

3.2.4 Sowing

The seeds of the rice variety Kanchana were dry dibbled along rows at a spacing of 15 cm × 10 cm @ 2-3 seeds per hole. The seed rate adopted was 80 kg/ha.

3.2.5 Fertilizer application

Urea (46% N), Super phosphate (18% P_2O_5) and Muriate of Potash (60% K_2O) were used for meeting the nutrient requirements. Fertilizer application was done as per the package of practices recommendation of Kerala Agricultural University (KAU, 1996) @ 70:35:35 kg of N, P_2O_5 and K_2O respectively. Half of the nitrogen and the full dose of phosphorus and potassium were applied basally at the time of sowing. Quarter dose of the nitrogen was applied at the active tillering stage and the remaining quarter at the panicle initiation stage.

3.2.6 Irrigation

The field was irrigated occasionally when there was a dry spell.

3.2.7 Weeding

Weeding was done so as to maintain the required densities of weeds as per the treatment requirements. The weed densities were maintained by thinning till 60 DAS. In weed free treatments, all the weeds were removed.

3.2.8 Plant protection

Methyl parathion (Metacid) @ 0.05 per cent was used for the control of rice bug.

3.2.9 Harvesting

The crop was harvested manually from the net plots at maturity. Threshing was done using a mechanical thresher. The produce was cleaned by winnowing and subsequently dried and weighed.

3.3 Observations recorded

3.3.1 On rice

3.3.1.1 Date of emergence after sowing

Date of emergence of rice after sowing could not be adequately recorded because of the uneven sprouting of the seeds. However, it was observed that most of the plants emerged after 6-10 days of sowing.

3.3.1.2 Height at 60 DAS

The height of ten sample hills was recorded from ground level to the tip of the longest leaf at 60 DAS.

3.3.1.3 Leaf area at 60 DAS

The length and breadth of the third leaf from the top of the middle tiller was taken for ten hills randomly for every plot. Then the leaf area was calculated using the formula, Length $\times$Breadth$\times$0.75 (Gomez, 1972).

3.3.1.4 Mean number of tillers at 60 DAS

Ten hills were selected randomly to find the number of tillers per hill.

3.3.1.5 Height at harvest

The height of ten sample rice hills was recorded from the ground level to the tip of the longest panicle at harvest.

3.3.1.6 Leaf area at harvest

The length and breadth of the boot leaf of the middle tiller was taken for ten hills chosen randomly for every plot. Then the leaf area was worked out using the formula, Length × Breadth × 0.75. This was multiplied by the number of leaves per tiller, the number of tillers per hill and the plant density per m^2 to find the leaf area per m^2.

3.3.1.7. Mean number of tillers at harvest

The number of tillers was recorded for ten hills chosen randomly in every plot.

3.3.1.8 Mean number of productive tillers at harvest

From the ten hills selected for counting the number of tillers, the number of productive tillers was also recorded.

3.3.1.9 Total bio-mass at harvest

The aboveground portion of three rice hills was cut close to the ground level from within the net plot for every plot. This was then oven dried at 80±5°C for 72 hours to compute the drymatter production.

3.3.1.10 Grain yield

The crop was harvested from each net plot area, threshed and winnowed to obtain the grain yield from every plot. The grain and chaff weight were recorded in g/m^2. Proportional yield loss was calculated by subtracting the yield from the weedfree yield and then dividing by the weedfree yield.

3.3.1.11 Straw yield

After threshing, the straw was weighed separately and the weight was recorded in g/m^2.

3.3.1.12 1000 grain weight

One hundred grains were counted from every plot, weighed and multiplied by ten to get 1000 grain weight which was expressed in grams.

3.3.2 On weeds

3.3.2.1 Date of emergence after sowing rice

Both *S. interrupta* and *I. miliacea* emerged in patches in the field making it difficult to assess the exact day of emergence. However it was concluded that more than 50% of the *S. interrupta* emerged in the first week of sowing of rice. The mild raking done while sowing rice facilitated the weed seeds to come up to the surface to sprout. However, *I. miliacea* emerged a few days later than *S. interrupta* i.e. during the second week after sowing rice, which was its peak period of germination.

3.3.2.2 Mean number of tillers at 60 DAS

Mean number of tillers was computed for *S. interrupta* by selecting ten plants at random and counting the number of tillers in each plant. The number of tillers per *I. miliacea* plant could not be counted because of its spreading nature, which makes it difficult to identify individual plants.

3.3.2.3 Height at 60 DAS

The height of *S. interrupta* at 60 DAS was recorded by choosing ten plants from every plot and measuring from ground level to the tip of the tallest tiller. Since *I. miliacea* was of trailing nature, it was decided not to record its height since the data might be misleading.

3.3.2.4 Mean number of tillers at harvest of rice

Ten *S. interrupta* plants were chosen at random and their tillers were counted. For finding out the number of tillers of *I. miliacea,* a 0.5m × 0.5m quadrat was used and the number of *I. miliacea* tillers in the enclosed area was recorded.

3.3.2.5 Height at harvest of rice

The height of *S. interrupta* at harvest of rice was measured by selecting ten plants from every plot and measuring the height from the ground level to the tallest tiller. The height of *I. miliacea* was not recorded because its height may not give a true picture of its growth owing to its spreading nature.

3.3.2.6 Drymatter production at harvest of rice

The drymatter production of both the weeds was recorded by marking an area of 0.5m × 0.5m using a quadrat within the net plot area. The above ground parts of the weeds were then cut and collected separately. This was then dried in a hot air oven at 80±5°C for 72 hours and weighed.

A few other observations like the leaf area of *S. interrupta*, number of leaves per tiller of paddy, number of leaves per tiller of *S. interrupta*, number of leaves per tiller of *I. miliacea* were also recorded. The factors for finding the leaf area of *S. interrupta* and *I. miliacea* based on their length and breadth were also computed using the graphical method.

3.4 Data analysis

The data collected in both the years were analysed using the statistical package 'MSTAT' (Freed, 1986).

3.5 Model-fitting

The entire model fitting was done using the statistical package 'STATISTICA' (StatSoft Inc., 1995). Models were fitted for the mean values of the treatments.

3.5.1 Fitting of single-weed density models

The following single weed density- crop loss models were used in the study.

(1) The rectangular hyperbolic model proposed by Cousens (1985) in the form

$$Y_L = \frac{Id}{1 + Id/A}$$

relating percentage yield loss (Y_L) to the weed density (d) was fitted for the densities of *S. interrupta* and *I. miliacea* separately. In this model the parameters I and A are interpreted as the percentage yield loss as the weed density approaches zero and the percentage yield loss as the weed density approaches infinity respectively.

(2) The model proposed by Hakansson (1983)

$$Y_L = \frac{ad^b}{1 + ad^b}$$

relating proportional yield loss (Y_L) to weed density (d) was also fitted for the densities of *S. interrupta* and *I. miliacea* and used for comparison with other models. Here a and b are the parameters associated with the model.

(3) The empirical model proposed by Watkinson (1981) is given by

$$Y_L = 1 - (1 + ad)^{-b}$$

where Y_L is the proportion of yield lost , d represents the density of *S. interrupta* or *I. miliacea* and a and b are the parameters associated with the model. This was also fitted to the data for comparative evaluation with other models.

(4) The second model proposed by Watkinson (1981) was also fitted for the weeds separately. The model is given by

$$Yc = Ywf \, / \, (1 + \beta Nw)^b$$

where

Yc = the crop yield in a unit area

Ywf = weed free yield from the same unit area

Nw = weed density in the same unit area

β, b = parameters

(5) The model proposed by Swinton and Lyford (1996) using the MMF (Morgan-Mercer-Flodin) model (Morgan et al., 1975) was also fitted for crop yield against weed density. The model takes the form,

$$Y = \frac{\beta\gamma + \alpha D^\delta}{\gamma + D^\delta}$$

where Y is the crop yield, D is the weed density, α is the minimum yield or lower asymptote as weed density approaches infinity, β is the maximum yield (weed-free yield), γ is the curvature measure that determines the point at which yield reaches its lower asymptote and δ is the curvature measure that determines the point at which yield begins to decline at a decreasing rate.

(6) Ngouajio et al. (1999c) improved upon the Swinton and Lyford (1996) model to include crop density and arrived at the model

$$Y = \frac{\beta\gamma + \alpha\left(\frac{Dw}{Dc}\right)^{\delta}}{\gamma + \left(\frac{Dw}{Dc}\right)^{\delta}}$$

where Y is the crop yield, Dw is the weed density, Dc is the crop density and α, β, γ and δ are parameters. This model was fitted for the densities of *S. interrupta* and *I. miliacea* separately.

(7) A simple one parameter expression for yield loss (Y_L) as a function of the relative weed density (Nw/Nc) where Nw is the number of weeds m^{-2} and Nc the number of crop plants m^{-2} proposed by Kropff and Spitters (1991) given by

$$Y_L = \frac{a\frac{Nw}{Nc}}{1 + a\frac{Nw}{Nc}}$$

was also fitted for the data. Here the parameter 'a' characterizes the competitive effect of the weed on the crop.

(8) The model proposed by Schweizer (1973) which relates proportion of yield lost (Y_L) to weed density (d) was also fitted to the data. The model is given by

$$Y_L = ad + bd^2 + cd^3$$

where a, b and c are the parameters associated with the model.

(9) The model proposed by Hammerton (1964) was also fitted to the data for comparison with the other models. This model also uses weed density (d) as the independent variable and the proportion of yield lost (Y_L) as the dependent variable. The model is given by

$$Y_L = ad + bd^2$$

where a and b are the parameters associated with the model.

(10) Covarelli (1984) proposed a model to predict crop yield losses which was also fitted to the data for comparison with other models. The model is given by

$$Y_L = ad$$

where Y_L represents the proportional yield loss, d the weed density and a is the parameter associated with the model.

(11) Marra and Carlson (1983) related proportional yield loss (Y_L) to weed density (d) using the model

$$Y_L = ad^b$$

where a and b are the parameters associated with the model. The data was fitted to this model and the observed and predicted yield losses were calculated.

(12) The model proposed by Dew (1972) was also fitted to the single weed density data and the fit was examined. The model takes the form,

$$Y_L = a\sqrt{d}$$

where Y_L represents the proportional yield loss, d the weed density and 'a' the parameter associated with the model.

(13) Weise (1971) proposed a model which is given by

$$Y_L = ad + b\sqrt{d}$$

where Y_L represents the proportional yield lost, d the weed density and a, b represent the parameters associated with the model. The observed and predicted values were fitted graphically for comparison with other models.

(14) Wilson and Cussans (1983) proposed a model which takes the form

$$Y_L = b\,(1 - \exp(-ad))$$

where Y_L represents the proportional yield loss, d the weed density and a, b represent the parameters associated with the model. This model was also fitted and curves plotted for the observed and expected yield losses for evaluation of its relative efficiency over the other models.

(15) The model proposed by Zakharenko (1968) given by

$$Y_L = 1 - \exp(-ad)$$

was also fitted to the data relating proportional yield loss (Y_L) to weed density (d). Here 'a' represents the parameter associated with the model. The observed and expected yield losses were plotted graphically.

(16) The model proposed by Chisaka (1977) relating proportional yield loss (Y_L) to weed density (d) given by

$$Y_L = \frac{ad}{1 + ad}$$

was also fitted to the data and the predicted yield loss was calculated. Here 'a' represents the parameter associated with the model. The observed and predicted proportional yield losses were plotted graphically.

(17) Wilcockson (1977) proposed a model given by

$$Y_L = \frac{ad}{1 + bd}$$

which was also fitted to the data to study the feasibility of the model. Here Y_L represents the proportional yield loss and d the weed density and a, b the parameters associated with the model. The observed and predicted yield losses were calculated and plotted graphically.

(18) Hakansson (1983) also proposed the model given by

$$Y_L = \frac{ad + bd^2}{1 + ad + bd^2}$$

where Y_L represents the proportional yield loss, d the weed density and a, b are the parameters. This model was also fitted and compared with the other models.

(19) The model proposed by Carlson et al. (1981) relating proportional yield loss (Y_L) to weed density (d) was also fitted to the data. The model is given by

$$Y_L = \frac{ad + bd^2}{(1 + cd)^2}$$

where a, b and c are the parameters associated with the model. The data were fitted graphically using the above equation.

Further, other plausible models suggested by Cousens (1985) like

$$Y_L = c\left(1-(1+ad)^{-b}\right)$$

$$Y_L = \frac{ad+bd^2}{1+cd+fd^2}$$

$$Y_L = ad+bd^2+cd^3+fd^4$$

$$Y_L = ad^b+cd^f$$

were tested for their fitness with the data. Here Y_L represents the proportional yield loss, d the weed density and a, b, c and f the parameters.

3.5.2 Fitting of multi- species models

Rice eco-system is usually infested by a mixed stand of weeds belonging to more than one species. Hence to explain their combined effects, which may not be often the sum of their individual effects, we have to depend on multi-species models. Most of the multi species models based on weed densities and yield loss were fitted to the data and discussed .

(1) Swinton et al. (1994a) expanded the original equation of Cousens' (1985) hyperbolic model to account for multiple weed species. The multivariate form of the model is given by

$$Y_L = \frac{\sum I_i d_i}{1+\frac{\sum I_i d_i}{A}}$$

where Y_L is the percentage yield loss, d_i the density of the i^{th} weed (i = 1 to n, for n weed species) and I_i and A are the parameters to be estimated from the data. I_i represents percentage crop yield loss associated with the first weed of species i per unit density, as weed density of the first weed species approaches zero and A represents the maximum percentage crop yield loss as weed density of the first weed species approaches infinity. A test of goodness of fit was performed for the above model and the observed and predicted yield losses were represented graphically.

(2) Swinton et al. (1994b) proposed that the initial slope parameters (I_1 and I_2 for the two weed species in the study) could be used to calculate competitive indices for each weed species. That was accomplished by dividing the lowest I value by the largest I value. The density of the weed with the lowest I value is then multiplied by the ratio obtained in the previous step, thus converting its numbers to the equivalent density of the weed with the highest I value. The total competitive load would then be the sum of density equivalents of both species. The multiple weed species field data were plotted using the equation.

$$Y_L = \frac{Iw}{\left(1 + \frac{Iw}{A}\right)}$$

where Y_L is the percentage crop yield loss, I is the largest I value from the most competitive species and w is the total density equivalent.

(3) Berti and Zanin (1994) assumed a hypothetical species characterized by parameters I and A both equal to 100 which was taken as the reference species for finding the total competitive effect of a mixed infestation. The density of each weed species of the mixed infestation was transformed into Density Equivalent (Deq) defined as the density of the reference species which determines a percent yield loss (Y_L) equal to that caused by the weed being examined at the density observed. For species j which has the parameters Ij and Aj, the Deqj is then

$$Deqj = \frac{Ij\,Dj}{100 + Ij\,Dj\left(\frac{100}{Aj} - 1\right)}$$

The total competitive effect of a mixed infestation is then given by

$$Y_L = \frac{100\,\text{Deqt}}{1 + \text{Deqt}}$$

with $\text{Deqt} = \sum_j \text{Deqj}$ for the j weed species present. This model was fitted to the data and the predicted yield loss was calculated.

3.5.3 Fitting of new models

Models such as

$$Y_L = a + bd_1 + cd_1^2 + dd_2$$

$$Y_L = a + bd_1 + cd_2$$

$$Y_L = a + bd_2 + cd_2^2 + dd_1$$

$$Y_L\,(\%) = a + bd_1 + cd_2 + dd_1^2 + ed_1d_2 + fd_2^2$$

where Y_L – proportional yield loss of paddy
d_1 – density of *S. interrupta*
d_2 – density of *I. miliacea* and
$Y_L(\%)$ – percentage yield loss of paddy

were also fitted to the yield loss – weed density data of the two weeds and their parameters were estimated.

3.6 Estimation of the threshold weed densities

The threshold weed densities of *S. interrupta* and *I. miliacea* were calculated based on a fixed cost notion i.e., the total economic input of hand weeding per hectare. The economic losses were computed based on the yield loss per hectare for all the weed combinations. The selling price of paddy fixed at the Agricultural Research Station, Mannuthy was taken as the standard, as also the labour costs.

The threshold weed densities hence could be defined as the maximum permissible weed densities that cause a yield loss at par with the fixed cost.

Threshold line represents the boundary beyond which control measure is mandatory. Along the threshold line, the yield loss is equal to the cost of weed control. A logical variable was defined which takes the value '0' when there is no necessity for handweeding and '1' when handweeding is warranted i.e. when the economic loss exceeds the cost of weed control.

RESULTS

4. RESULTS

The results of the experiment conducted at ARS, Mannuthy during the periods May 1999 to September 1999 and May 2000 to September 2000 are discussed below. Though only the experiment conducted during 1999 formed part of the research work, the results ensuing from the experiment conducted during 2000 are also considered so as to improve the fitness of the models.

The following observations were recorded

(a) On the Crop

(i) Height at 60 DAS(Days after sowing)

(ii) Leaf area at 60 DAS

(iii) Mean number of tillers at 60 DAS

(iv) Height at harvest

(v) Leaf area at harvest

(vi) Mean number of tillers at harvest

(vii) Mean number of productive tillers at harvest

(viii) Total bio-mass at harvest

(ix) Grain yield

(x) Straw yield

(xi) 1000 grain weight

(b) On the weeds

(i) Mean number of tillers at 60 DAS

(ii) Height at 60 DAS

(iii) Mean number of tillers at harvest of rice

(iv) Height at harvest of rice

(v) Dry matter production at harvest of rice

As a prelude for fitting the model the observations on the above said characters were analysed as a 5^2 factorial experiment.

Table 1a. Parameters recorded on paddy

Treatments	Height at 60 DAS (cm)		Leaf area per leaf at 60 DAS (cm^2)		No. of tillers at 60 DAS		Height at harvest (cm)		Leaf area per leaf at harvest (cm^2)		No. of tillers at harvest	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
S_0I_0	66.00	51.30	21.32	28.37	10.50	12.40	70.50	68.23	23.64	17.92	11.50	7.20
S_0I_2	65.00	45.60	17.74	25.04	10.20	9.70	71.25	65.05	21.39	17.43	10.90	7.15
S_0I_4	64.25	47.40	19.13	24.06	10.00	10.90	65.25	66.95	23.77	17.12	11.10	7.20
S_0I_{16}	60.75	49.20	19.13	21.31	8.80	9.80	63.75	68.93	17.58	17.59	9.80	7.95
S_0I_{32}	60.00	50.5	18.68	23.00	8.20	11.70	63.25	70.20	19.33	14.66	8.90	6.05
S_2I_0	61.00	45.90	16.13	27.83	9.00	11.90	67.25	65.25	19.27	15.86	10.60	6.15
S_2I_2	60.75	50.60	15.45	28.28	8.80	11.20	66.75	67.93	19.50	15.08	9.80	6.95
S_2I_4	60.25	44.40	13.83	21.67	8.75	9.00	66.00	60.93	17.99	13.59	10.10	6.55
S_2I_{16}	60.00	54.50	15.40	26.38	8.30	10.80	65.75	69.23	18.50	16.61	9.10	6.10
S_2I_{32}	57.00	47.30	14.79	27.84	6.90	10.90	63.00	64.95	17.02	15.02	8.50	5.30
S_4I_0	59.50	47.30	15.75	22.25	5.00	8.50	65.25	67.50	17.99	13.68	11.00	8.05
S_4I_2	58.75	47.10	15.05	28.10	5.20	8.50	63.00	66.30	16.23	16.41	9.30	7.15
S_4I_4	57.50	53.80	13.51	27.32	5.00	11.20	62.75	72.15	18.47	16.42	7.30	6.70
S_4I_{16}	57.25	53.90	13.32	26.00	4.80	9.40	62.50	68.33	16.01	15.66	6.30	6.50
S_4I_{32}	56.00	53.00	11.70	26.13	4.30	9.70	61.25	69.05	14.87	15.56	6.90	5.35
$S_{16}I_0$	57.00	44.70	12.21	22.25	5.20	8.80	62.75	65.83	14.36	16.34	5.40	5.80
$S_{16}I_2$	56.75	48.40	11.20	24.93	5.50	10.30	60.25	69.50	14.84	14.43	5.80	5.15
$S_{16}I_4$	55.75	50.30	9.04	25.85	4.90	8.30	58.00	62.00	13.49	14.92	4.90	6.20
$S_{16}I_{16}$	55.50	53.00	8.98	30.08	4.80	10.60	56.25	66.73	12.74	16.07	4.70	4.85
$S_{16}I_{32}$	54.00	55.40	9.99	30.95	4.70	9.70	54.25	66.98	10.67	14.88	4.30	6.25
$S_{32}I_0$	55.00	48.50	9.62	21.95	4.85	8.50	60.75	61.45	12.74	13.02	5.20	4.70
$S_{32}I_2$	54.50	58.50	10.35	26.08	4.75	10.40	59.25	72.00	11.76	18.58	5.00	6.00
$S_{32}I_4$	54.00	50.80	10.26	23.20	4.35	7.70	56.75	65.68	10.50	13.97	4.30	4.75
$S_{32}I_{16}$	53.50	55.60	10.42	27.69	4.26	8.50	53.50	72.35	11.00	19.86	4.20	4.70
$S_{32}I_{32}$	53.00	48.80	10.49	23.77	4.54	9.40	53.75	68.18	10.49	14.66	4.00	5.00
Sem	0.2502	1.0553	0.3572	0.7222	0.1311	0.3539	0.3404	0.6333	0.2683	0.5884	0.0416	0.1392
LSD(0.05)	0.7303	3.0804	1.0426	2.1081	0.3827	1.0330	0.9936	1.8486	0.7832	1.7175	0.1214	0.4063

LSD - Least Significant Difference

Table 1a. Contd…

Treatments	No. of productive tillers at harvest		Total drymatter at harvest (g m^{-2})		Grain yield (g m^{-2})		Straw yield (g m^{-2})		1000 grain weight	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
S_0I_0	11.20	7.15	783.35	1607.32	173.00	173.25	870.54	687.50	24.48	22.96
S_0I_2	10.15	6.85	775.98	1592.63	146.20	150.00	754.46	575.00	23.94	20.09
S_0I_4	9.50	7.15	627.37	1470.78	136.16	159.38	716.52	637.50	24.16	21.37
S_0I_{16}	8.90	7.85	605.68	1457.40	123.88	11.38	676.34	662.50	23.53	21.31
S_0I_{32}	8.90	5.80	567.37	1283.41	122.76	147.75	656.25	575.00	23.29	20.44
S_2I_0	10.50	6.15	526.96	1412.75	125.00	173.00	651.79	550.00	22.81	20.46
S_2I_2	9.80	6.55	501.3	1200.15	115.00	146.25	616.07	443.75	22.76	20.79
S_2I_4	10.00	6.15	498.01	1063.59	117.19	107.88	625.00	425.00	22.55	20.39
S_2I_{16}	9.05	5.10	456.32	1110.01	111.61	123.88	571.43	512.50	23.46	23.28
S_2I_{32}	8.25	4.90	428.03	1012.84	84.82	99.13	424.11	525.00	23.71	22.24
S_4I_0	10.75	7.40	515.20	1305.48	111.61	116.00	535.71	500.00	22.75	21.51
S_4I_2	9.20	6.30	498.90	1181.22	110.49	118.38	524.55	600.00	22.69	22.69
S_4I_4	7.30	6.35	462.56	1124.03	100.45	153.13	488.84	525.00	22.84	22.12
S_4I_{16}	6.25	5.55	439.72	1124.83	106.03	131.88	502.23	525.00	21.49	23.18
S_4I_{32}	6.50	5.05	401.92	1074.58	99.33	108.38	459.82	500.00	21.57	21.98
$S_{16}I_0$	5.30	5.45	410.48	1109.98	91.52	83.25	497.77	387.50	21.91	22.63
$S_{16}I_2$	5.20	4.70	370.03	943.58	90.40	68.38	484.38	350.00	21.23	21.09
$S_{16}I_4$	4.50	5.95	351.82	795.89	80.36	58.63	417.41	350.00	20.97	19.84
$S_{16}I_{16}$	4.10	4.50	350.41	752.54	89.29	88.00	428.57	412.50	20.12	21.53
$S_{16}I_{32}$	4.05	6.10	332.84	721.10	84.82	94.50	421.88	481.25	19.88	20.76
$S_{32}I_0$	4.90	4.10	299.83	571.58	56.92	60.88	284.60	331.25	20.59	21.04
$S_{32}I_2$	4.60	5.70	297.41	474.75	47.99	57.10	265.63	481.25	20.00	21.81
$S_{32}I_4$	4.30	4.00	298.33	456.92	45.76	49.25	200.89	281.25	19.78	22.01
$S_{32}I_{16}$	4.00	4.50	294.51	437.31	43.53	60.50	18527	387.50	19.60	22.69
$S_{32}I_{32}$	3.80	4.40	287.73	447.73	45.76	27.13	198.66	400.00	19.59	21.62
SEm	0.0841	0.1365	2.3291	13.8735	1.5079	6.9258	4.5967	23.3269	0.1028	0.226
LSD (0.05)	0.2455	0.3984	6.7985	40.4959	4.4015	20.2160	13.4175	68.0897	0.3001	0.6597

Table 1b. Parameters recorded on *S. interrupta* and *I. miliacea*

Treatments	No. of tillers of *S. interrupta* at 60 DAS		Height of *S. interrupta* at 60 DAS (cm)		No. of tillers of *S. interrupta* at harvest of rice		Height of *S. interrupta* at harvest of rice (cm)		Drymatter production of *S. interrupta* at harvest of rice(g m^{-2})		Drymatter production of *I. miliacea* at harvest of rice (g m^{-2})	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
S_0I_0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S_0I_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	200.0	250.0
S_0I_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	250.0	180.0
S_0I_{16}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	290.0	160.0
S_0I_{32}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	320.0	470.0
S_2I_0	13.9	3.7	92.7	54.4	16.1	8.1	103.1	107.4	220.0	150.0	0.0	0.0
S_2I_2	13.2	3.8	89.4	56.0	15.9	6.5	102.9	113.8	235.0	270.0	190.0	100.0
S_2I_4	12.9	5.3	89.2	56.2	15.3	6.3	101.0	115.8	170.0	160.0	240.0	160.0
S_2I_{16}	12.3	5.3	87.7	67.1	14.7	8.2	101.7	112.0	135.0	150.0	250.0	160.0
S_2I_{32}	11.1	3.4	88.1	56.4	14.1	6.8	97.3	120.2	195.0	150.0	260.0	380.0
S_4I_0	12.6	6.4	91.5	55.3	14.9	8.3	100.7	117.3	260.0	350.0	0.0	0.0
S_4I_2	11.2	5.5	89.0	58.5	14.2	8.2	101.3	11.3	290.0	190.0	80.0	140.0
S_4I_4	11.1	5.5	88.8	69.7	13.2	8.6	100.3	114.7	195.0	240.0	120.0	190.0
S_4I_{16}	10.9	6.1	88.2	60.5	12.5	10.9	98.6	117.1	220.0	130.0	110.0	210.0
S_4I_{32}	10.3	5.7	87.1	69.6	12.3	9.5	93.4	116.1	200.0	240.0	120.0	240.0
$S_{16}I_0$	10.7	5.2	89.4	61.6	13.4	8.4	100.6	116.9	300.0	300.0	0.0	0.0
$S_{16}I_2$	9.7	4.8	87.9	69.7	13.2	9.9	100.1	121.5	380.0	400.0	70.0	80.0
$S_{16}I_4$	9.3	3.9	86.4	55.6	12.7	10.2	97.4	119.7	420.0	270.0	80.0	130.0
$S_{16}I_{16}$	8.4	5.5	85.6	69.6	12.0	9.8	92.3	118.9	390.0	220.0	109.0	140.0
$S_{16}I_{32}$	7.6	4.1	83.2	75.6	11.1	9.6	93.7	124.2	320.0	400.0	110.0	160.0
$S_{32}I_0$	9.8	5.2	88.2	61.2	11.2	8.8	98.9	126.3	450.0	380.0	0.0	0.0
$S_{32}I_2$	9.1	4.1	86.3	72.8	10.3	10.8	96.3	133.8	440.0	610.0	60.0	70.0
$S_{32}I_4$	8.8	5.0	85.1	72.9	9.7	9.9	95.7	126.0	430.0	580.0	60.0	70.0
$S_{32}I_{16}$	8.3	5.4	83.9	80.7	9.4	9.4	93.4	129.0	430.0	550.0	70.0	130.0
$S_{32}I_{32}$	7.2	5.9	81.2	71.1	8.6	9.3	91.2	128.4	400.0	490.0	80.0	150.0
SEm	0.0751	0.2509	0.2234	1.698	0.0387	0.3003	0.3127	1.4938	1.4142	14.53	1.2984	13.01
LSD (0.05)	0.2192	0.7324	0.6521	4.9564	0.1130	0.8766	0.9128	4.3603	4.1280	42.41	3.7899	37.9754

4.1 Weed density effects on crop and weeds

4.1.1 Effect on crop

(i) Height of paddy at 60 DAS

The presence of the weeds *S. interrupta* and *I. miliacea* had significant influence on the height of paddy at 60 DAS in 1999. However the difference in height between the weed free treatments and weedy treatments in 2000 was not significant. The data are presented in Table 1a.

(ii) Leaf area at 60 DAS

The length of paddy leaves at 60 DAS was significantly influenced by the presence of *S. interrupta* and was relatively unaffected by the presence of *I. miliacea* in 1999. However the breadth of paddy leaves was not affected by both the weed species in 1999. As the length of paddy leaves were influenced by the presence of *S. interrupta* the leaf area was also found to be affected by the presence of *S. interrupta.* However in the year 2000, the leaf area of paddy was found to be relatively unaffected by the effect of *S. interrupta* and *I. miliacea.* The data are presented in Table 1a.

(iii) Mean number of tillers at 60 DAS

The number of tillers of paddy at 60 DAS was reduced significantly due to the presence of both *S. interrupta* and *I. miliacea* in the year 1999. However the number of tillers of paddy at 60 DAS was found to be unaffected by the presence of *S. interrupta* and *I. miliacea* in the year 2000.

(iv) Height at harvest

Both *S. interrupta* and *I. miliacea* were found to have significant influence on the height of paddy at harvest in 1999. However in 2000, the height of paddy was not influenced by the presence of the two weeds.

(v) Leaf area at harvest

Leaf area of paddy at harvest was found to be significantly influenced by the presence of *S. interrupta* and *I. miliacea* in 1999. But in 2000, *S. interrupta* alone has affected the leaf area of paddy.

(vi) Mean number of tillers at harvest

The individual effects of *S. interrupta* and *I. miliacea* as also their combined effect were found to be significant on the mean number of tillers of paddy. Both the weeds were found to reduce the number of tillers in paddy. But in 2000, only *S. interrupta* reduced the number of tillers in paddy.

(vii) Mean number of productive tillers of paddy at harvest

In both the years 1999 and 2000, *S. interrupta* was found to reduce the number of productive tillers of paddy. *I. miliacea* also had some significant effect in reducing the number of productive tillers in paddy in 1999.

(viii) Total bio-mass at harvest

S. interrupta and *I. miliacea* significantly reduced the bio-mass of paddy at harvest in both the years 1999 and 2000.

(ix) Grain yield

The grain yield of paddy was influenced significantly by *S. interrupta* in both the years. However in 1999, *I. miliacea* also had some influence on the grain yield of paddy (Appendix 1a).

(x) Straw yield

S. interrupta reduced the straw yield of paddy in both the years.

(xi) 1000 grain weight

In the year 1999, the test weight or 1000 grain weight of paddy was found to be reduced by the presence of the weeds *S. interrupta* and *I. miliacea.* But in 2000, there was no significant influence in test weight of paddy by the weeds.

4.1.2. Effect on weeds

(i) Mean number of tillers at 60 DAS

The number of tillers of *S. interrupta* was significantly reduced in 1999 and 2000 due to intra-specific competition between *S. interrupta* plants. But in 1999, *I. miliacea* was also found to have had a significant influence on determining the number of tillers of *S. interrupta*. This shows the presence of both inter and intra-specific competition in *S. interrupta* in 1999 (Table 1b).

(ii) Height at 60 DAS

In 1999, the height of *S. interrupta* was reduced both due to intra-specific competition and interspecific competition between weeds. But in the year 2000, only intra-specific competition had a significant effect on the height of *S. interrupta.*

(iii) Mean number of tillers at harvest of rice

The number of tillers of *S. interrupta* at harvest of rice was found to be significantly influenced by the presence of both *S. interrupta* and *I. miliacea* in 1999. However, there was only intraspecific competition that affected the number of tillers of *S. interrupta* in 2000.

(iv) Height at harvest of rice

The height of *S. interrupta* at harvest stage of rice was found to be significantly affected by intraspecific competition in the years 1999 and 2000. There was also significant interspecific competition between *S. interrupta* and *I. miliacea* affecting the height of *S. interrupta* in the year 1999.

(v) Drymatter production at harvest of rice

The drymatter production of *S. interrupta* was affected significantly by intraspecific and interspecific competition in 1999. But in 2000, the drymatter production of *S. interrupta* was found to be affected by intraspecific competition only.

The drymatter production of *I. miliacea* was significantly affected by the presence of *S. interrupta* and *I. miliacea* in the year 1999. However the influence of *S. interrupta* alone was found to be significant in 2000 (Appendix 1b).

To sum up, most of the weed characteristics observed did influence the crop. The extent of influence especially based on the individual weed densities as also on their combined densities at varying levels can be well depicted by fitting suitable models.

Various researchers have studied single weed crop models. The adaptability of some well-known models has been tried here.

4.2 Predicting yield losses from weed density:

4.2.1. Prediction using single species models:

The hyperbolic equation of Cousens (1985) relating yield loss to weed density was fitted to grain yield data. The parameters were estimated and are presented in Table 2. The parameters I, the percentage yield loss as the weed density approaches zero (the initial slope of the curve); and A, the percentage yield loss as weed density approaches infinity (asymptotic yield loss) were found to vary slightly over the years.

Table 2. Estimates of parameters for the model by Cousens (1985) for *S. interrupta* and *I. miliacea*

Weed	Year	Parameter estimates		R^2
		I (%)	A(%)	
S. interrupta	1999	19.2832 (8.8400)[†]	67.3186** (9.8425)	0.9518
	2000	7.9787 (4.3018)	87.9890 (27.7162)	0.9224
I. miliacea	1999	15.9736** (0.9928)	31.3285** (0.5046)	0.9989
	2000	8.9430 (13.8100)	26.1933 (12.6522)	0.5329

[†] Figures in parenthesis are the standard errors of the parameters

** Significant at 1% level of significance

The predicted grain yield losses obtained using the model due to *S. interrupta* and *I. miliacea* are given in Table 3 & 4 and Fig. 3a, 3b, 3c & 3d.

Fig. 3a. Cousens (1985) model fitted for *S. interrupta* (1999 data)

Yield loss = I*d/(1+I*d/A)
where d = density of *S. interrupta*
y=19.28x/(1+19.28x/67.32)

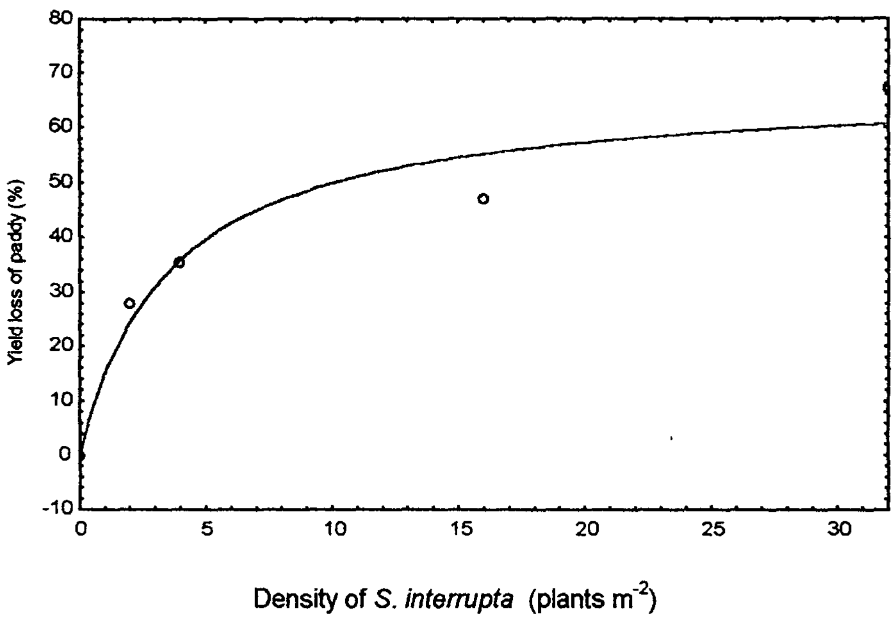


Fig. 3b. Cousens (1985) model fitted for *S. interrupta* (2000 data)

Yield loss=I*d/(1+I*d/A)
where d - Density of *S. interrupta*
y=7.98x/(1+7.98x/87.99)

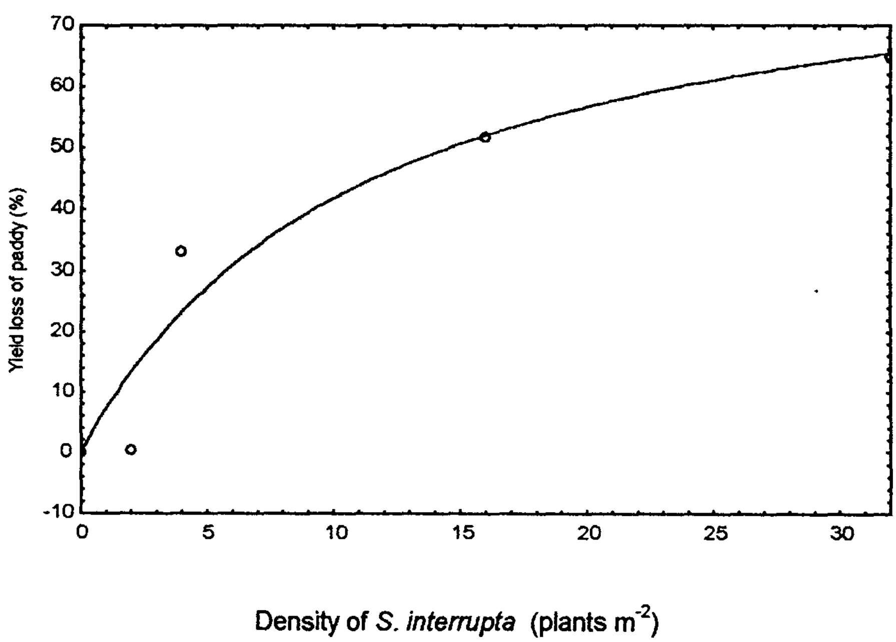


Table 3. The observed yield losses and the predicted yield losses obtained from the model by Cousens (1985) for *S. interrupta*

S. interrupta density per m²	1999 Observed yield loss (%)	1999 Predicted# yield loss (%)	2000 Observed yield loss (%)	2000 Predicted# yield loss(%)
0	0.000	0.000	0.000	0.000
2	27.746	24.519	0.144	13.508
4	35.486	35.946	33.045	23.420
16	47.098	55.261	51.948	52.088
32	67.098	60.697	64.863	65.438

By fitting the equation, $Y_L = \frac{Id}{1+\frac{Id}{A}}$

Fig. 3c. Cousens (1985) model fitted for *I. miliacea* (1999 data)

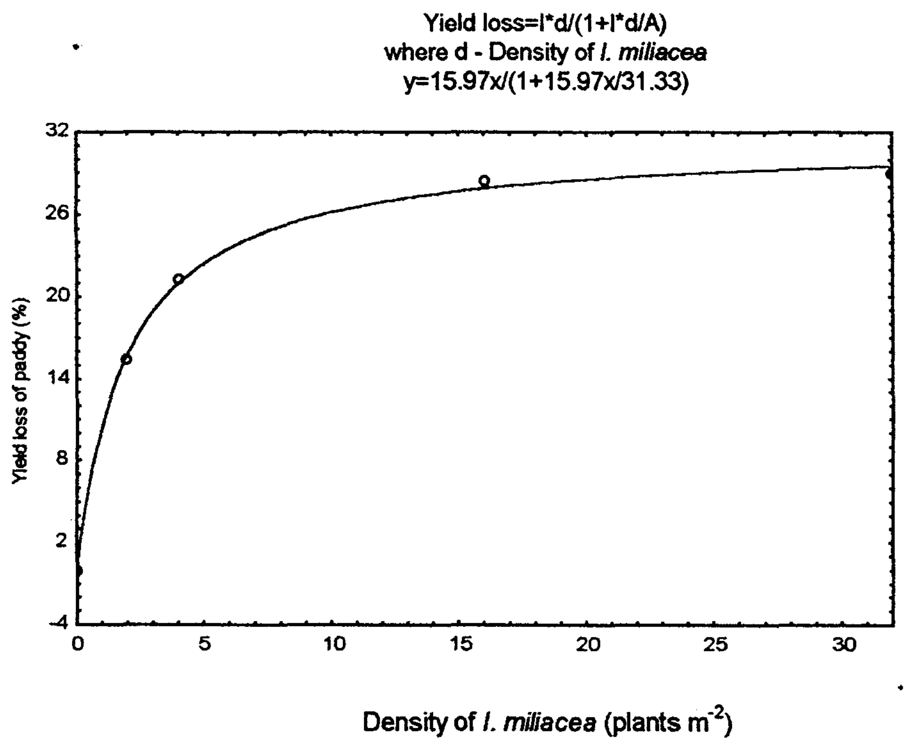


Fig. 3d. Cousens (1985) model fitted for *I. miliacea* (2000 data)

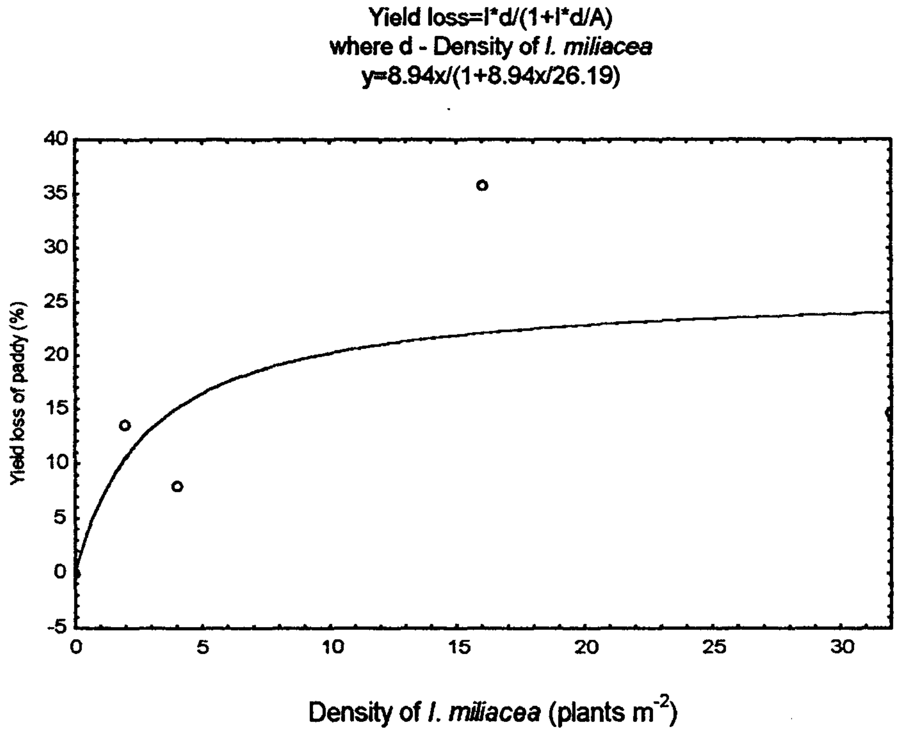


Table 4. The observed yield losses and the predicted yield losses obtained from the model by Cousens (1985) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Observed yield loss (%)	Predicted# yield loss(%)	Observed yield loss (%)	Predicted# yield loss(%)
0	0.000	0.000	0.000	0.000
2	15.491	15.817	13.420	10.628
4	21.295	21.021	8.009	15.121
16	28.393	27.908	35.714	22.140
32	29.040	29.519	14.719	23.997

By fitting the equation, $Y_L = \frac{Id}{1+\frac{Id}{A}}$

The observed and predicted yield losses were found to be close in the case of *S. interrupta* and *I. miliacea* except for *I. miliacea* in the year 2000.

The model proposed by Hakansson (1983) relating proportional yield loss to weed density was fitted to the data. The parameters estimated are given in Table 5.

Table 5. Estimates of parameters for the first model by Hakansson (1983) for *S. interrupta* and *I. miliacea*

Weed	Year	Parameter estimates		R^2
		a	b	
S. interrupta	1999	0.2469* (0.0742)†	0.5505* (0.1165)	0.9752
	2000	0.0765 (0.562)	0.9501* (0.2733)	0.9184
I. miliacea	1999	0.1720** (0.0246)	0.2701* (0.0526)	0.9831
	2000	0.1225 (0.2010)	0.2689 (0.5581)	0.4846

† Figures given in parenthesis are the standard errors of the estimates
* Significant at 5% level of significance
** Significant at 1% level of significance

The predicted and observed proportional yield losses due to *S. interrupta* and *I. miliacea* are given in Table 6 & 7 and Fig 4a, 4b, 4c & 4d.

Fig. 4a. Hakansson's (1983) model fitted for *S. interrupta* (1999 data)

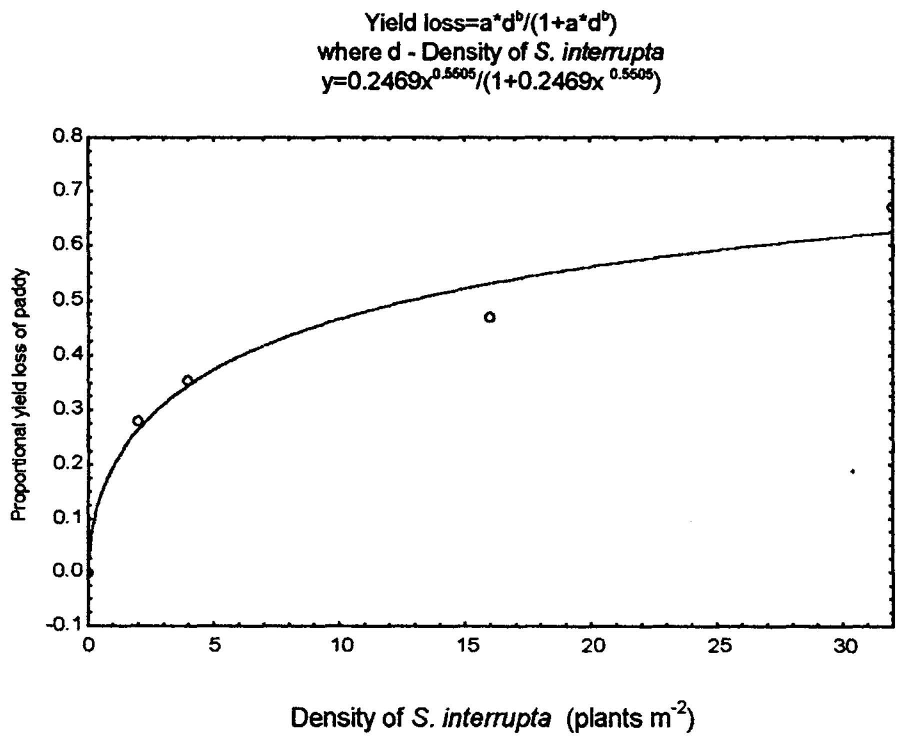


Fig. 4b. Hakansson's (1983) model fitted for *S. interrupta* (2000 data)

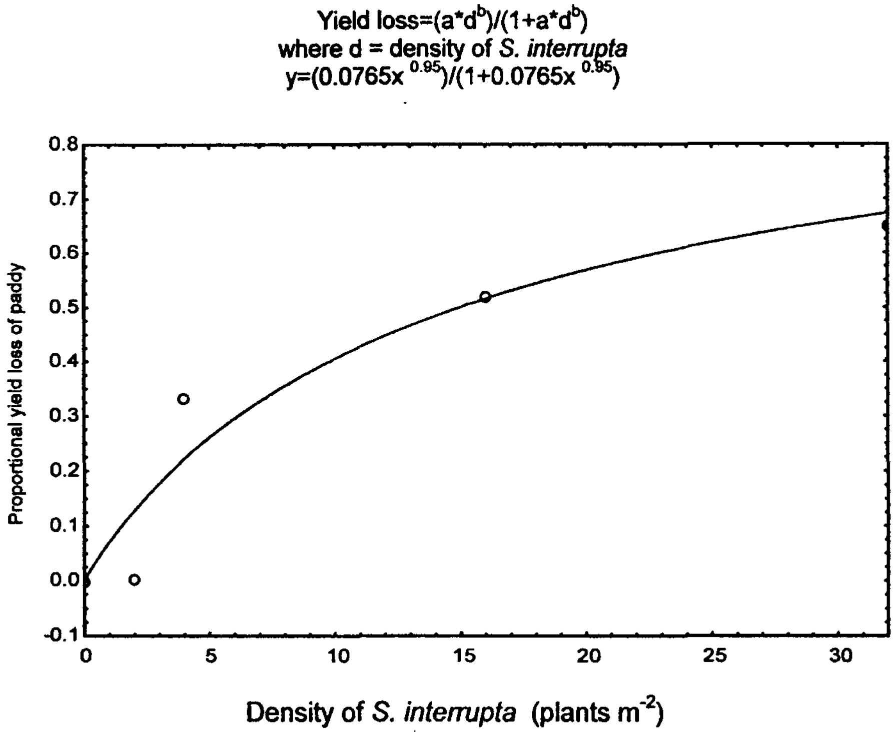


Table 6. The observed yield losses and the predicted yield losses obtained from the first model of Hakansson (1983) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield losses		Proportional yield losses	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2656	0.0014	0.1287
4	0.3549	0.3462	0.3304	0.2220
16	0.4710	0.5318	0.5195	0.5158
32	0.6710	0.6246	0.6486	0.6730

By fitting the equation, $Y_L = \frac{ad^b}{1+ad^b}$

Fig. 4c. Hakansson's (1983) model fitted for *I. miliacea* (1999 data)

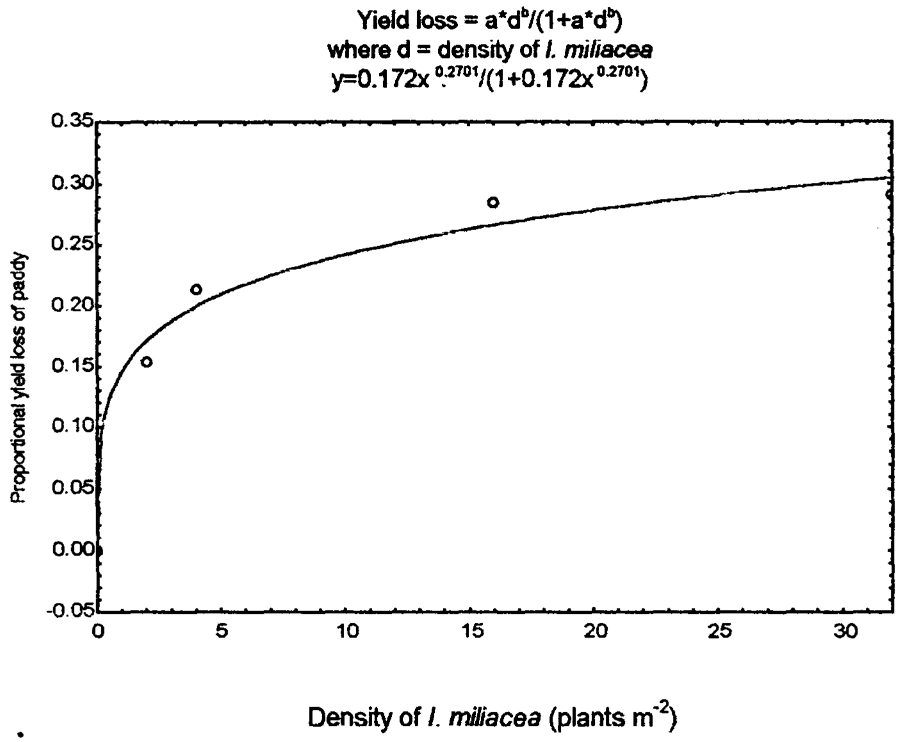


Fig. 4d. Hakansson's (1983) model fitted for *I. miliacea* (2000 data)

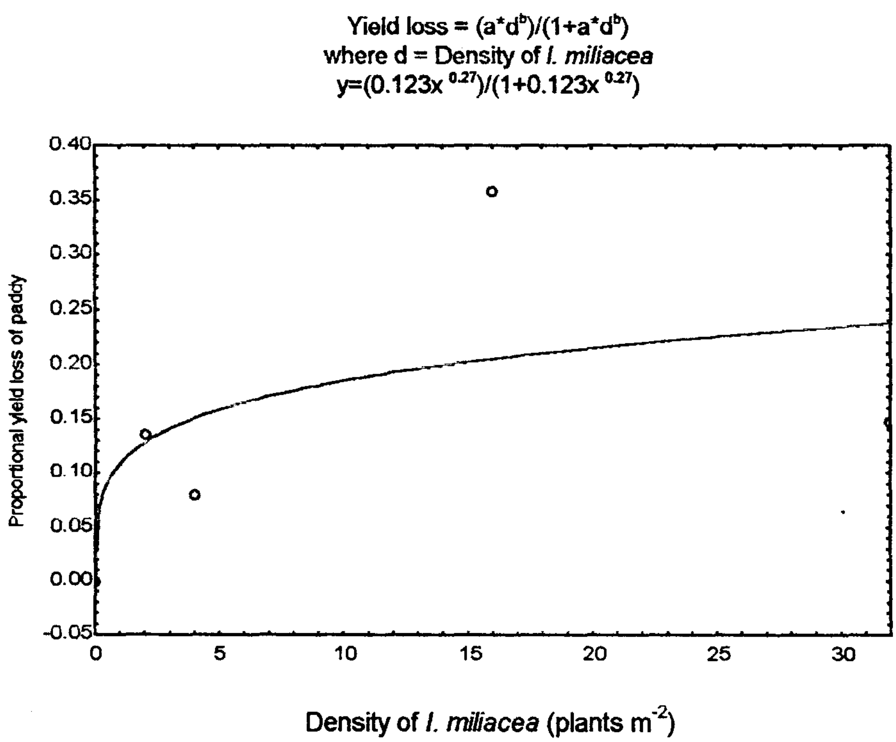


Table 7. The observed yield losses and the predicted yield losses obtained for the first model of Hakansson (1983) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Observed yield loss	Predicted# yield loss	Observed yield loss	Predicted# yield loss
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1717	0.1342	0.1286
4	0.2129	0.2000	0.0801	0.1510
16	0.2839	0.2666	0.3571	0.2052
32	0.2904	0.3048	0.1472	0.2373

By fitting the equation, $Y_L = \frac{ad^b}{1+ad^b}$

Table 8. Estimates of parameters for the first model by Watkinson (1981) for *S. interrupta* and *I. miliacea*

Weed	Year	Parameter estimates		R^2
		a	b	
S. interrupta	1999	0.9887*	0.2744*	0.9672
	2000	0.1143 (0.2325) #	0.7009 (0.9023)	0.9214
I. miliacea	1999	7.3239*	0.0662*	0.9896
	2000	4.2422 (38.5081)	0.0560 (0.1329)	0.5003

Figures in parenthesis are the standard errors of the parameters.
* Standard errors could not be computed because the matrix was ill conditioned.

The observed proportional yield losses and the predicted proportional yield losses using the model for *S. interrupta* and *I. miliacea* are given in Table 9 and 10 and Fig.5a, 5b, 5c & 5d.

Fig. 5a. Watkinson's (1981) first model fitted for *S. interrupta* (1999 data)

Yield loss = $1-(1+a*d)^{-b}$
where d = density of *S. interrupta*
$y=1-(1+0.9887x)^{-0.2744}$

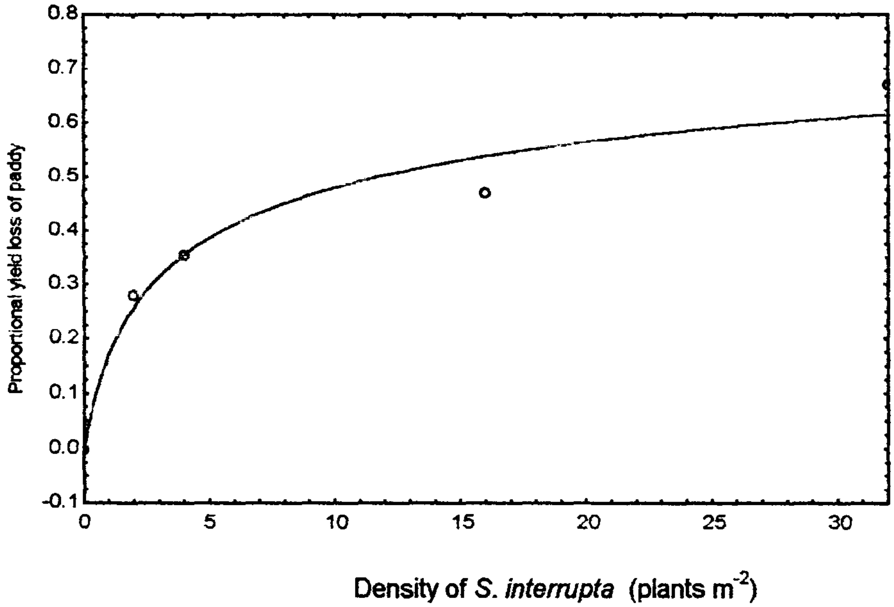


Fig. 5b. Watkinson's (1981) first model fitted for *S. interrupta* (2000 data)

Yield loss = $1-(1+a*d)^{-b}$
where d = Density of *S. interrupta*
$y=1-(1+0.1143x)^{-0.701}$

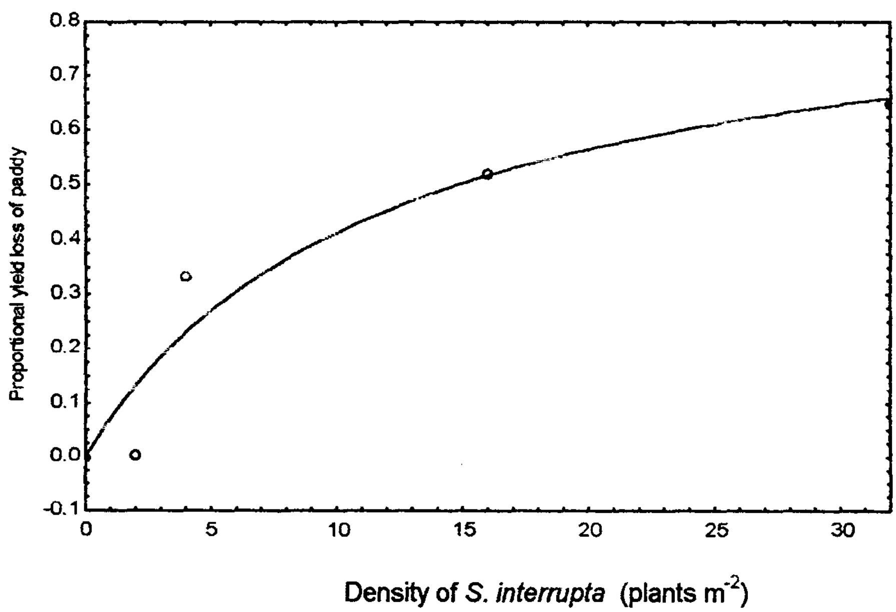


Table 9. The observed yield losses and predicted yield losses obtained from the first model by Watkinson (1981) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield losses		Proportional yield losses	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2587	0.0014	0.1343
4	0.3549	0.3554	0.3304	0.2319
16	0.4710	0.5391	0.5195	0.5175
32	0.6710	0.6157	0.6486	0.6598

By fitting the equation, $Y_L = 1 - (1 + ad)^{-b}$

Fig. 5c. Watkinson's (1981) first model fitted for *I. miliacea* (1999 data)

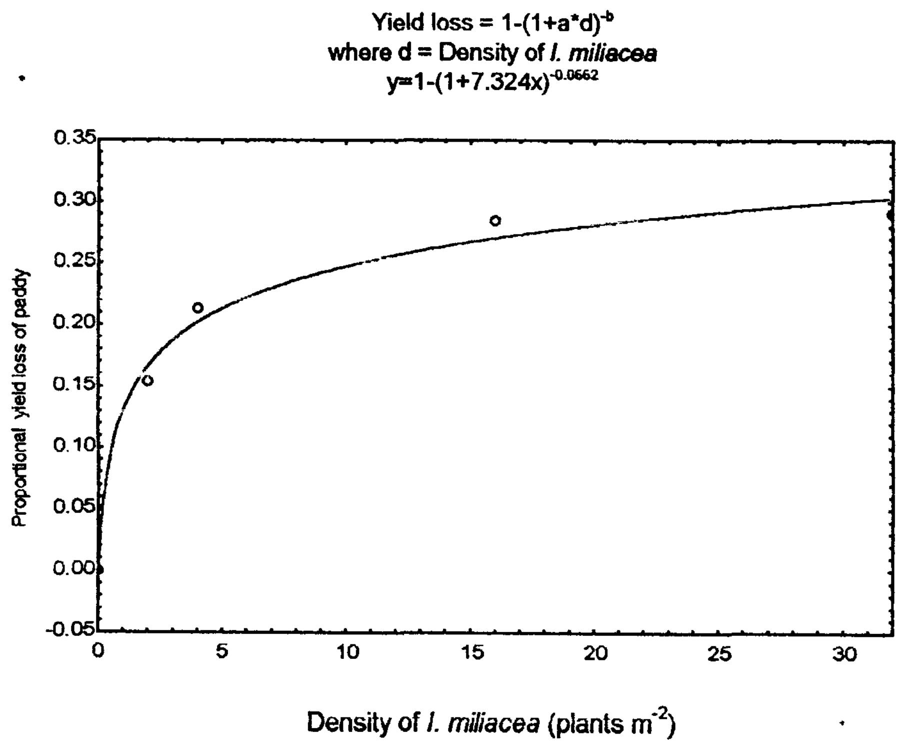


Fig. 5d. Watkinson's (1981) first model fitted for *I. miliacea* (2000 data)

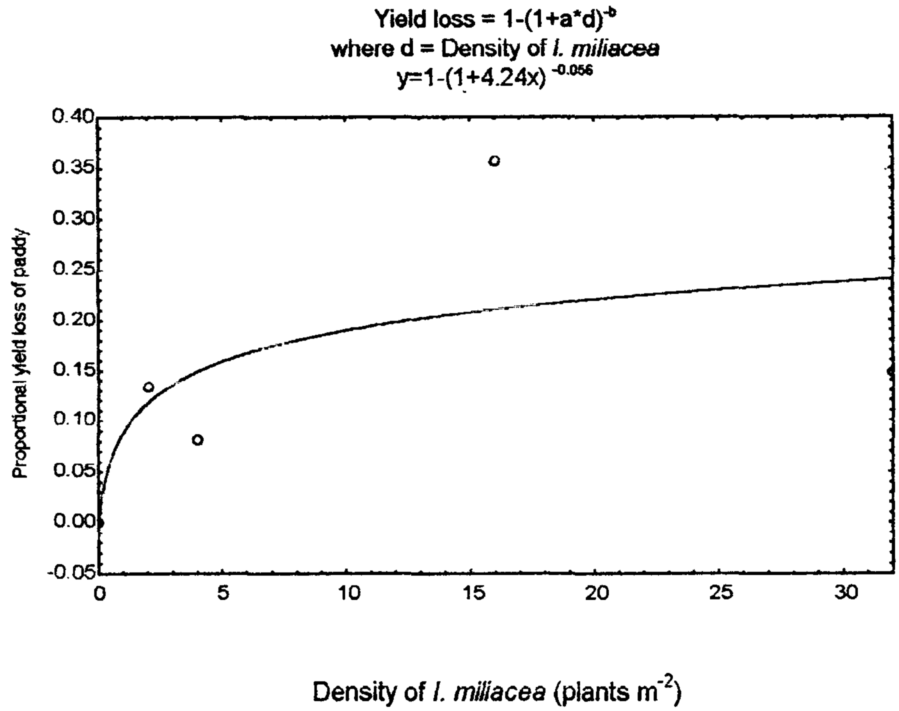


Table 10. The observed yield losses and predicted yield losses obtained from the first model by Watkinson (1981) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield losses		Proportional yield losses	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1664	0.1342	0.1184
4	0.2129	0.2021	0.0801	0.1493
16	0.2839	0.2708	0.3571	0.2110
32	0.2904	0.3033	0.1472	0.2407

By fitting the equation , $Y_L = 1 - (1 + ad)^{-b}$

The second model proposed by Watkinson (1981) relating crop yield to the weed density was also fitted for the given data. The parametric estimates are given in Table 11.

Table 11. Estimates of parameters for the second model proposed by Watkinson (1981) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates			R^2
		Ywf	β	b	
S. interrupta	1999	147.8965†	-0.0009†	-35.381†	0.8377
	2000	179.2581†	0.1515†	0.6278†	0.9255
I. miliacea	1999	4.9335†	-0.313†	0.0900†	----
	2000	4.7942†	-0.0313†	0.0697†	----

† Standard errors could not be computed because the matrix was ill conditioned.

The observed yield and the predicted yield obtained by fitting the model are given in Table 12 & 13 and Fig.6a, 6b, 6c & 6d.

Fig. 6a. Watkinson's (1981) second model fitted for *S. interrupta* (1999 data)

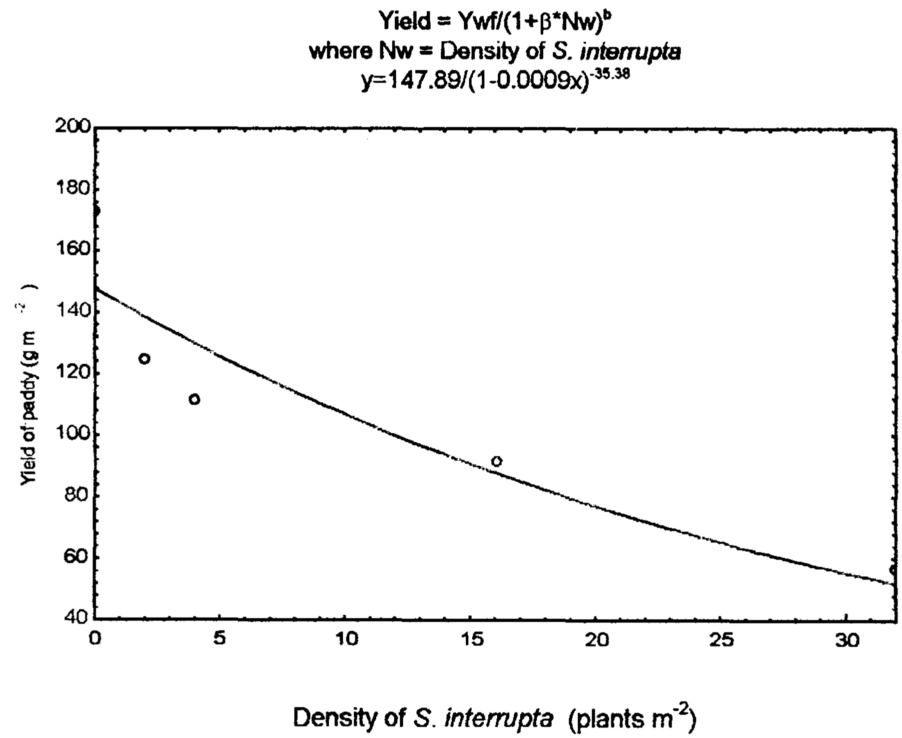


Fig. 6b. Watkinson's (1981) second model fitted for *S. interrupta* (2000 data)

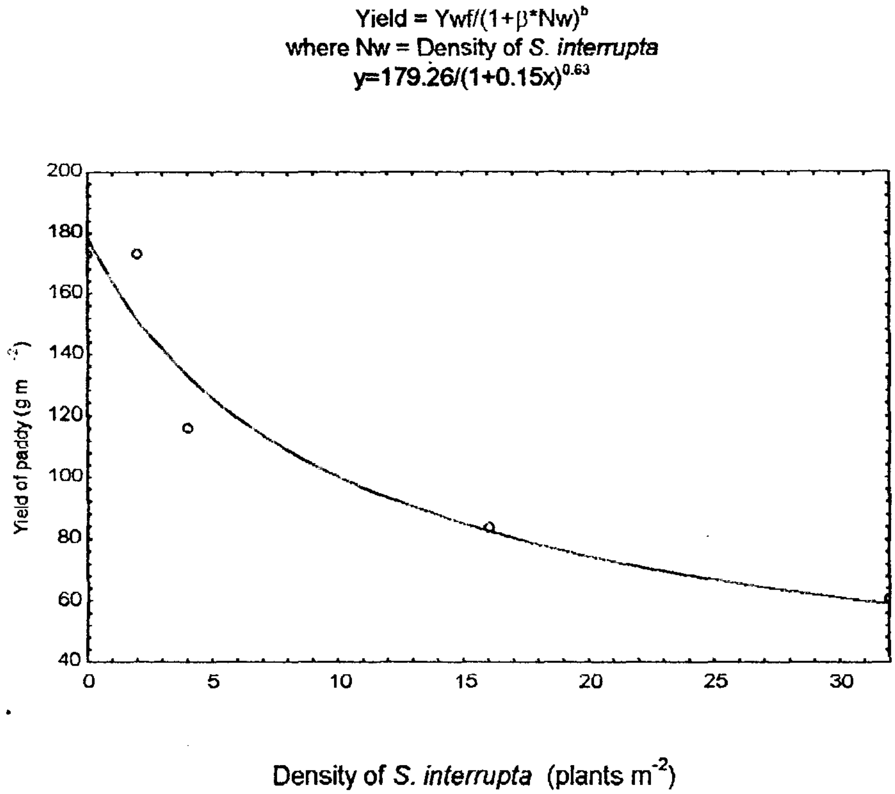


Table 12. The observed yield losses and predicted yield losses obtained from the second model proposed by Watkinson (1981) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Observed yield (gm^{-2})	Predicted[#] yield (gm^{-2})	Observed yield (gm^{-2})	Predicted[#] yield (gm^{-2})
0	173.00	147.9	173.25	179.26
2	125.00	138.67	173.00	151.81
4	111.61	130.01	116.00	133.14
16	91.52	88.05	83.25	82.77
32	56.92	52.02	60.88	59.15

By fitting the equation , $Yc = \dfrac{Ywf}{(1+\beta\, Nw)^b}$

Fig. 6c. Watkinson's (1981) second model fitted for *I. miliacea* (1999 data)

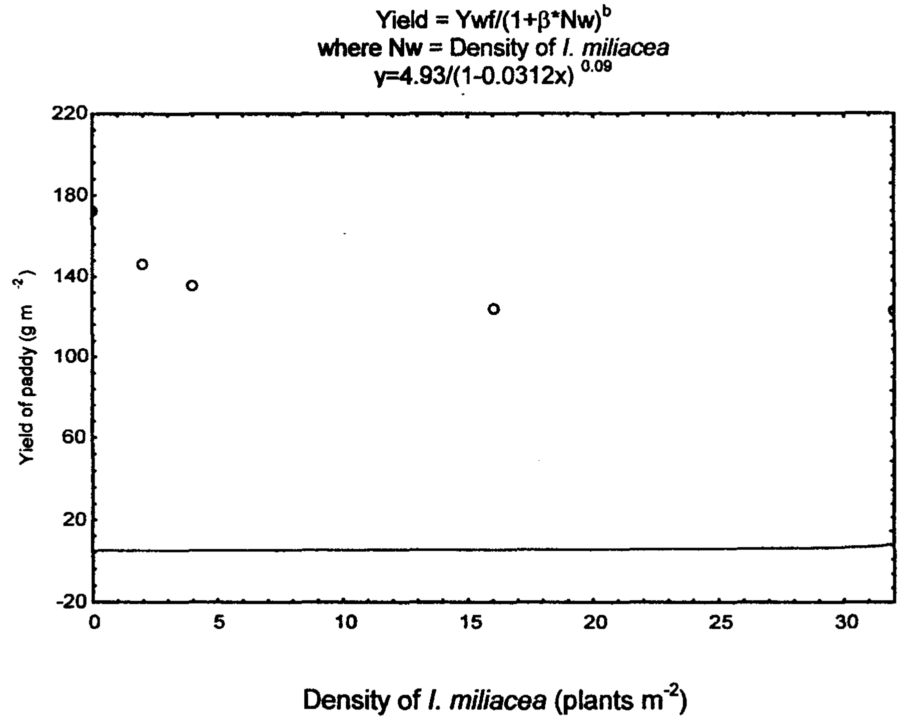


Fig. 6d. Watkinson's (1981) second model fitted for *I. miliacea* (2000 data)

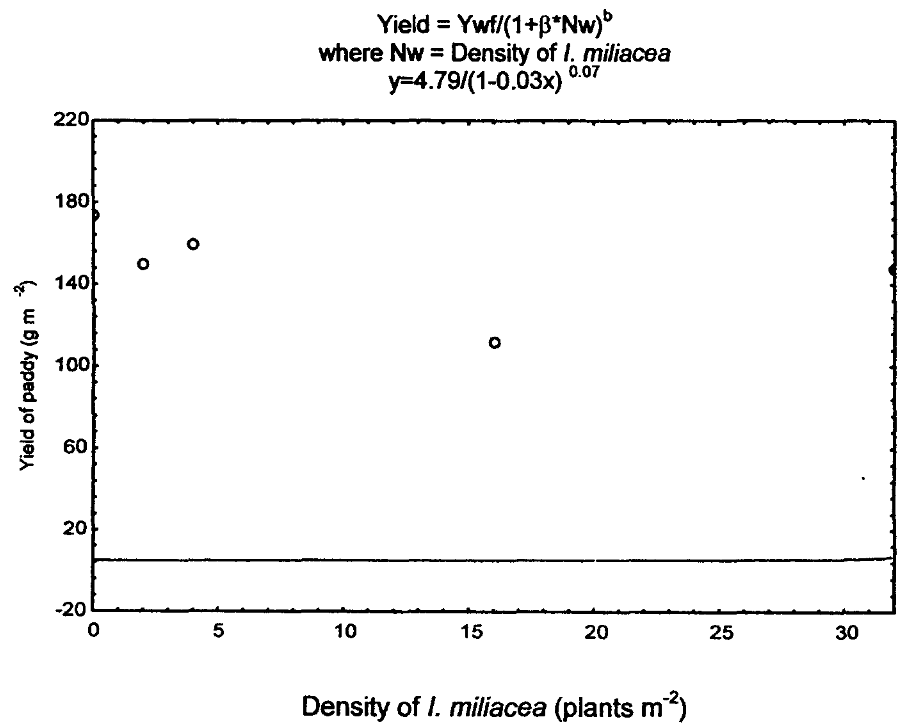


Table 13. The observed yield losses and predicted yield losses obtained from the second model proposed by Watkinson (1981) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Observed yield (gm^{-2})	Predicted# yield (gm^{-2})	Observed yield (gm^{-2})	Predicted# yield (gm^{-2})
0	173.0	4.93	173.25	4.79
2	146.2	4.96	150.00	4.82
4	136.16	4.99	159.375	4.84
16	123.88	5.25	111.375	5.03
32	122.76	13.63	147.75	11.95

By fitting the equation, $Yc = \frac{Ywf}{(1+\beta Nw)^b}$

Table 14. Estimates of parameters for the model by Swinton and Lyford (1996) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates				R^2
		β	γ	∝	δ	
S. interrupta	1999	107.791~	-1.0275~	107.798~	0.0398~	0.029
	2000	172.8862 (30.9692)†	-8974×10^5 (1.0278×10^{11})	86.7099 (22.6404)	22.2586 (139.460)	0.853
I. miliacea	1999	83.8126~	-0.3145~	113.368~	0.0000~	---
	2000	174.279~	-0.2612~	150.302~	1.4×10^{-5}~	0.366

† Figures in parenthesis are the standard errors of the estimates.
~ Standard errors could not be computed as the matrix was ill conditioned.

The observed yield and predicted yield computed using the model are presented in Table 15&16 and Fig 7a, 7b, 7c & 7d.

Fig. 7a. Swinton and Lyford (1996) model fitted for *S. interrupta* (1999 data)

Yield = $(\beta*\gamma+\alpha*D^{\delta})/(\gamma+D^{\delta})$
where D = Density of *S. interrupta*
$y=(107.79*(-1.03)+107.798x^{0.04})/((-1.03)+x^{0.04})$

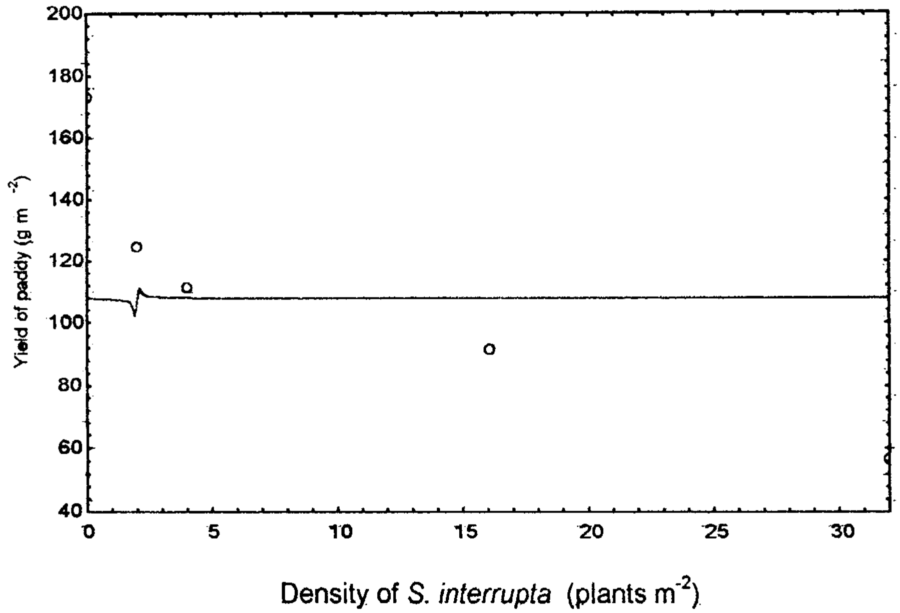


Fig. 7b. Swinton and Lyford (1996) model fitted for *S. interrupta* (2000 data)

Yield = $(\beta*\gamma+\alpha*D^{\delta})/(\gamma+D^{\delta})$
where D = Density of *S. interrupta*
$y=(172.8*(-8.9*10^{8})+86.7x^{22.3})/(-8.9*10^{8}+x^{22.3})$

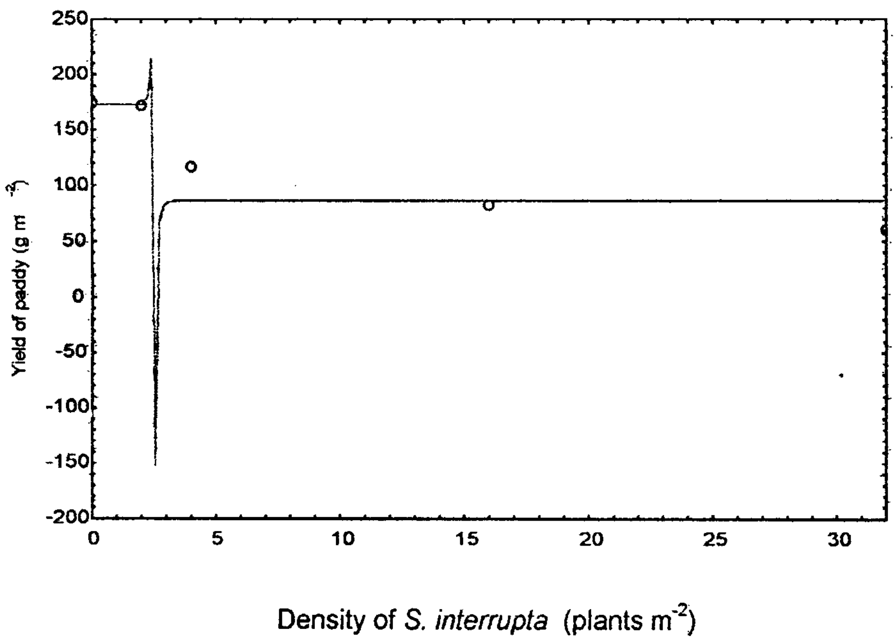


Table 15. The observed yield and predicted yield obtained from the model by Swinton and Lyford (1996) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Observed yield (gm^{-2})	Predicted# yield (gm^{-2})	Observed yield (gm^{-2})	Predicted# yield (gm^{-2})
0	173.00	107.79	173.25	172.89
2	125.00	124.36	173.00	173.37
4	111.61	108.04	116.00	86.71
16	91.52	107.88	83.25	86.71
32	56.92	107.86	60.875	86.71

#By fitting the equation, $Y = \dfrac{\beta\gamma + \alpha D^{\delta}}{\gamma + D^{\delta}}$

Fig. 7c. Swinton and Lyford (1996) model fitted for *I. miliacea* (1999 data)

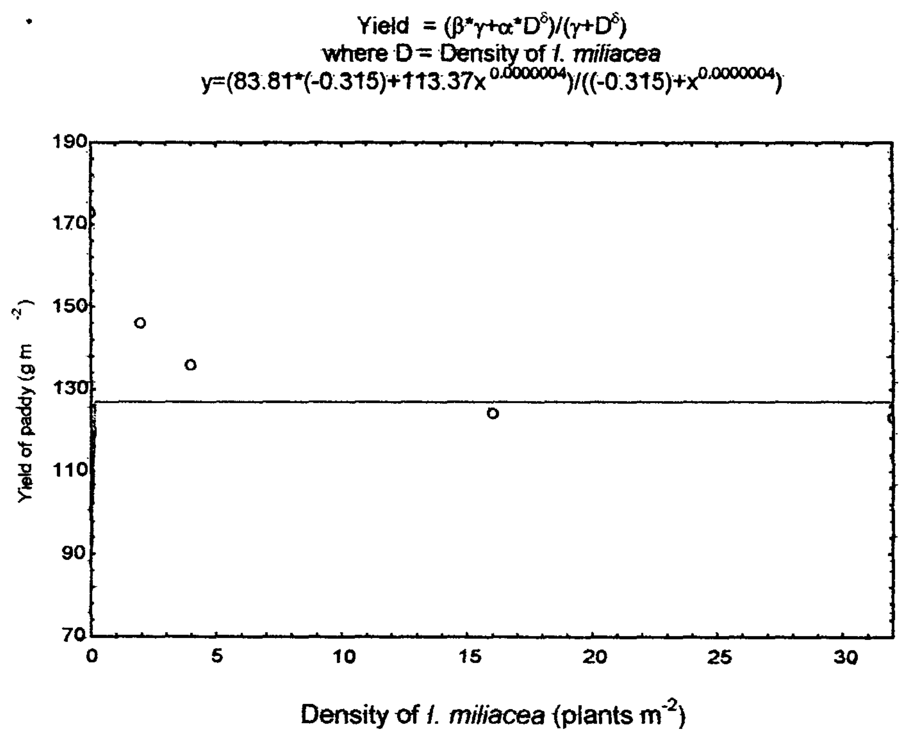


Fig. 7d. Swinton and Lyford (1996) model fitted for *I. miliacea* (2000 data)

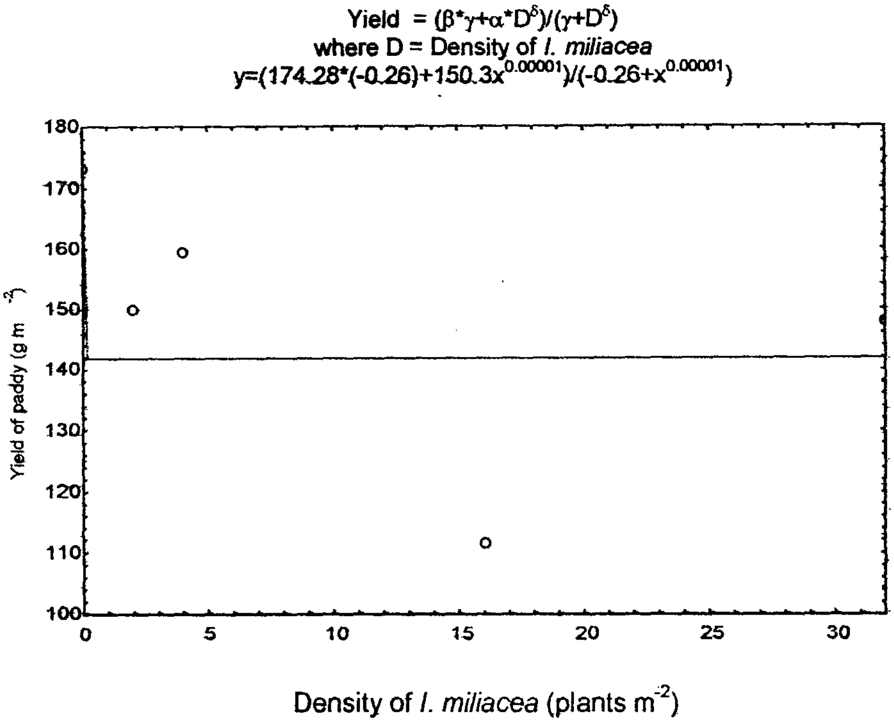


Table 16. The observed yield and predicted yield obtained from the model by Swinton and Lyford (1996) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Observed yield (gm^{-2})	Predicted# yield (gm^{-2})	Observed yield (gm^{-2})	Predicted# yield (gm^{-2})
0	173.0	83.81	173.25	174.28
2	146.20	126.92	150.00	141.83
4	136.16	126.92	159.375	141.83
16	123.88	126.92	111.375	141.83
32	122.76	126.92	147.75	141.83

#By fitting the equation, $Y = \dfrac{\beta\gamma + \alpha D^{\delta}}{\gamma + D^{\delta}}$

The model fitted by Ngouajio *et al* (1999c) modifying the model proposed by Swinton and Lyford (1996) so as to include crop density into the model was also fitted to the data. The parametric estimates are presented in Table 17.

Table 17. Estimates of parameters for the model by Ngouajio *et al.* (1999c) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates				R^2
		β	γ	∝	δ	
S. interrupta	1999	172.50~	42177.99~	-5895600~	0.31418~	0.9862
	2000	74.8280~	0.2218~	128.5826~	1×10^{-6}~	-----
I. miliacea	1999	172.988~	0.0126~	120.8233~	1.2354~	0.9997
	2000	171.420 (48.4907)†	0.0089 (0.1807)	130.1954 (29.8035)	1.5617 (7.7290)	0.5427

† Figures in parenthesis are the standard errors of the estimates.
~ Standard errors could not be computed as the matrix was ill conditioned.

The observed yield and predicted yield calculated using the model are presented in Table 18&19 and Fig 8a, 8b, 8c & 8d.

Fig. 8a. The model proposed by Ngouajio *et al.* (1999c) fitted for *S. interrupta* (1999 data)

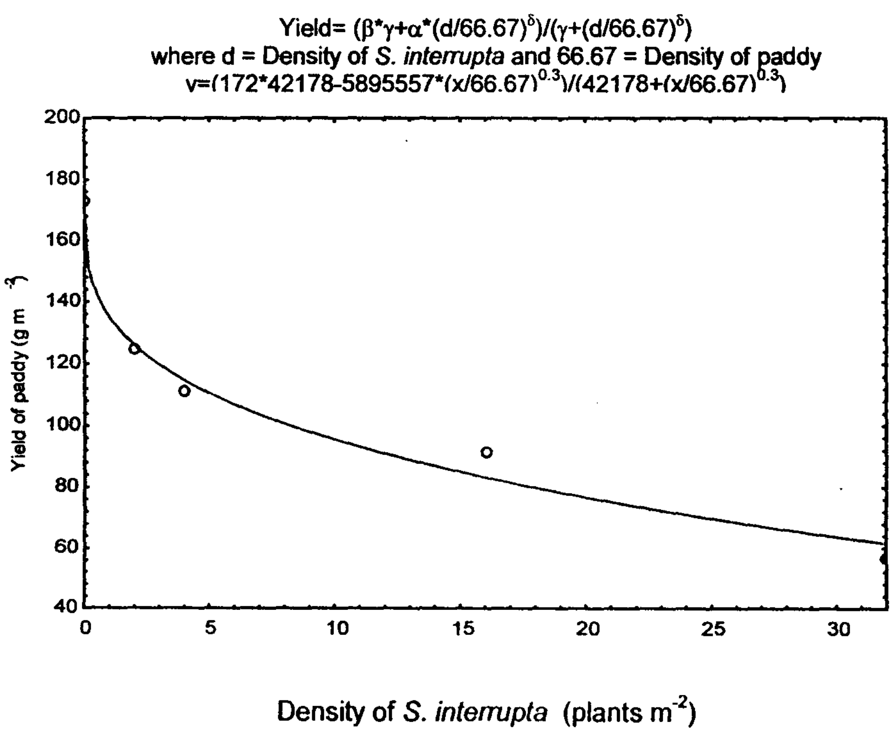


Fig. 8b. The model proposed by Ngouajio *et al.* (1999c) fitted for *S. interrupta* (2000 data)

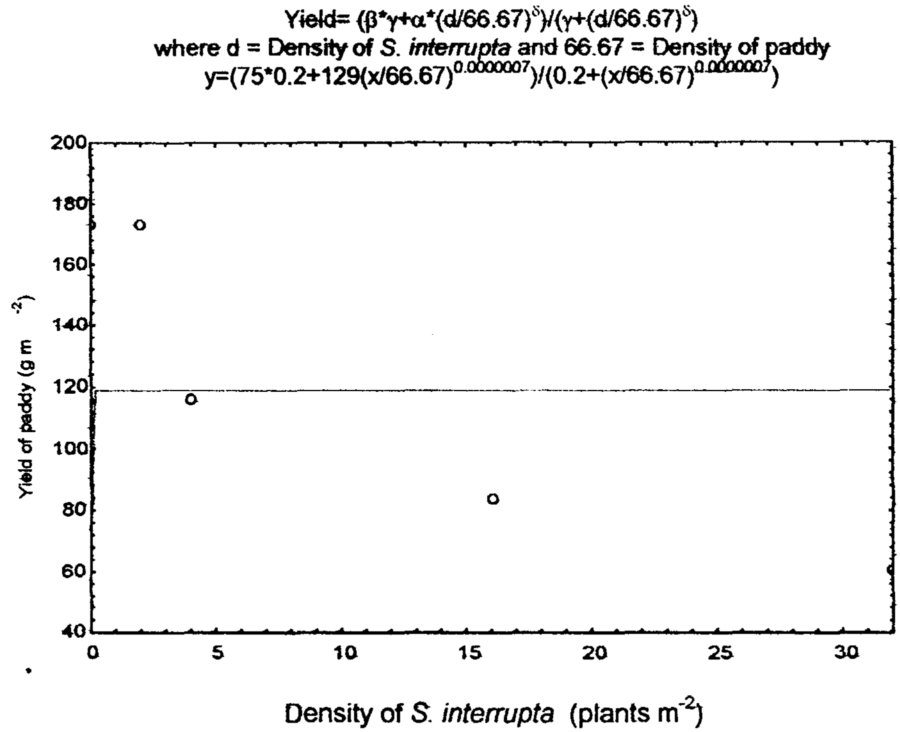


Table 18. The observed yield and the predicted yield obtained by fitting the model by Ngouajio *et al.* (1999c) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Observed yield (gm^{-2})	Predicted# yield (gm^{-2})	Observed yield (gm^{-2})	Predicted# yield (gm^{-2})
0	173.00	172.50	173.25	74.83
2	125.00	126.05	173.00	118.83
4	111.61	114.75	116.00	118.83
16	91.52	83.23	83.25	118.83
32	56.92	61.51	60.87	118.83

Using the model, $Y = \dfrac{\beta\gamma + \alpha\left(\dfrac{Dw}{Dc}\right)^{\delta}}{\gamma + \left(\dfrac{Dw}{Dc}\right)^{\delta}}$

Fig. 8c. The model proposed by Ngouajio *et al.* (1999c) fitted for *I. miliacea* (1999 data)

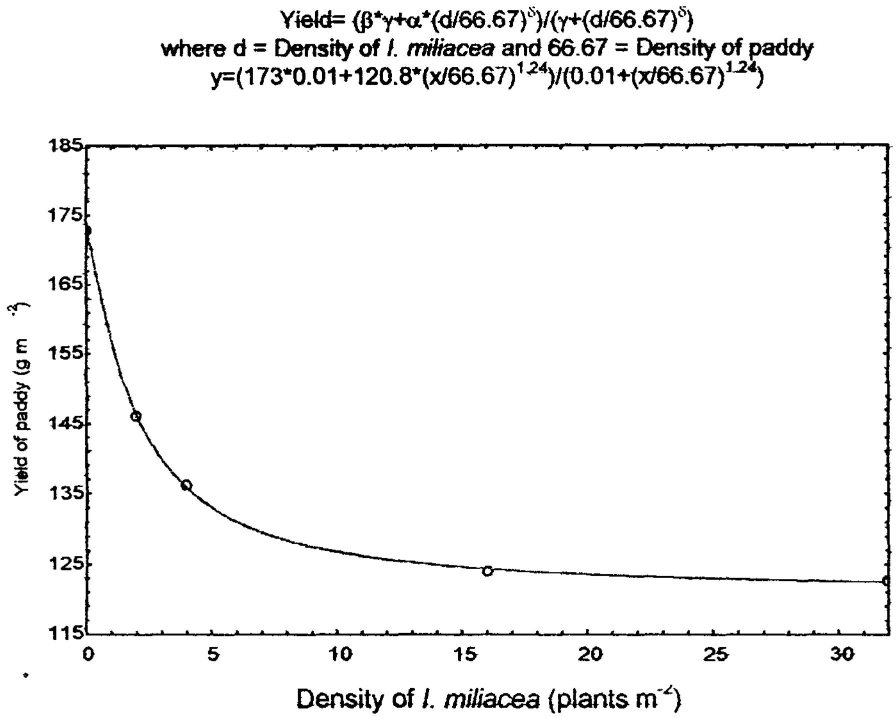


Fig. 8d. The model proposed by Ngouajio *et al.* (1999c) fitted for *I. miliacea* (2000 data)

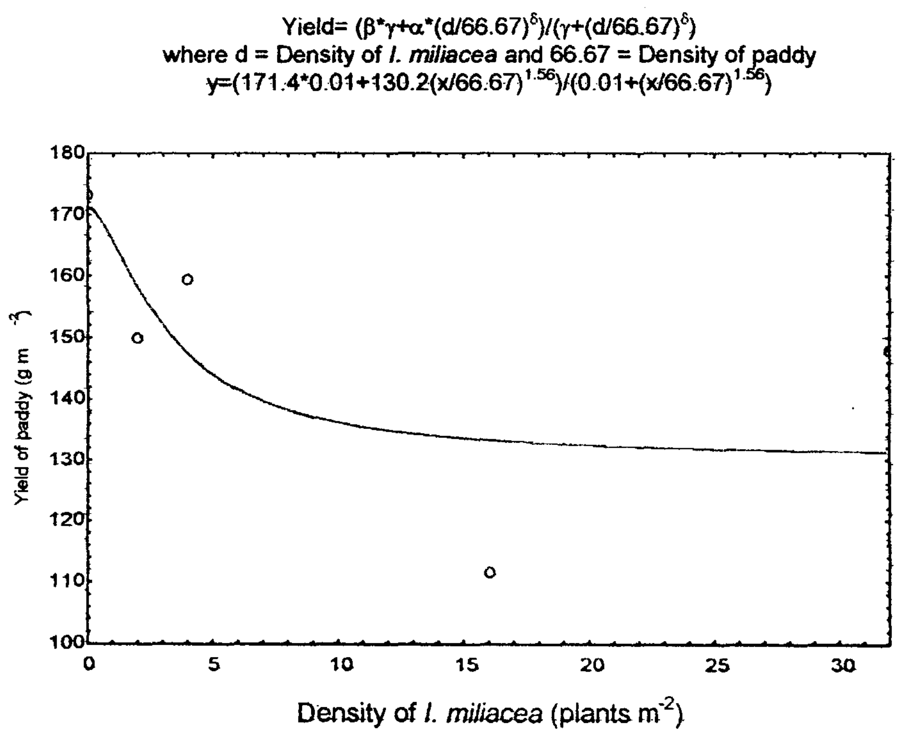


Table 19. The observed yield and the predicted yield obtained by fitting the model by Ngouajio *et al.* (1999c) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Observed yield (gm^{-2})	Predicted[#] yield (gm^{-2})	Observed yield (gm^{-2})	Predicted[#] yield (gm^{-2})
0	173.00	172.99	173.25	171.42
2	146.20	146.33	150.00	158.23
4	136.16	135.90	159.38	147.45
16	123.88	124.39	111.38	133.34
32	122.76	122.40	147.75	131.32

Using the model, $Y = \dfrac{\beta\gamma + \alpha\left(\dfrac{Dw}{Dc}\right)^{\delta}}{\gamma + \left(\dfrac{Dw}{Dc}\right)^{\delta}}$

The simple one parameter model proposed by Kropff and Spitters (1991) relating yield loss to relative weed density was also fitted to the data. The parametric estimates obtained by fitting the model are presented in Table 20.

Table 20. Estimates of parameters for the model by Kropff and Spitters (1991) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimate 'a'	R^2
S. interrupta	1999	5.5735* (1.6960)~	0.8273
	2000	4.4979* (1.0408)	0.9173
I. miliacea	1999	1.2975 (0.4826)	0.2163
	2000	0.8679 (0.4834)	0.0265

~ Figures in parenthesis are the standard errors of the estimates.
* Significant at 5% level of significance

The observed and predicted yield losses obtained by fitting the model are presented in Table 21 &22 and Fig. 9a, 9b, 9c & 9d.

Fig. 9a. Kropff and Spitters (1991) model fitted for *S. interrupta* (1999 da

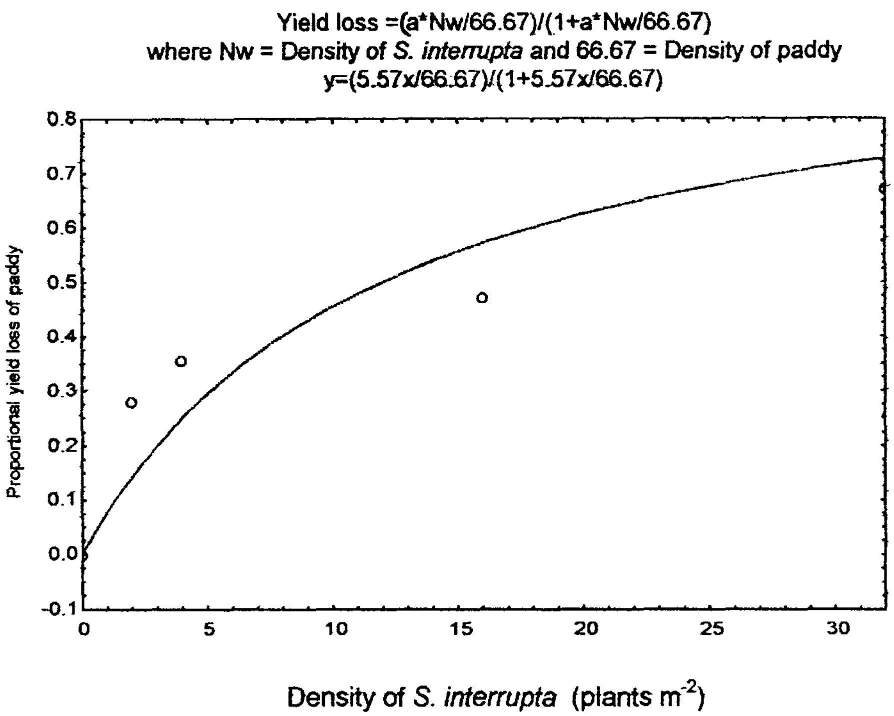


Fig. 9b. Kropff and Spitters (1991) model fitted for *S. interrupta* (2000 dat

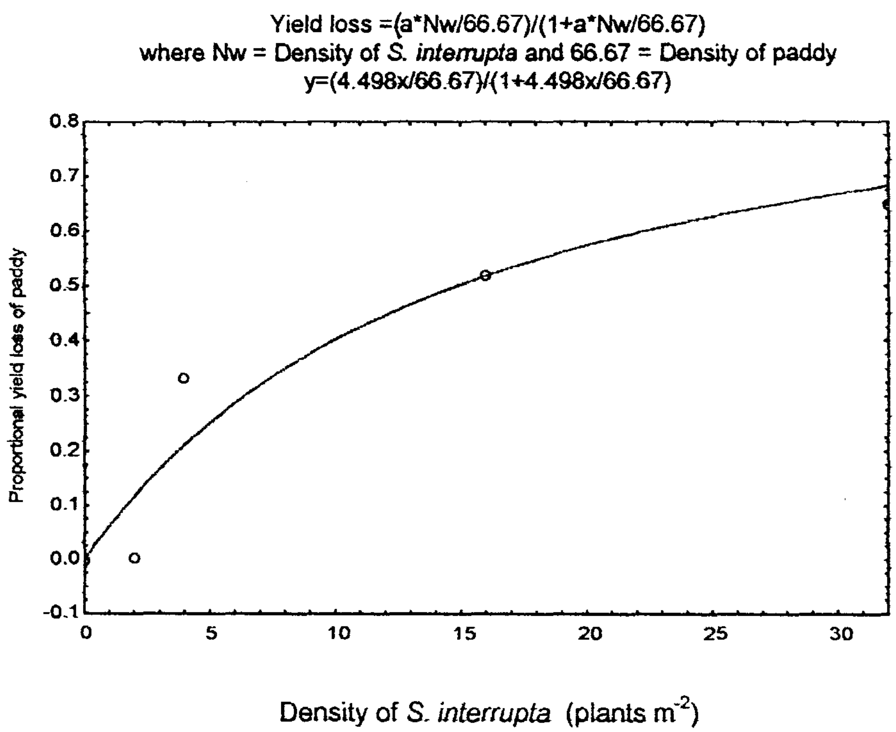


Fig. 9d. Kropff and Spitters (1991) model fitted for *I. miliacea* (2000 data)

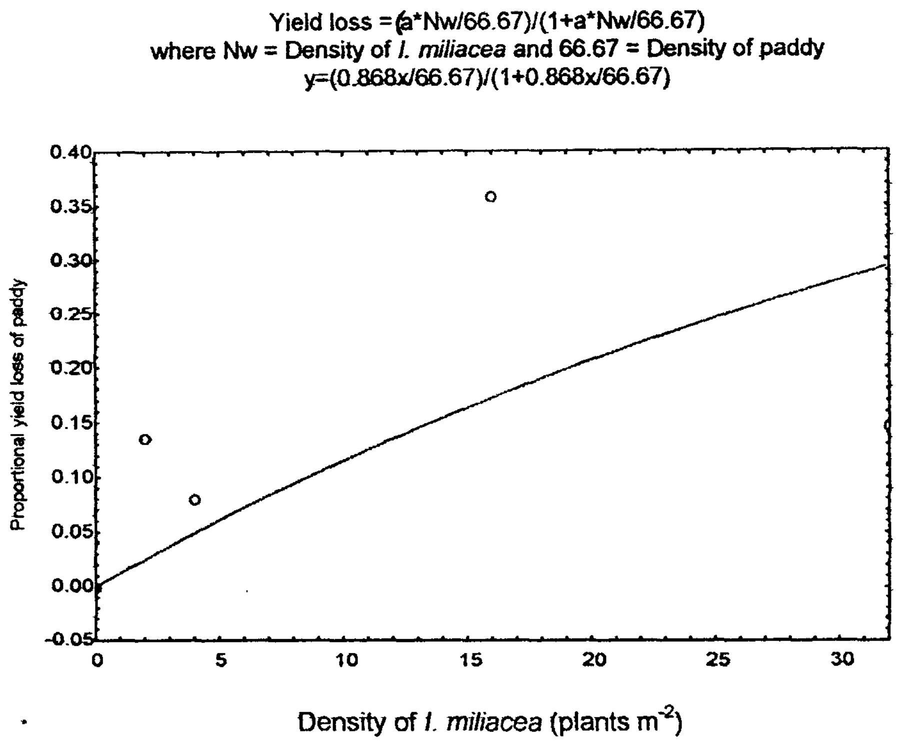


Table 22. The observed yield losses and predicted yield losses obtained b ...ing the model proposed by Kropff and Spitters (1991) for *I. miliace*...

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.0375	0.1342	0.0254
4	0.2129	0.0722	0.0801	0.0495
16	0.2839	0.2375	0.3571	0.1724
32	0.2904	0.3838	0.1472	0.2941

By fitting the equation, $Y_L = \frac{a\frac{Nw}{Nc}}{1 + a\frac{Nw}{Nc}}$

The model proposed by Schweizer (1973) which relates proportio eld loss to weed density was fitted to the data and the parametric estim are presented in Table 23.

Table 23. Estimates of parameters for the model by Schweizer (19 for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates			R^2
		a	b	c	
S. interrupta	1999	0.1308* (0.0139)[†]	-0.0093* (0.0014)	0.0002* (0.00003)	0.9851
	2000	0.0749 (0.0365)	-0.0036 (0.0036)	0.00006 (0.00008)	0.927
I. miliacea	1999	0.0761** (0.0062)	-0.0052* (000006)	0.0001* (0.00001)	0.987
	2000	0.0331 (0.019)	-0.0005 (0.002)	-0.00001 (0.00004)	0.902

[†] Figures in parenthesis are the standard errors of the estimates

* Significant at 5 % level of significance

** Significant at 1 % level of significance

The observed yield losses and predicted yield losses calculated fi he model are presented in Table 24 & 25 and Fig. 10a, 10b, 10c & 10d.

Fig. 10a. Schweizer's (1973) model for *S. interrupta* (1999 data)

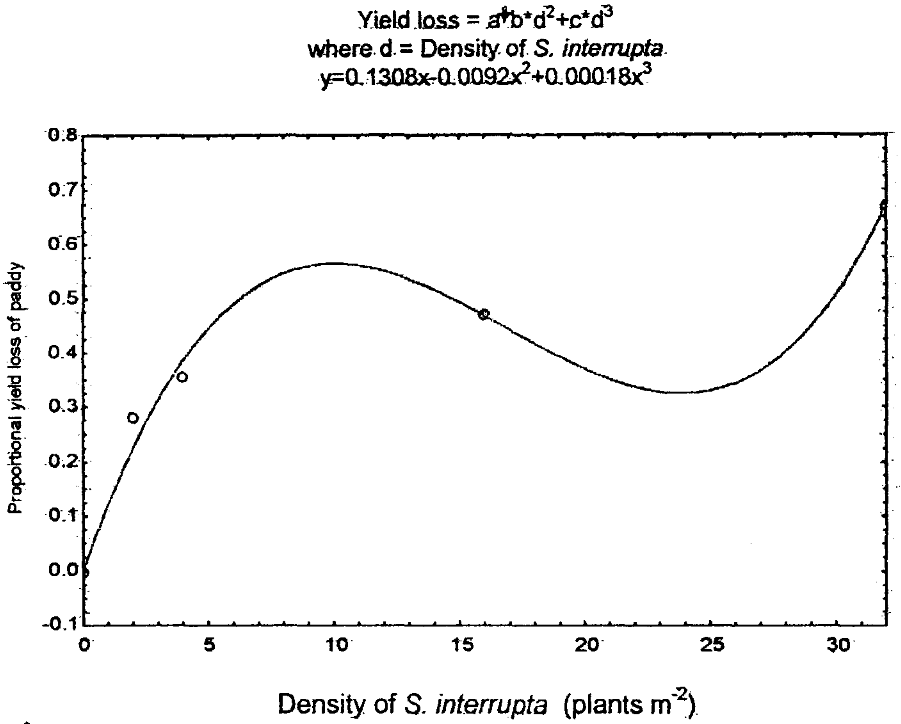


Fig. 10b. Schweizer's (1973) model for *S. interrupta* (2000 data)

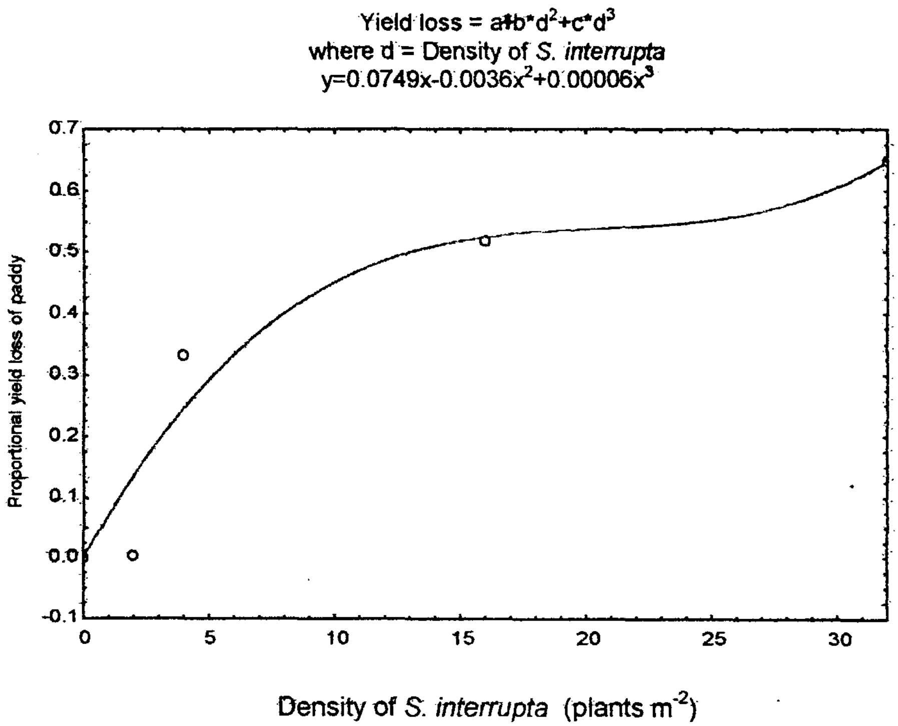


Table 24. The observed yield losses and predicted yield losses obtained by [illegible]ng the model by Schweizer (1973) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2261	0.0014	0.1360
4	0.3549	0.3869	0.3304	0.2463
16	0.4710	0.4690	0.5195	0.5247
32	0.6710	0.6712	0.6486	0.6481

#By fitting the model, $Y_L = ad + bd^2 + cd^3$

Fig. 10c. Schweizer's (1973) model for *I. miliacea* (1999 data)

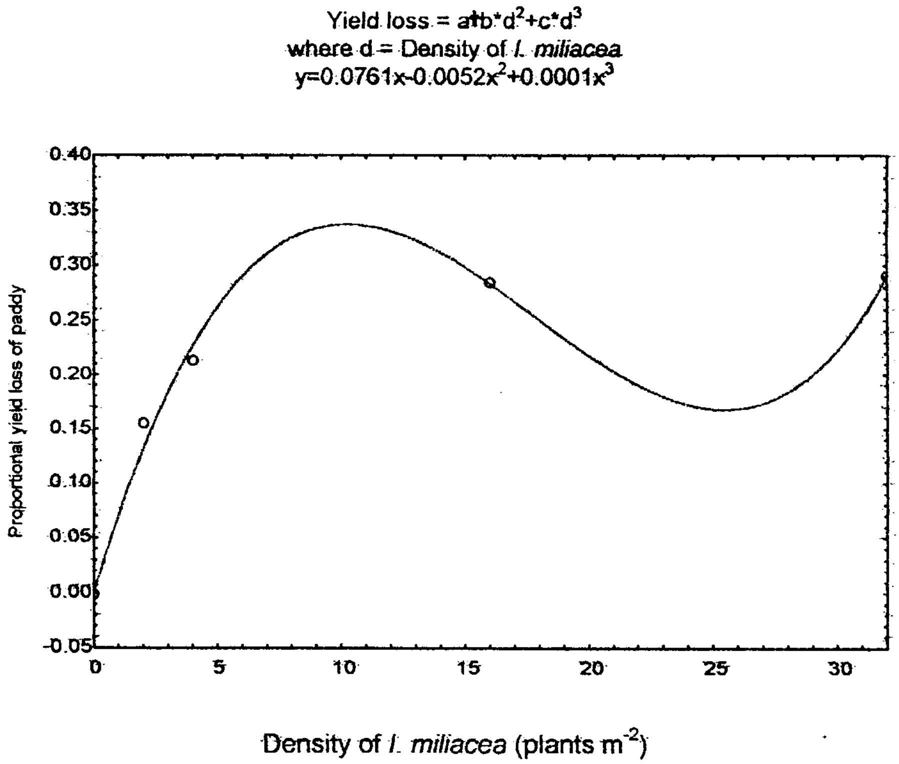


Fig. 10d. Schweizer's (1973) model for *I. miliacea* (2000 data)

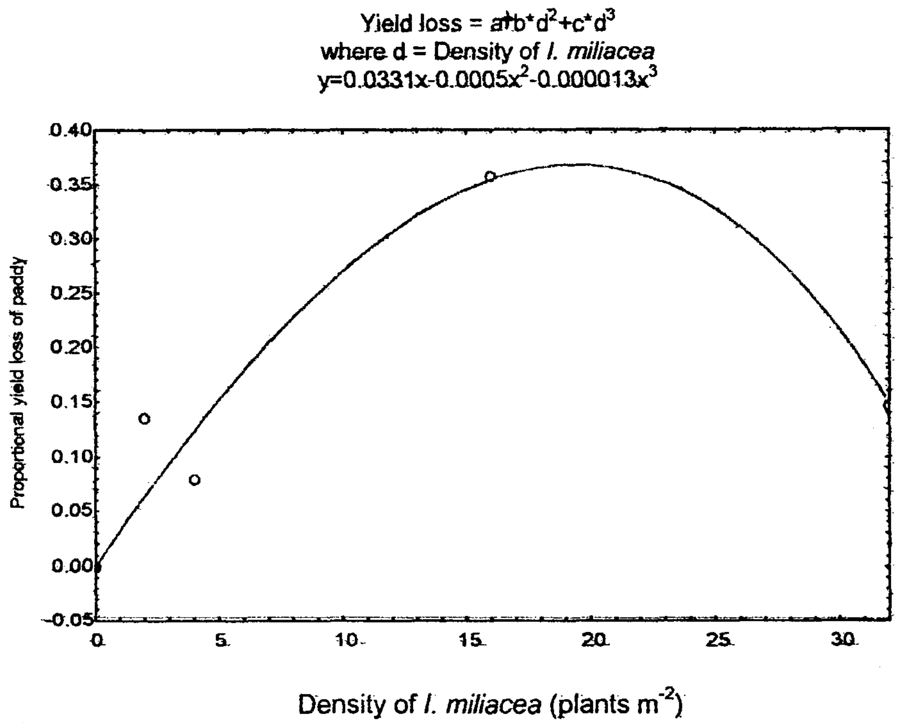


Table 25. The observed yield losses and predicted yield losses obtained by the model by Schweizer (1973) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1321	0.1342	0.0641
4	0.2129	0.2272	0.0801	0.1239
16	0.2839	0.2830	0.3571	0.3544
32	0.2904	0.2905	0.1472	0.1475

#By fitting the model, $Y_L = ad + bd^2 + cd^3$

The model proposed by Hammerton (1964) was also fitted to the yield - weed density data and the parameters are presented in Table 26.

Table 26. Estimates of parameters for the model by Hammerton (196 … or *S. interrupta* and *I. miliacea*

Weed	Year	Parameter estimates		R^2
		a	b	
S. interrupta	1999	0.0526 (0.0175)†	-0.0010 (0.0006)	0.7150
	2000	0.0501* (0.0118)	-0.0009 (0.0004)	0.9089
I. miliacea	1999	0.0343* (0.0093)	-0.0008 (0.0003)	0.6545
	2000	0.0386** (0.0056)	-0.0011* (0.0002)	0.8982

† Figures in parenthesis are the standard errors of the estimates
*Significant at 5% level of significance
**Significant at 1% level of significance

The observed yield losses and the predicted yield losses obtained fro … e model are given in Table 27 & 28 and Fig.11a, 11b, 11c & 11d.

Fig. 11a. Hammerton's (1964) model for *S. interrupta* (1999 data)

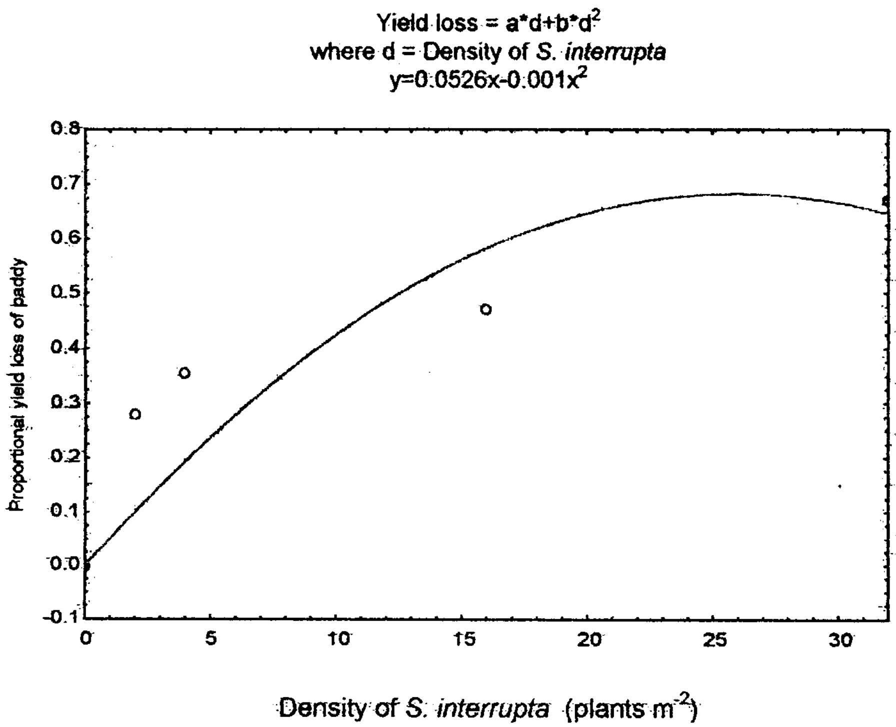


Fig. 11b. Hammerton's (1964) model for *S. interrupta* (2000 data)

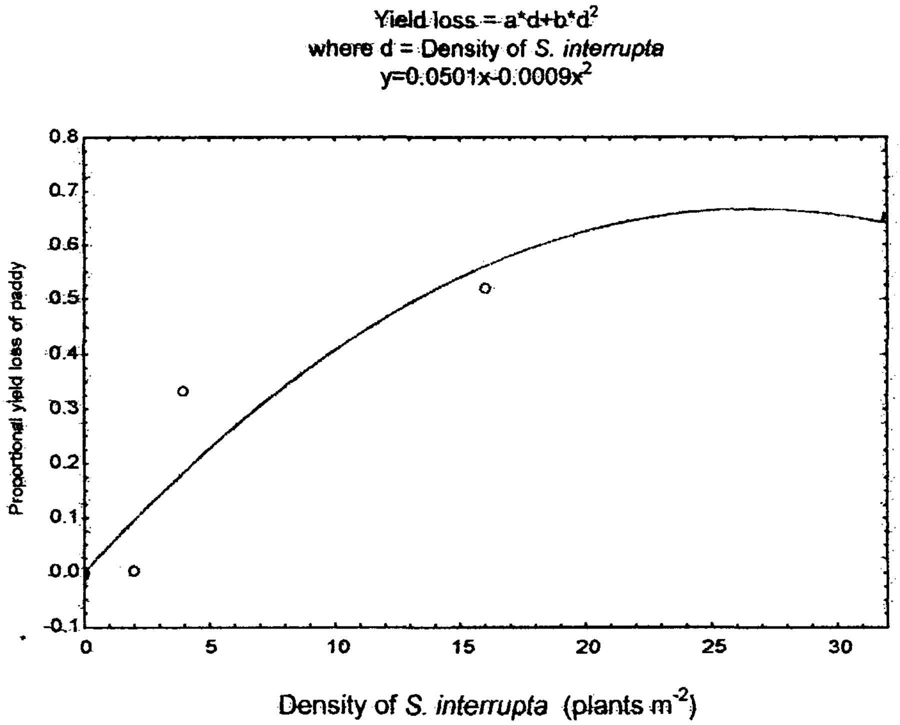


Table 27. The observed yield losses and the predicted yield losses obtained by the model by Hammerton (1964) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.1012	0.0014	0.0964
4	0.3549	0.1943	0.3304	0.1853
16	0.4710	0.5825	0.5195	0.5607
32	0.6710	0.6463	0.6486	0.6402

#By fitting the equation, $Y_L = ad + bd^2$

Fig. 11c. Hammerton's (1964) model for *I. miliacea* (1999 data)

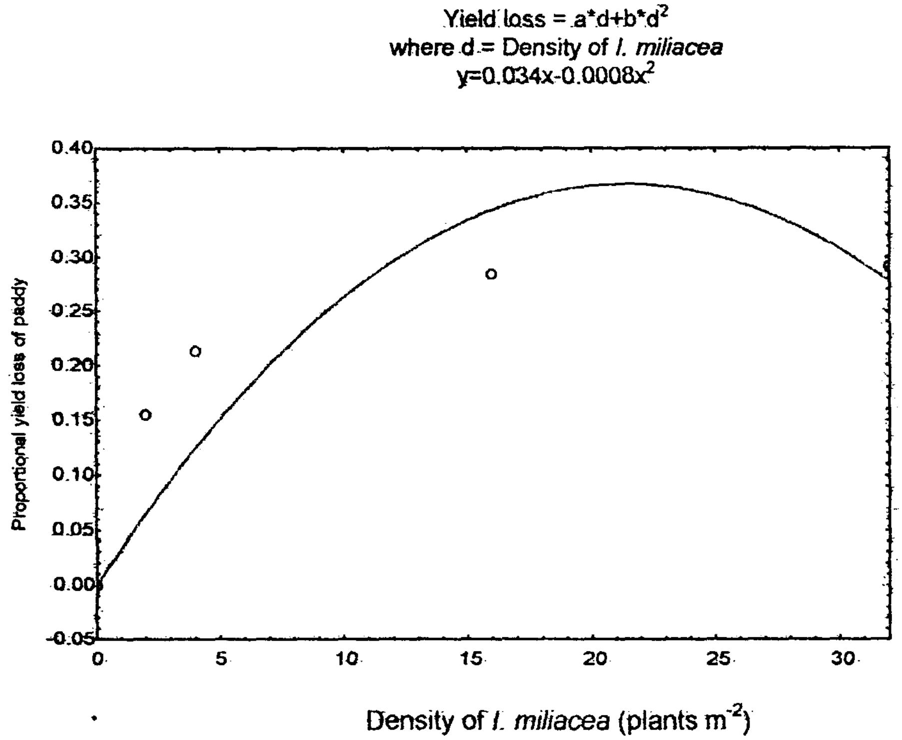


Fig. 11d. Hammerton's (1964) model for *I. miliacea* (2000 data)

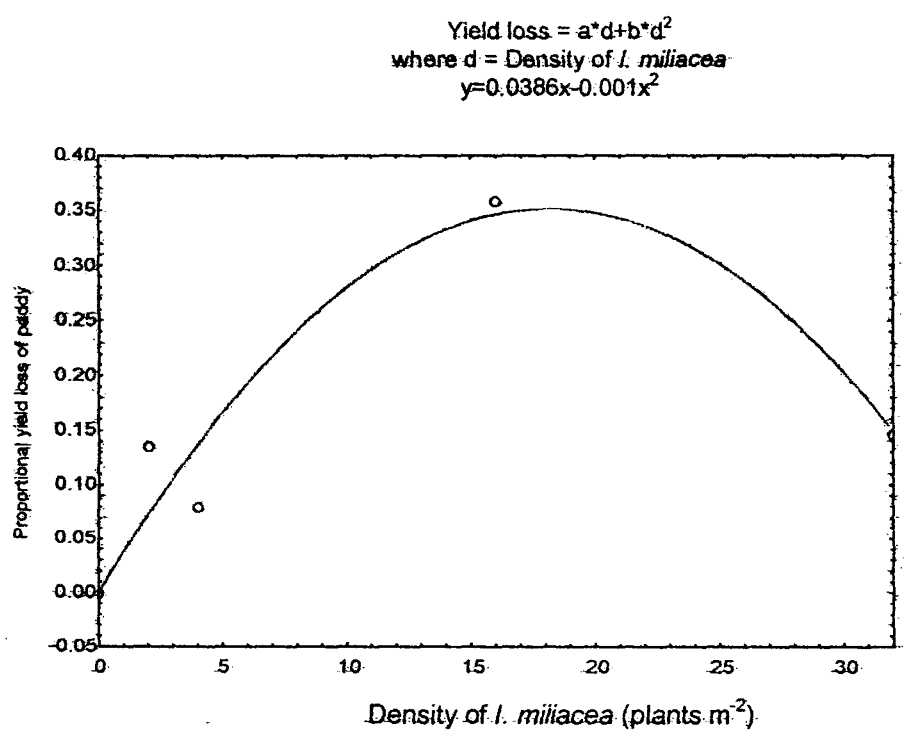


Table 28. The observed yield losses and the predicted yield losses obtained the model by Hammerton (1964) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.0654	0.1342	0.0730
4	0.2129	0.1244	0.0801	0.1375
16	0.2839	0.3437	0.3571	0.3463
32	0.2904	0.2772	0.1472	0.1492

#By fitting the equation , $Y_L = ad + bd^2$

The model proposed by Covarelli (1984) was also fitted to the yield weed density data. The parametric estimates are presented in Table 29

Table 29. Estimates of parameters for the model by Covarelli (1984) *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimate 'a'	R^2
S. interrupta	1999	0.0238 (0.0051)†	0.4432
	2000	0.0234** (0.0041)	0.7450
I. miliacea	1999	0.0115 (0.0034)	--
	2000	0.0085 (0.0039)	--

† Figures in parenthesis are the standards errors of the estimates
** Significant at 1% level of significance

The observed yield losses and predicted yield losses obtained by fittin model are presented in Table 30 & 31 and Fig.12a, 12b, 12c & 12d.

Fig. 12a. Covarelli's (1984) model fitted for *S. interrupta* (1999 data)

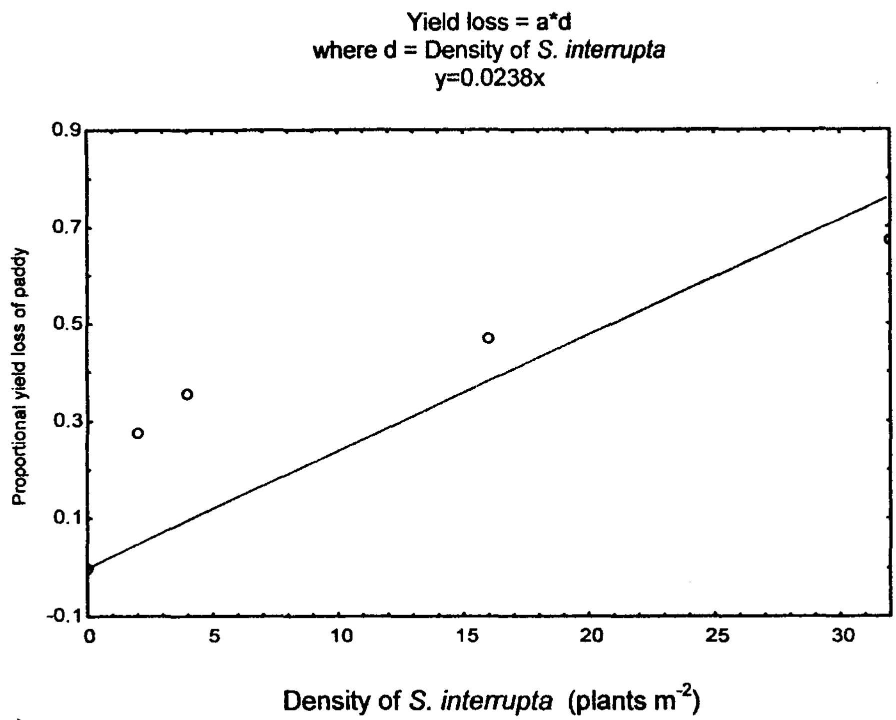


Fig. 12b. Covarelli's (1984) model fitted for *S. interrupta* (2000 data)

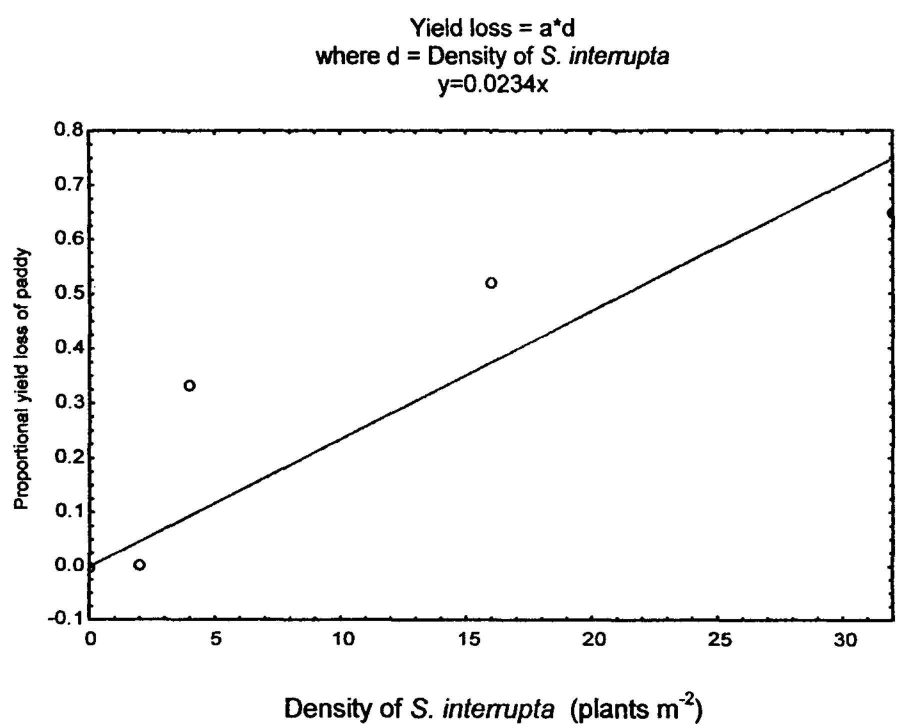


Table 30. The observed yield losses and the predicted yield losses obtained fi the model by Covarelli (1984) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.0477	0.0014	0.0468
4	0.3549	0.0953	0.3304	0.0935
16	0.4710	0.3813	0.5195	0.3741
32	0.6710	0.7626	0.6486	0.7481

#By fitting the equation, $Y_L = ad$

Fig. 12c. Covarelli's (1984) model fitted for *I. miliacea* (1999 data)

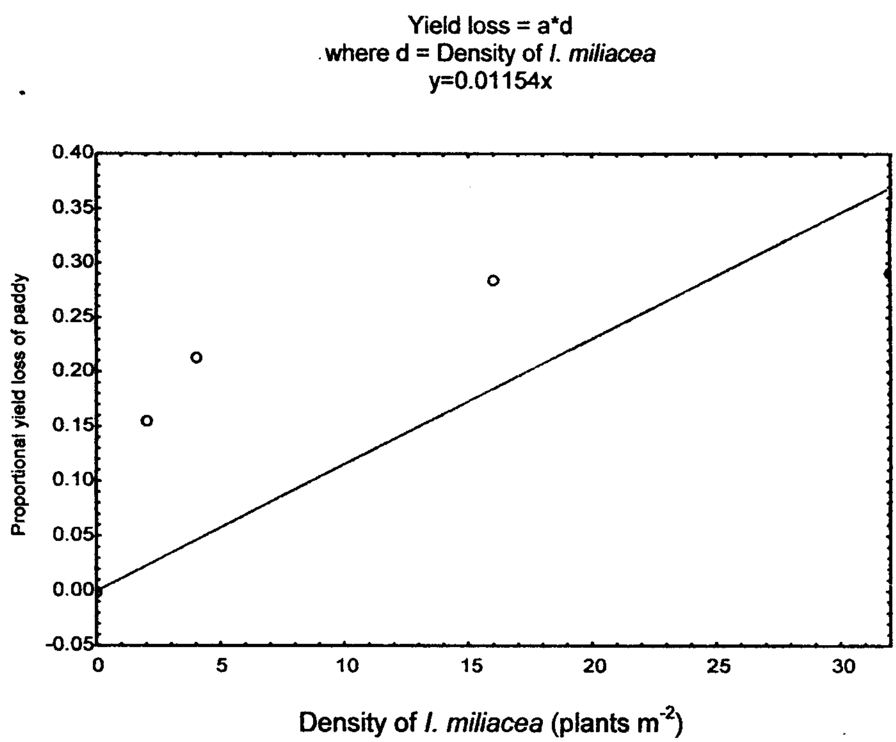


Fig. 12d. Covarelli's (1984) model fitted for *I. miliacea* (2000 data)

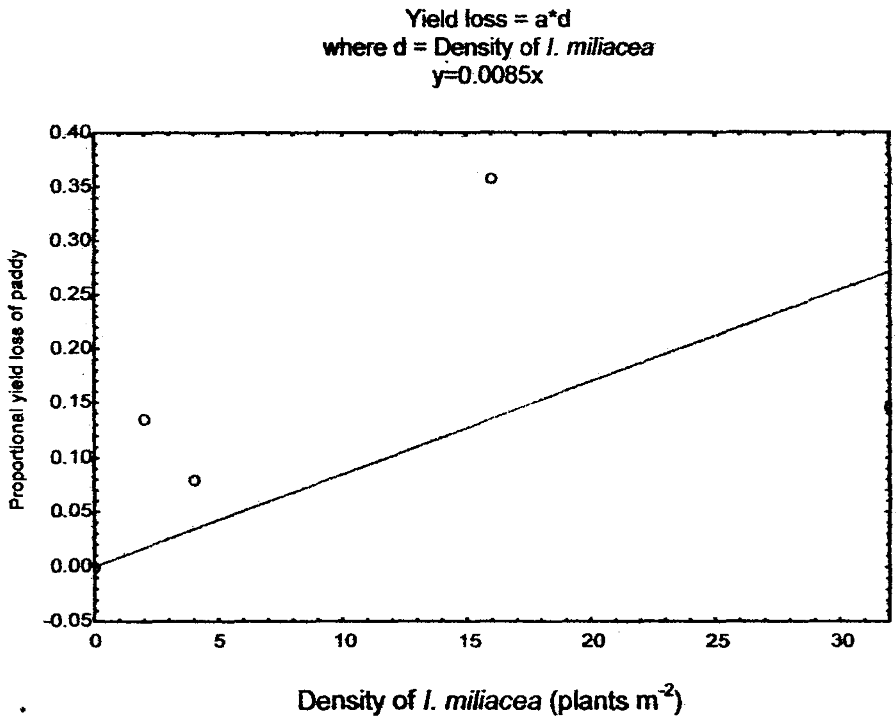


Table 31. The observed yield losses and the predicted yield losses obtained fr the model by Covarelli (1984) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.0231	0.1342	0.0169
4	0.2129	0.0461	0.0801	0.0339
16	0.2839	0.1846	0.3571	0.1355
32	0.2904	0.3692	0.1472	0.2711

#By fitting the equation ,$Y_L = ad$

The model proposed by Marra and Carlson (1983) was also fitted to t given yield loss-weed density data for *S. interrupta* and *I. miliacea*. The paramet estimates obtained and presented in Table 32.

Table 32. Estimates of parameters for the model by Marra and Carlson (1983) f
S. *interrupta* and *I. miliacea*

Weed	Year	Parameter estimates		R^2
		a	b	
S. interrupta	1999	0.2185** (0.0257)†	0.3119** (0.0405)	0.9862
	2000	0.1065 (0.0584)	0.5360 (0.1744)	0.8906
I. miliacea	1999	0.1507** (0.0160)	0.2034* (0.0387)	0.9807
	2000	0.1135 (0.0863)	0.2102 (0.2720)	0.4801

† Figures in parenthesis are the standard errors of the estimates
* Significant at 5% level of significance
** Significant at 1% level of significance

The observed yield losses and predicted yield losses obtained by fitting t model are presented in Table 33 & 34 and Fig.13a, 13b, 13c &13d.

Fig. 13a. Marra and Carlson's (1983) model fitted for *S. interrupta* (1999 data)

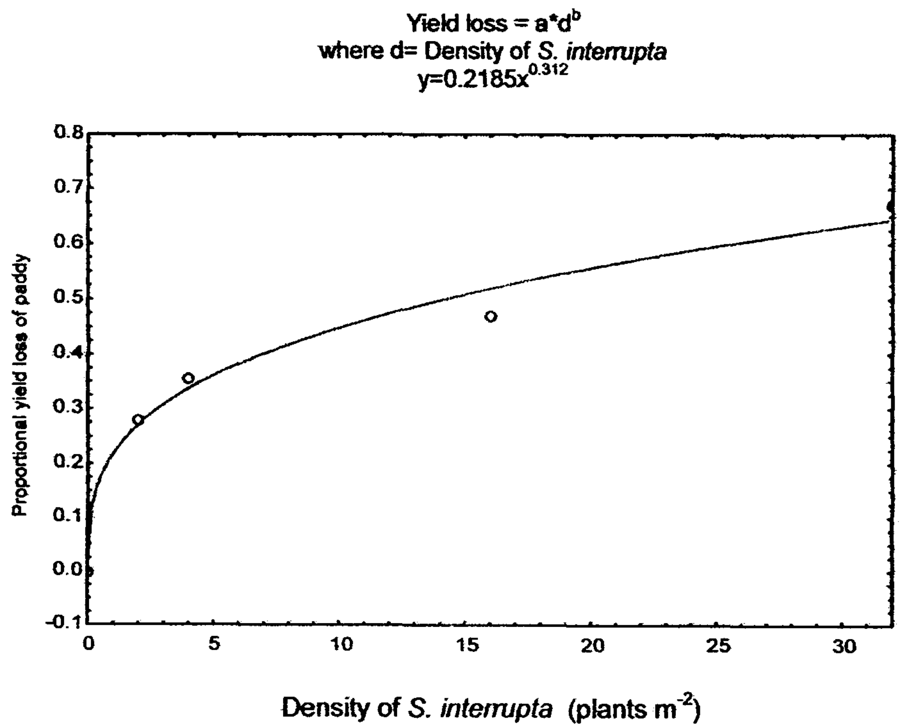


Fig. 13b. Marra and Carlson's (1983) model fitted for *S. interrupta* (2000 data)

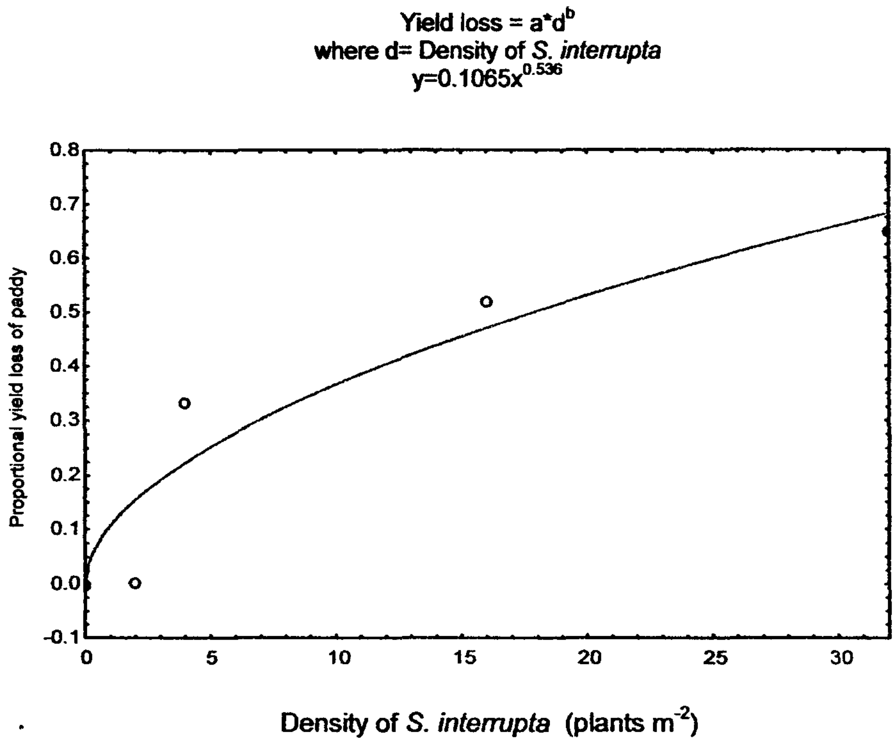


Table 33. The observed yield losses and the predicted yield losses obtained fro the model by Marra and Carlson (1983) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2713	0.0014	0.1544
4	0.3549	0.3368	0.3304	0.2239
16	0.4710	0.5190	0.5195	0.4708
32	0.6710	0.6443	0.6486	0.6826

#By fitting the equation ,$Y_L = ad^b$

Fig. 13c. Marra and Carlson's (1983) model fitted for *I. miliacea* (1999 data)

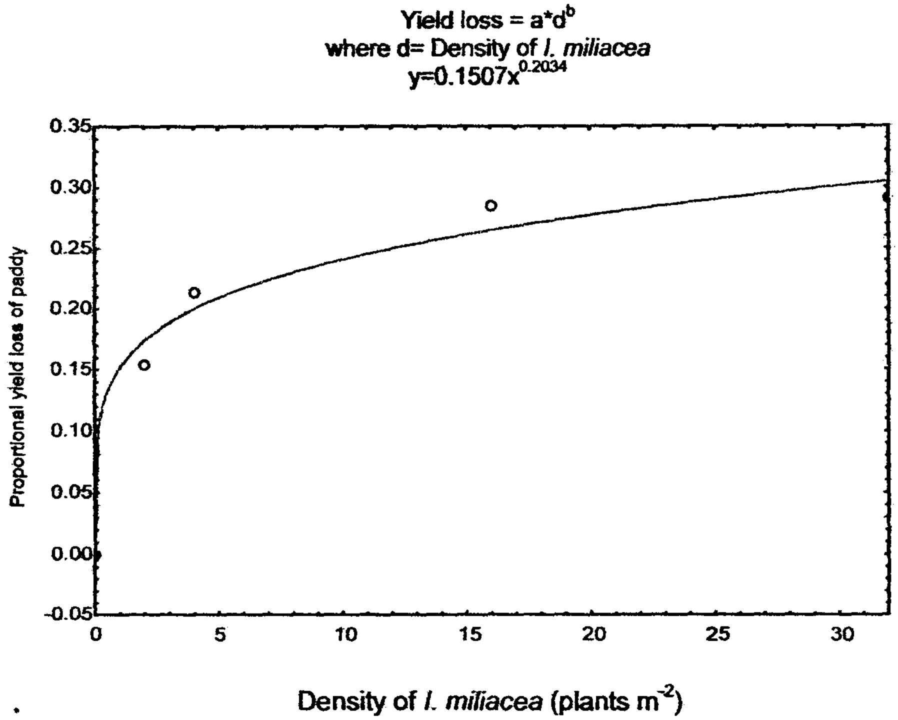


Fig. 13d. Marra and Carlson's (1983) model fitted for *I. miliacea* (2000 data)

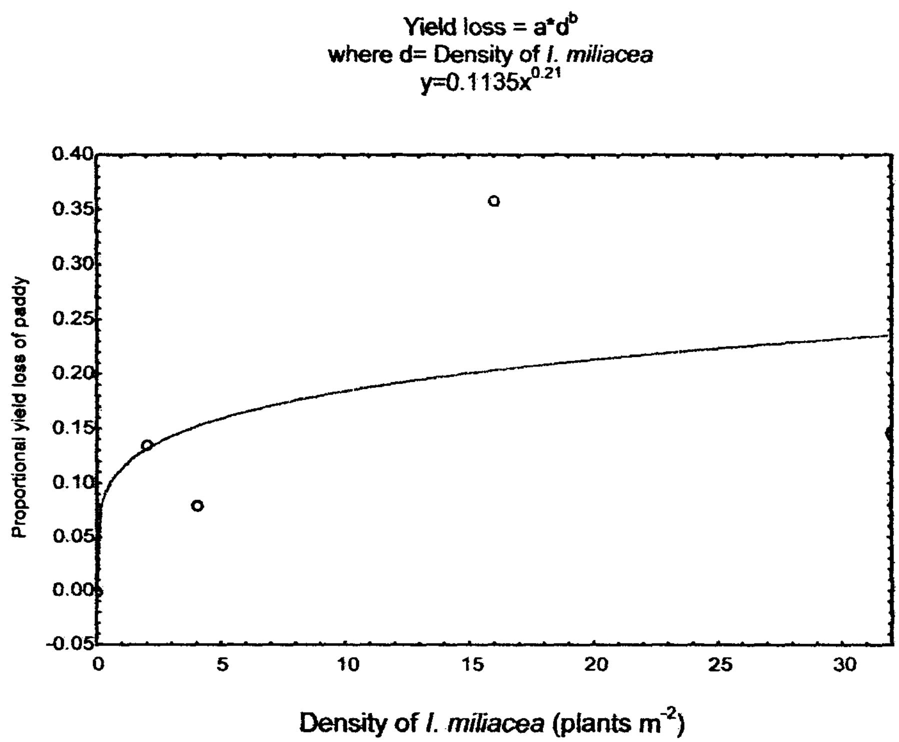


Table 34. The observed yield losses and the predicted yield losses obtained fro the model by Marra and Carlson (1983) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1735	0.1342	0.1314
4	0.2129	0.1998	0.0801	0.1520
16	0.2839	0.2649	0.3571	0.2034
32	0.2904	0.3050	0.1472	0.2353

#By fitting the equation , $Y_L = ad^b$

The model proposed by Dew (1972) was fitted to the yield loss-weed densit data of *S. interrupta* and *I. miliacea*. The parameters obtained are presented in Tab 35.

Table 35. Estimates of parameters for the model by Dew (1972) for *S. interrupt* and *I. miliacea*

Weed	Year	Parametric estimate 'a'	R^2
S. interrupta	1999	0.1256** (0.0101)†	0.9052
	2000	0.1187** (0.0134)	0.8889
I. miliacea	1999	0.0634 (0.0089)	0.6959
	2000	0.0483 (0.0148)	0.3266

† Figures in parenthesis are the standard errors of the estimates.
** Significant at 1% level of significance

The observed yield losses and the predicted yield losses obtained by fittin the model are given in Table 36 & 37 and Fig.14a, 14b, 14c &14d.

Fig. 14a. Dew's (1972) model fitted for *S. interrupta* (1999 data)

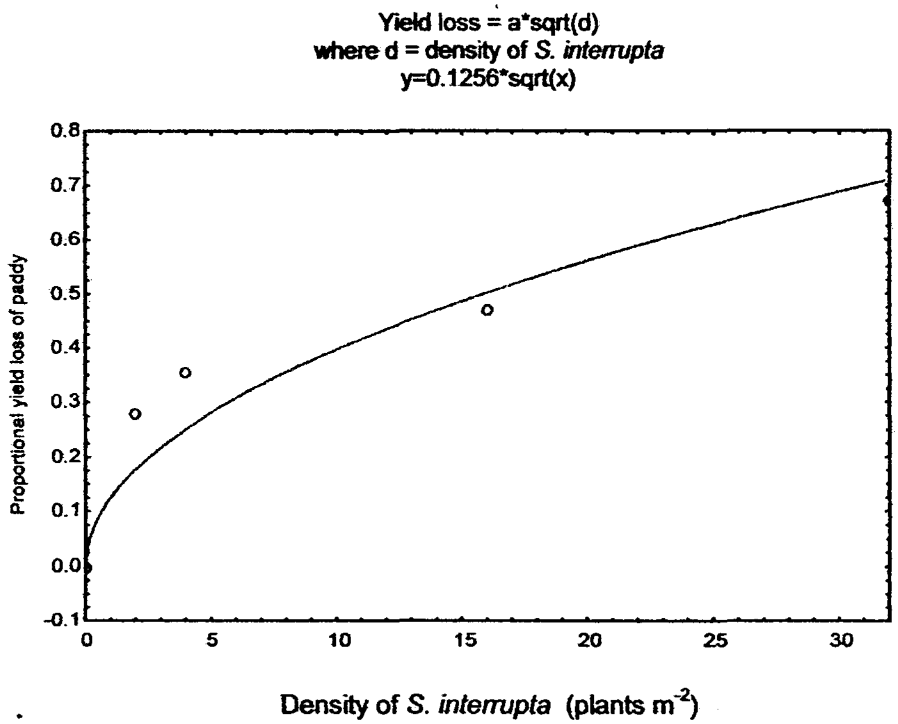


Fig. 14b. Dew's (1972) model fitted for *S. interrupta* (2000 data)

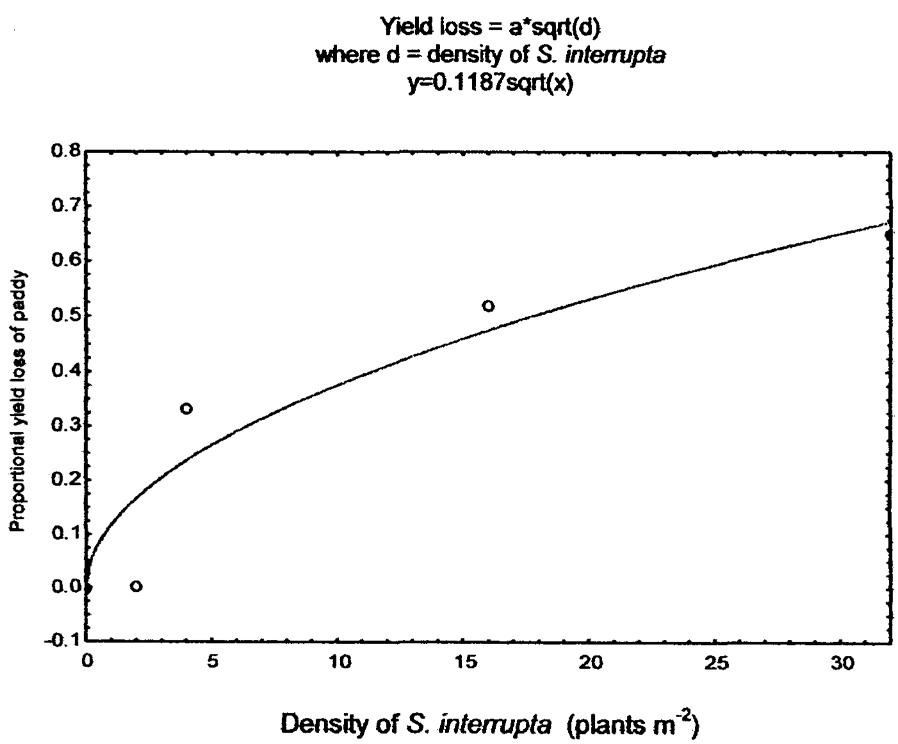


Table 36. The observed yield losses and the predicted yield losses obtained from the model by Dew (1972) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.1776	0.0014	0.1679
4	0.3549	0.2512	0.3304	0.2374
16	0.4710	0.5023	0.5195	0.4748
32	0.6710	0.7104	0.6486	0.6715

By fitting the equation , $Y_L = a\sqrt{d}$

Fig. 14c. Dew's (1972) model fitted for *I. miliacea* (1999 data)

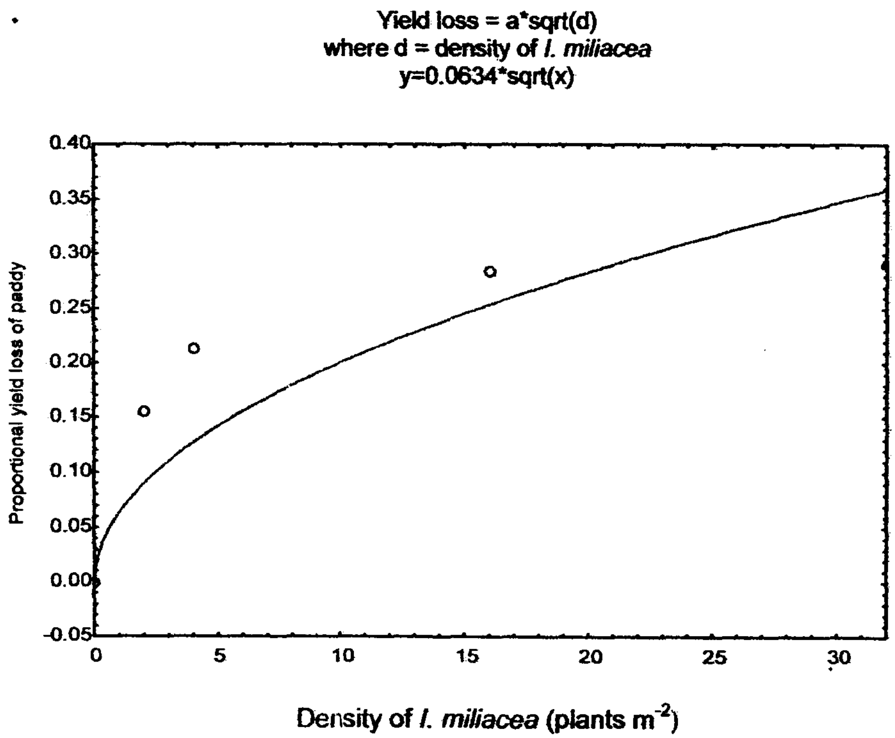


Fig. 14d. Dew's (1972) model fitted for *I. miliacea* (2000 data)

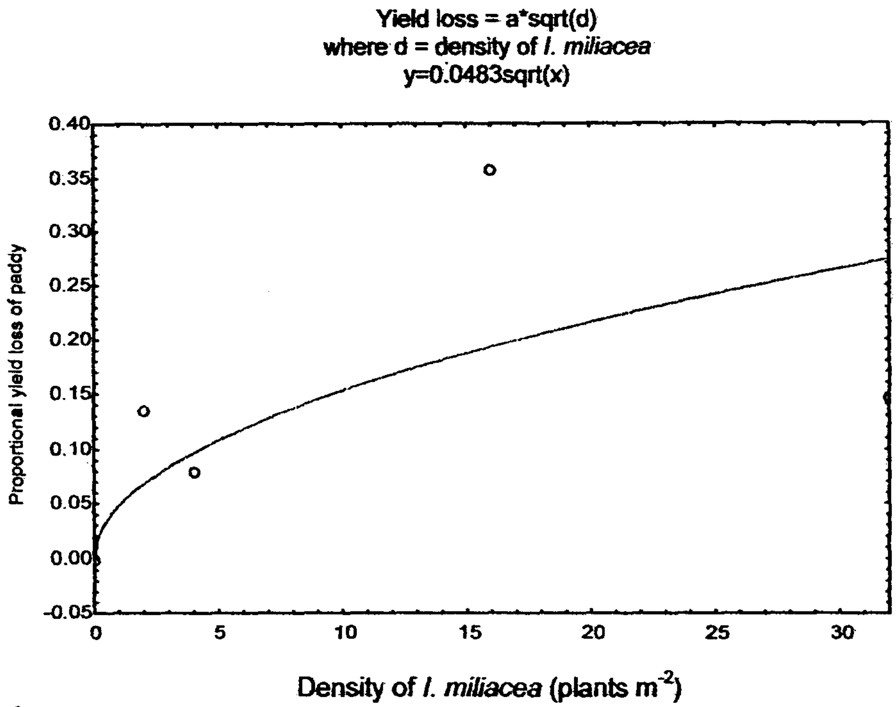


Table 37. The observed yield losses and the predicted yield losses obtained from the model by Dew (1972) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.0897	0.1342	0.0683
4	0.2129	0.1268	0.0801	0.0967
16	0.2839	0.2536	0.3571	0.1933
32	0.2904	0.3586	0.1472	0.2734

By fitting the equation , $Y_L = a\sqrt{d}$

The model proposed by Weise (1971) was also fitted for the yield loss – weed density data for *S. interrupta* and *I. miliacea*. The estimated values of the parameters are presented in Table 38.

Table 38. Estimates of parameters for the model by Weise (1971) for *S. interrupta* and *I. miliacea*

Weed	Year	Parameter estimates		R^2
		a	b	
S. interrupta	1999	-0.0131 (0.0056)[†]	0.1876** (0.0274)	0.9665
	2000	0.0003 (0.0121)	0.1175 (0.0596)	0.8889
I. miliacea	1999	-0.0139** (0.0009)	0.1294** (0.0046)	0.9959
	2000	-0.0155 (0.01)	0.1216 (0.0491)	0.6253

[†] Figures in parenthesis are the standard errors of the parametric estimates.
** Significant at 1% level of significance

The observed yield losses and the predicted yield losses obtained by fitting the model are presented in Table 39 & 40 and Fig. 15a, 15b, 15c & 15d.

Fig. 15a. Weise's (1971) model fitted for *S. interrupta* (1999 data)

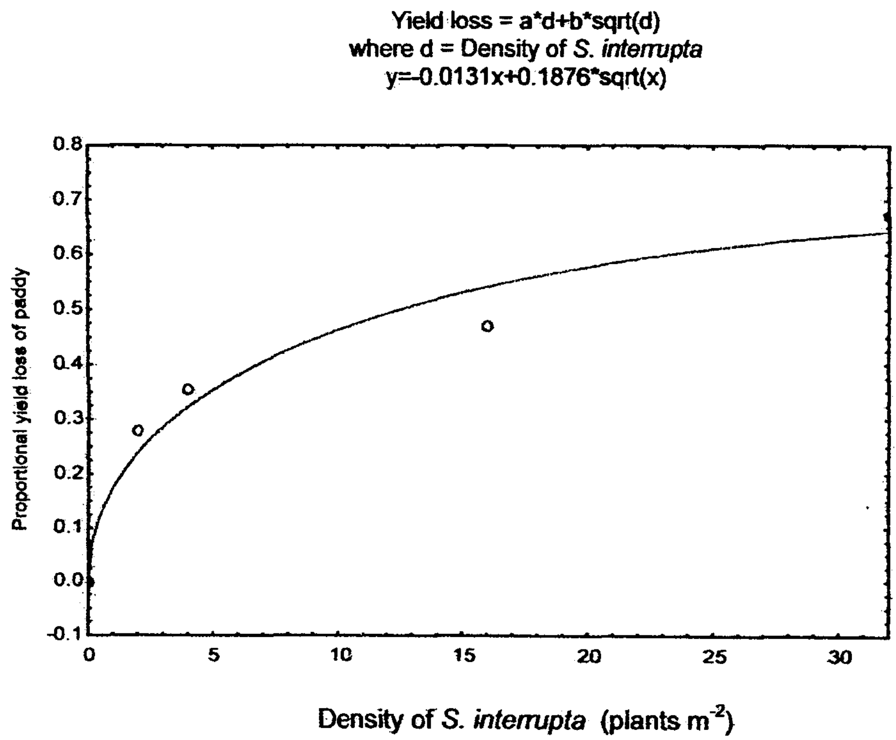


Fig. 15b. Weise's (1971) model fitted for *S. interrupta* (2000 data)

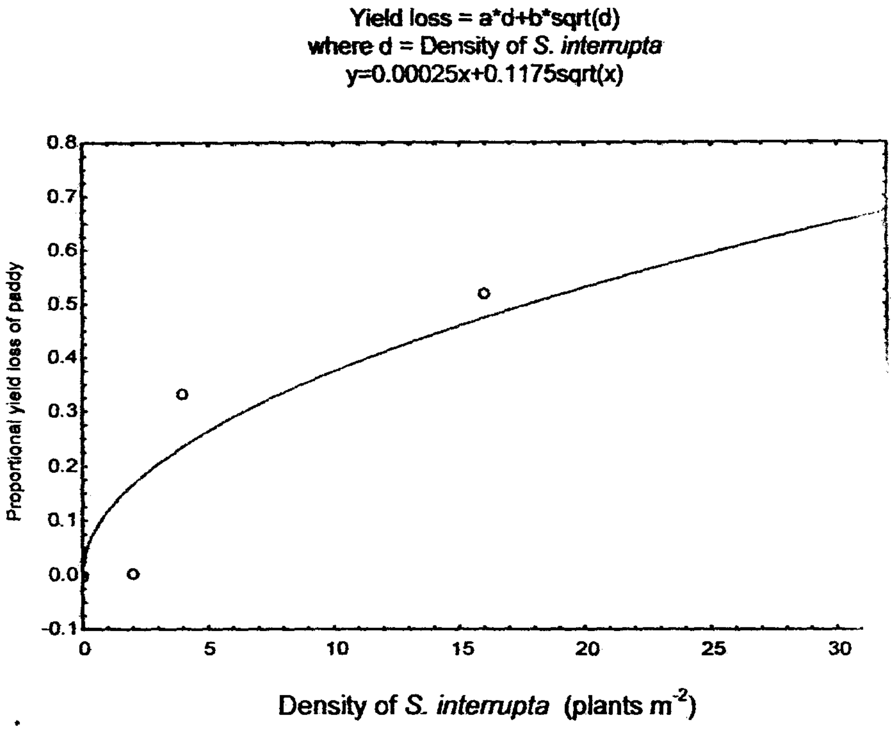


Table 39. The observed yield losses and the predicted yield losses obtained from the model by Weise (1971) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2391	0.0014	0.1667
4	0.3549	0.3229	0.3304	0.2360
16	0.4710	0.5410	0.5195	0.4741
32	0.6710	0.6424	0.6486	0.6728

By fitting the equation, $Y_L = ad + b\sqrt{d}$

Fig. 15c. Weise's (1971) model fitted for *I. miliacea* (1999 data)

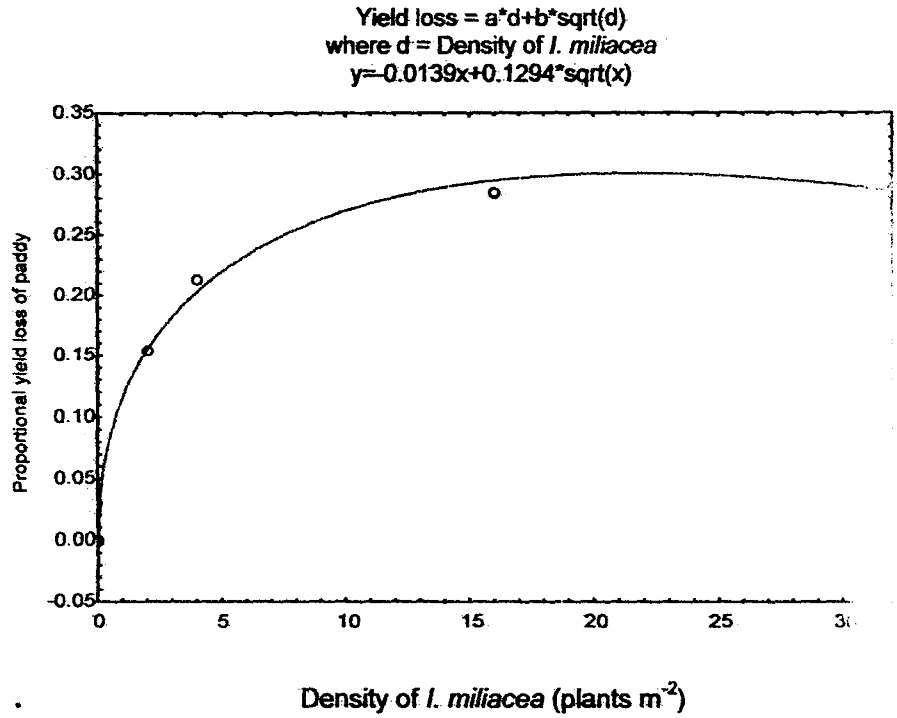


Fig. 15d. Weise's (1971) model fitted for *I. miliacea* (2000 data)

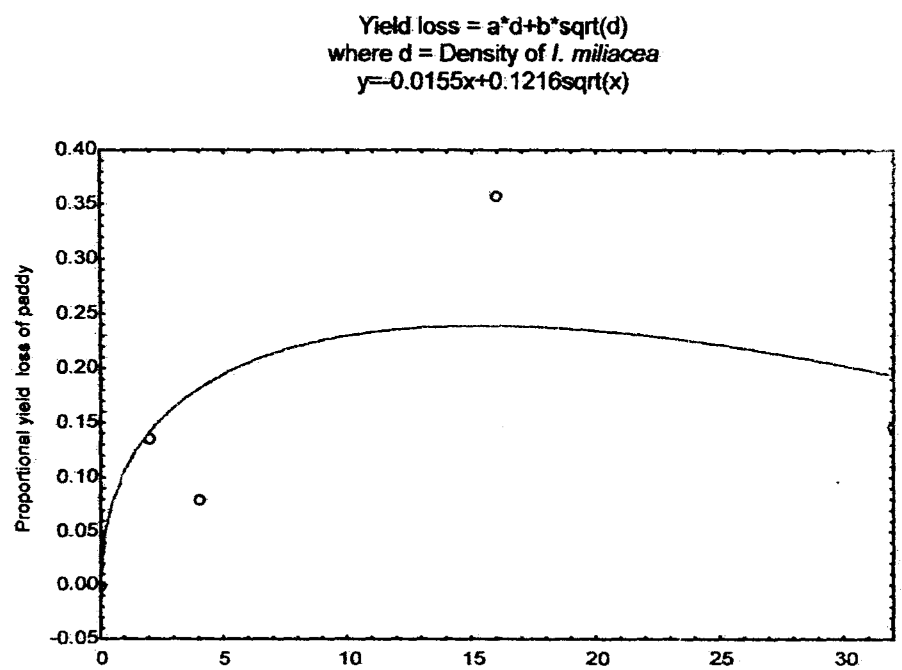


Table 40. The observed yield losses and the predicted yield losses obtained from the model by Weise (1971) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1551	0.1342	0.1411
4	0.2129	0.2030	0.0801	0.1814
16	0.2839	0.2947	0.3571	0.2391
32	0.2904	0.2863	0.1472	0.1931

By fitting the equation , $Y_L = ad + b\sqrt{d}$

The model proposed by Wilson and Cussans (1983) was also fitted to the yield loss – weed density data for *S. interrupta* and *I. miliacea*. The parameters estimated are presented in Table 41.

Table 41. Estimates of parameters for the model by Wilson and Cussans (1983) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates		R^2
		b	a	
S. interrupta	1999	0.5789** (0.0684)†	0.2596 (0.1162)	0.9165
	2000	0.6617* (0.1226)	0.1070 (0.0579)	0.9243
I. miliacea	1999	0.2867** (0.0043)	0.3638** (0.0194)	0.9981
	2000	0.2425* (0.0749)	0.2289 (0.2065)	0.5740

† Figures in parenthesis are the standard errors of the estimates.
* Significant at 5% level of significance
** Significant at 1% level of significance

The observed yield losses and the predicted yield losses determined by the model for *S. interrupta* and *I. miliacea* are presented in Table 42 & 43 and Fig. 16a, 16b, 16c & 16d.

Fig. 16a. Wilson and Cussans (1983) model fitted for *S. interrupta* (1999 data)

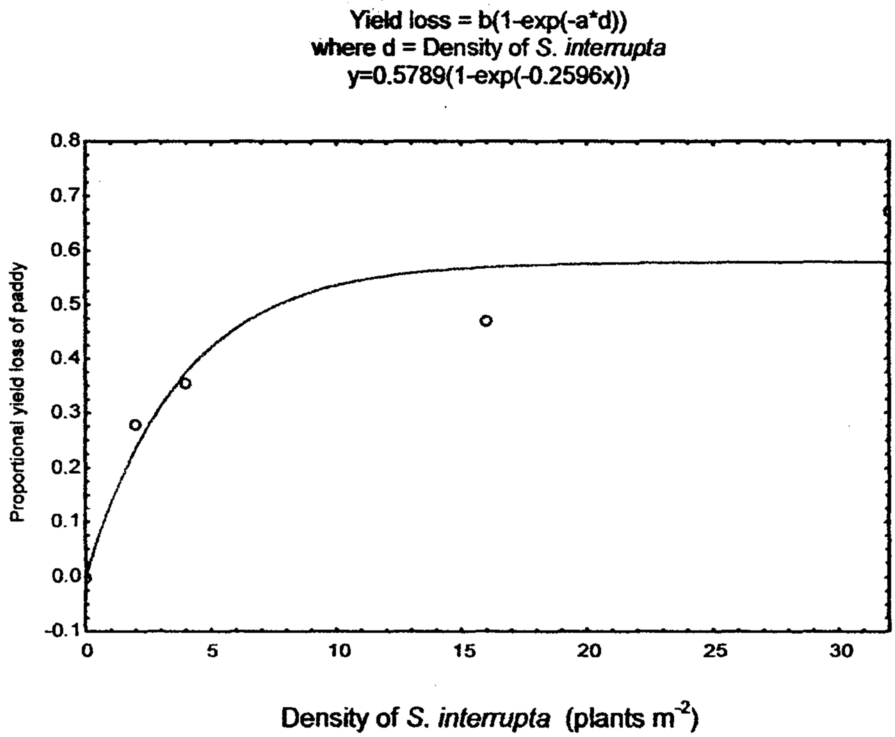


Fig. 16b. Wilson and Cussans (1983) model fitted for *S. interrupta* (2000 data)

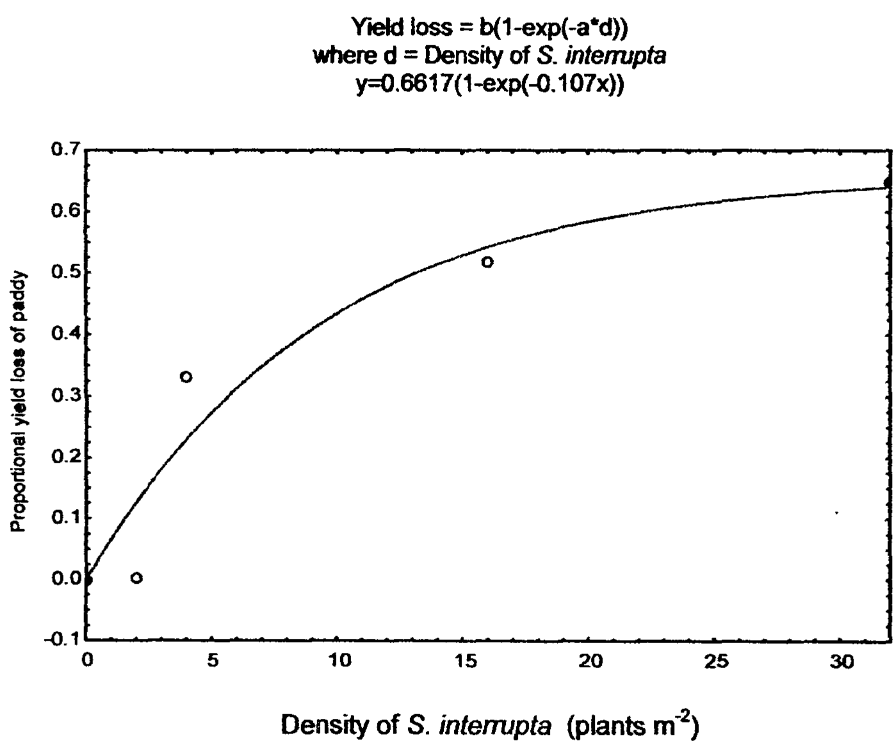


Table 42. The observed yield losses and the predicted yield losses obtained from the model by Wilson and Cussans (1983) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2345	0.0014	0.1275
4	0.3549	0.3740	0.3304	0.2305
16	0.4710	0.5698	0.5195	0.5423
32	0.6710	0.5788	0.6486	0.6402

By fitting the equation, $Y_L = b\,(1 - \exp(-ad))$

Fig. 16c. Wilson and Cussans (1983) model fitted for *I. miliacea* (1999 data)

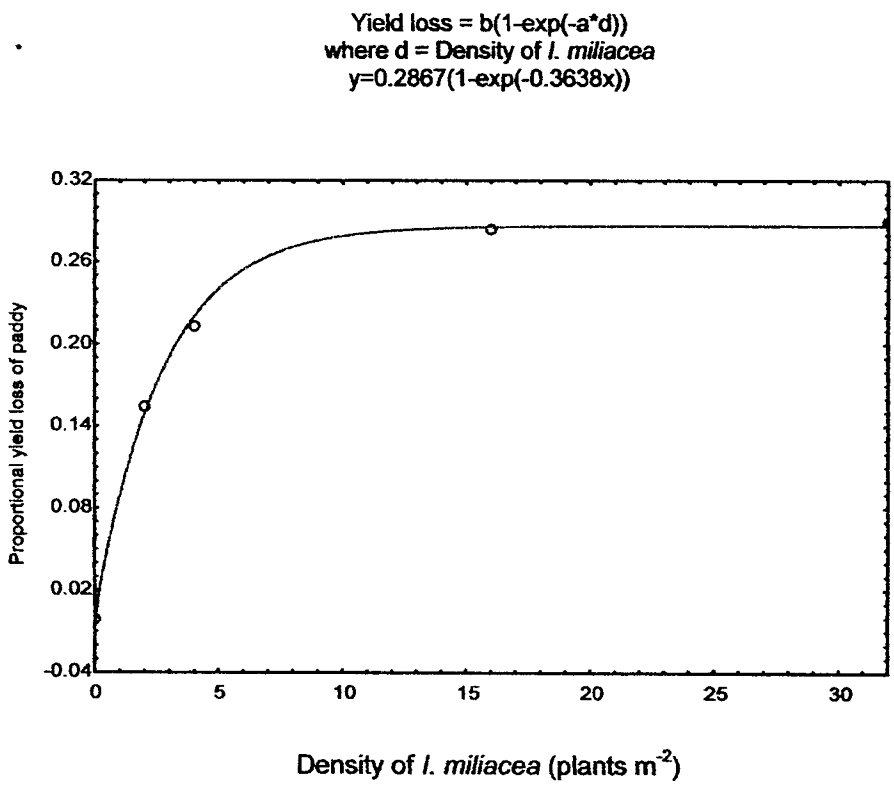


Fig. 16d. Wilson and Cussans (1983) model fitted for *I. miliacea* (2000 data)

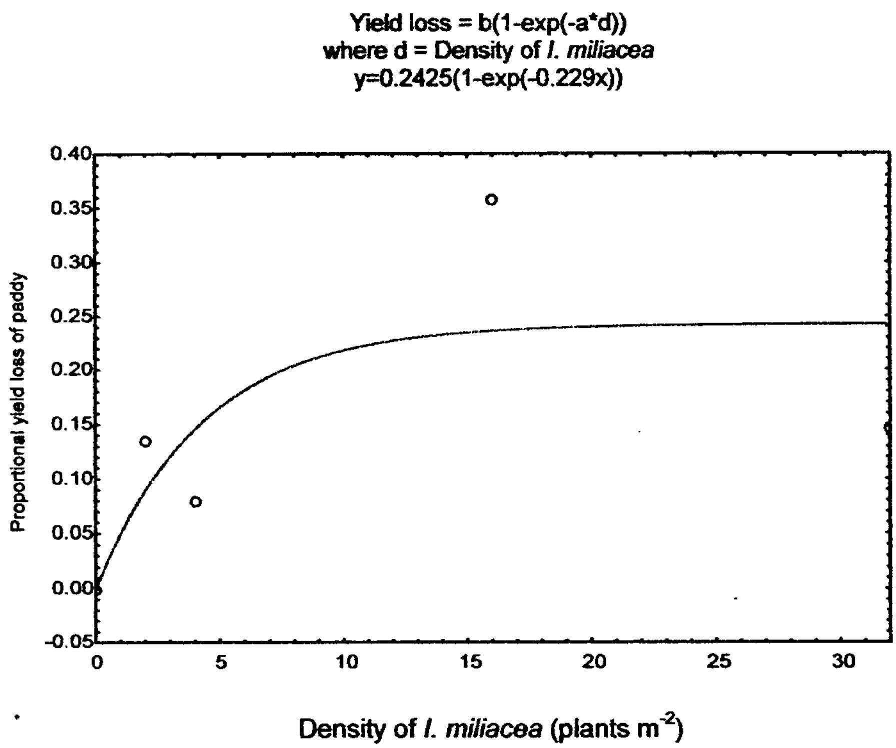


Table 43. The observed yield losses and the predicted yield losses obtained from the model by Wilson and Cussans (1983) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1482	0.1342	0.0891
4	0.2129	0.2198	0.0801	0.1455
16	0.2839	0.2859	0.3571	0.2363
32	0.2904	0.2867	0.1472	0.2424

By fitting the equation, $Y_L = b\,(1 - \exp(-ad))$

The model proposed by Zakharenko (1968) was also fitted to the yield loss – weed density data. The parameters estimated are presented in Table 44.

Table 44. Estimates of parameters for the model by Zakharenko (1968) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimate 'a'	R^2
S. interrupta	1999	0.0446* (0.0146)[†]	0.6616
	2000	0.0415* (0.0097)	0.8678
I. miliacea	1999	0.0148* (0.0050)	0.0685
	2000	0.0104 (0.0053)	–

[†] Figures in parenthesis are the standard errors of the estimates
* Significant at 5% level of significance

The observed yield losses and the predicted yield losses from the model are presented in Table 45 & 46 and Fig.17a, 17b, 17c & 17d.

Fig. 17a. Zakharenko's (1968) model fitted for *S. interrupta* (1999 data)

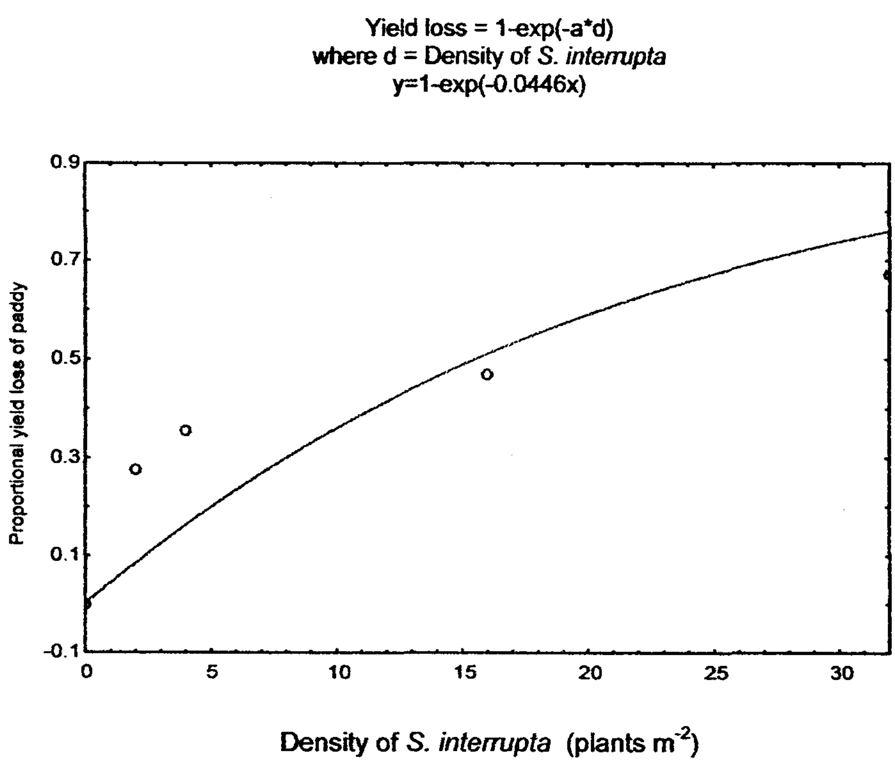


Fig. 17b. Zakharenko's (1968) model fitted for *S. interrupta* (2000 data)

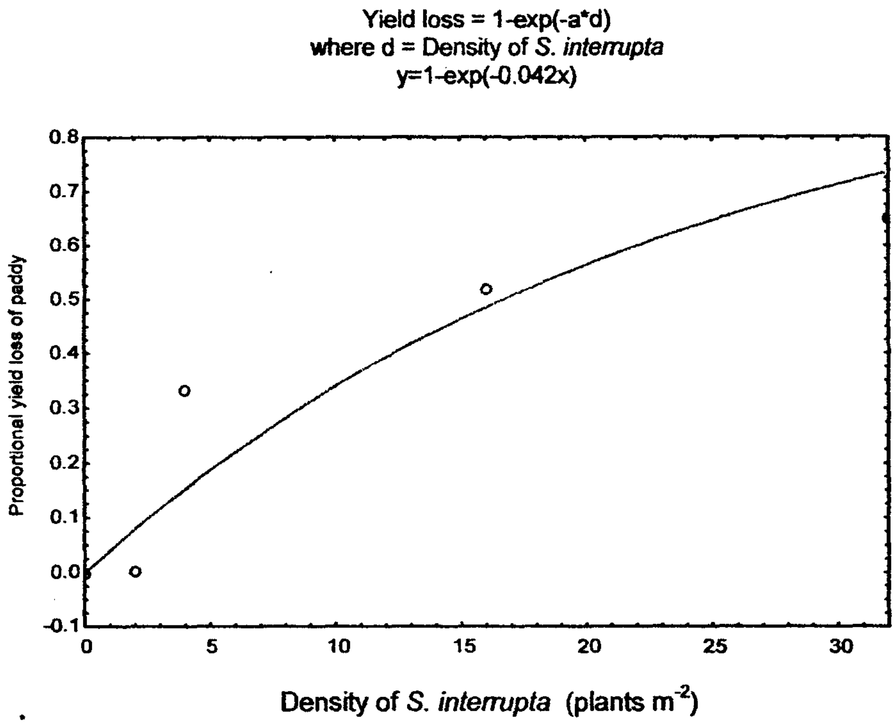


Table 45. The observed yield losses and the predicted yield losses obtained from the model by Zakharenko (1968) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.0854	0.0014	0.0797
4	0.3549	0.1634	0.3304	0.1531
16	0.4710	0.5102	0.5195	0.4856
32	0.6710	0.7601	0.6486	0.7354

#By fitting the equation , $Y_L = 1 - \exp(-ad)$

Fig. 17c. Zakharenko's (1968) model fitted for *I. miliacea* (1999 data)

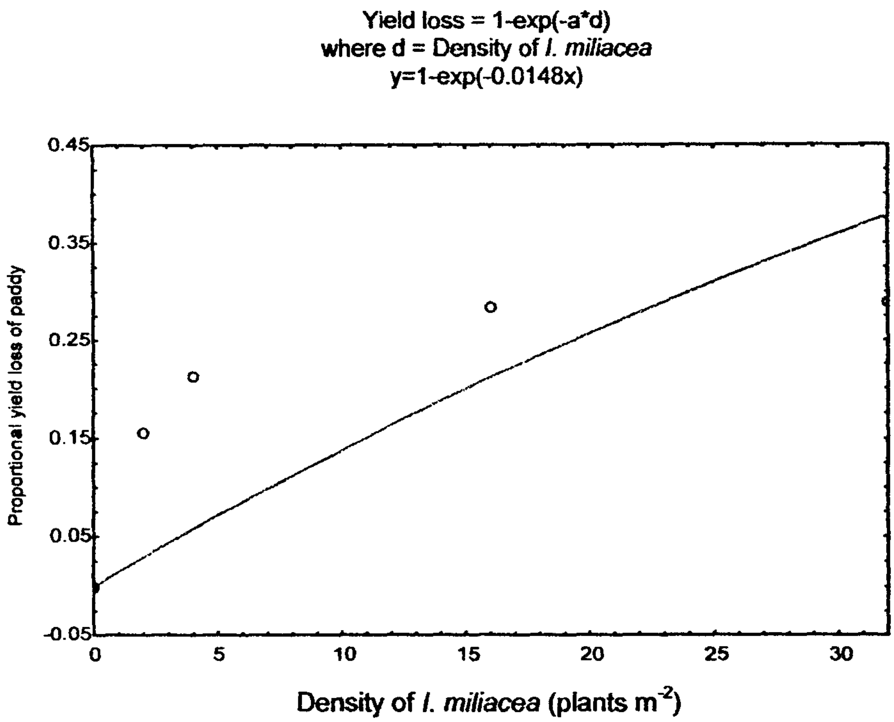


Fig. 17d. Zakharenko's (1968) model fitted for *I. miliacea* (2000 data)

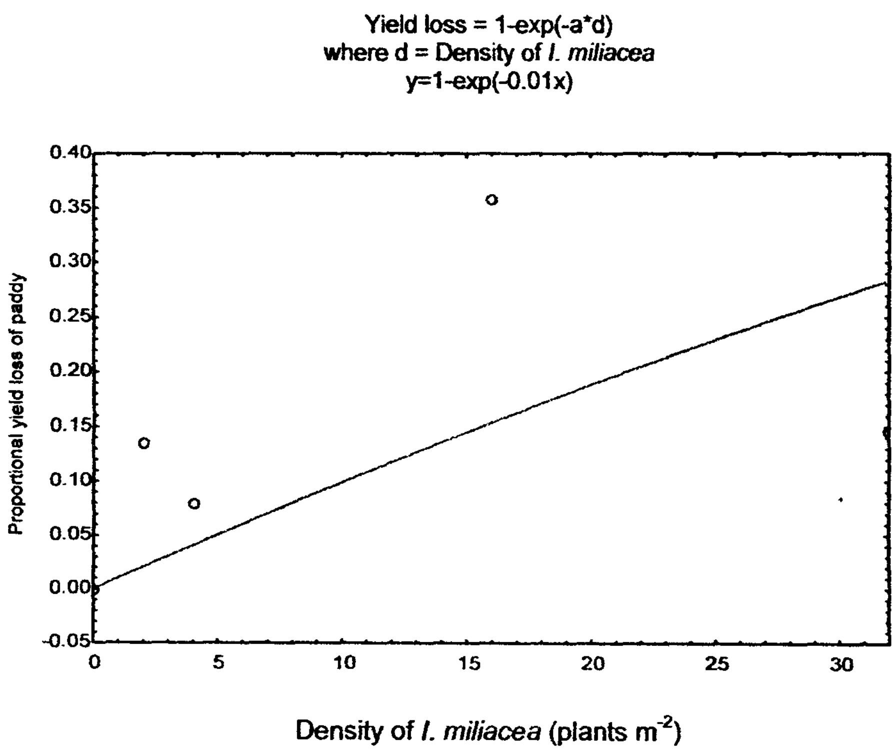


Table 46. The observed yield losses and the predicted yield losses obtained from the model by Zakharenko (1968) for *I. miliacea*

I. miliacea density per m²	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.0292	0.1342	0.0206
4	0.2129	0.0576	0.0801	0.0408
16	0.2839	0.2114	0.3571	0.1536
32	0.2904	0.3781	0.1472	0.2837

#By fitting the equation ,Y_L = 1- exp (-ad)

The model proposed by Chisaka (1977) relating yield loss to weed density was also fitted to the data. The parametric estimates are given in Table 47.

Table 47. Estimates of parameters for the model by Chisaka (1977) for *S. interrupta* and *I. miliacea*

Weed	Year	Parameter 'a'	R^2
S. interrupta	1999	0.0856* (0.0258)†	0.8273
	2000	0.0675* (0.0165)	0.9173
I. miliacea	1999	0.0195 (0.0072)	0.2163
	2000	0.0130 (0.0072)	0.0265

† Figures in parenthesis are the standard errors of the estimate.
* Significant at 5% level of significance

The observed yield losses and the predicted yield losses estimated by the model for *S. interrupta* and *I. miliacea* are presented in Table 48 & 49 and Fig.18a, 18b, 18c & 18d.

Fig. 18a. Chisaka's (1977) model fitted for *S. interrupta* (1999 data)

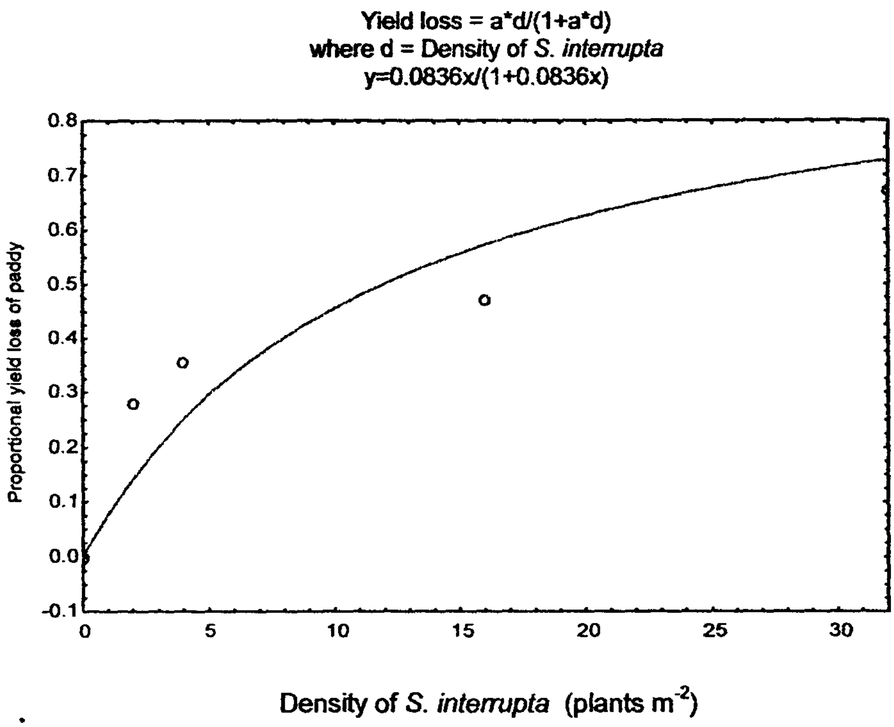


Fig. 18b. Chisaka's (1977) model fitted for *S. interrupta* (2000 data)

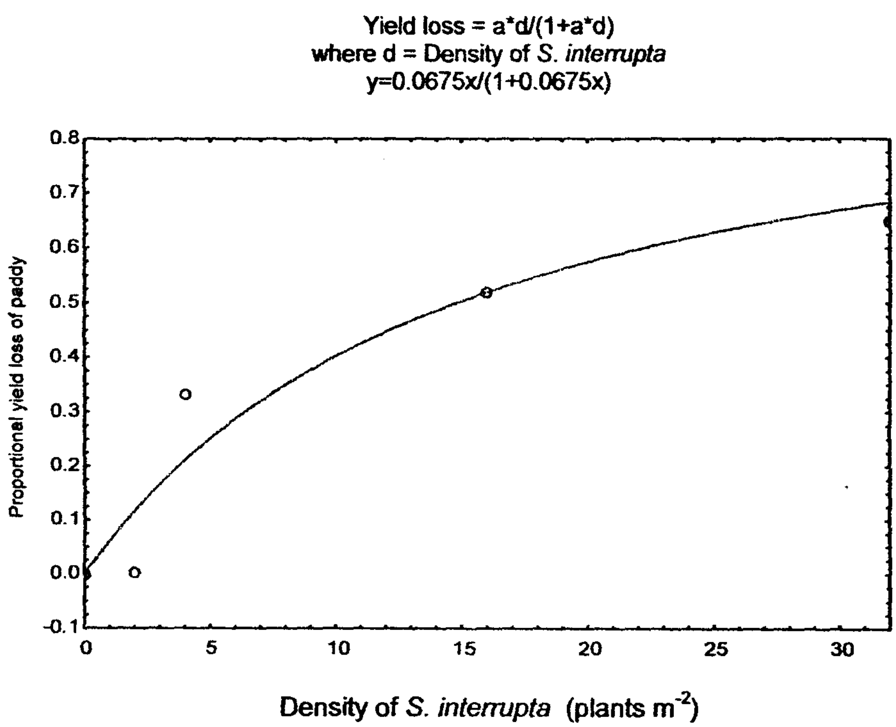


Table 48. The observed yield losses and the predicted yield losses obtained from the model by Chisaka (1977) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.1432	0.0014	0.1189
4	0.3549	0.2506	0.3304	0.2125
16	0.4710	0.5722	0.5195	0.5191
32	0.6710	0.7279	0.6486	0.6834

#By fitting the equation , $Y_L = \frac{ad}{1+ad}$

Fig. 18c. Chisaka's (1977) model fitted for *I. miliacea* (1999 data)

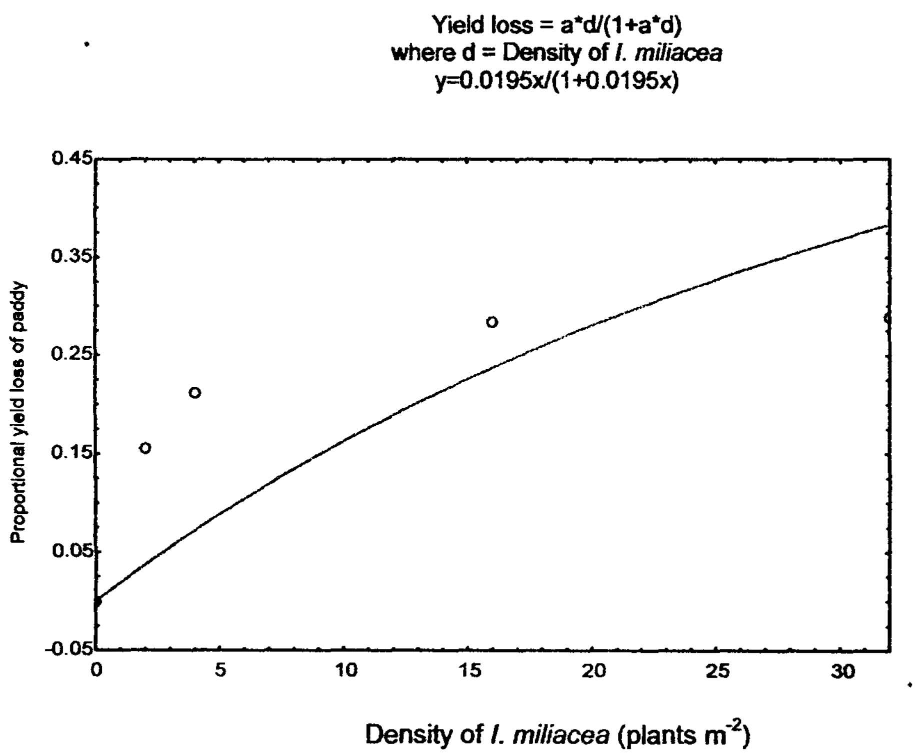


Fig. 18d. Chisaka's (1977) model fitted for *I. miliacea* (2000 data)

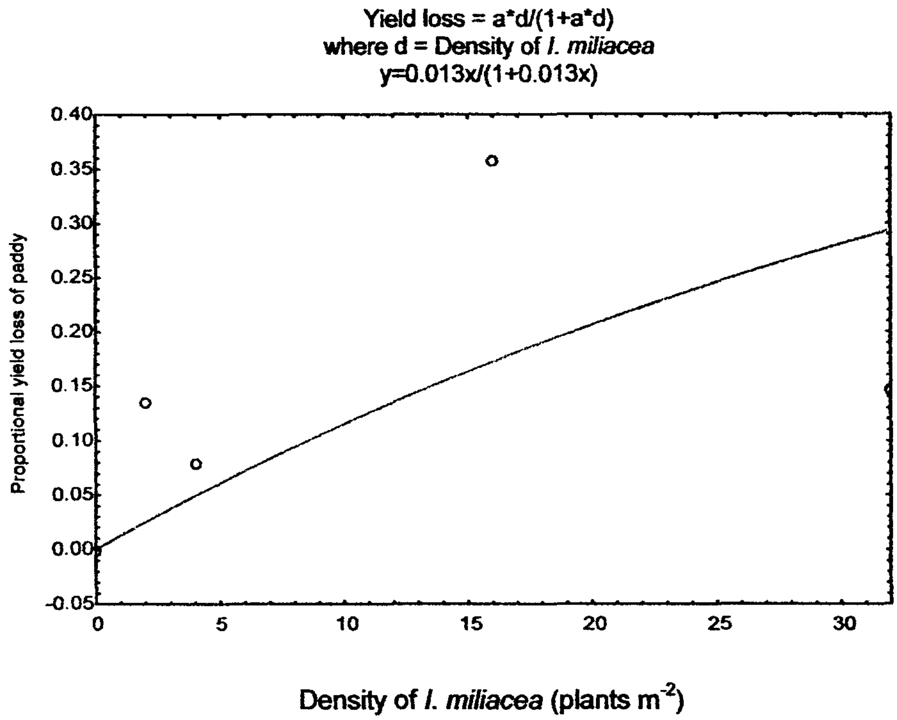


Table 49. The observed yield losses and the predicted yield losses obtained from the model by Chisaka (1977) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.000
2	0.1549	0.0375	0.1342	0.0254
4	0.2129	0.0722	0.0801	0.0495
16	0.2839	0.2375	0.3571	0.1724
32	0.2904	0.3838	0.1472	0.2941

#By fitting the equation , $Y_L = \frac{ad}{1+ad}$

The model proposed by Wilcockson (1977) was also fitted to the yield loss-weed density data for *S. interrupta* and *I. miliacea*. The parameters estimated are given in Table 50.

Table 50. Estimates of parameters for the model by Wilcockson (1977) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates		R^2
		b	a	
S. interrupta	1999	0.1925†	0.2865†	0.9518
	2000	0.0798 (0.0484)#	0.0907 (0.0845)	0.9224
I. miliacea	1999	0.1597†	0.5099†	0.9988
	2000	0.0894†	0.3414†	0.5328

Figures in parenthesis are the standard errors of the estimates

† Standard errors could not be computed, as of the matrix was ill-conditioned

The observed yield losses calculated from the model for *S. interrupta* and *I. miliacea* are presented in Table 51 & 52 and Fig.19a, 19b, 19c & 19d.

Fig. 19a. Wilcockson's (1977) model fitted for *S. interrupta* (1999 data)

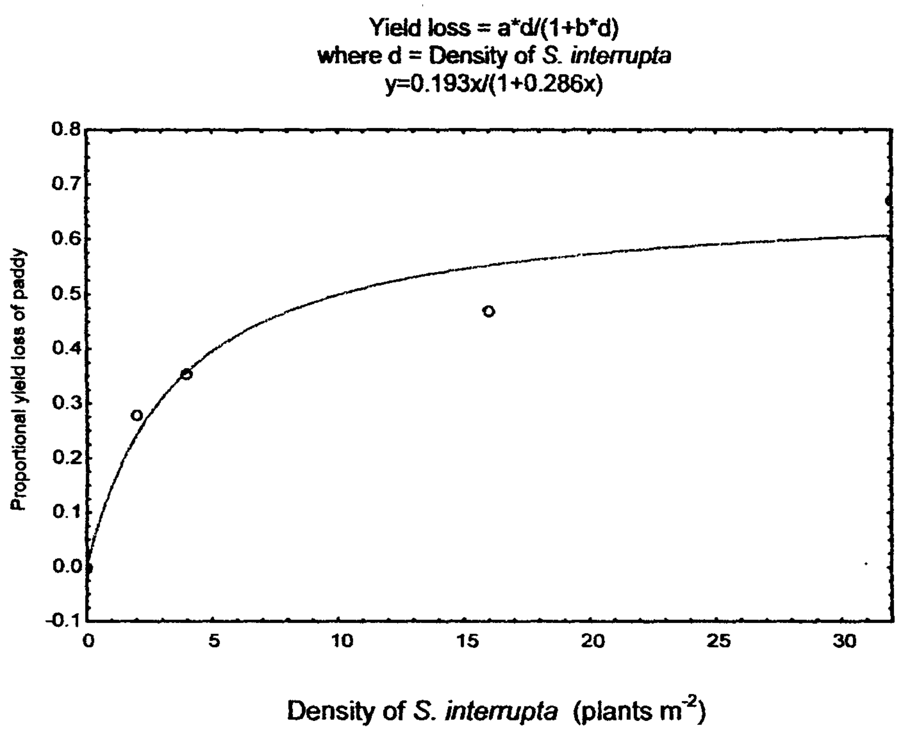


Fig. 19b. Wilcockson's (1977) model fitted for *S. interrupta* (2000 data)

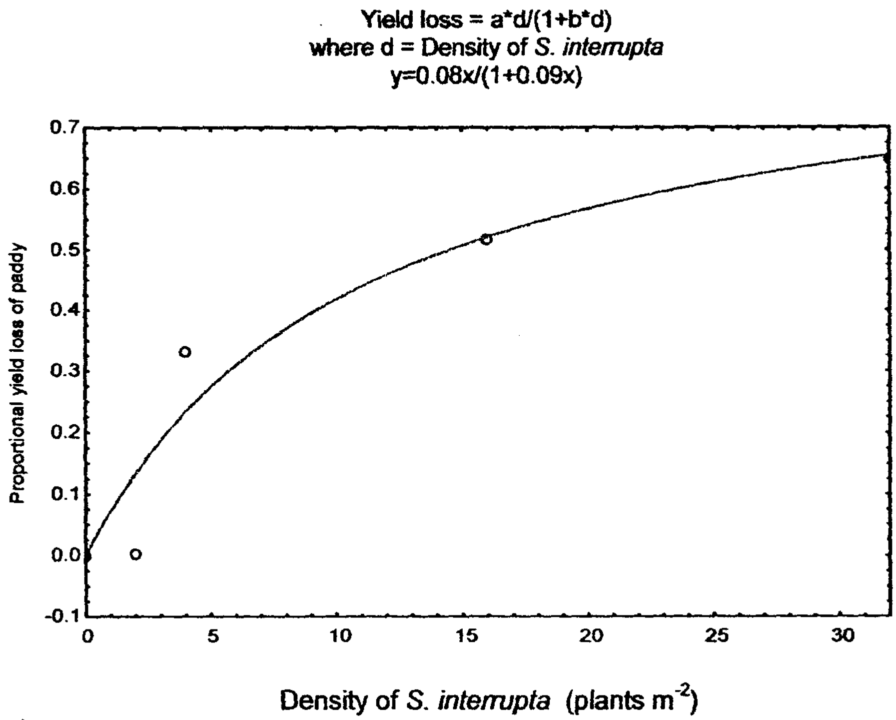


Table 51. The observed yield losses and the predicted yield losses obtained from the model by Wilcockson (1977) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2452	0.0014	0.1351
4	0.3549	0.3595	0.3304	0.2342
16	0.4710	0.5526	0.5195	0.5209
32	0.6710	0.6070	0.6486	0.6544

#By fitting the equation, $Y_L = \frac{ad}{1+bd}$

Fig. 19c. Wilcockson's (1977) model fitted for *I. miliacea* (1999 data)

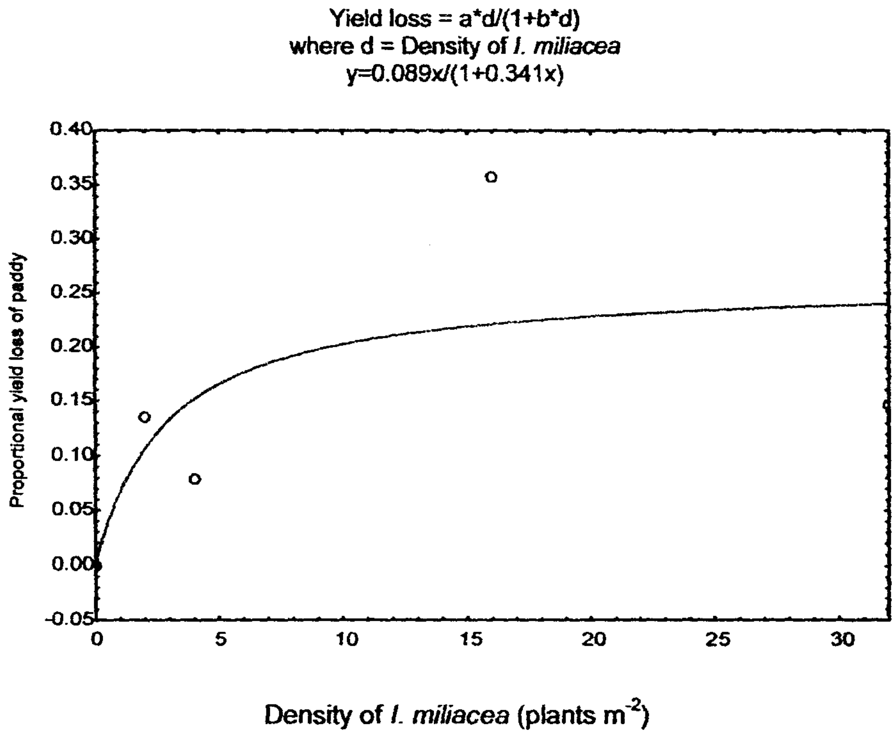


Fig. 19d. Wilcockson's (1977) model fitted for *I. miliacea* (2000 data)

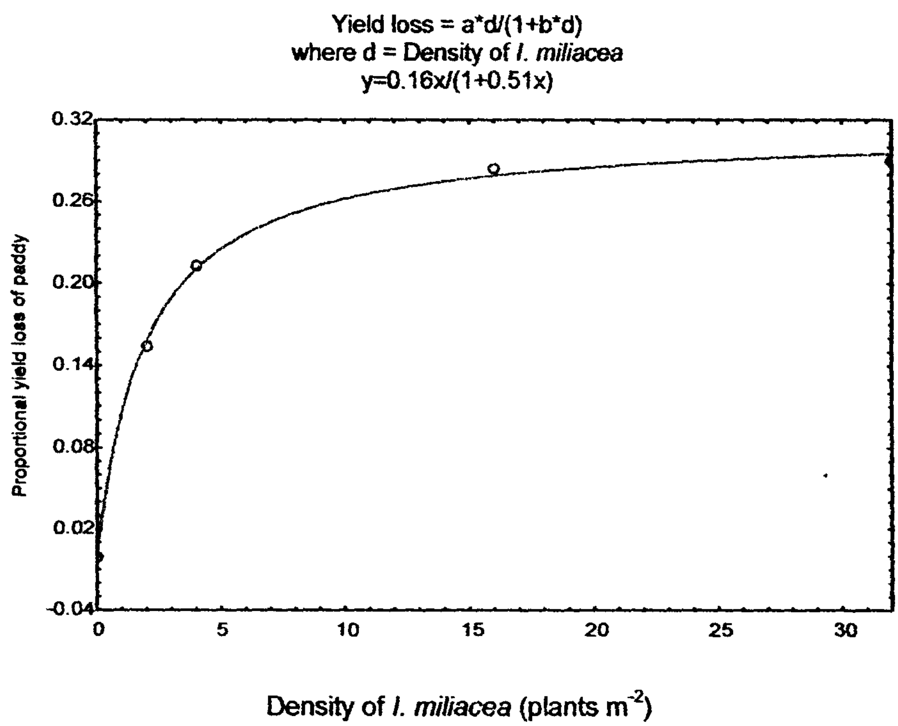


Table 52. The observed yield losses and the predicted yield losses obtained from the model by Wilcockson (1977) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1582	0.1342	0.1063
4	0.2129	0.2102	0.0801	0.1512
16	0.2839	0.2791	0.3571	0.2214
32	0.2904	0.2952	0.1472	0.2400

#By fitting the equation , $Y_L = \frac{ad}{1+bd}$

The second model proposed by Hakansson (1983) relating yield loss to weed density was also fitted to the data. The parametric estimates obtained from the model are presented in Table 53.

Table 53. Estimates of parameters for the second model by Hakansson (1983) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates		R^2
		a	b	
S. interrupta	1999	0.1254* (0.0383)[†]	-0.0022 (0.0014)	0.9037
	2000	0.0794 (0.0318)	-0.0007 (0.0014)	0.9228
I. miliacea	1999	0.0537* (0.0135)	-0.0013 (0.0004)	0.8193
	2000	0.0532* (0.0117)	-0.0015* (0.0004)	0.8654

[†] Figures in parenthesis are the standard errors of the estimates
* Significant at 5% level of significance

The observed yield losses and the predicted yield losses calculated from the model for *S. interrupta* and *I. miliacea* are given in Table 54 & 55 and Fig.20a, 20b, 20c & 20d.

Fig. 20a. Hakansson's (1983) second model fitted for *S. interrupta* (1999 data)

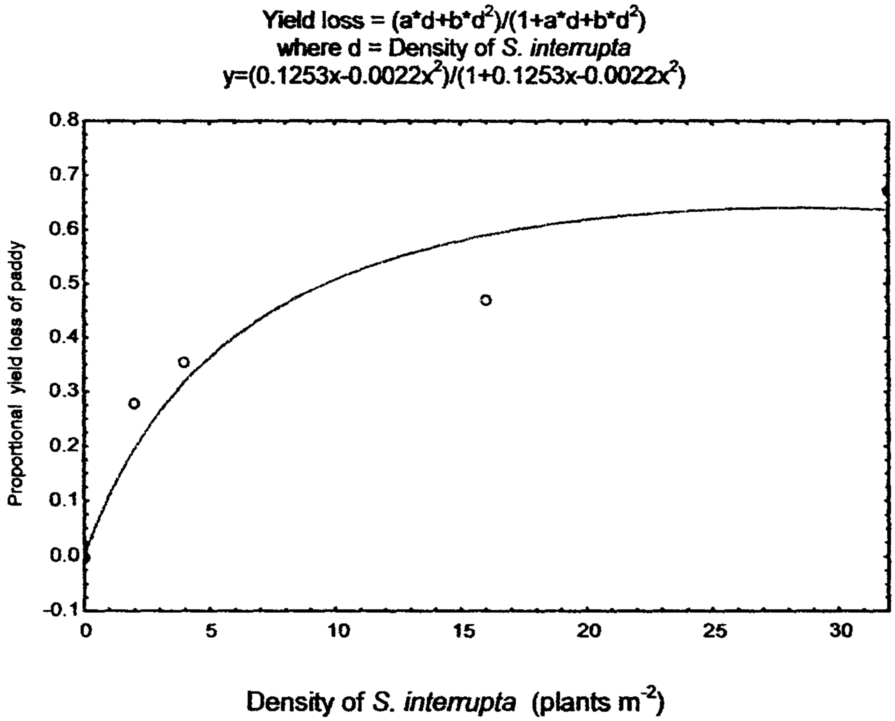


Fig. 20b. Hakansson's (1983) second model fitted for *S. interrupta* (2000 data)

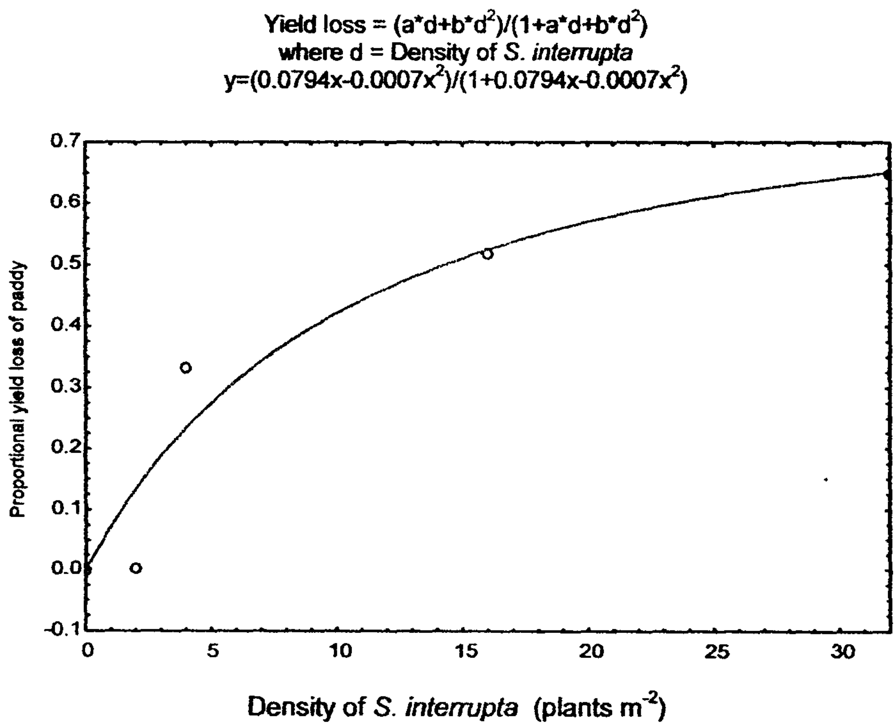


Table 54. The observed yield losses and the predicted yield losses obtained from the second model by Hakansson (1983) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted[#]	Observed	Predicted[#]
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.1948	0.0014	0.1350
4	0.3549	0.3179	0.3304	0.2348
16	0.4710	0.5903	0.5195	0.5239
32	0.6710	0.6366	0.6486	0.6505

#By fitting the model, $Y_L = \dfrac{ad + bd^2}{1 + ad + bd^2}$

Fig. 20c. Hakansson's (1983) second model fitted for *I. miliacea* (1999 data)

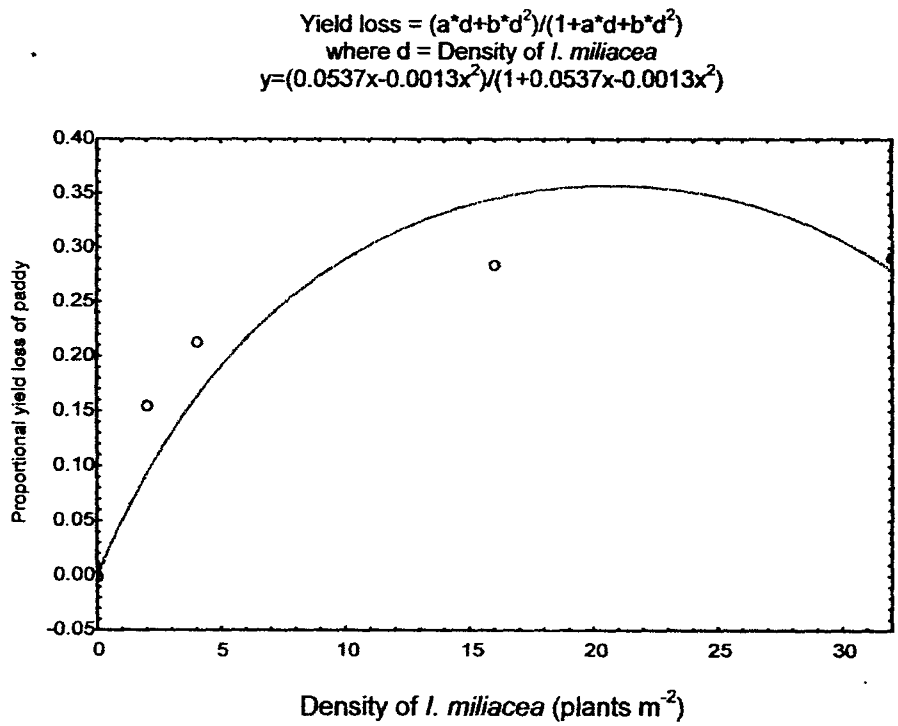


Fig. 20d. Hakansson's (1983) second model fitted for *I. miliacea* (2000 data)

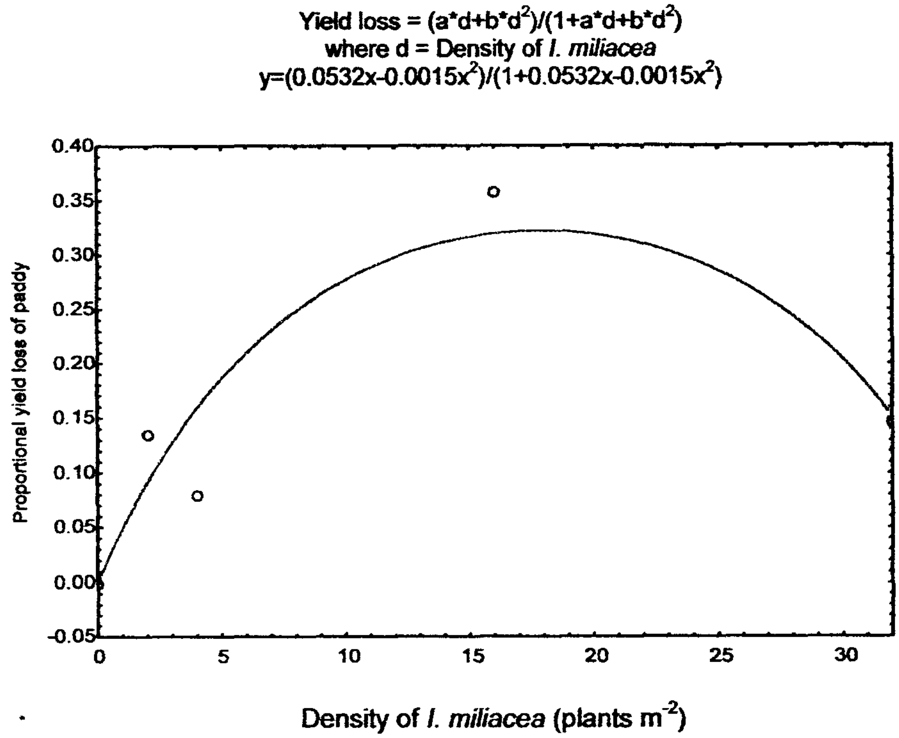


Table 55. The observed yield losses and the predicted yield losses obtained from the model by Hakansson (1983) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.0928	0.1342	0.0913
4	0.2129	0.1626	0.0801	0.1590
16	0.2839	0.3452	0.3571	0.3198
32	0.2904	0.2798	0.1472	0.1512

#By fitting the model, $Y_L = \dfrac{ad + bd^2}{1 + ad + bd^2}$

The model proposed by Carlson *et al.* (1981) was also fitted to the yield loss-weed density data. The estimated parameters are presented in Table 56.

Table 56. Estimates of parameters for the model by Carlson *et al.* (1981) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates			R^2
		a	b	c	
S. interrupta	1999	0.1928	0.0552	0.2865	0.9518
	2000	0.0737	0.0007	0.0370	0.9242
I. miliacea	1999	0.1289	0.0125	0.2069	0.9999
	2000	0.0328	-0.0009	-0.0064	0.9033

N.B: Standard errors could not be computed, as the matrix was ill conditioned

The observed yield losses and predicted yield losses obtained from the model for *S. interrupta* and *I. miliacea* are presented in Table 57 & 58 and Fig. 21a, 21b, 21c & 21d.

Fig. 21a. The model proposed by Carlson *et al.* (1981) fitted for *S. interrupta* (1999 data)

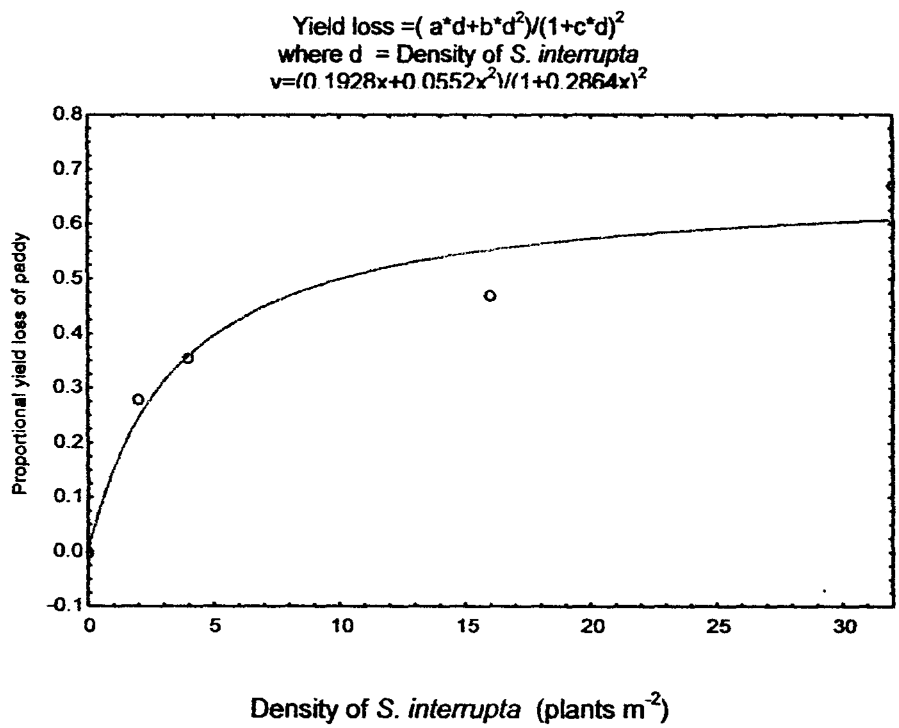


Fig. 21b. The model proposed by Carlson *et al.* (1981) fitted for *S. interrupta* (2000 data)

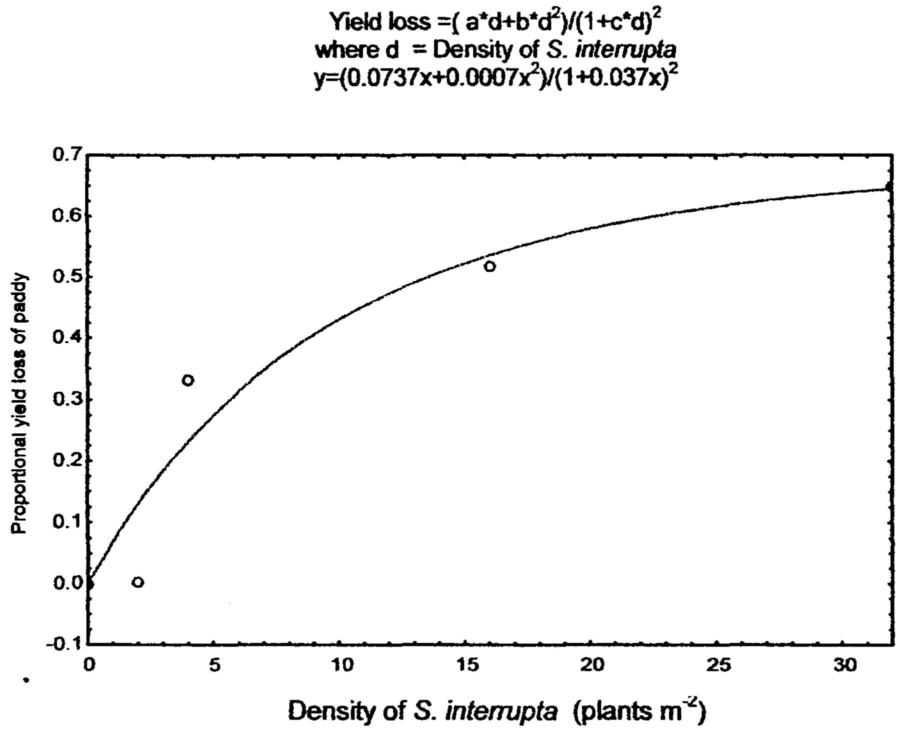


Table 57. The observed yield losses and the predicted yield losses obtained from the model by Carlson *et al.* (1981) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2452	0.0014	0.1302
4	0.3549	0.3595	0.3304	0.2322
16	0.4710	0.5526	0.5195	0.5358
32	0.6710	0.6070	0.6486	0.6444

#Using the model, $Y_L = \frac{ad + bd^2}{(1 + cd)^2}$

Fig. 21c. The model proposed by Carlson *et al.* (1981) fitted for *I. miliacea* (1999 data)

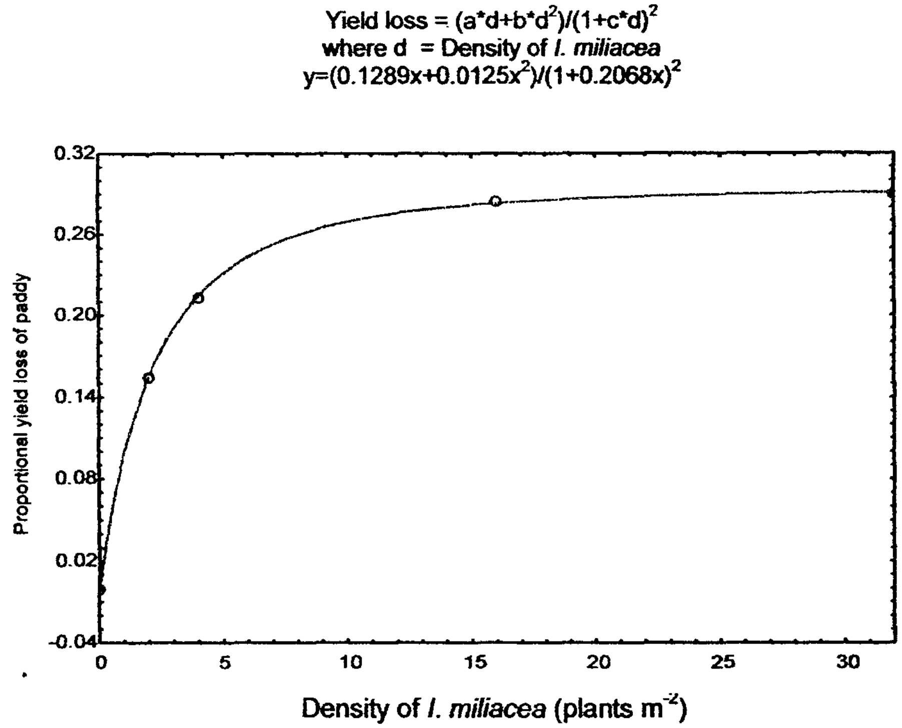


Fig. 21d. The model proposed by Carlson *et al.* (1981) fitted for *I. miliacea* (2000 data)

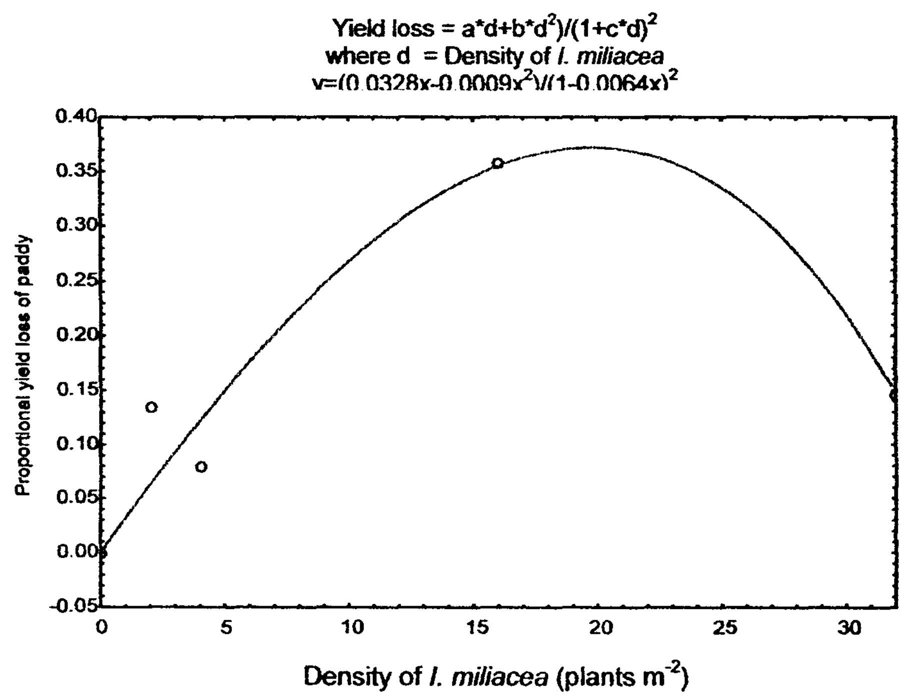


Table 58. The observed yield losses and the predicted yield losses obtained from the model by Carlson *et al.* (1981) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1540	0.1342	0.0635
4	0.2129	0.2142	0.0801	0.1226
16	0.2839	0.2829	0.3571	0.3551
32	0.2904	0.2910	0.1472	0.1473

#Using the model, $Y_L = \dfrac{ad + bd^2}{(1+cd)^2}$

Some other plausible models suggested by Cousens (1985) were also fitted to yield loss-weed density data. The parametric estimates of these models are presented in Table 59, 60, 61& 62.

Table 59. Estimates of parameters for the first model suggested by Cousens (1985) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates#			R^2
		c	a	b	
S. interrupta	1999	8.5529	2.4987	0.0173	0.9751
	2000	0.6811	0.0123	8.6571	0.9244
I. miliacea	1999	0.2947	0.1939	2.2587	0.9999
	2000	0.2425	0.0014	166.442	0.5736

N.B: Standard errors could not be computed, as the matrix was ill conditioned

\# For the model, $Y_L = c(1 - (1 + ad)^{-b})$

Table 60. Estimates of parameters for the second model suggested by Cousens (1985) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates#				R^2
		a	b	c	f	
S. interrupta	1999	0.3204 †	28141.82	5432.648	43053.58	0.9887
	2000	-56113.4	-0.0073	0.6410	-0.0170	0.9999
I. miliacea	1999	0.1386	0.0036	0.4149	0.0134	0.9999
	2000	0.0335	-0.0010	-0.0082	-0.0002	0.9040

† Standard errors could not be computed, as the matrix was ill conditioned

For the model, $Y_L = \frac{ad + bd^2}{1 + cd + fd^2}$

Table 61. Estimates of parameters for the third model suggested by Cousens (1985) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates#				R^2
		a	b	c	f	
S. interrupta	1999	0.2056** (0.0)†	-0.038** (0.0)	0.0024** (0.0)	-0.00004** (0.0)	1.00
	2000	-0.1212** (0.0)	0.0719** (0.0)	-0.0057** (0.0)	0.000112** (0.0)	1.00
I. miliacea	1999	0.1093** (0.0)	-0.018** (0.0)	0.0011** (0.0)	-0.00002** (0.0)	1.00
	2000	0.1352** (0.0)	-0.0398** (0.0)	0.0030** (0.0)	-0.00006 (0.0)	1.00

For the model, $Y_L = ad + bd^2 + cd^3 + fd^4$

† Figures in parenthesis are the standard errors of the estimates

** Significant at 1% level of significance

Table 62. Estimates of parameters for the fourth model suggested by Cousens (1985) for *S. interrupta* and *I. miliacea*

Weed	Year	Parametric estimates#				R^2
		a	b	c	f	
S. interrupta	1999	0.1093	0.3120	0.1093	0.3120	0:9862
	2000	0.0533	0.5360	0.0533	0.5360	0.8906
I. miliacea	1999	0.0754	0.2034	0.0754	0.2034	0.9807
	2000	0.0568	0.2102	0.0568	0.2102	0.4801

#For the model, $Y_L = ad^b + cd^f$

N.B: Standard errors could not be computed, as the matrix was ill conditioned

The observed yield losses and the predicted losses obtained from the models suggested by Cousens (1985) for *S. interrupta* and *I. miliacea* are given in Table 63, 64, 65, 66, 67, 68, 69 & 70 and Fig. 22a, 22b, 22c, 22d, 23a, 23b, 23c, 23d, 24a, 24b, 24c, 24d, 25a, 25b, 25c & 25d

Fig. 22a. The first model suggested by Cousens (1985) fitted for *S. interrupta* (1999 data)

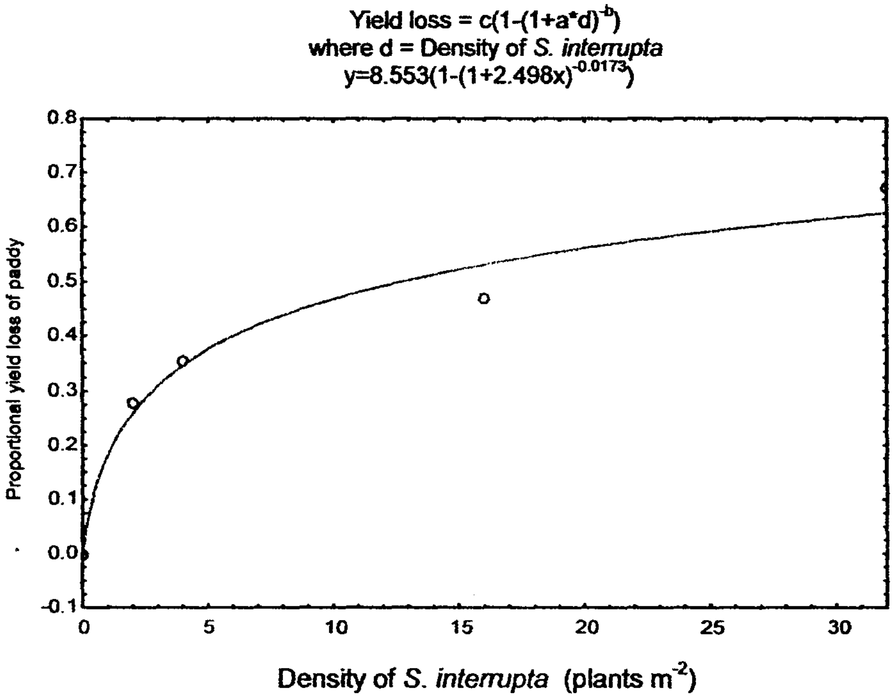


Fig. 22b. The first model suggested by Cousens (1985) fitted for *S. interrupta* (2000 data)

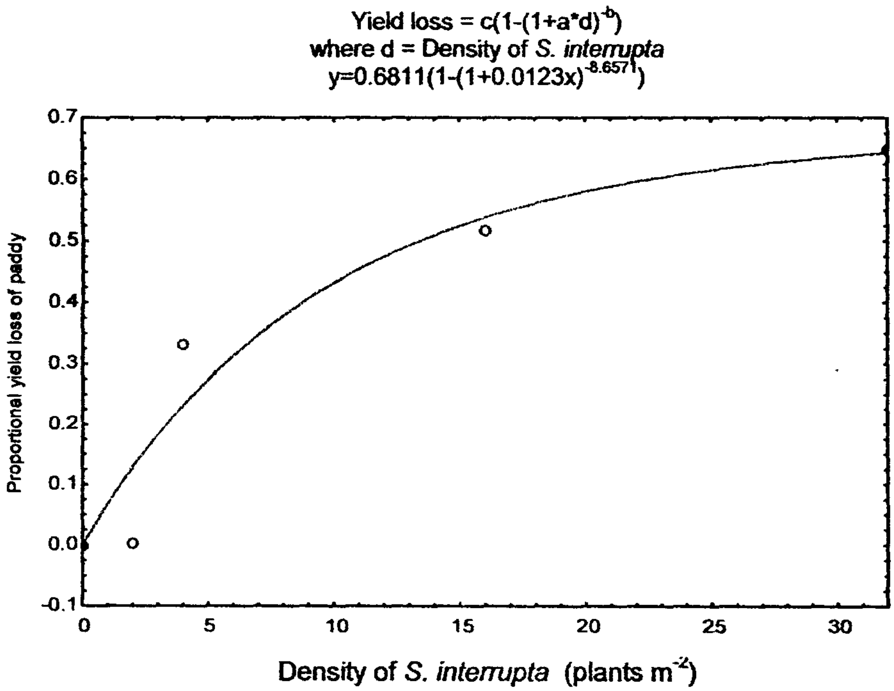


Table 63. The observed yield losses and the predicted yield losses obtained from the first model suggested by Cousens (1985) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2604	0.0014	0.1295
4	0.3549	0.3468	0.3304	0.2322
16	0.4710	0.5310	0.5195	0.5379
32	0.6710	0.6248	0.6486	0.6429

#For the model, $Y_L = c\,(1-(1+ad)^{-b})$

Fig. 22c. The first model suggested by Cousens (1985) fitted for *I. miliacea* (1999 data)

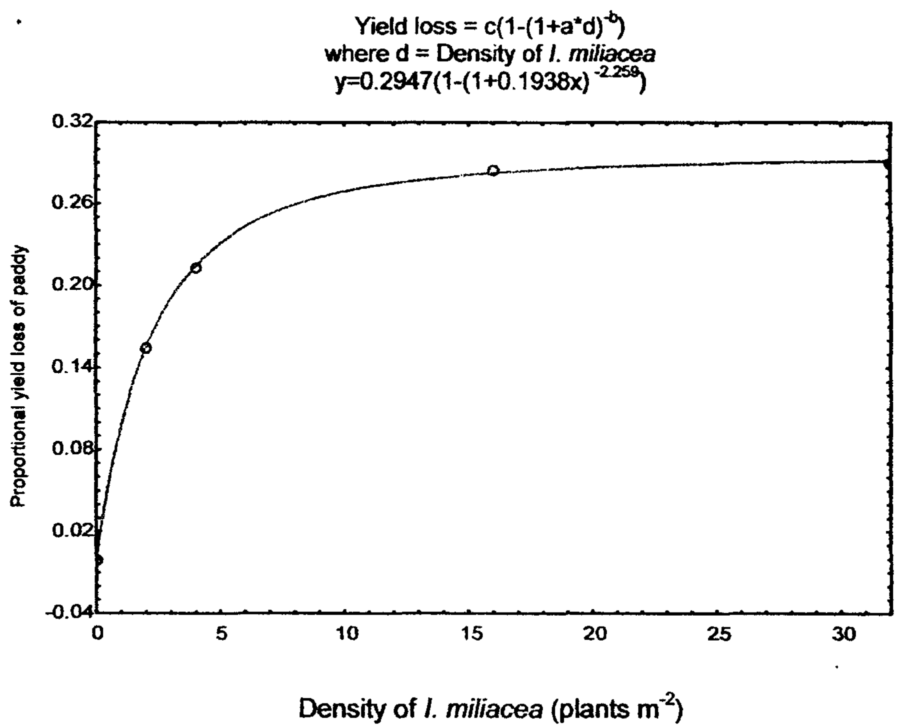


Fig. 22d. The first model suggested by Cousens (1985) fitted for *I. miliacea* (2000 data)

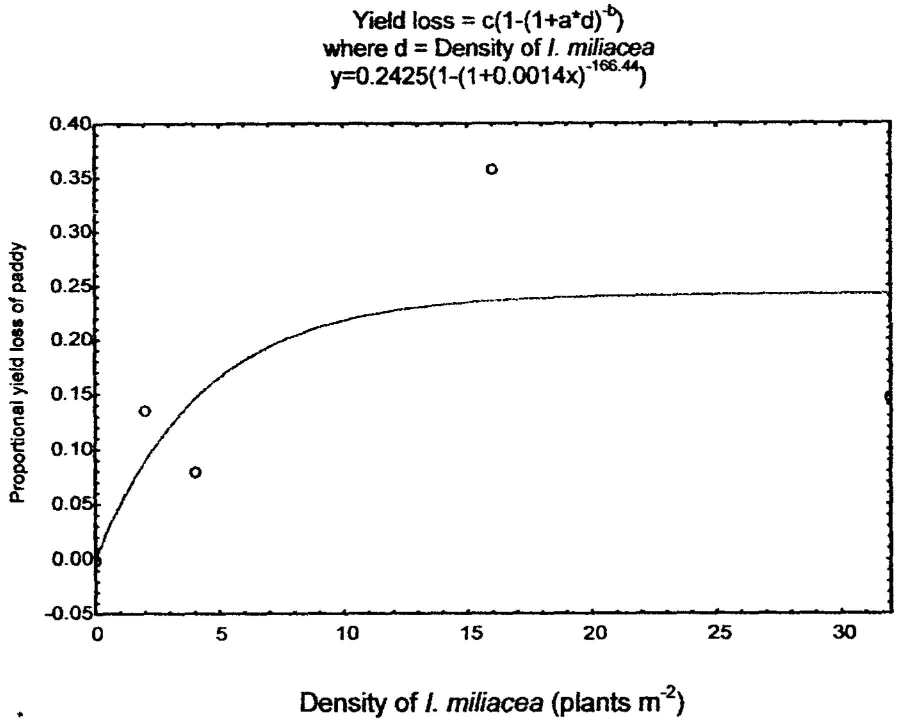


Table 64. The observed yield losses and the predicted yield losses obtained from the first model suggested by Cousens (1985) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1541	0.1342	0.0892
4	0.2129	0.2141	0.0801	0.1454
16	0.2839	0.2826	0.3571	0.2360
32	0.2904	0.2913	0.1472	0.2423

#For the model, $Y_L = c\ (1 - (1 + ad)^{-b})$

Fig. 23a. The second model suggested by Cousens (1985) fitted for *S. interrupta* (1999 data)

Yield loss=(a*d+b*d^2)/(1+c*d+f*d^2)
where d = Density of *S. interrupta*
y=(0.3204x-0.0073x^2)/(1+0.641x-0.0169x^2)

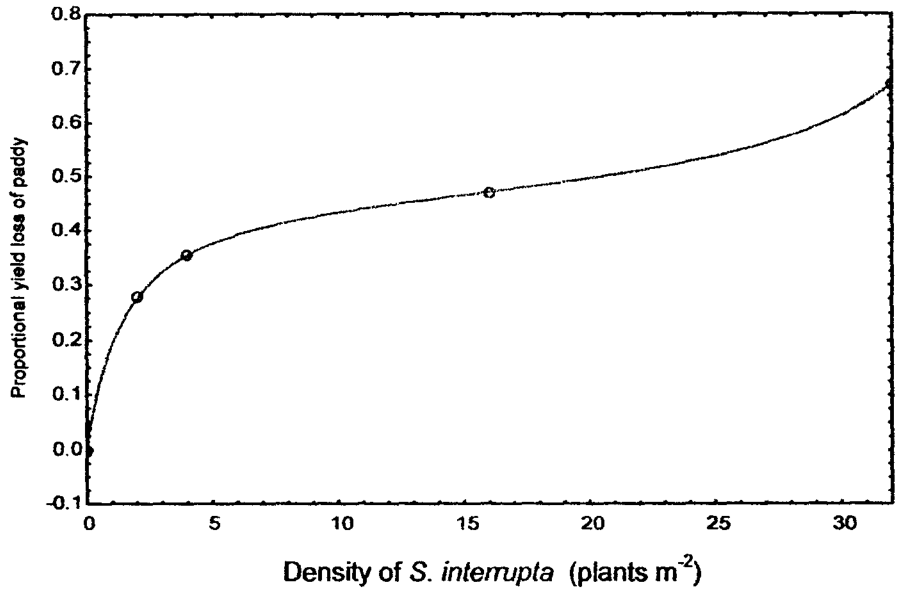


Fig. 23b. The second model suggested by Cousens (1985) fitted for *S. interrupta* (2000 data)

Yield loss=(a*d+b*d^2)/(1+c*d+f*d^2)
where d = Density of *S. interrupta*
y=(-56113.42x+28141.82x^2)/(1+5432.65x+43053.58x^2)

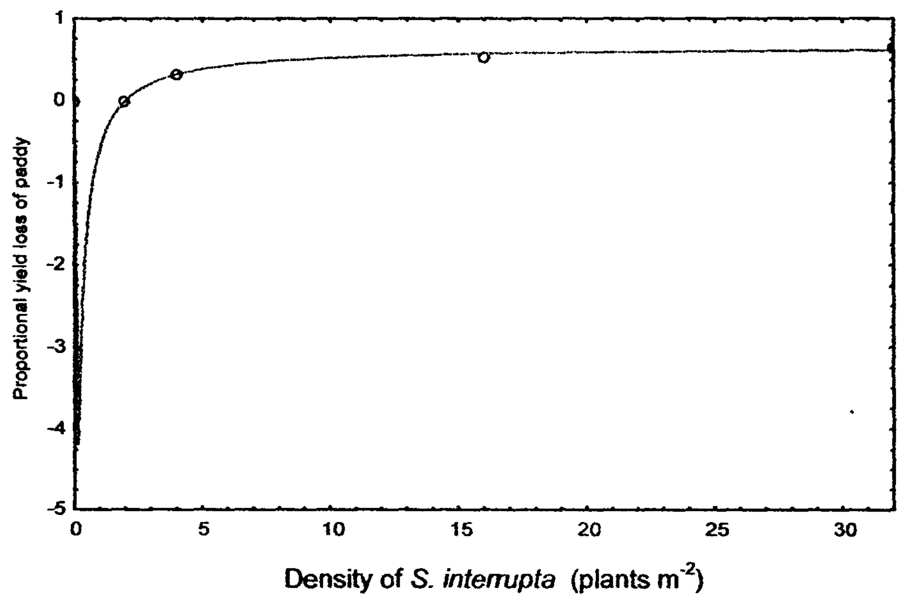


Table 65. The observed yield losses and the predicted yield losses obtained from the second model suggested by Cousens (1985) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2763	0.0014	0.0019
4	0.3549	0.3538	0.3304	0.3178
16	0.4710	0.4715	0.5195	0.5677
32	0.6710	0.6715	0.6486	0.6105

#For the model, $Y_L = \frac{ad + bd^2}{1 + cd + fd^2}$

Fig. 23c.The second model suggested by Cousens (1985) fitted for *I. miliacea* (1999 data)

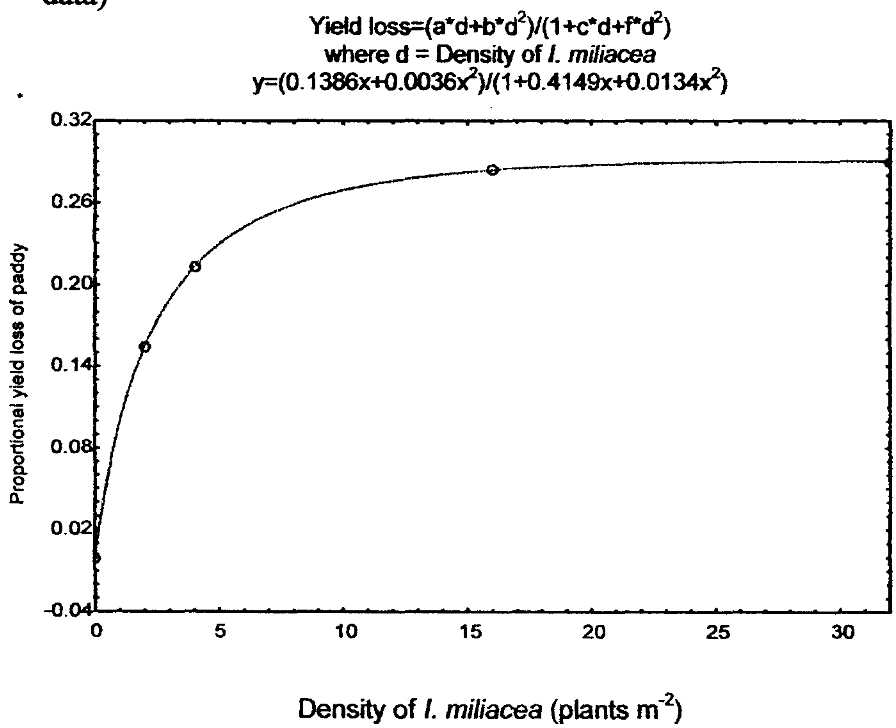


Fig. 23d. The second model suggested by Cousens (1985) fitted for *I. miliacea* (2000 data)

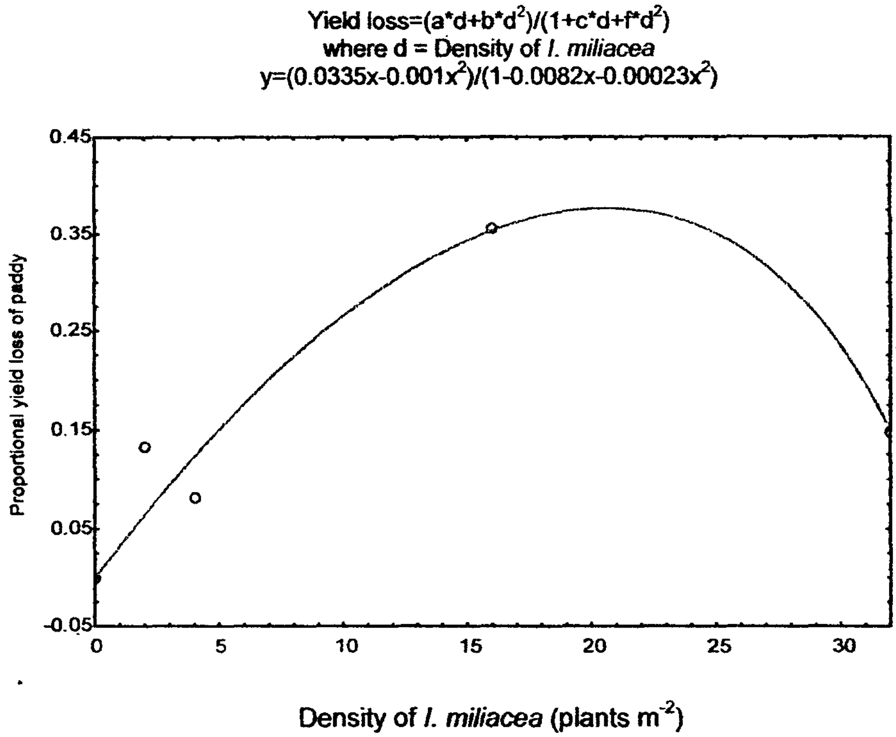


Table 66. The observed yield losses and the predicted yield losses obtained from the second model suggested by Cousens (1985) for *I. miliacea*

I. miliacea density per m^2	1999 Proportional yield loss		2000 Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1549	0.1342	0.0642
4	0.2129	0.2130	0.0801	0.1229
16	0.2839	0.2838	0.3571	0.3536
32	0.2904	0.2904	0.1472	0.1501

#For the model, $Y_L = \dfrac{ad + bd^2}{1 + cd + fd^2}$

Fig. 24a. The third model suggested by Cousens (1985) fitted for *S. interrupta* (1999 data)

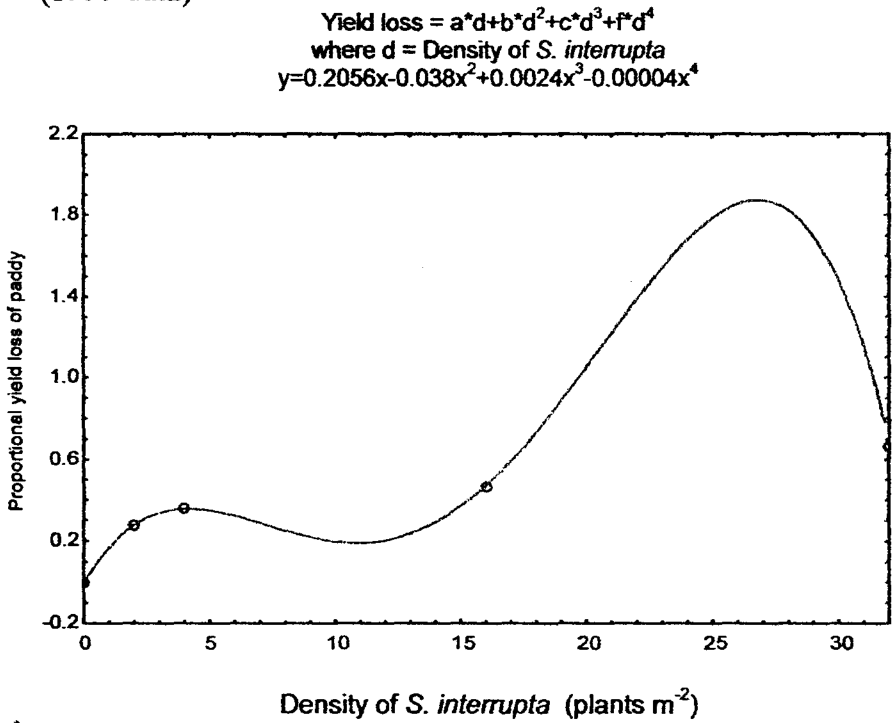


Fig. 24b. The third model suggested by Cousens (1985) fitted for *S. interrupta* (2000 data)

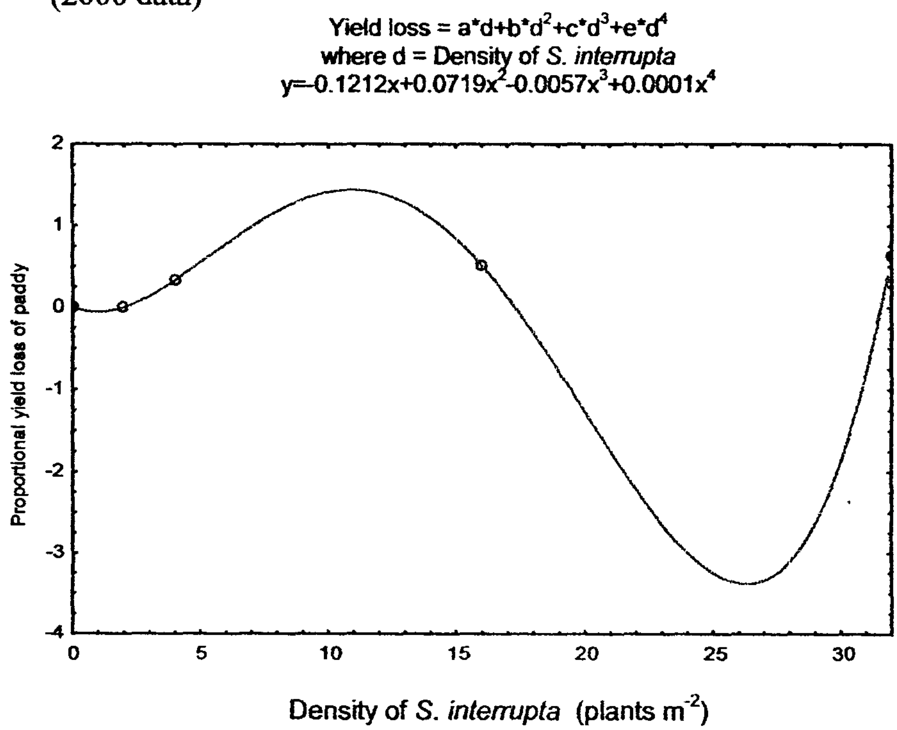


Table 67. The observed yield losses and the predicted yield losses obtained from the third model suggested by Cousens (1985) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2775	0.0014	0.0014
4	0.3549	0.3549	0.3304	0.3304
16	0.4710	0.4710	0.5195	0.5195
32	0.6710	0.6710	0.6486	0.6486

#For the model, $Y_L = ad + bd^2 + cd^3 + fd^4$

Fig. 24c. The third model suggested by Cousens (1985) fitted for *I. miliacea* (1999 data)

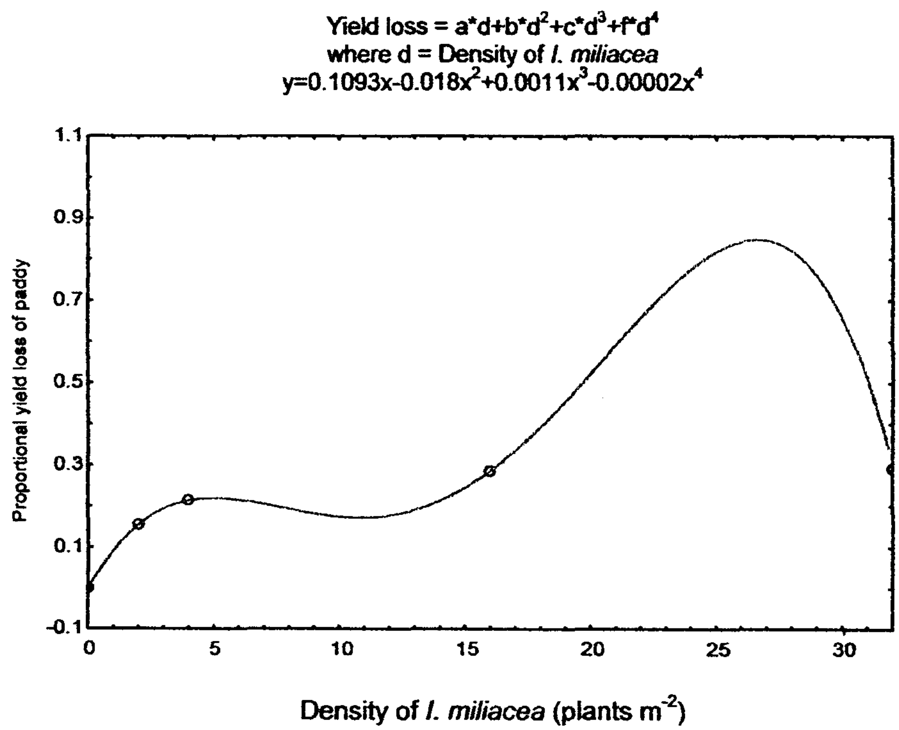


Fig. 24d. The third model suggested by Cousens (1985) fitted for *I. miliacea* (2000 data)

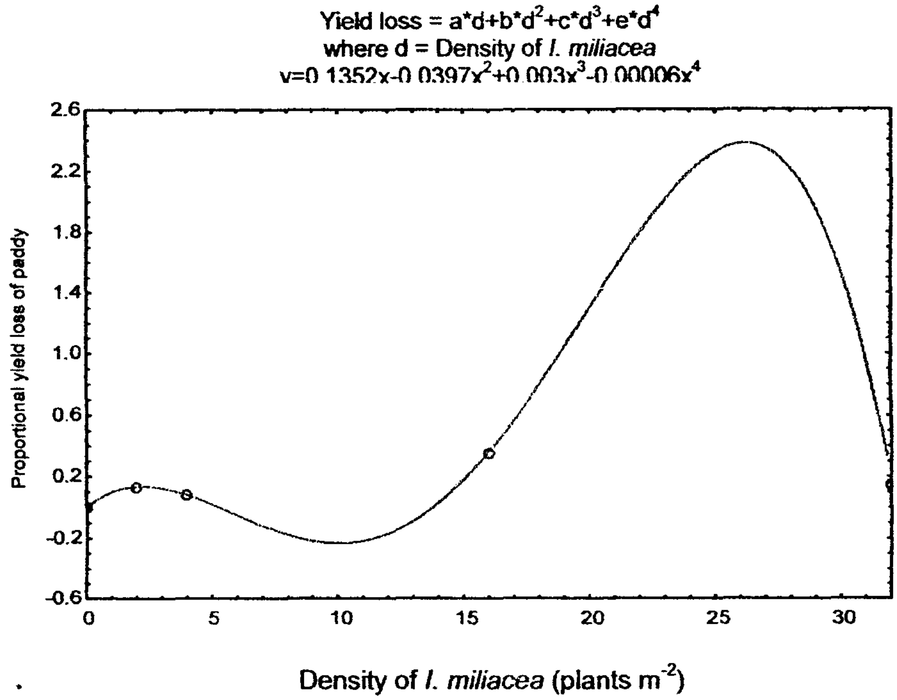


Table 68. The observed yield losses and the predicted yield losses obtained from the third model suggested by Cousens (1985) for *I. miliacea*

I. miliacea density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.1549	0.1549	0.1342	0.1342
4	0.2129	0.2129	0.0801	0.0801
16	0.2839	0.2839	0.3571	0.3571
32	0.2904	0.2904	0.1472	0.1472

#For the model, $Y_L = ad + bd^2 + cd^3 + fd^4$

Table 69. The observed yield losses and the predicted yield losses obtained from the fourth model suggested by Cousens (1985) for *S. interrupta*

S. interrupta density per m^2	1999		2000	
	Proportional yield loss		Proportional yield loss	
	Observed	Predicted#	Observed	Predicted#
0	0.0000	0.0000	0.0000	0.0000
2	0.2775	0.2713	0.0014	0.1544
4	0.3549	0.3368	0.3304	0.2239
16	0.4710	0.5190	0.5195	0.4708
32	0.6710	0.6443	0.6486	0.6826

#For the model, $Y_L = ad^b + cd^f$

Fig. 25c. The fourth model suggested by Cousens (1985) fitted for *I. miliacea* (1999 data)

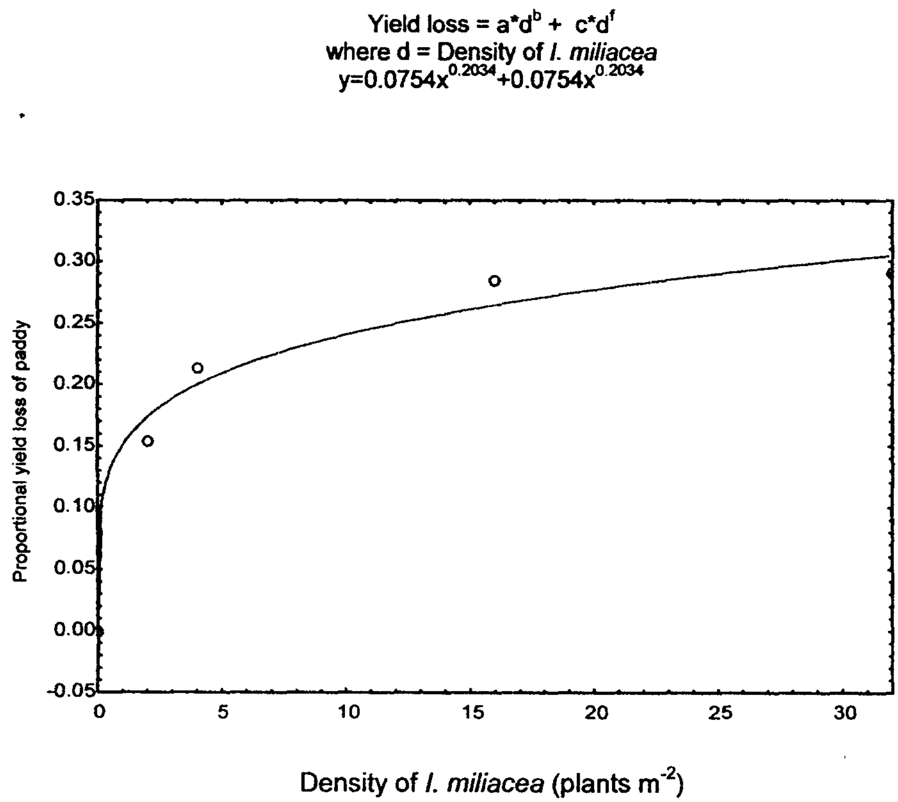


Fig. 25a. The fourth model suggested by Cousens (1985) fitted for *S. interrupta* (1999 data)

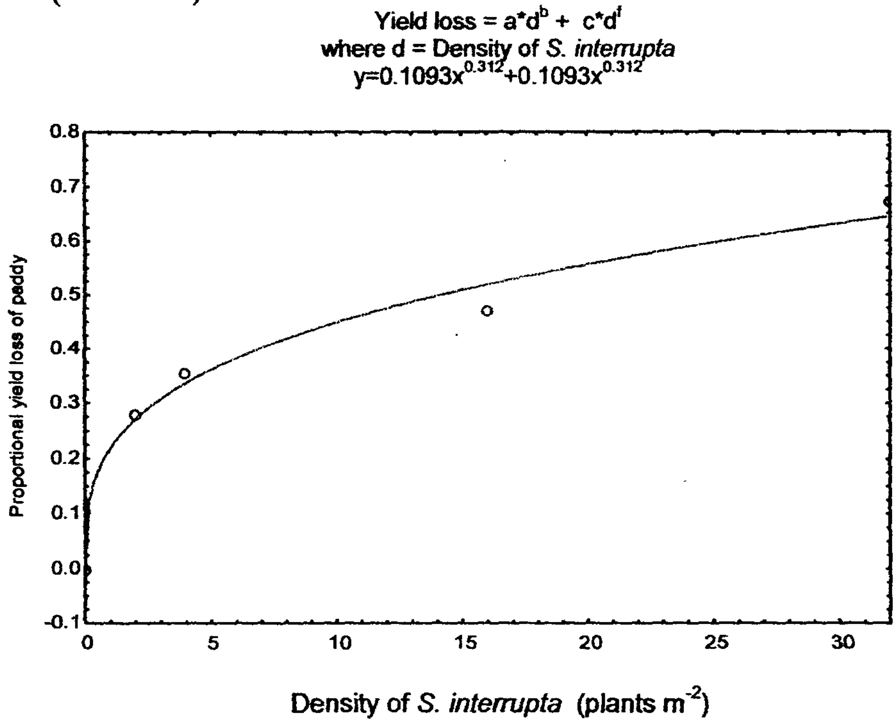


Fig. 25b. The fourth model suggested by Cousens (1985) fitted for *S. interrupta* (2000 data)

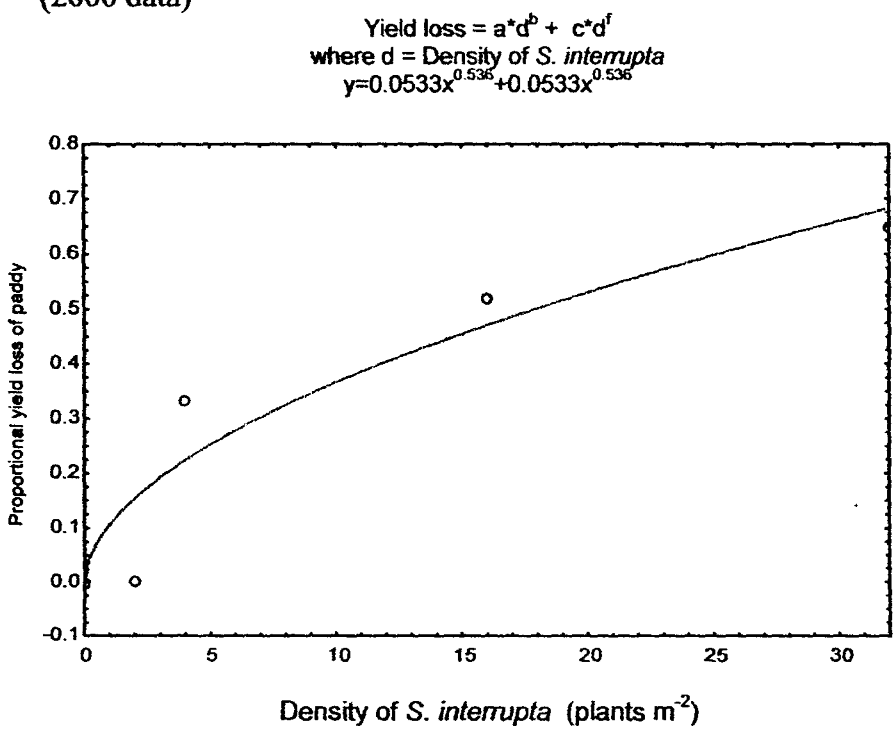


Table 71. Estimates of parameters for the Cousens multivariate model proposed by Swinton *et al.* (1994a)

Year	Parametric estimates			R^2
	I_1	I_2	A	
1999	17.5948** (5.7623)[†]	2.5656** (0.7626)	72.2437** (6.5973)	0.8455
2000	8.2941 (5.3609)	1.3145** (0.4616	91.2769** (29.3664)	0.8207

[†] Figures in parenthesis are the standard errors of the estimates

** Significant at 1% level of significance

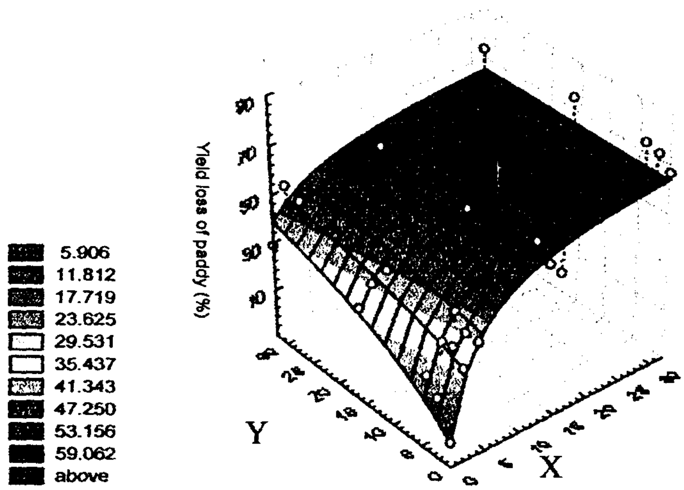
The observed yield losses and the predicted yield losses using the model are given in Table 72 and Fig. 26a & 26b.

Fig. 26a. Cousens multivariate model fitted for the year 1999

Yield loss = $(I_1 {*} d_1 + I_2 {*} d_2)/(1+(I_1 {*} d_1 + I_2 {*} d_2)/A)$

where d_1 = Density of *S. interrupta* and d_2 = Density of *I. miliacea*

z=(17.59x+2.57y)/(1+(17.59x+2.57y)/72.24)



X – Density of *S. interrupta* (plants m^{-2})

Y – Density of *I. miliacea* (plants m^{-2})

Fig. 26b. Cousens multivariate model fitted for the year 2000

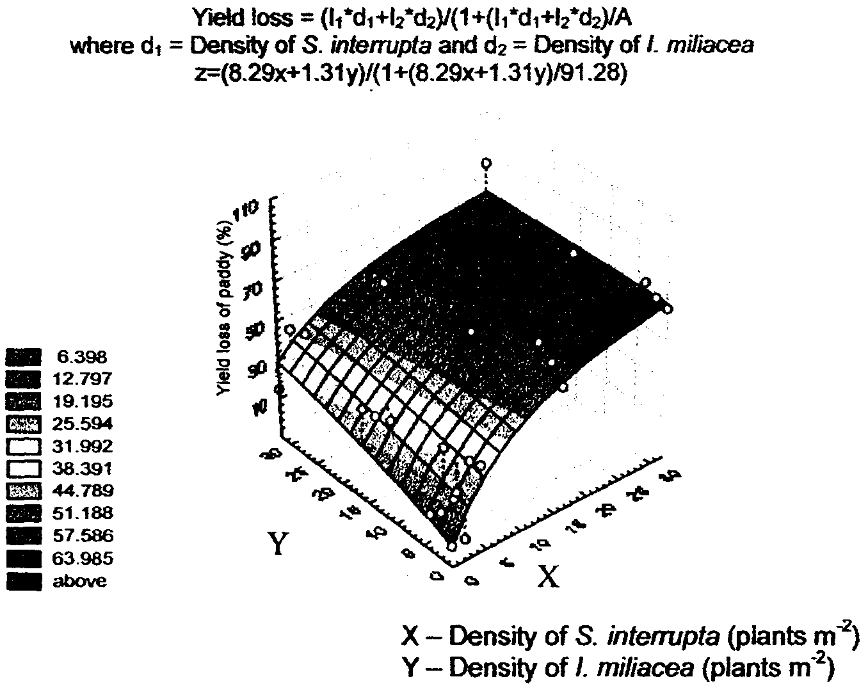


Table 72. The observed yield losses and the predicted yield losses obtained from the Cousens multivariate model proposed by Swinton *et al.* (1994a)

S. interrupta density per m^2	*I. miliacea* density per m^2	1999		2000	
		Observed yield loss (%)	Predicted# yield loss (%)	Observed yield loss (%)	Predicted# yield loss (%)
0	0	0.00	0.00	0.00	0.00
0	2	15.49	4.79	13.42	2.56
0	4	21.29	8.99	8.01	4.97
0	16	28.39	26.18	35.71	17.09
0	32	29.04	38.43	14.72	28.79
2	0	27.74	23.66	0.14	14.04
2	2	33.52	25.88	15.58	15.87
2	4	32.26	27.90	37.73	17.63
2	16	35.49	37.09	28.50	26.64
2	32	50.97	44.71	42.79	35.71
4	0	35.49	35.65	33.05	24.33
4	2	36.13	36.92	31.67	25.72
4	4	41.94	38.11	11.62	27.05
4	16	38.71	43.83	23.88	34.01
4	32	42.58	49.02	37.45	41.24
16	0	47.10	57.49	51.59	54.08

S. interrupta density per m²	*I. miliacea* density per m²	1999		2000	
		Observed yield loss (%)	Predicted# yield loss (%)	Observed yield loss (%)	Predicted# yield loss (%)
16	2	47.74	57.70	60.53	54.51
16	4	53.55	57.91	66.16	54.93
16	16	48.39	59.02	49.21	57.27
16	32	50.97	60.27	45.46	59.96
32	0	67.10	64.03	64.86	67.92
32	2	72.26	64.09	67.03	68.09
32	4	73.55	64.16	71.57	68.26
32	16	74.84	64.53	65.08	69.22
32	32	73.55	64.97	84.34	70.38

By fitting the equation, $Y_L = \frac{I_1 d_1 + I_2 d_2}{1 + \frac{(I_1 d_1 + I_2 d_2)}{A}}$

Swinton *et al.*(1994) used I_1 and I_2 from the above model to obtain competitive indices which were used to obtain the total competitive load and predicted yield losses. The parametric estimates obtained by using the model are presented in Table 73.

Table 73. Estimates of parameters obtained for the model by Swinton *et al.* (1994b)

Year	Parametric estimates		R^2
	I	A	
1999	17.5948** (4.2833)†	72.2437** (6.0815)	0.8455
2000	8.2941* (2.9755)	91.2769** (19.5192)	0.8207

† Figures in parenthesis are the standard errors of the estimates.
* Significant at 5% level of significance
** Significant at 1% level of significance

The densities of the weed with the highest I (*S. interrupta*), the density equivalents of the weed with lower I (*I. miliacea*) in terms of the weed with higher I (*S. interrupta*), the total competitive load, the observed yield losses (%) and the predicted yield losses using the model are discussed in Table 74 & 75 and Fig. 27a & 27b.

Fig. 27a. Model proposed by Swinton *et al.* (1994b) fitted for the year 1999

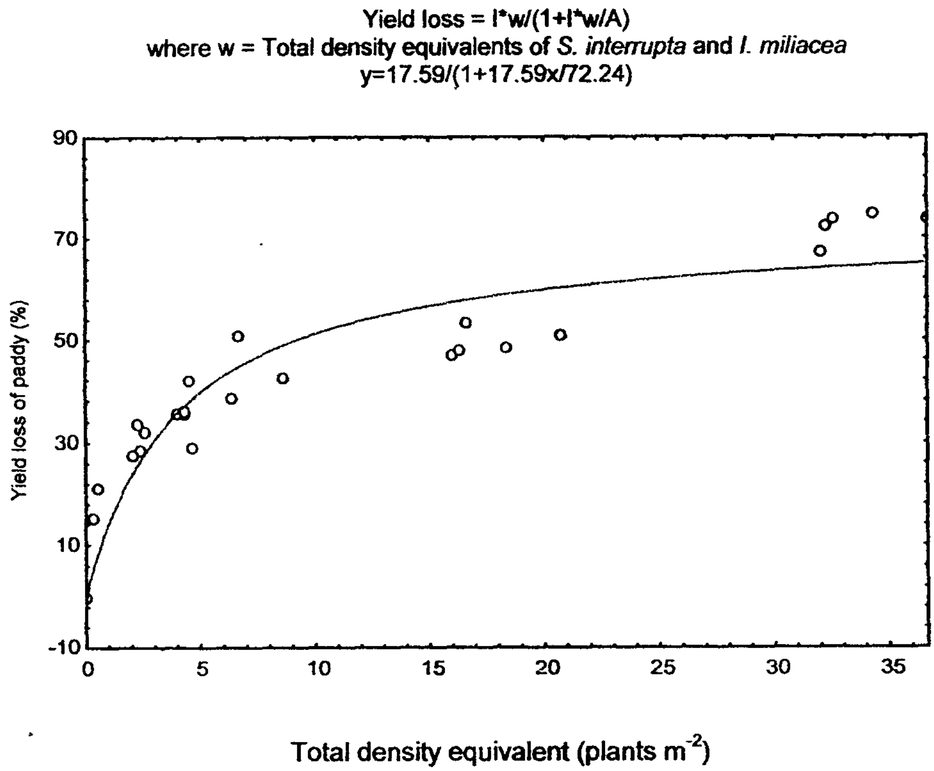


Table 74. The observed yield losses and the predicted yield losses obtained from the model proposed by Swinton *et al.* (1994b) for 1999

Density of *S. interrupta* per m^2	Density equivalent of *I. miliacea* in terms of *S. interrupta* per m^2	Total competitive load (w)	Observed yield loss (%)	Predicted[#] yield loss (%)
0	0.0000	0.0000	0.00	0.00
0	0.2916	0.2916	15.49	4.79
0	0.5833	0.5833	21.29	8.99
0	2.3330	2.3330	28.39	26.18
0	4.6660	4.6660	29.04	38.43
2	0.0000	2.0000	27.74	23.66
2	0.2916	2.2916	33.53	25.88
2	0.5833	2.5833	32.26	27.90
2	2.3330	4.3330	35.49	37.09
2	4.6660	6.6660	50.97	44.71
4	0.0000	4.0000	35.49	35.65
4	0.2916	4.2916	36. 13	36.92
4	0.5833	4.5833	41.94	38.11
4	2.3330	6.3330	3 8.71	43.83
4	4.6660	8.6660	42.58	49.02

Density of *S. interrupta* per m²	Density equivalent of *I. miliacea* in terms of *S. interrupta* per m²	Total competitive load (w)	Observed yield loss (%)	Predicted# yield loss (%)
16	0.0000	16.000	47.10	57.49
16	0.2916	16.2916	47.75	57.70
16	0.5833	16.5833	53.55	57.91
16	2.3330	18.3330	48.39	59.02
16	4.6660	20.6660	50.97	60.27
32	0.0000	32.0000	67.10	64.03
32	0.2916	32.2916	72.26	64.09
32	0.5833	32.5833	73.55	64.16
32	2.3330	34.3330	74.84	64.53
32	4.6660	36.6660	73.55	64.97

\# By fitting the model, $Y_L = \frac{Iw}{1 + \frac{Iw}{A}}$

Fig. 27b. Model proposed by Swinton *et al.* (1994b) fitted for the year 2000

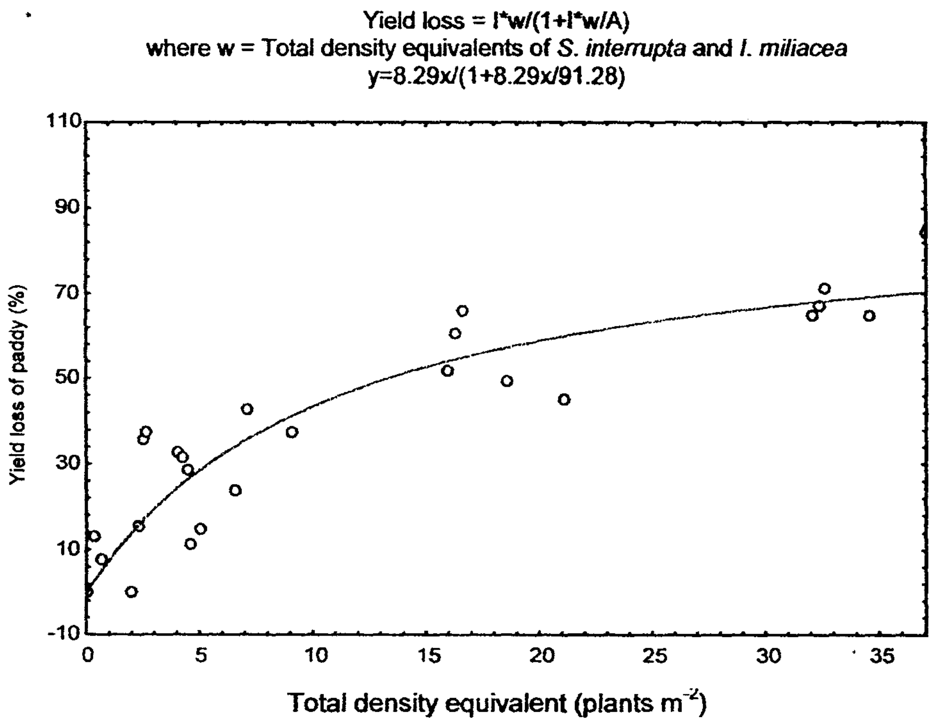


Table 75. The observed yield losses and the predicted yield losses obtained from the model proposed by Swinton *et al.* (1994b) for 2000

Density of *S. interrupta* per m^2	Density equivalent of *I. miliacea* in terms of *S. interrupta* per m^2	Total competitive load (w)	Observed yield loss (%)	Predicted[#] yield loss (%)
0	0.0000	0.0000	0.00	0.00
0	0.3170	0.3170	13.42	2.56
0	0.6339	0.6339	8.01	4.97
0	2.5358	2.5358	35.71	17.09
0	5.0715	5.0715	14.72	28.79
2	0.0000	2.0000	0.14	14.04
2	0.3170	2.3170	15.58	15.87
2	0.6339	2.6339	37.73	17.63
2	2.5358	4.5358	28.50	26.64
2	5.0715	7.0715	42.79	35.71
4	0.0000	4.0000	33.05	24.33
4	0.3170	4.3170	31.67	25.72
4	0.6339	4.6339	11.62	27.05
4	2.5358	6.5358	23.88	34.01
4	5.0715	9.0715	37.45	41.24
16	0.0000	16.0000	51.95	54.08
16	0.3170	16.3170	60.53	54.51
16	0.6339	16.6339	66.16	54.93
16	2.5358	18.5358	49.21	57.27
16	5.0715	21.0715	45.46	59.96
32	0.0000	32.0000	64.86	67.92
32	0.3170	32.3170	67.03	68.09
32	0.6339	32.6339	71.57	68.26
32	2.5358	34.5358	65.08	69.22
32	5.0715	37.0715	84.34	70.38

By fitting the model, $Y_L = \dfrac{Iw}{1 + \dfrac{Iw}{A}}$

Berti and Zanin (1994) converted the weed densities into density equivalents of a reference species thereby estimating the yield losses. The density equivalents of the two weed species in terms of the reference species, the total density equivalent and the yield loss estimated for 1999 and 2000 are presented in Table 76 & 77 respectively.

Table 76. The yield losses (%) estimated using the total density equivalents Berti and Zanin (1994) for 1999

Density equivalent of *S. interrupta* per m^2	Density equivalent of *I. miliacea* per m^2	Total density equivalent (Deqt)	Estimated yield loss (%)#
0.0000	0.0000	0.0000	0.000
0.0000	0.1879	0.1879	15.82
0.0000	0.2662	0.2662	21.02
0.0000	0.3871	0.3871	27.91
0.0000	0.4188	0.4188	29.52
0.3248	0.0000	0.3248	24.52
0.3248	0.1879	0.5127	33.89
0.3248	0.2662	0.5910	37.15
0.3248	0.3871	0.7120	41.59
0.3248	0.4188	0.7437	42.65
0.5612	0.0000	0.5612	35.95
0.5612	0.1879	0.7491	42.83
0.5612	0.2662	0.8274	45.28
0.5612	0.3871	0.9483	48.67
0.5612	0.4188	0.9800	49.50
1.2352	0.0000	1.2352	55.26
1.2352	0.1879	1.4231	58.73
1.2352	0.2662	1.5012	60.02
1.2352	0.3871	1.6223	61.87
1.2352	0.4188	1.6540	62.32
1.5443	0.0000	1.5443	60.70
1.5443	0.1879	1.7322	63.40
1.5443	0.2662	1.8105	64.42
1.5443	0.3871	1.9314	65.89
1.5443	0.4188	1.9632	66.25

Using the equation, $Y_L = \frac{100\,\text{Deqt}}{1 + \text{Deqt}}$

Table 77. The yield losses (%) estimated using the total density equivalents Berti and Zanin (1994) for 2000

Density equivalent of *S. interrupta* per m^2	Density equivalent of *I. miliacea* per m^2	Total density equivalent(Deqt)	Estimated yield loss (%)#
0.0000	0.0000	0.0000	0.00
0.0000	0.1189	0.1189	10.63
0.0000	0.1782	0.1782	15.12
0.0000	0.2844	0.2844	22.14
0.0000	0.3157	0.3157	24.00
0.1562	0.0000	0.1562	13.51
0.1562	0.1189	0.2751	21.57
0.1562	0.1782	0.3343	25.06
0.1562	0.2844	0.4405	30.58
0.1562	0.3157	0.4719	32.06
0.3058	0.0000	0.3058	23.42
0.3058	0.1189	0.4248	29.81
0.3058	0.1782	0.4840	32.62
0.3058	0.2844	0.5902	37.11
0.3058	0.3157	0.6216	38.33
1.0872	0.0000	1.0872	52.09
1.0872	0.1189	1.2061	54.67
1.0872	0.1782	1.2653	55.86
1.0872	0.2844	1.3715	57.83
1.0872	0.3157	1.4029	58.38
1.8933	0.0000	1.8933	65.44
1.8933	0.1189	2.0123	66.80
1.8933	0.1782	2.0715	67.44
1.8933	0.2844	2.1777	68.53
1.8933	0.3157	2.2090	68.84

Using the equation, $Y_L = \frac{100\,\text{Deqt}}{1+\text{Deqt}}$

4.2.3. Prediction using proposed new models

The estimated parameters obtained by fitting the model

$$Y_L = a + bd_1 + cd_1^2 + dd_2 \qquad (1)$$

where Y_L – proportional yield loss

d_1 – density of *S. interrupta*

d_2 – density of *I. miliacea* and

a, b, c, d – the parameters associated with the model

are given in Table 78.

Table 78. Estimates of parameters for model 1

Year	Parametric estimates				R^2
	a	b	c	d	
1999	0.2331** (0.0286)†	0.0189** (0.0054)	-0.0002 (0.0002)	0.0033* (0.0013)	0.8567
2000	0.1252** (0.0405)	0.0316** (0.0076)	-0.0005 (0.0002)	0.0034 (0.0018)	0.8174

† Figures in parenthesis are the standard errors of the estimates.
* Significant at 5% level of significance
** Significant at 1% level of significance

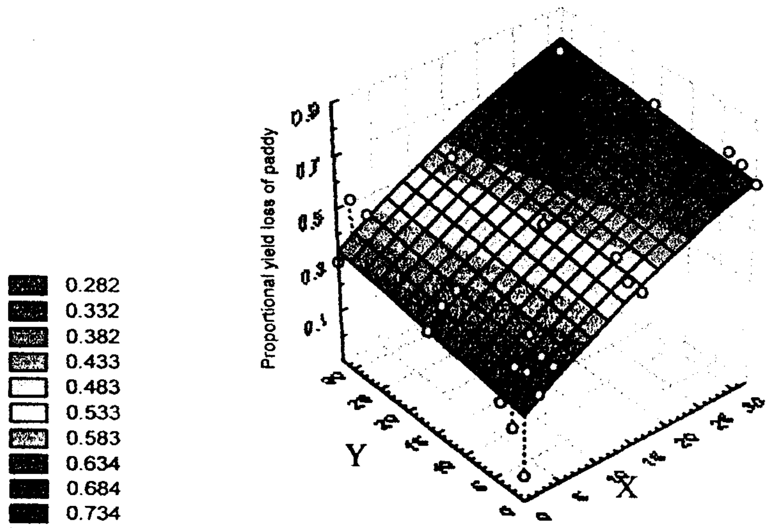
The observed yield losses and the predicted yield losses obtained from the model are given in Table 79 and Fig. 28a & 28b.

Fig. 28a. The first model proposed fitted for the year 1999

Yield loss = $a+b*d_1+c*d_1^2 + d*d_2$

where d_1 = Density of *S. interrupta* and d_2 = Density of *I. miliacea*

$z=0.2313+0.0189x-0.00015x^2+0.0033y$



X – Density of *S. interrupta* (plants m^{-2})

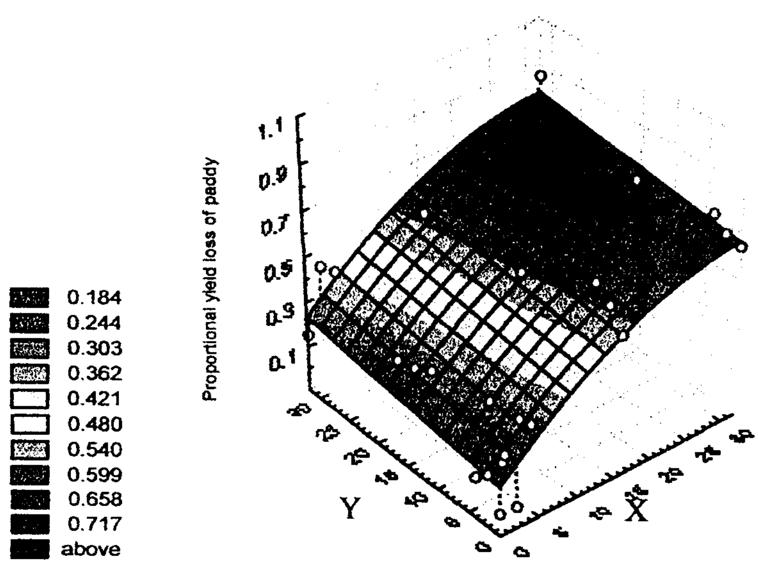
Y – Density of *I. miliacea* (plants m^{-2})

Fig. 28b. The first model proposed fitted for the year 2000

Yield loss = $a+b*d_1+c*d_1^2 + d*d_2$

where d_1 = Density of *S. interrupta* and d_2 = Density of *I. miliacea*

$z=0.125+0.032x-0.0005x^2+0.0034y$



X – Density of *S. interrupta* (plants m^{-2})

Y – Density of *I. miliacea* (plants m^{-2})

Table 79. The observed yield losses and the predicted yield losses obtained from model 1

Density of *S. interrupta* per m^2	Density of *I. miliacea* per m^2	1999		2000	
		Proportional yield loss		Proportional yield loss	
		Observed	Predicted#	Observed	Predicted#
0	0	0.0000	0.2313	0.0000	0.1252
0	2	0.1549	0.2379	0.1342	0.1319
0	4	0.2129	0.2445	0.0801	0.1387
0	16	0.2839	0.2839	0.3571	0.1793
0	32	0.2904	0.3365	0.1472	0.2335
2	0	0.2775	0.2686	0.0014	0.1865
2	2	0.3353	0.2752	0.1558	0.1933
2	4	0.3226	0.2817	0.3773	0.2001
2	16	0.3549	0.3212	0.2850	0.2407
2	32	0.5097	0.3738	0.4278	0.2949
4	0	0.3549	0.3046	0.3304	0.2443
4	2	0.3613	0.3112	0.3167	0.2510
4	4	0.4194	0.3178	0.1162	0.2578
4	16	0.3871	0.3572	0.2388	0.2985
4	32	0.4258	0.4098	0.3745	0.3527
16	0	0.4710	0.4948	0.5195	0.5138
16	2	0.4775	0.5014	0.6053	0.5206
16	4	0.5355	0.5080	0.6616	0.5273
16	16	0.4839	0.5474	0.4921	0.5680
16	32	0.5097	0.6000	0.4545	0.6222
32	0	0.6710	0.6794	0.6486	0.6683
32	2	0.7226	0.6860	0.6703	0.6750
32	4	0.7355	0.6925	0.7157	0.6818
32	16	0.7484	0.7320	0.6508	0.7225
32	32	0.7355	0.7846	0.8434	0.7767

By fitting the model, $Y_L = a+bd_1+cd_1^2+dd_2$

The linear model given by

$$Y_L = a+bd_1+cd_2 \qquad (2)$$

where Y_L – proportional yield loss of paddy

d_1 – density of *S. interrupta*

d_2 – density of *I. miliacea* and

a, b, c – parameters associated with the model

was also fitted to the proportional yield loss – weed density data.

The parameters were estimated from the model and are presented in Table 80.

Table 80. Estimates of parameters for model 2

Year	Parametric estimates			R^2
	a	b	c	
1999	0.2444** (0.0250)[†]	0.0140** (0.0013)	0.0033* (0.0013)	0.8506
2000	0.1640** (0.0377)	0.0170** (0.0019)	0.0034 (0.0019)	0.7832

[†] Figures in parenthesis are the standard errors of the estimates.

* Significant at 5% level of significance

** Significant at 1% level of significance

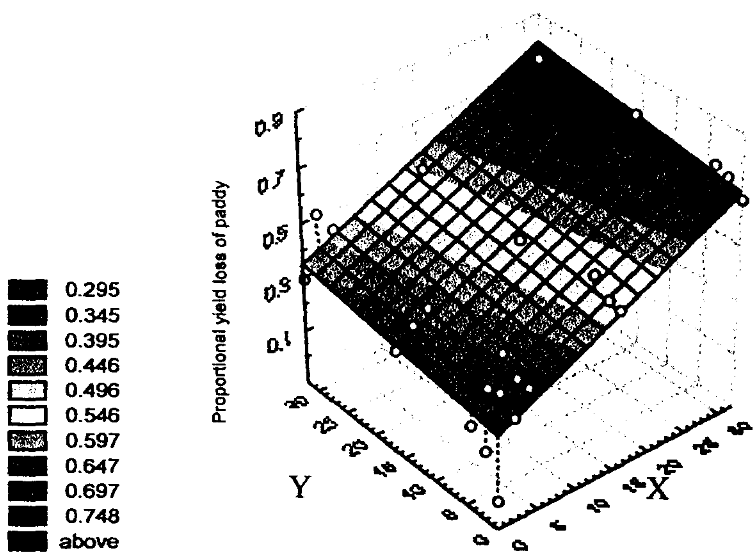
The observed yield losses and the predicted yield losses obtained by fitting the linear model are presented in Table 81 and Fig. 29a & 29b.

Fig. 29a. The second model proposed fitted for the year 1999

Yield loss = $a+b*d_1+c*d_2$

where d_1 = Density of *S. interrupta* and d_2 = Density of *I. miliacea*

z=0.2444+0.014x+0.0033y



X – Density of *S. interrupta* (plants m^{-2})

Y – Density of *I. miliacea* (plants m^{-2})

Fig. 29b. The second model proposed fitted for the year 2000

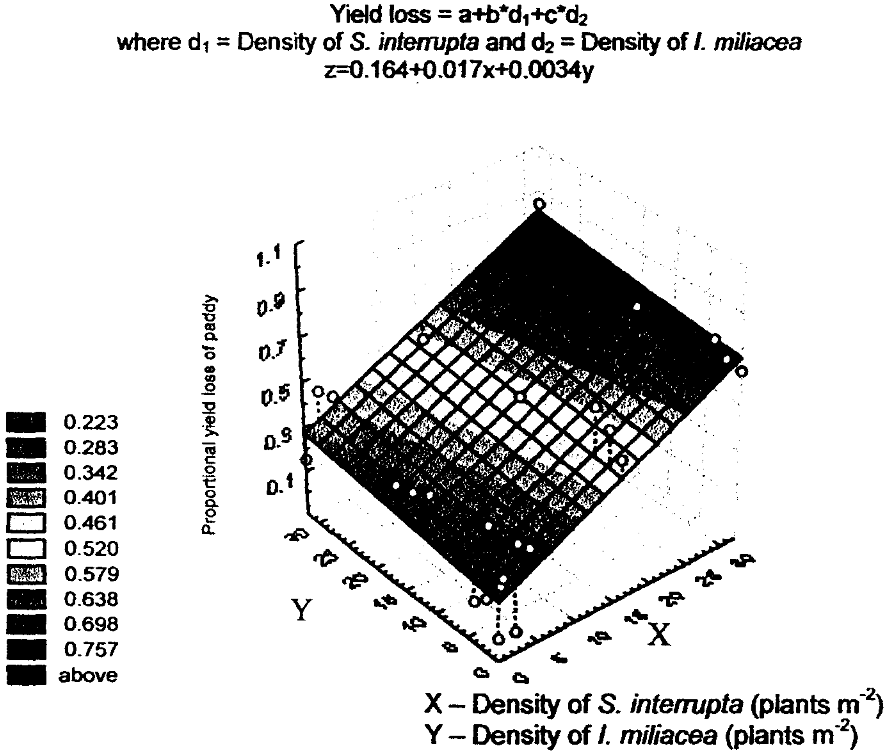


Table 81. The observed yield losses and the predicted yield losses obtained from model 2

Density of *S. interrupta* per m^2	Density of *I. miliacea* per m^2	1999		2000	
		Proportional yield loss		Proportional yield loss	
		Observed	Predicted#	Observed	Predicted#
0	0	0.0000	0.2444	0.0000	0.1640
0	2	0.1549	0.2510	0.1342	0.1708
0	4	0.2129	0.2576	0.0801	0.1776
0	16	0.2839	0.2970	0.3571	0.2182
0	32	0.2904	0.3496	0.1472	0.2724
2	0	0.2775	0.2725	0.0014	0.1980
2	2	0.3353	0.2790	0.1558	0.2048
2	4	0.3226	0.2856	0.3773	0.2116
2	16	0.3549	0.3250	0.2850	0.2522
2	32	0.5097	0.3776	0.4278	0.3064
4	0	0.3549	0.3005	0.3304	0.2320
4	2	0.3613	0.3070	0.3167	0.2388
4	4	0.4194	0.3136	0.1162	0.2456
4	16	0.3871	0.3531	0.2388	0.2862
4	32	0.4258	0.4056	0.3745	0.3404
16	0	0.4710	0.4686	0.5195	0.4360

Density of *S. interrupta* per m^2	Density of *I. miliacea* per m^2	1999		2000	
		Proportional yield loss		Proportional yield loss	
		Observed	Predicted#	Observed	Predicted#
16	2	0.4775	0.4752	0.6053	0.4428
16	4	0.5355	0.4817	0.6616	0.4495
16	16	0.4839	0.5212	0.4921	0.4902
16	32	0.5097	0.5738	0.4545	0.5444
32	0	0.6710	0.6928	0.6486	0.7080
32	2	0.7226	0.6993	0.6703	0.7148
32	4	0.7355	0.7059	0.7157	0.7215
32	16	0.7484	0.7454	0.6508	0.7622
32	32	0.7355	0.7979	0.8434	0.8164

By fitting the model, $Y_L = a+bd_1+cd_2$

The model given by

$$Y_L = a+bd_2+cd_2^2+dd_1 \quad (3)$$

where Y_L – proportional yield loss
d_2 – density of *I. miliacea*
d_1 – density of *S. interrupta* and
a, b, c, d – parameters associated with the model
was also fitted to the data.

The parameters estimated from the model are presented in Table 82.

Table 82. Estimates of parameters for model 3

Year	Parametric estimates				R^2
	a	b	c	d	
1999	0.2443** (0.0288)†	0.0071 (0.0054)	-0.0001 (0.0002)	0.0140** (0.0013)	0.8543
2000	0.1540** (0.0439)	0.0072 (0.0082)	-0.0001 (0.0003)	0.0170** (0.0020)	0.7855

† Figures in parenthesis are the standard errors of the estimates.
** Significant at 1% level of significance

The observed yield losses and the predicted yield losses obtained from the model are given in Table 83 and Fig. 30a & 30b.

Fig. 30a. The third model proposed fitted for the year 1999

Yield loss = $a+b^*d_2+c^*d_2^2 + d^*d_1$

where d_1 = Density of *S. interrupta* and d_2 = Density of *I. miliacea*

$z=0.2343+0.0071x-0.00012x^2+0.014y$

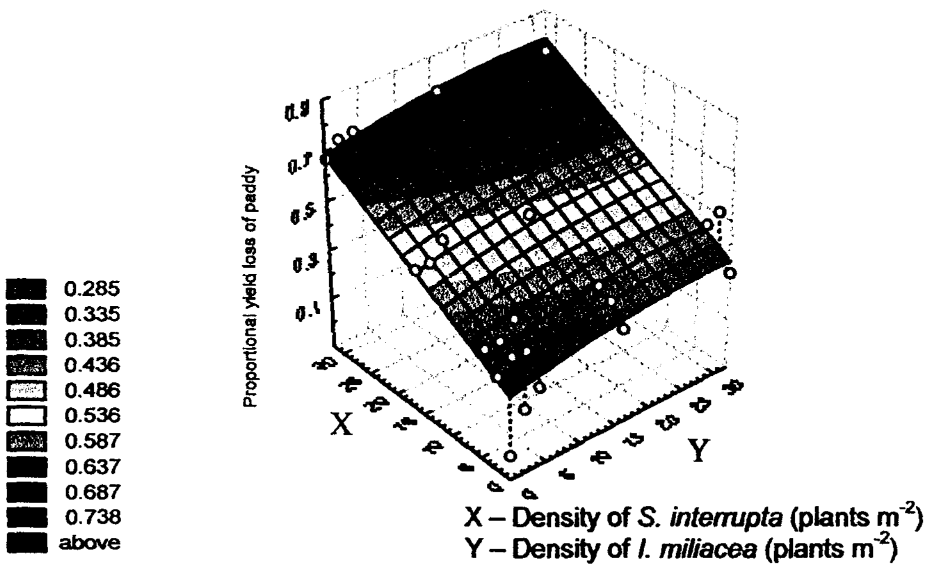


Fig. 30b. The third model proposed fitted for the year 2000

Yield loss = $a+b^*d_2+c^*d_2^2 + d^*d_1$

where d_1 = Density of *S. interrupta* and d_2 = Density of *I. miliacea*

$z=0.154+0.007x-0.00012x^2+0.017y$

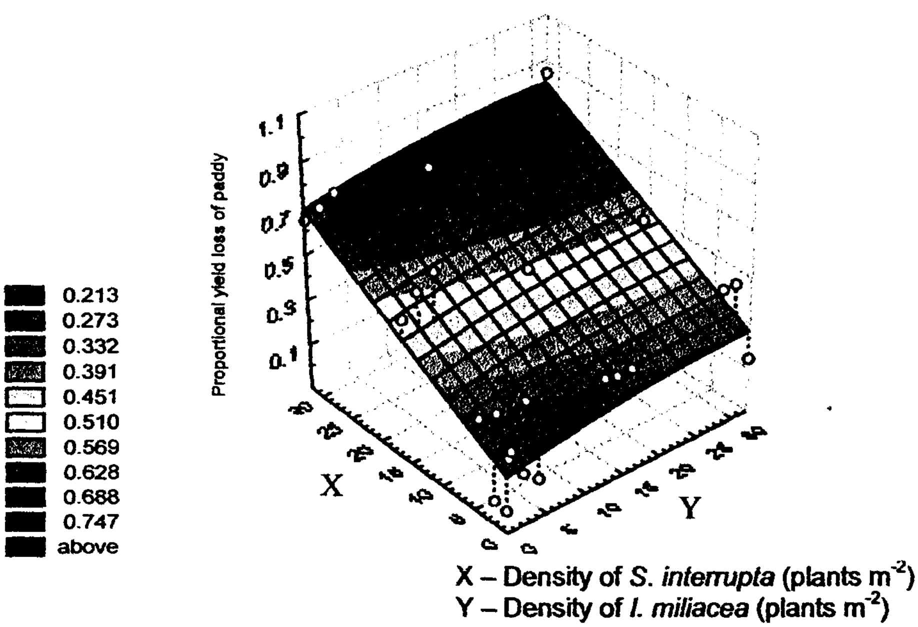


Table 83. The observed yield losses and the predicted yield losses obtained from model 3

Density of *S. interrupta* per m²	Density of *I. miliacea* per m²	1999		2000	
		Proportional yield loss		Proportional yield loss	
		Observed	Predicted#	Observed	Predicted#
0	0	0.0000	0.2343	0.0000	0.1539
0	2	0.1549	0.2480	0.1342	0.1678
0	4	0.2129	0.2608	0.0801	0.1807
0	16	0.2839	0.3174	0.3571	0.2384
0	32	0.2904	0.3392	0.1472	0.2621
2	0	0.2775	0.2623	0.0014	0.1879
2	2	0.3353	0.2760	0.1558	0.2018
2	4	0.3226	0.2888	0.3773	0.2147
2	16	0.3549	0.3454	0.2850	0.2724
2	32	0.5097	0.3672	0.4278	0.2961
4	0	0.3549	0.2903	0.3304	0.2219
4	2	0.3613	0.3040	0.3167	0.2358
4	4	0.4194	0.3168	0.1162	0.2487
4	16	0.3871	0.3734	0.2388	0.3064
4	32	0.4258	0.3953	0.3745	0.3301
16	0	0.4710	0.4584	0.5195	0.4259
16	2	0.4775	0.4722	0.6053	0.4398
16	4	0.5355	0.4850	0.6616	0.4527
16	16	0.4839	0.5416	0.4921	0.5103
16	32	0.5097	0.5364	0.4545	0.5341
32	0	0.6710	0.6826	0.6486	0.6979
32	2	0.7226	0.6963	0.6703	0.7118
32	4	0.7355	0.7091	0.7157	0.7247
32	16	0.7484	0.7657	0.6508	0.7823
32	32	0.7355	0.7875	0.8434	0.8061

#By fitting the equation, $Y_L = a + bd_2 + cd_2^2 + dd_1$

The model given by

$$Y_L = a + bd_1 + cd_2 + dd_1^2 + ed_1d_2 + fd_2^2 \qquad (4)$$

where Y_L – yield loss of paddy (%)
d_1 – density of *S. interrupta*
d_2 – density of *I. miliacea* and
a, b, c, d, e, f – parameters associated with the model

was also fitted to the yield loss-weed density data of both the weed species. The parameters estimated from the model are given in Table 84.

Table 84. Estimates of parameters for model 4

Year	Parametric estimates						R^2
	a	b	c	d	e	f	
1999	20.3214** (3.3603)#	2.0595** (0.5391)	0.8771 (0.5391)	-0.0154 (0.0160)	-0.0154 (0.0160)	-0.0120 (0.0160)	0.8744
2000	10.3781 (5.0029)	3.2655 (0.8026)	0.8219 (0.3187)	-0.0457 (0.0238)	-0.0097 (0.0158)	-0.0118 (0.0238)	0.8232

#Figures in parenthesis are the standard errors of the estimates

** Significant at 1% level of significance

The observed yield losses and the predicted yield losses obtained from the model are given in Table 85 and Fig. 31a & 31b.

Fig. 31a. The fourth model proposed fitted for the year 1999

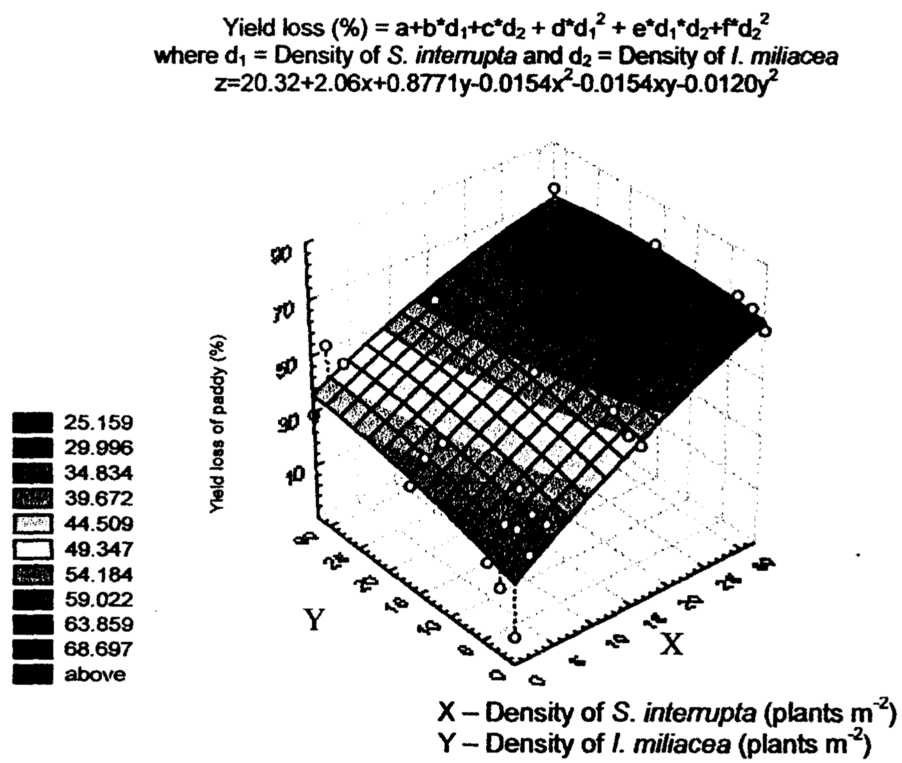


Fig. 31b. The fourth model proposed fitted for the year 2000

Yield loss (%) = $a+b*d_1+c*d_2 + d*d_1^2 + e*d_1*d_2+f*d_2^2$
where d_1 = Density of *S. interrupta* and d_2 = Density of *I. miliacea*
$z=10.3781+3.2655x+0.8220y-0.0457x^2-0.0097x*y-0.0118y$

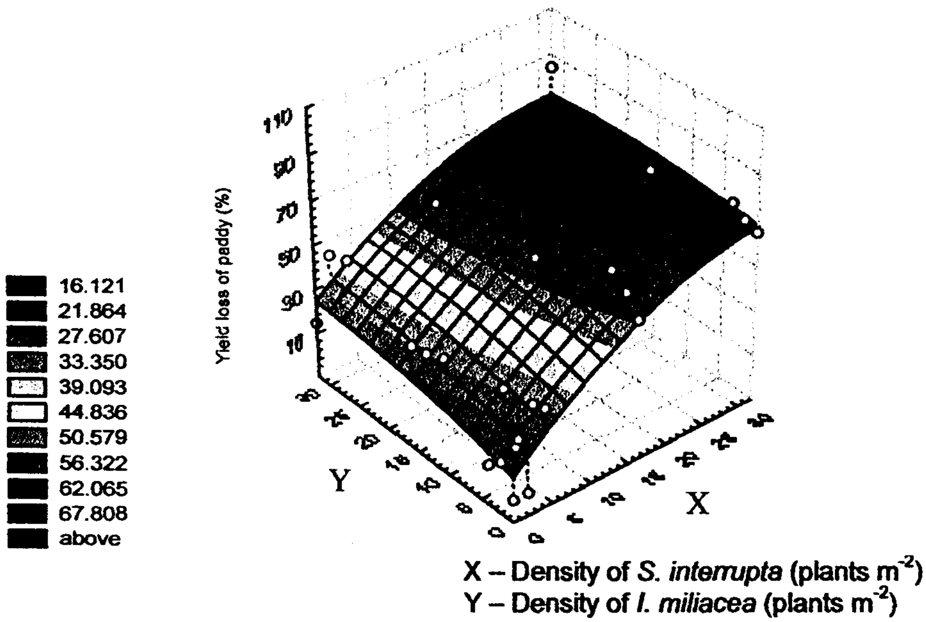


Table 85. The observed yield losses and the predicted yield losses obtained from model 4

Density of *S. interrupta* per m^2	Density of *I. miliacea* per m^2	1999		2000	
		Observed yield loss (%)	Predicted# yield loss (%)	Observed yield loss (%)	Predicted# yield loss (%)
0	0	0.00	20.32	0.00	10.38
0	2	15.49	22.03	13.42	11.97
0	4	21.29	23.64	8.01	13.48
0	16	28.39	31.29	35.71	20.49
0	32	29.04	36.14	14.72	24.54
2	0	27.75	24.38	0.14	16.73
2	2	33.53	26.02	15.58	18.28
2	4	32.26	27.57	37.73	19.75
2	16	35.49	34.86	28.50	26.53
2	32	50.97	39.21	42.78	30.27
4	0	35.49	28.31	33.04	22.71
4	2	36.13	29.90	31.67	24.23
4	4	41.94	31.38	11.62	25.65
4	16	38.71	38.30	23.88	32.20
4	32	42.58	42.16	37.45	35.63

Density of *S. interrupta* per m^2	Density of *I. miliacea* per m^2	1999		2000	
		Observed yield loss (%)	Predicted# yield loss (%)	Observed yield loss (%)	Predicted# yield loss (%)
16	0	47.10	49.33	51.95	50.92
16	2	47.75	50.54	60.53	52.20
16	4	53.55	51.66	66.16	53.39
16	16	48.39	56.36	49.21	58.55
16	32	50.97	57.26	45.45	60.12
32	0	67.10	70.45	64.86	68.04
32	2	72.26	71.17	67.03	69.02
32	4	73.55	71.79	71.57	69.90
32	16	74.84	73.53	65.08	73.19
32	32	73.55	70.49	84.34	72.28

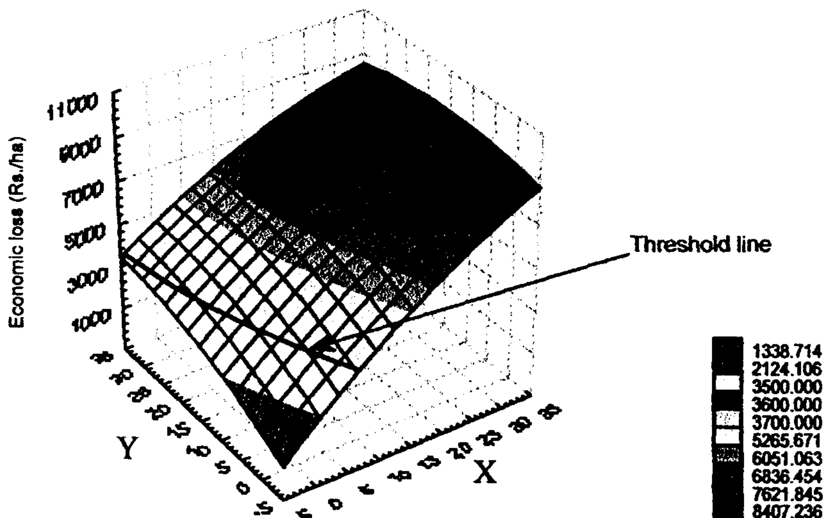
#By fitting the equation, $Y_L = a + bd_1 + cd_2 + dd_1^2 + ed_1d_2 + fd_2^2$

4.3 Estimation of threshold weed densities

The threshold weed densities of *S. interrupta* and *I. miliacea* were calculated based on a fixed cost notion. Since the yield losses were found to be rather consistent with increased weed densities during 1999, the same data were used for calculation of threshold. The economic losses were calculated over all the densities of *S. interrupta* and *I. miliacea* taking the price of paddy to be Rs. 7 per kg. The labour charges were taken to be Rs. 144 per man-day with the labour requirement to be one-labourer per 10 cents, which were the prevailing rates and norms at ARS, Mannuthy. Fig. 32 shows the threshold line above which weed control is essential. Table 86 shows the economic losses incurred due to the presence of varying densities of *S. interrupta* and *I. miliacea*, the cost of hand weeding and a logical variable which shows whether weed control is necessary.

Fig. 32. The threshold weed densities descriptor

Economic loss=2460.9+249.4d_1+106.2d_2-1.8d_1^2-1.9d_1*d_2-1.5d_2^2
where d_1 = Density of *S. interrupta* and d_2 = Density of *I. miliacea*



X – Density of *S. interrupta* (plants m^{-2})
Y – Density of *I. miliacea* (plants m^{-2})

Table 86. Threshold weed densities descriptor

Density of *S. interrupta* per m^2	Density of *I. miliacea* per m^2	Grain yield of paddy (kg ha^{-1})	Grain yield loss (kg ha^{-1})	Economic loss (Rs. ha^{-1})	Cost of hand-weeding (Rs. ha^{-1})	Logical variable
0	0	1730.0	0.0	0.0	3600.0	0
0	2	1462.0	268.0	1876.0	3600.0	0
0	4	1361.6	368.4	2578.8	3600.0	0
0	16	1238.8	491.2	3438.4	3600.0	0
0	32	1227.6	502.4	3516.8	3600.0	0
2	0	1250.0	480.0	3360.0	3600.0	0
2	2	1150.0	580.0	4060.0	3600.0	1
2	4	1171.9	558.1	3906.7	3600.0	1
2	16	1116.1	613.9	4297.3	3600.0	1
2	32	848.2	881.8	6172.6	3600.0	1
4	0	1116.1	613.9	4297.3	3600.0	1
4	2	1104.9	625.1	4375.7	3600.0	1
4	4	1004.5	725.5	5078.5	3600.0	1
4	16	1060.3	669.7	4687.9	3600.0	1
4	32	993.3	736.7	5156.9	3600.0	1

Density of *S. interrupta* per m^2	Density of *I. miliacea* per m^2	Grain yield of paddy (kg ha^{-1})	Grain yield loss (kg ha^{-1})	Economic loss (Rs. ha^{-1})	Cost of hand-weeding (Rs. ha^{-1})	Logical variable
16	0	915.2	826.0	5703.6	3600.0	1
16	2	904.0	814.8	5782.0	3600.0	1
16	4	803.6	926.4	6484.8	3600.0	1
16	16	892.9	837.1	5859.7	3600.0	1
16	32	848.2	881.8	6172.6	3600.0	1
32	0	569.2	1160.8	8125.6	3600.0	1
32	2	479.9	1250.1	8750.7	3600.0	1
32	4	457.6	1272.4	8906.8	3600.0	1
32	16	435.3	1294.7	9062.9	3600.0	1
32	32	457.6	1272.4	8906.8	3600.0	1

DISCUSSION

5. DISCUSSION

Weeds are a major problem in rice leading to losses as high as 80% (Smith, 1988). The time of emergence and their extent of influence on the crop are rather specific in nature. But a study of relationship between yield loss of paddy and a major weed or two major weeds will throw light on the precautions that are to be taken by a farmer to avoid the onslaught of weeds on the crop. *Sacciolepis interrupta* and *Isachne miliacea* are the two predominant weeds of semi dry rice in Kerala. Most of the weeds do have some characteristics of their own which widely influence the yield of the crop. All the characteristics that were recorded both on the crop and weeds were subjected to a 5^2 factorial RBD analysis.

In 1999, the height of paddy at 60 DAS, number of tillers at 60 DAS, height of paddy at harvest, leaf area of paddy at harvest, number of tillers at harvest, number of productive tillers at harvest, total bio-mass of paddy at harvest, grain yield of paddy, straw yield of paddy and test weight of paddy were found to be significantly influenced by the presence of *S. interrupta* and *I. miliacea.* However, leaf area of paddy at 60 DAS was found to be affected by *S. interrupta* only. The number of tillers of *S. interrupta* at 60 DAS, the height of *S. interrupta* at 60 DAS, the number of tillers of *S. interrupta* at harvest of rice, height of *S. interrupta* at harvest of rice, drymatter production of *S. interrupta* and drymatter production of *I. miliacea* were found to be affected by both intraspecific and interspecific competition.

In 2000, the total bio-mass of paddy at harvest was found to be influenced by *S. interrupta* and *I. miliacea*. However, the number of tillers of paddy at harvest, number of productive tillers of paddy at harvest, grain yield of paddy and straw yield of paddy were found to be affected due to the presence of *S. interrupta* only. Some of the weed characteristics like number of tillers of *S. interrupta* at 60 DAS, height of *S. interrupta* at 60 DAS, number of tillers of

S. interrupta at harvest of rice, height of *S. interrupta* at harvest of rice, drymatter production of *S. interrupta* and drymatter production of *I. miliacea* were also found to be influenced significantly by the presence of *S. interrupta*.

The variation in the characteristics that were influenced by the weeds between the years may be mainly due to the fluctuations in climatic factors like onset of monsoon, relative humidity, daily range of temperature, sunshine hours etc. during the periods under observation.

The weeds do influence the crop through certain yield reducing characteristics of their own. A healthy competition of characters namely leaf area index (LAI), number of tillers of both the weeds and the crop could ultimately reduce the yield of the crop, as the yield of weeds is of no economic use for the farmer.

In Kerala, the cost of handweeding is high, as labour charge is the maximum in Kerala compared to all other states. Handweeding may be an ideal situation, but compared to the cost of spraying a pre-emergence herbicide, it may be very high. A balance has to be struck between the maximum yield loss that a farmer could bear in comparison with handweeding when there is an attack by weeds. The threshold weed densities, of course, become a curious observation.

5.1 Prediction of yield losses based on weed density models

5.1.1 Prediction based on single weed species models

Many researchers who have thrown light on weed crop competition have worked on a single weed species as the major thrust area in any crop; not necessarily rice. The success of fitting the well-known models expounded by researchers in this field has been first tried. Since the natural weed infestations usually include numerous weed species, multi-species models were also tried.

Roger Cousens may be regarded as a pioneer researcher in this field. From Table 3 and Fig. 3a & 3b, it is evident that the model proposed by Cousens (1985) fitted well to the single species data of *S. interrupta* This rectangular hyperbolic model was also found to fit well in several other crops. (Zanin & Sattin, 1988; Streibig *et al.,* 1989; Caussanel *et al.,* 1990; Wilson & Wright, 1990; McLennan *et al.,* 1991; Weaver, 1991; Norris, 1992). The data for *I. miliacea* in 2000 did not fit well into the hyperbolic model (Table 4 and Fig. 3c & 3d). *I. miliacea* being a prostrate species and with highly flexible characteristics might be having a differential mode of influence on the crop characteristics. The good fit obtained for *I. miliacea* in 1999 for the hyperbolic model may be an isolated phenomenon. The parameter I, the percentage yield loss as density approaches zero for *S. interrupta* in 1999 was higher than that in 2000 (Table 2). The parameter A, the percentage yield loss as density approaches infinity was higher in 2000 than in 1999. The variations in A and I may be due to the relative time of weed emergence of weed and crop and soil type.

The model proposed by Hakansson (1983) was found to fit well to the single species data on *S. interrupta* (From Table 6 and Fig.4a & 4b). However *I. miliacea* because of its differential growth characteristics did not fit into the model. The good fit of the model for *I. miliacea* in 1999 may be an isolated phenomenon. The parameters 'a' and 'b' of the model were found to vary between the years. The parameters 'a' and 'b' were found to be significant for the year 1999 for *S. interrupta* and *I. miliacea* and only 'b' was found to be significant for *S. interrupta* in 2000 (Table 5).

The first model proposed by Watkinson (1981) was also found to fit the data on *S. interrupta* and *I. miliacea* well for both 1999 and 2000 (Table 8 and Fig.5a & 5b) except for *I. miliacea* in 2000 (Table 10 and Fig. 15c & 15d). The relatively low deviation of the observed yield losses from the predicted yield losses (From Table 9) shows the close fit of *S. interrupta* for the model.

I. miliacea in 1999 (Table 34 and Fig. 13c & 13d), but failed to explain much of the variation for *I. miliacea* in 2000. The parameters 'a' and 'b' associated with the model were found to be significant for the year 1999 for both *S. interrupta* and *I. miliacea* (Table 32).

The model proposed by Dew (1972) was also fitted to the proportional yield loss – weed density data. The parameter 'a' associated with the model was found to be significant for both *S. interrupta* and *I. miliacea* for 1999 and 2000 (Table 35). The model fitted well for *S. interrupta* ($R^2 > 0.88$) in both 1999 and 2000. The fit for *I. miliacea* in 1999 was considered good, but was weak in 2000 (Table 37 and Fig. 14c & 14d). Table 36 and Fig. 14a & 14b show the good fit obtained for *S. interrupta* using the model.

The model proposed by Weise (1971) was fitted to proportional yield loss – weed density data of *S. interrupta* and *I. miliacea.* The model fitted well for *S. interrupta* in both 1999 and 2000 (R^2=0.97 and 0.89, from Table 39 and Fig. 15a & 15b). The model also fitted well for the data on *I. miliacea* in 1999 (Table 40 and Fig. 15c & 15d). But it fitted comparatively weakly to the data on *I. miliacea* in 2000 (R^2 = 0.63 from Table 38). From Tables 39 & 40 and Fig. 15a, 15b, 15c &15d, we can conclude that the model proposed by Weise (1971) explained the variability in yield loss due to weed density relatively well.

The yield loss – weed density relationship model proposed by Wilson and Cussans (1983) was fitted to the data. The data for *S. interrupta* showed a good fit with the model with $R^2 > 0.90$. The parameter 'b' was found to be significant for both *S. interrupta* and *I. miliacea* for 1999 and 2000 (Table 41). However parameter 'a' was found to be significant for only *I. miliacea* in 1999. The fit of the model for *I. miliacea* was relatively weak for 2000. However this model was found to explain more variation than most other models (Table 42 & 43 and Fig. 16a, 16b, 16c & 16d).

The model proposed by Zakharenko (1968) relating proportional yield loss to weed density was also fitted to the single species data of 1999 and 2000. The model was found to be a fairly good fit for *S. interrupta* in both 1999 and 2000 (Table 45 and Fig. 17a & 17b). The parameter 'a' of the model was also found to be significant for *S. interrupta* in 1999 & 2000 (Table 44). However the model failed to explain the variation due to *I. miliacea* in both 1999 and 2000 (Table 46 and Fig. 17c & 17d). The weak fit for *I. miliacea* may be attributed to the differential growth characteristics of the weed.

The model proposed by Chisaka (1977) relating proportional yield loss to weed density was also fitted for the single species data. The model fitted well for *S. interrupta* (Table 48 and Fig. 18a & 18b) but showed a poor fit for *I. miliacea* (Table 49 and Fig. 18c & 18d). The parameter 'a' associated with the model was also found to be significant for *S. interrupta* in both 1999 and 2000. The poor fit of the model to *I. miliacea* may be the result of the spreading nature of *I. miliacea,* which has more effect on leaf area than crop density.

The model proposed by Wilcockson (1977) was also fitted to the yield loss – weed density data. The model fitted well for *S. interrupta* in both 1999 and 2000 (Table 51 and Fig. 19a & 19b). However the parameters 'a' and 'b' associated with the model were found to be not significant (Table 50). The model fitted well for *I. miliacea* in 1999 but had a weak fit in 2000 (Table 52 and Fig. 19c & 19d). This model can be considered as a good model, since it could explain more variation than most other models.

The second model proposed by Hakansson (1983) relating yield loss to weed density was fitted to the data (Table 53). Though the model fitted well to both *S. interrupta* and *I. miliacea* in 1999 and 2000 (Table 54 & 55), the pattern of the curves (Fig.20a, 20b, 20c & 20d) show that the model fails to explain the true inherent trend in the data on *S. interrupta* and *I. miliacea.* The model showed an initial upward trend and after reaching a maximum fell steeply; that it does not explain the true relationship.

The model proposed by Carlson *et al.* (1981) was also fitted to the given data and the fit was examined (Table 57 & 58). The R^2 was high for both *S. interrupta* and *I. miliacea* in 1999 and 2000 (Table 56). The curves (Fig. 21a, 21b, 21c & 21d) pictured a true yield loss - weed density relationship. But for *I. miliacea* data on 2000 the curve showed a sharp dip (Fig. 21d).

A few plausible models as suggested by Cousens (1985) were also tried on the yield loss – weed density data. The first model was found to fit well to the data of *S. interrupta* and *I. miliacea* for 1999 and 2000 (Table 63 & 64 and Fig. 22a, 22b, 22c & 22d). The second model apparently explained 100% of the variation, with Fig. 23a, 23b, 23c & 23d justifying the same. But Fig. 23d again showed a sharp dip. The third model also had a good fit (Table 67 & 68) but Fig. 24a, 24b, 24c & 24d explained a zigzag relationship. The fourth model was found to fit well for *S. interrupta* in 1999 and 2000 (Table 69 and Fig. 25a & 25b), but the fit was found to be relatively weak for *I. miliacea* in 2000 (Table 70 and Fig. 25d).

All the single weed species models that were tried and found to fit to the exact nature of yield loss - weed density relationship followed a hyperbolic pattern. Most of them resounded the Cousens' way of description of the relationship. A broad conclusion could that a modification of the Cousens' model still bounces back to the same model. In addition, the Cousens' model has parameters that are simple and sensible to explain.

5.1.2 Prediction based on multi-species models

Swinton *et al.* (1994a) expanded Cousens (1985) model to get a multi-species model which was used to explain the variation in yield loss (%) by both *S. interrupta* and *I. miliacea* taken together. The model was found to fit well for the given data in 1999 and 2000 (R^2 = 0.82, from Table 72). The parameters associated with model (I_1, I_2 and A) were also found to be significant in 1999 and

2000 except I_1 in 2000 (Table 71). The parameters are found to vary over the years which shows the influence of weather parameters on yield loss and weed density. The response surfaces are given in Fig. 26a & 26b.

Swinton *et al.* (1994b) expressed the densities of the weed with lesser I (from Cousens' multivariate model) in terms of the weed with higher I. These density equivalents were summed together to get total density equivalents which are used for fitting a multi-species model. This multi-species model was fitted to the given data. The R^2 and predicted values obtained were the same as that of the Cousens' multivariate model (Table 73, 74 & 75). The model fitted the data well with an R^2 of 0.85 for 1999 and 0.82 for 2000 respectively (Table 73).The advantage of this model is that the dimensionality of the surface is reduced to two from three thereby the surface collapsing to a curve (Fig. 27a & 27b).

Berti and Zanin (1994) estimated yield losses by converting all the weed densities into the densities of a reference species. The estimated yield loss (%) calculated using the method suggested by them was found to agree closely with the observed yield loss (%) (Table 76 & 77). Since there was only an arithmetic work up of the yield losses, no parametric estimation was necessitated and as such there was no specific model fitted rather than a numerical step by step processing of data.

5. 1.3 Prediction using other new models

The first model tried was found to have a good fit with an R^2 of 0.86 for 1999 and 0.82 for 2000 (Table 78). Out of the four parameters a, b, c & d associated with the model, a & b were found to be significant in both 1999 and 2000. The observed yield losses and the predicted yield losses were found to be fairly close (Table 79) in 1999 and 2000.The response surfaces are given in Fig. 28a & 28b.

The second model tried was the linear model, which explained 85% of the variation in 1999 and 78% in 2000. Out of the three parameters (a, b & c) associated with the model, a and b were found to be significant in both 1999 and 2000 (Table 80). The observed yield losses and expected yield losses were found to be close in 1999 and 2000 (Table 81 and Fig. 29a & 29b).

The third model tried was found to explain 85% of the variation in 1999 and 79% of the variation in 2000 (Table 82). Out of the four parameters (a, b, c & d) associated with the model, only a and d were found to be significant in 1999 and 2000. The deviation between the observed yield losses and the predicted yield losses was found to be very less. (Table 83 and Fig. 30a & 30b).

The fourth model which was fitted for the yield loss (%) and weed density data of *S. interrupta* and *I. miliacea* was found to have a better fit than any other multi-species model. The model explained 87% of the variation in 1999 and 82% of the variation in 2000 (Table 84). Out of the six parameters (a, b, c, d, e & f) associated with the model, a and b were found to be significant in 1999 and a was found to be significant in 2000. The proximity of the predicted yield losses and the observed yield losses shows the excellent fit of the model. (Table 85 and Fig. 31a & 31b).

The existing multi-species models are only an extension in one way or other of the single species Cousens' model. Cousens' model in its multispecies setup becomes complicated with the addition of more parameters to accommodate the added species.

The new models tried of course are rather simpler. The inadequacy of fit of the extended new models as regard to certain parameters could be that the second weed species viz., *I. miliacea* is having a peculiar way of competition due to its prostrate way of growth. If certain other weed species were examined in lieu of *I. miliacea*, i.e., that which has a better canopy competition, the new models might prove a much better descriptor of competition rather than having a redundant model.

5.2 Interpretation of threshold weed densities

The threshold weed densities could be defined as the maximum permissible weed densities that cause a yield loss at par with the fixed cost.

In Table 86, the last column indicates whether control measure should be taken (or handweeding should be done) or not for all weed densities. In the last column '0' indicates that there is no necessity of undertaking handweeding operations as the economic loss will be less than the cost of hand weeding. '1' indicates that the economic loss at that weed density will be greater than the cost of handweeding. From this we can conclude that *I. miliacea* even at 32 plants m^{-2} does not pose much of a hazard to rice farming, but the presence of even two *S. interrupta* plants m^{-2} will prove a loss for the farmer.

Hence the same may be regarded as a threshold i.e., weeding has to start immediately on detection of two *S. interrupta* plants m^{-2} at the earliest; that before the establishment of weeds in its full cover, yield loss can be thwarted to the maximum possible extent. The threshold line is indicated in Fig.32 above which control measure is necessary and below which there is not much of an economic loss.

SUMMARY

6. SUMMARY

Two field experiments were conducted one in the year 1999 and the other in 2000 to study the relationship between weed density and crop loss in semi-dry rice. Crop characteristics like height at 60 DAS, leaf area at 60 DAS, mean number of tillers at 60 DAS, height at harvest, leaf area at harvest, mean number of tillers at harvest, mean number of productive tillers at harvest, total bio-mass at harvest, grain yield, strain yield, 1000 grain weight and weed characteristics like mean number of tillers at 60 DAS, height at 60 DAS, mean number of tillers at harvest of rice, height at harvest of rice and drymatter production at harvest of rice were recorded.

.In the year 1999, *Sacciolepis interrupta* and *Isachne miliacea* were found to have had a significant influence on the height of paddy at 60 DAS, number of tillers of paddy at 60 DAS, height of paddy at harvest, leaf area of paddy at harvest, height of paddy at harvest, leaf area of paddy at harvest, number of tillers of paddy at harvest, number of productive tillers of paddy at harvest, total bio-mass of paddy at harvest, grain yield of paddy, test weight of paddy, number of tillers of *S. interrupta* at 60 DAS, height of *S. interrupta* at 60 DAS, number of tillers of *S. interrupta* at harvest, height of *S. interrupta* at harvest and drymatter production of *S. interrupta* at harvest of rice. However leaf area of paddy at 60 DAS was found to be affected by *S. interrupta* alone.

In the year 2000, the total bio-mass of paddy at harvest was found to be affected by both *S. interrupta* and *I. miliacea*. However *S. interrupta* alone influenced crop characteristics like leaf area of paddy at harvest, number of tillers of paddy at harvest, number of productive tillers of paddy at harvest and grain yield of paddy and weed characteristics like number of tillers of *S. interrupta* at 60 DAS, height of *S. interrupta* at 60 DAS, number of tillers of *S. interrupta* at harvest, height of *S. interrupta* at harvest and drymatter production of *S. interrupta*.

The following were the models fitted to estimate yield losses due to weed density.

(1) Single species models:

Model proposed by	Model	Parametric description
1. Cousens (1985)	$Y_L(\%) = \frac{Id}{1 + \frac{Id}{A}}$	Y_L – percentage yield loss d – weed density I – percentage yield loss as d → 0 A - percentage yield loss as d →α
2. Hakansson (1983)	$Y_L = \frac{ad^b}{1 + ad^b}$	Y_L – proportional yield loss d – weed density a, b – parameters
3. Watkinson (1981)	$Y_L = 1 - (1 + ad)^{-b}$	Y_L – proportional yield loss d – weed density a, b – parameters
4. Watkinson (1981)	$Yc = \frac{Ywf}{(1 + \beta Nw)^b}$	Y_C – crop yield Nw – weed density Ywf, β, b – parameters
5. Swinton and Lyford (1996)	$Y = \frac{\beta\gamma + \alpha D^\delta}{\gamma + D^\delta}$	Y – Crop yield D – weed density α,β,γ,δ – parameters
6. Ngouajio *et al.* (1999c)	$Y = \frac{\beta\gamma + \alpha\left(\frac{Dw}{Dc}\right)^\delta}{\gamma + \left(\frac{Dw}{Dc}\right)^\delta}$	Y – crop yield Dw– weed density Dc – crop density α,β,γ,δ – parameters
7. Kropff and Spitters (1991)	$Y_L = \frac{a\frac{Nw}{Nc}}{I + a\frac{Nw}{Nc}}$	Y_L – crop yield Nw – weed density Nc – crop density a – parameter
8. Schweizer (1973)	$Y_L = ad + bd^2 + cd^3$	Y_L – proportional yield loss d – weed density a, b, c – parameters
9. Hammerton (1964)	$Y_L = ad + bd^2$	Y_L – proportional yield loss d – weed density a, b – parameters
10. Covarelli (1984)	$Y_L = ad$	Y_L – proportional yield loss d – weed density a – parameter

Model proposed by	Model	Parametric description
11. Marra and Carlson (1983)	$Y_L = ad^b$	Y_L – proportional yield loss d – weed density a, b – parameters
12. Dew (1972)	$Y_L = a\sqrt{d}$	Y_L – proportional yield loss d – weed density a – parameter
13. Weise (1971)	$Y_L = ad + b\sqrt{d}$	Y_L – proportional yield loss d – weed density a, b – parameters
14. Wilson and Cussans (1983)	$Y_L = b\,(1 - \exp^{(-ad)})$	Y_L – proportional yield loss d – weed density a, b – parameters
15. Zakharenko (1968)	$Y_L = 1 - \exp^{(-ad)}$	Y_L – proportional yield loss d – weed density a – parameter
16. Chisaka (1977)	$Y_L = \frac{ad}{1+ad}$	Y_L – proportional yield loss d – weed density a – parameter
17. Wilcockson (1977)	$Y_L = \frac{ad}{1+bd}$	Y_L – proportional yield loss d – weed density a, b – parameters
18. Hakansson (1983)	$Y_L = \frac{ad+bd^2}{1+ad+bd^2}$	Y_L – proportional yield loss d – weed density a, b – parameters
19. Carlson *et al.* (1981)	$Y_L = \frac{ad+bd^2}{(1+cd)^2}$	Y_L – proportional yield loss d – weed density a, b, c – parameters
20. Cousens (1985)	$Y_L = c\,(1 - (1 + ad)^{-b})$ $Y_L = \frac{ad+bd^2}{1+cd+fd^2}$ $Y_L = ad + bd^2 + cd^3 + fd^4$ $Y_L = ad^b + cd^f$	Y_L – proportional yield loss d – weed density a, b, c, f – parameters

The models proposed by Cousens (1985), Hakansson (1983), Watkinson (1981), Marra and Carlson (1983), Wilson and Cusssans (1983), Wilcockson (1977), Carlson *et al.* (1981) and the first and fourth models proposed by Cousens (1985) were found to explain most of the variation (around 90%) in the yield loss-weed density relationship; the models being fitted for the individual densities of *S. interrupta* and *I. miliacea* separately (Tables 3, 4, 6, 7, 9,10, 33, 34, 42, 43, 51, 52, 57, 63, 64, 69 & 70). However the models proposed by

Ngouajio *et al.* (1999), Kropff and Spitters (1991), Dew (1972), Zakharenko (1968) and Chisaka (1977) explained the yield loss-*S. interrupta* density relationship well (Table 18, 21, 36, 45 & 48).

From Fig. 3a, 3b, 3c, 3d, 4a, 4b, 4c, 4d, 5a, 5b, 5c, 5d, 8a, 8b, 9a, 9b, 13a, 13b, 13c, 13d, 14a, 14b, 16a, 16b, 16c, 16d, 17a, 17b, 18a, 18b, 19a, 19b, 19c, 19d, 21a, 21b, 22a, 22b, 22c, 22d, 25a, 25b, 25c and 25d it is evident that the nature of yield loss-weed density relationship is purely hyperbolic in nature. The I and A parameters of the Cousens (1985) model resounds a logistic explanation of the yield loss-weed density relationship. We may conclude that the Cousens (1985) model may be regarded as the most apt model in explaining the yield loss-*S. interrupta* density relationship. The poor fit of the yield loss-*I. miliacea* density for most of the models may be purely due to its prostrate nature of growth.

Swinton *et al.* (1994a) expanded the Cousens model to accommodate more than one weed species. The model fitted well (Table 71 & 72 and Fig. 26a & 26b) with the data on *S. interrupta* and *I. miliacea* for both the years 1999 and 2000. The expanded model had to accommodate extra set of parameters to explain the effect of the added species.

To reduce the complexity, Swinton *et al.* (1994b) defined density equivalents (Table 74 & 75 and Fig. 27a & 27b) so that the dimensionality of the problem got reduced and ultimately the response surface contracted to a response curve. The fitted model truly explained the nature of relationship between the crop and the weed species.

Berti and Zanin (1994) developed a numerical algorithm to estimate the percentage yield loss. The numerical exercise worked out resulted in expected yield losses in close proximity with the observed yield losses (Table 76 & 77).

The new multispecies models proposed are:

S.No	Model	Parametric description
1.	$Y_L = a + bd_1 + cd_1^2 + dd_2$	Y_L – proportional yield loss
2.	$Y_L = a + bd_1 + cd_2$	Y_L (%) – percentage yield loss
3.	$Y_L = a + bd_2 + cd_2^2 + dd_1$	d_1 – density of *S. interrupta*
4.	$YL (\%) = a + bd_1 + cd_2 + dd_1^2 + ed_1d_2 + fd_2^2$	d_2 – density of *I. miliacea* a, b, c, d, e, f – parameters

All the new models proposed fitted well to the data with the exception that the higher terms did not contribute much to the explanation of variation in the yield loss (Table 78, 79, 80, 81, 82, 83, 84 & 85 and Fig. 28a, 28b, 29a, 29b, 30a, 30b, 31a & 31b). This might be due to the fact that the competition of *I. miliacea* was poorer because of its prostrate nature of growth. The new models will definitely work out better with any two weed species having a sound intraspecific and interspecific competition.

The threshold weed densities are worked out in Table 86 which indicates the optimum weed densities of *S. interrupta* and *I. miliacea* beyond which weeding is to start with. The threshold weed densities worked out point towards the extent of the hazardous effect of the weeds on the crop especially that of *S. interrupta*. Fig. 32 highlights a threshold line which may be regarded as a cut-off line to read out threshold weed densities.

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APPENDICES

APPENDIX 1a

Abstract of analysis of variance of various characters recorded on paddy

Source	Degrees of freedom	Mean squares for			
		Height at 60 DAS (cm)		Leaf area per leaf at 60 DAS (cm^2)	
		1999	2000	1999	2000
S. interrupta(S)	4	127.72**	26.07	140.43**	12.29
I. miliacea(I)	4	21.56**	44.29	6.12	10.85
Interaction(SxI)	16	1.42	24.24	2.05	16.36

Source	Degrees of freedom	Mean squares for			
		No. of tillers at 60 DAS		Height at harvest (cm)	
		1999	2000	1999	2000
S. interrupta(S)	4	53.35**	7.66	196.66**	16.21
I. miliacea(I)	4	2.54**	1.02	66.06**	25.37
Interaction(SxI)	16	0.36	2.64	3.88	17.23

Source	Degrees of freedom	Mean squares for			
		Leaf area per leaf at harvest (cm^2)		No. of tillers at harvest	
		1999	2000	1999	2000
S. interrupta(S)	4	157.14**	4.61	71.18**	6.97*
I. miliacea(I)	4	16.77**	8.69	8.46**	1.27
Interaction(SxI)	16	2.90	0.72	1.01**	0.94

Source	Degrees of freedom	Mean squares for			
		No. of productive tillers at harvest		Total drymatter at harvest ($g\ m^{-2}$)	
		1999	2000	1999	2000
S. interrupta(S)	4	68.29**	8.10*	204350.00**	1428272.85**
I. miliacea(I)	4	8.68**	1.26	18037.06**	129461.18**
Interaction(SxI)	16	0.81**	1.12	2820.85**	6957.66

RELATIONSHIP BETWEEN WEED DENSITY AND YIELD LOSS IN SEMI-DRY RICE

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Sacciolepis interrupta and *Isachne miliacea* are two major problem weeds of rice in Kerala. An investigation on the quantum of crop loss incurred due to different densities of these weeds was undertaken to study the extent of damage inflicted on the crop which would necessitate early control of these weeds.

The observations recorded on the various crop and weed characteristics were analysed as a 5^2 factorial experiment. It was found that crop characteristics like total bio- mass of paddy at harvest, number of tillers of paddy at harvest, number of productive tillers at harvest, grain yield and strain yield. And weed characteristics like number of tillers of *S. interrupta* at 60 DAS, height of *S. interrupta* at 60 DAS, number of tillers of *S. interrupta* at harvest of rice, dry matter production of *S. interrupta* and drymatter production of *I. miliacea* were found to be affected by the weeds. The intra and interspecific competition was also brought to light based on the analysis.

Single weed species models like that of Cousens (1985), Hakansson (1983), the first model of Watkinson (1981), Marra and Carlson (1983), Wilson and Cussans (1983), Wilcockson (1977) and Carlson *et al.* (1981) fitted well to the yield loss – *S. interrupta/ I. miliacea* density relationship whereas those models proposed by Ngouajio *et al.* (1999), Kropff and Spitters (1991), Dew (1972), Zakharenko (1968) and Chisaka (1977) fitted well only to the yield loss – *S. interrupta* density relationship.

The extended version of the Cousens (1985) model by Swinton *et al.* (1994a) to a multi-species model was also fitted to the data and the same explained the yield loss – *S. interrupta* + *I. miliacea* densities relationship to a considerable extent. The reduced form of the multispecies model to an equivalent single species model as worked out by Swinton *et al.* (1994b) also had a good fit. The numerical assessment of yield loss – *S. interrupta* + *I. miliacea* density

relationship as illustrated by Berti and Zanin (1994) revealed the extent of damage on the crop by the weeds.

The new curvilinear models tried also explained the yield loss – weed density relationship with the exception that the role of *I. miliacea* deterring the yield of crop could not be highlighted due to its peculiar way of growth.

The threshold weed densities worked out on a economic loss basis revealed that even the presence of two *S. interrupta* plants in a square meter area was hazardous for the crop whereas even the presence of 32 *I. miliacea* plants in the same stipulated area was not as detrimental as *S. interrupta*.