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Research Bulletin

Effect of crop-crop diversity on insect pests A meta analysis

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Castor + Cowpea

Pigeonpea + Groundnut

Pigeonpea + Sunflower

Castor + Clusterbean

Pigeonpea + Greengram

Pigeonpea + Blackgram

Pigeonpea + Cluster bean

Pigeonpea + Blackgram

Pigeonpea + Groundnut

Pigeonpea + Maize

Caster + Groundnut

Caster

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Executive Summary

Considering the potential role of crop-crop diversity in managing the insect pest populations, several studies looked into the relationship between crop diversity and incidence of insect pests. In order to consolidate the understanding, several qualitative literature reviews were attempted to draw some generalizations, often based on the vote counting method. The generalizations drawn from such qualitative literature reviews suffer from lack of any statistical validity. This bulletin is an attempt to synthesize the studies on the relationship between the crop-crop diversity and incidence of insect pests through meta-analysis or a quantitative analysis of the results published. The data were taken from thirty-one studies which were related to agro-eco systems and conducted under field conditions and reported results as number of insects in treatment and control. Taking these data effect size was computed and its statistical significance estimated. It was found that the effect size varied from -29.16 to 14.75 with a mean effect size of -1.5 indicating that the average density of insect pests on an average was 1.5 standard deviations less in the crop-diverse situation as compared to the monoculture. In a majority of studies the effect size was observed to be negative indicating the reduction in insect pests in the presence of crop-crop diversity. The studies included in the analysis were found to be heterogeneous in terms of crops studied, insect pests and the experimental design. A separate analysis was conducted for lepidopteran and non-lepidopteran insect pests, which showed that the effect size was more in case of lepidopteran insects than in case of non-lepidopteran insect pests. The effect size in case of the natural enemies in crop diverse situations was found to be positive indicating an increase in their number. This finding corroborates the 'natural enemy hypothesis' as one of the pest reducing factors. Finally, attention is drawn to the limitation of meta analysis as it is, like any other statistical tool, prone to be misued.

Effect of crop-crop diversity on insect pests
A Meta analysis

1.0 Introduction

Rainfed agriculture is characterized by low productivity owing to the poor production environment in terms of poor soils, inadequate and erratic rainfall and low investment capacity of the farmers. Further more, crop production in rainfed conditions is highly prone to biotic stress. Among the causes of biotic stress, incidence of insect pests contributes significantly to the yield risk. In order to cope with the biotic and abiotic stress, farmers in dryland regions have diversified their cropping systems, which is more evident in the larger number of crops grown (Walker and Ryan, 1990). Whereas the large farmers grow different crops on different plots, small and marginal farmers often grow more than one crop either as inter or mixed crops. In contrast, irrigated agriculture tends to favor crop specialization. Diversified cropping systems allow the farmers to meet their diverse family needs, make better utilization of available family and farm resources and are also less vulnerable to incidence of insect pests.

Crop diversity is a situation wherein different crops are grown simultaneously in a given piece of land. Crop-crop, crop-border and crop-weed diversities are different forms of crop diversity (Baliddawa, 1985). Intercropping and mixed cropping systems are among the more popular forms of crop-crop diversity practiced in rainfed agriculture. These systems provide opportunities to create situations that are less pest-prone compared to single crop situations or monocultures. The genetic uniformity of monocultures leads to susceptibility to the pests (Bhatnagar and Davies, 1979). Use of plant species diversity in agro ecosystems is a fairly old method of reducing crop losses due to pests (Theunissen and Den Ouden, 1980). Research in diversified agro-ecosystems demonstrated that these systems tend to support less herbivore load than the corresponding monocultures (Altieri and Letourneau, 1982; Risch, 1981).

The possible impacts of crop-diversity on the incidence of insect pests have attracted the attention of researchers. Several reviews of such studies were attempted to draw conclusions on the impact of crop diversity on insect pest incidence. These reviews are more qualitative summaries of the studies and the conclusions drawn are not based on any statistical or quantitative analysis. These reviews are subjective and often based on vote-counting method. They do not consider the magnitude of the impact and sample size observed in the individual studies and in the process the valuable information available in the original studies is ignored. When studies reporting differential impact are included in the review, it becomes that much more difficult to draw conclusion on the overall impact of the treatment under question. Hence, the validity of these conclusions remains questionable. It is only possible to draw some generalizations, which have little statistical validity, and it is also not possible to quantify the magnitude of the effect of treatment.

Most of the reviews (e.g. Balidawwa, 1985 and Srinivasa Rao *et al* 2002) attempted to examine the impact of crop diversification on insect pest incidence also suffer from the above-mentioned limitations. Given below is a summary of qualitative literature survey on the impact of crop diversification on insect pests (Table 1). From such exercises, only subjective generalizations can be drawn rather than any quantified effect of interest, which has some statistical validity.

Table1. A typical vote count of effect of crop-crop diversity on incidence of insect pests.

Agro ecosystem	Pest	Effect	Reference
Blackgram+ greengram	Jassids	More population than sole crops	Singh and Singh, 1977
Pigeonpea+ paddy	Pod borer	Incidence s reduced than sole crop of pigeonpea	Satpathy *et al.*, 1977
Pigeonpea intercropped	Majority of insect pests	Reduction of pests	Singh and Singh1978
Cowpea+maize	*Maruca testulalis*	Damage to flowers was less	Bhatnagar and Davies, 1979
Pigeonpea+sorghum	*Helicoverpa armigera*	No difference was noticed	
Beans+maize	*Empoasca krameri* Ross and Moore	Reduction of pest	Hohmann *et al.*, 1980
Pigeonpea+moong, urd, cowpea and soybean	Many insect pests	Did not increase than sole pigeonpea	Chaudhary *et al.*, 1980
Cowpea+maize	*M.testulalis* *C.ptychora*.M and *M.sojostedti*.T.	Increased Decreased	Matteson,1982
Pigeonpea+pearlmillet	*H.armigera*	More Damage	Deokar *et al.* 1983
Cowpea+maize	*M.sojostedti* and *C. ptychora*	Incidence increased	Ezueh and Taylor, 1984
Blackgram+ pigeonpea, Sesamum and sorghum	Majority of insect pests	Low incidence	Dhuri *et al.*, 1986
Pigeonpea+maize	*Catochrysops cnejus*, *Exelastis atmosa*W.	Low incidence	Dash*et al*. , 1987
Cowpea+maize and Bean+maize	*Megalurothrips sojostedti*.	Reduction of thrips	Kyamanywar and Tukahirwa, 1988
Pigeonpea+soybean, sorghum and dry paddy	*Helicoverpa*	Low incidence	AICPIP, 1989

Agro ecosystem	Pest	Factor/Effect	Reference
Pigeonpea+fingermillet or blackgram	*H.armigera* *G. critica, M. testualis* and *C. gibbosa*	Low incidence No effect	Patnaik *et al.,* 1989
Soybean mixed crop	*Chrysodeixis acuta*	Incidence reduced	Singh *et al.* 1990
Pigeonpea,cowpea intercropped	*Luperodes sp*.	No difference	Manoharan and Chandramohan, 1991
Groundnut+sorghum	*Empoasaca kerri* P	Reduced	Singh *et al.* 1991
Sole pigeonpea	*Melanogromyza obtusa* M	More infestation	Yadav *et al.* 1992
Pigeonpea+mungbean	*M.obtusa*	Low incidence	Dahiya *et al.,* 1992
Blackgram,castor and sesamum+pigeonpea	*Spilosma obliqua*	Low infestation	Yadava *et al.,* 1992
Pigeonpea intercropped	*H.armigera*	Non significant	Sachan, 1992
Pigeonpea+*V.mungo*	*H.armigera* and *M.obtusa*	Reduction of pests	Kumar *et al.,* 1992
Short duration pigeonpea stip intercropped with sorghum	*H.armigera*	Low incidence and required less sprays	Pawar, 1993
Pigeonpea intercropping	Pod borers	No effect/reduction	Sharma and Pandey, 1993
Cowpea+sorghum	*M. sojostedti,* *Clavigrella sp* *M.testulalis*	Reduction of pests No effect	Alghali, 1993 a
Maize+cowpea+sorghum	*M.testulalis*	Reduction of pest	Omolo *et al.,* 1993
Common bean intercropped	*M.testulalis* *M.vitrata*	Low incidence No effect	Karel, 1984 and 1993 Saxena *et al.* 1992 and Alghali 1993 b
Cotton intercropped with groundnut, soybean, cowpea and mungbean	*H.armigera*	Low incidence	Venugopal Rao *et al.,* 1995
Cowpea+sorghum	*Ophiomyia phaseoli*.	Reduced and higher yields	Jagdish *et al.* 1995
Pigeonpea+ groundnut and Chickpea+coriander	*H.armigera*	Low incidence and additional income	Sekhar *et al.* 1995

Agro ecosystem	Pest	Factor/Effect	Reference
Pigeonpea+sorghum	*H.armigera*	Higher eggs and larval population	Hegde and Lingappa, 1996
Pigeonpea+sorghum, greengram and groundnut	*E. kerri*	Highest reduction	Sekhar *et al*. 1997
Cowpea+maize, pepper and cassava	*M. sjostedti*, *A.craccivora* K. , *Mylabris sp.*	Reduction of pests	Emeasor and Ezueh, 1997
Pigeonpea+coriander	*H.armigera*	Low incidence	AICPIP, 1998
Groundnut+ pigeonpea, bajra	Many insect pests except jassids	Reduced	Nath and Singh 1998
Pigeonpea+sorghum	*H. armigera*	Decrease in pod damage	Mohammed and Rao, 1998
Cotton+okra,sesame and Pigeonpea,pearlmillet as barrier crops	Many insect pests	No effect	Dhawan *et al*., 1998
Cotton+legumes	*B. tabaci, and* *A. biguttula*	Reduction of pests	Jambhrunkar *et al*., 1998
Cotton+clusterbean or greengram	leaf hoppers, aphids, thrips and white flies	Low incidence	Balasubramanian *et al*., 1998
Short and medium duration pigeonpea + sorghum or castor	Many insect pests including pod borers excepting *C.gibbosa*	Lower incidence than sole crop of pigeonpea	Srinivasa Rao, 2001

(Baliddawa, 1985 and Srinivasa Rao *et al*., 2002)

The above example is a typical vote-counting exercise wherein the number of studies reporting different results are counted and the data on sample size, magnitude of effect etc are ignored. The conclusions emerging from such an exercise lack any statistical validity.

An alternative procedure to deal with the limitations of the qualitative synthesis of studies was put forward initially by Glass (1976) and came to be known as meta analysis. The quantification of effect of crop diversification on the incidence of insect pests through statistical synthesis of published results or meta analysis is attempted here. The purpose of this bulletin is to synthesize the information on the crop diversity – pest population relationship and to draw statistically valid conclusions using meta analysis as a tool.

2.0 Meta analysis

2.1 Meaning

Meta analysis is secondary analysis of published results. As a concept it was used by the statisticians to combine results from several independent studies. The method, however, gained ground in research after Glass (1976) proposed that a large body of literature, often yielding conflicting results, could be subject to a secondary analysis that would integrate the findings. This analysis, also called 'analysis of analyses' has been extensively used in social and medical sciences. However, it is applied rarely in entomological studies. There were few attempts to synthesize the impact of crop diversification on the incidence of insect pests. On the other hand, the method was described as 'wave of the future' and as being potentially useful tool for policy makers in dealing with conflicting evidences regarding the problem at hand.

One of the extensively used measures in meta analysis is the 'effect size' which integrates the results from different experiments on a given subject into an index. In other words, the effect size gives the relative magnitude of the experimental treatment (Thalheimer and Cook, 2002). When computed across different experiments, the effect sizes allow us compare the magnitude of effect observed in different experiments. Although percent improvements can be used to compare the treatment over control, such calculations are difficult to interpret and often difficult to use in fair comparisons across different studies.

2.2 Procedure

Meta analysis is a sequential and methodical process and starts with careful selection of studies keeping the objective of the analysis in view. Once the studies are selected, the key features of the studies are organized into a database that enables a better interpretation of the results of the analysis.

Selection of studies. A review of the literature covering the period from1980 to 2004 was conducted on ten journals: *Agriculture, Ecosystems and Environment, Bulletin of Entomological Research, Ecological Entomology, Ecology, Entomologia Experimentalis et Applicata, Environmental Entomology, Indian Journal of Entomology, Shashpa, Journal of Applied Ecology, Journal of Economic Entomology,* and *Oecologia*. Data for the meta analysis were gathered from the published studies in these journals for comparing the abundance of herbivorous insects in diversified crops versus monocultures; diversification was considered as inclusion of other crops or weeds in the experimental area. The selection of the published articles for the analysis was restricted by the following conditions; (1) only studies on agro ecosystems were considered; (2) experiments that were conducted under field conditions; (3) where results were expressed as number of insects per treatment; and (4) data on the number of natural enemies and damage to the economic product were included. Thus, we did not include studies on i) Diversification of natural systems or forests, ii) Experiments performed in laboratories, glass houses or potted plants, or iii) Studies reporting results as correlations. Additionally the meta analysis contained studies that provided means, standard deviations (or standard errors) and sample size of control and treatment groups, variables necessary for calculation of effect sizes. In addition to this, various articles where only standard error of mean and least significant difference and 't' tests were given were also included.

Selection of data. Some experiments in the selected studies were performed in a confounded manner (factorial or split-plot designs). In those cases, only results within the same variable were considered. For example, if the experiment was conducted as a 2x2 factorial, where levels a_0 and a_1 of factor A (diversification) were compared with levels b_0 and b_1 of factor B (fertilizer levels), only the results for a_0b_0 and a_1b_0 were used in the meta analysis. To reduce the effects of non-independence, the results for only one species or life stage and one treatment per study were considered.

The choice of the species was based, first, on the focus of the paper; if all species were given the same level of importance, the most abundant was chosen. When results were presented for several sampling dates, we selected the date of highest difference between treatment and control plots. When more than one diversification treatment was compared with the control treatments, the treatment of greatest difference from the control was selected. In case of natural enemies, the studies combined the related species into one unit or group for observation. In such cases, the prominent species was included for the analysis.

One of the indices, the effect size (Cohen, 1977), has been used widely in meta analysis (Glass, 1977, Glass et al, 1981; Strube and Hartmann, 1983; Wolf 1986). The effect size(*g*) expresses the standardized difference between means (μ) of treatments(t) and control groups(c) so that

$$g = (\mu_t - \mu_c)/ \sigma$$

Where ó is the standard deviation.

The combined effect size of a series of experiments indicates the magnitude of the effect observed. Replacing the sample estimates for the population parameters we get

$$g_i = (m_t - m_c)/s_c$$

where g_i is the effect size for experiment i, m_t and m_c are means for treatments and control groups, respectively, and s_c is the standard deviation of the control group.

However, Hedges (1981, 1982) demonstrated that g_i and s_c are biased estimators, and he proposed the following alternative method for obtaining unbiased estimates of pooled variance and effect size.

$$s_i^2 = [(n_t - 1)(s_t)^2 + (n_c - 1)(s_c)^2] / (n_t + n_c - 2)$$

where

s_i = pooled variance
n_t = sample size of treatments
n_c = sample size of control
s_c = standard deviation of control
s_t = standard deviation of treatment

$$d_i = g_i * [1 - \{3/(4n-2)-1\}]$$

d_i=unbiased estimate of effect size *g:*

In most of the literature this distinction between g_i and d_i is not observed and hence *g* is taken as effect size. In this bulletin, we computed the effect size *d*, corrected for small sample bias as mentioned above.

Thus data on means and standard deviation are the minimum data set required to compute effect size for a given study. However, many of the studies do not report such information in which case appropriate alternative formulae were used to compute the effect size. For the studies that did not report the standard deviations, the effect size was calculated based on the standard error mean (SEm), least significant difference (LSD or CD) and t- values. The following formulae (Thalheimer and Cook,2002) were used for the purpose.

When an experiment that uses a t-test does not list standard deviations, *g* is calculated as follows
$g = t^*[\{(n_t+n_c)/(n_t\ n_c)\}\{(n_t+n_c)/(nt + nc - 2)\}]^{0.5}$

where
t = t *values*
n_t = sample size of treatment
n_c = sample size of control

When an experiment that uses a t-test does not list standard deviations but does list standard errors (SE), the following relationship was used
$S = SE\ \sqrt{n}$
S=Standard deviation
SE = Standard error
n = sample size

The pooled effect size from several studies is usually calculated under the condition of large n_t and n_c (e.g. Smith & Glass, 1977; Harris & Rosenthal, 1985; Gurevitch et al., 1992). However, data for our analysis consisted mostly of small sample sizes, which generally corresponded to plot means. In this situation, the effect sizes and their variances are considerably biased if the methods developed for large sample sizes are used (Hedges & Olkin, 1985). Where n_t and n_c are small ($n<10$) and the number of studies , k, is large, the common effect size can be calculated by a weighted linear combination of *d* (Hedges & Olkin, 1985). The weighted mean of effect sizes, d_+, can be estimated by:

$$d_+ = d_1 w_1 + \ldots.. + d_k w_k$$

The weights of individual studies w_i, are estimated from the variances of effect sizes, v_i:
$w_i = (1/v_i)/\Sigma(1/v_i)$
$v_i = a_i + b_i d^2_M$

Where d_M is the mean of d_i for i = 1,……….k studies, and the constants a and b are estimated by:
$a = (N-2)[c(N-2)]^2 / [(n_t\ n_c)/N]\ (N-4)$
$b = \{(N-2)[c(N-2)]^2 - (N-4)\} / (N-4)$

The variance of d_+ for i = 1,……k and large k is calculated by
$v = [\Sigma\ (1/v_i)]^{-1}$
$N = \Sigma n_i$

The methods presented above are based on the assumption that effect sizes from different studies are homogenous, i.e. differences are due only to sampling error (Hedges & Olkin, 1985). The homogeneity of effect sizes can be tested by the Q test (Hedges 1982).

$$Q = \Sigma(d_i - d_+)^2 / v_i$$

If the Q statistic is higher than the chi-square value for k-1 degrees of freedom, the hypothesis of homogeneity of effect sizes is rejected (Hedges 1982; Hedges & Olkin, 1985).

One of the criticisms of meta analysis is that it does not consider the unpublished results which might contain non-significant differences between control and treatment groups resulting overestimates of population effect size. A measure called 'failsafe N' (N_{fs}), defined as the number of non-significant studies required to bring the effect size to a specific level, is suggested to address this issue. The fail safe N is given by

$$N_{fs} = N_{total} \text{ (mean effect size } d_+ - D_{crit}) / D_{crit}$$

Where N_{total} is the total number of studies and D_{crit} is the specified d value.

A failsafe N for a *d* value of 0.5 is computed here which is considered as moderate effect size.

We conducted an initial meta analysis by including all the studies for incidence of insect pests. On observing heterogeneity, we performed a second meta- analysis by grouping the studies into relatively homogeneous clusters and computed the mean effect size. Later, we also conducted third meta analysis by dividing the studies into two groups – those that focused on the lepidopteron insects and those that focused on non-lepidopteran insects - in order to see the differential impact, if any. Since there are only a limited number of studies reporting the data on natural enemies and grain damage, only one meta analysis was attempted. All the analysis was done using the software developed by Schwarzer (http://web.fu.berlin.de/gesund/gisu*engle/meta-e.htm.).

3.0 Results

3.1 Pest count

Following the criteria described above, thirty one studies were identified and included in the meta analysis. In addition, there were another twenty studies which were not included in the analysis as they did not report the information necessary to compute the effect size. A majority of such studies employed the Duncan's Multiple Range Test to test the differences across different treatments wherein the measures of variability were not presented. The selected papers covered a wide range of situations, pests, crops and forms of diversity and present a heterogeneous situation which is reflected in the *d* values (Table 2). The crops covered included maize, squash, soybean, pigeonpea, groundnut, cotton, broccoli etc. A wide range of insect pests were also included. Inter - and mixed cropping, the dominant forms of crop-crop diversity, constituted the treatments in the studies. The effect sizes in the studies included ranged from –29.16 to 14.75 with a mean effect size of –1.50. The effect size was found to be significant as the confidence interval did not include zero. It indicates that the average density of insect pests was 1.5 standard deviations less in the diverse systems than in the monocultures. The effect size was negative in a majority of studies indicating a reduction in pest incidence in the diversified systems than in the corresponding monocultures. Only in eight cases was the effect size found positive, which means an increase in the incidence of insect pests. The number of replications ranged from three to thirty with a median of four.

Table 2. Summary of the data included in the meta analysis and corresponding effect sizes (*d*)- **insect pest count**

S.No	Species	Family	Crop / treatment	*g*	*d*	Study
1	*Heliothis armigera*	Lepidoptera Noctuidae	Pigeonpea, intercropping	1.86	1.49	Chaudhary *et al*., 1980
2	*Maruca testulalis*	Lepidoptera: Pyralidae	Maize, cowpea, soyabean, intercropping	-3.00	-2.96	Amoako-Atta *et al*., 1983
3	*Megalurothrips sojostedti*	Thysanoptera: Thripidae	Maize, cowpea, intercropping	-0.23	-0.20	Ezueh and Taylor, 1984
4	*Phyllotreta cruciferae*	Coleoptera: Chrysomelidae	Collards, non host plants	-3.65	-2.65	Latheef and Ortiz, 1984
5	*Aproaerema modicella*	Lepidoptera: Gelechidae	Ground nut, intercropping	2.95	2.36	Logiswaran and Mohana sundaram, 1985
6	*Diaphania hyalinata*	Lepidoptera: Pyralidae	Squash-polycultures	-5.64	-4.90	Letourneau, 1986
7	*Diaphania hyalinata*	Lepidoptera: Pyralidae	Squash-polycultures	-3.80	-3.30	Letourneau, 1986
8	*Leptinotarsa decemlineata*	Coleoptera: Chrysomelidae	Potato-triculture	-5.19	-4.69	Horton and Capinera, 1987
9	*Leptinotarsa decemlineata*	Coleoptera: Chrysomelidae	Potato-triculture	-3.32	-3.00	Horton and Capinera, 1987
10	*Rhopalosiphum padi*	Homoptera: Aphididae	Oats, beans, mixed cropping	9.34	8.44	Helenius, 1989
11	*Frankliniella spp.*	Thysanoptera: Thripidae	Squash-polycultures	-5.38	-4.30	Letourneau, 1990 **a**
12	*Empoasca sp**	Homoptera: Cicadellidae	Squash-mixed stands	-3.38	-2.98	Letourneau, 1990 **b**
13	*Empoasca sp*	Homoptera: Cicadellidae	Squash-mixed stands	4.15	3.75	Letourneau, 1990 **b**
14	*Aproaerema modicella*	Lepidoptera: Gelechidae	Groundnut, intercropping	-5.14	-4.64	Bhaskaran and Thangavelu, 1990
15	*Erimyis ello*	Lepidoptera: Sphingidae	Cassava, intercropping	0.96	0.83	Gold *et al*, 1990

Contd...

Table 2. Summary of the data included in the meta analysis and corresponding effect sizes (*d*)- **insect pest count** Contd...

S.No	**Species**	**Family**	**Crop / treatment**	***g***	***d***	**Study**
16	*Chrysodeixis acuta*	Lepidoptera:Noctuidae	Soy bean, intercropping	15.60	14.75	Singh *et al*., 1990
17	*Ostrinia nubialis*	Lepidoptera:Pyralidae	Corn-inter/strip cropping	-2.38	-2.28	Tonhasca and Stinner, 1991
18	*Clavigralla spp.**	Hemiptera : Coreidae	Cowpea, maize intercropping	2.91	2.63	Gethi and Khaemba, 1991
19	*Ostrinia furnacalis*	Lepidoptera:Pyralidae	Maize, intercropping	-1.56	-1.36	Litsinger, 1991
20	*Ostrinia nubialis*	Lepidoptera:Pyralidae	Corn, weeds	-1.57	-1.37	Pavuk and Stinner, 1991
21	*Empoasca fabae*	Homoptera: Cicadellidae	Bean, weeds, intercrop	-5.17	-4.50	Andow, 1992
22	*Empoasca fabae*	Homoptera: Cicadellidae	Bean, weeds, intercrop	-1.26	-1.10	Andow, 1992
23	*Helicoverpa armigera*	Lepidoptera: Noctuidae	Maize-common bean, intercropping	-0.82	-0.71	Karel, 1993
24	*Maruca vitrata*	Lepidoptera:Pyralidae	Maize-common bean, intercropping	-3.83	-3.33	Karel, 1993
25	*Aphis gossypii*	Homoptera: Aphididae	Cotton, relay intercropping	-31.59	-29.16	Parajulee *et al*., 1997
26	*Aproaerema modicella*	Lepidoptera: Gelichidae	Ground nut, intercropping	-2.91	-2.68	Rajagopal and Hanumanthaswamy, 1999
27	*Trialeurodes vaporariourum*	Homoptera: Aleurodidae	Common bean, poor and non hosts	0.61	0.53	Smith *et al*, 2001
28	*Trichoplusia ni*	Lepidoptera: Noctuidae	Broccoli, intercropping	-4.32	-3.76	Hooks and Johnson, 2002
29	*Empoasca kerri*	Homoptera: Cicadellidae	Pigeonpea, intercropping	-4.73	-3.78	Srinivasa Rao *et al*., 2003
30	*Maruca vitrata*	Lepidoptera: Pyralidae	Pigeonpea, intercropping	-1.67	-1.34	Srinivasa Rao *et al*., 2004
31	*Helicoverpa armigera*	Lepidoptera: Noctuidae	Pigeonpea, intercropping	-2.69	-2.16	Srinivasa Rao *et al*., 2004

* Indicates the dominant species when several species were sampled.

Considering the variability observed in the effect sizes, the studies were subjected to cluster analysis to make clusters of studies which are relatively homogeneous. The thirty one studies were grouped into five different clusters based on the effect size. Out of these five clusters, one cluster was found to have twenty four studies, another four studies and each of the remaining three formed a cluster in itself. The average effect size of the cluster containing 24 studies was observed to be –1.94 with a standard error of 0.16 and was found to be statistically not significant. The mean effect size of the cluster with four studies was found to be 2.49 and statistically not significant (Table 3). Thus, the two clusters differed in the nature of effect. The homogeneity test (Q test) showed that the larger cluster with a significant Q value was still heterogeneous (Q=66.95 and p=<0.01) and the smaller cluster homogeneous with a non-significant Q value (Q=2.66 and p=0.45).Thus, in majority of the studies, polycultures were found to have less pest incidence, as indicated by the negative effect size, than the corresponding monocultures.

Table 3 Meta analysis results considering different number of studies (k): common effect size (d_+), standard error (SE), Q statistic and corresponding probability levels (p) for k-1 degrees of freedom and fail safe limits.

k	d_+	SE	p	Q	Fail safe N for 0.5
31!	-1.495	0.129	<0.01	135.89	65
24@	-1.939	0.158	<0.01	51.58	71
04#	2.490	0.472	0.637	1.69	16
16$	-2.078	0.181	<0.01	45.12	35
15*	-0.566	0.182	<0.01	74.19	42

! all experiments in the studies selected
@ Studies with effect size between 0.61 to –5.64
# Studies with effect size between 1.86 and 4.15
$ Studies dealing with lepidopteran insects
* Studies dealing with non-lepidopteran insects

In order to achieve further homogeneity, the studies were then grouped into those that studied lepidopteran pests (defoliators and borers) and those that dealt with non-lepidopteran pests (sap suckers and chewers) in mono- and polyculture situations. Out of the 31studies considered, sixteen dealt with lepidopteran pests and fifteen with non-lepidopteran pests. The impact of crop diversity was found to be more on the lepidopteran pests with a mean effect size of –2.08 compared to –0.57 in case of non-lepidopteran pests. The effect sizes in both cases were found to be statistically significant. These two clusters were also found to be heterogeneous as indicated by significant Q values.

The failsafe N for an effect size of 0.5 in all the cases was found to be considerably high which indicates that there should have been a large number of studies containing non-significant results and were not published and hence could not be included in the analysis.

3.2 Natural enemies

Similar to the analysis of pest incidence, the studies reporting data on the occurrence of natural enemies were subjected to meta analysis. Only seven studies were found to conform to the criteria described earlier. As expected, the effect sizes were found to be positive in five out of seven studies indicating an increase in the population of natural enemies of insect pests in crop diversity situations than in monocultures. The effect sizes varied from –1.56 to 4.77. The mean effect size was found to be statistically significant at 0.71. The Q test indicated that the studies were relatively heterogeneous (Table 4).

3.3 Damage

Some of the studies also reported damage to the economic product due to insect pests, which can also be examined for differential incidence of insect pests in monocultures and diverse crop systems. Nine such studies identified were subjected to meta analysis. The effect size was found to be negative in seven out of nine studies indicating a reduction in pest incidence in polycultures. The mean effect size indicated that the damage was 1.50 standard deviation units less in polycultures (Table 5).

4.0 Discussion

Most of the literature surveys conducted to synthesize the research results on the impact of crop diversity on the abundance of insect pests resorted to vote-counting method wherein the number of studies reporting positive, negative and no significant effect were considered for drawing some generalizations. Such generalizations often tend to be biased and inconclusive as they are based on results that may or may not agree with one another. There are subjective literature reviews that concluded beneficial effects, negative effects and non-significant effects of crop diversity on pest abundance. A majority of the literature surveys suggest a favourable impact of crop diversity in reducing pest numbers. However, such surveys do not consider the experimental methods, sample size and magnitude of the effect while drawing generalizations. In this analysis, we attempted to synthesize results from 31 experiments on the incidence of insect pests in diverse crop situations. Our results also suggest a reduction in insect pest incidence in polycultures with significant effect size. The effect size observed remained significant when all the chosen studies were considered together as well as when studies were grouped into relatively homogeneous clusters. It is to be noted however that the studies differed with respect to the crops and pests covered, experimental design, and the nature of treatments. In published literature on effect size, any effect size of about 0.8 is considered as large. The effect sizes observed in this study were much larger than 0.8. For example, the effect size with respect to lepidopteran pests was about 2.08 indicating a strong impact on the incidence of lepidopteran pests. The impact was not so large in case of non-lepidopteran pests (0.57). The differential behaviour of the lepidopteran and non-lepidopteran insects with respect to their host searching mechanisms, colonization and ability to move across and within fields could be the reason for the differential impact. The differences in incidence of pests were also reflected in the extent of damage with a significant effect size of 1.5.

The factors that contribute to reduced pest populations in intercropping include physical protection from wind, shading (Litsinger and Moody, 1976), prevention of dispersal (Kayumbo, 1975) production of adverse stimuli, olfactory stimuli camouflaged by main crop (Aiyer, 1949), presence of natural enemies (Russell, 1989; Tonhasca, 1993) and availability of food (Fukai and Trenbath, 1993). A combination of lowered resource concentration, trap cropping, various diversionary mechanisms,

Table 4. Summary of the data included in the meta analysis and corresponding effect sizes (*d*)- **natural enemies**

S.No	Species	Family	Crop / treatment	*g*	*d*	Study
1	*Cotesia* sp	Hymenoptera: Braconidae	Groundnut, intercropping	-1.95	-1.56	Logiswaran and Mohana sundaram, 1985
2	*Goniozus* sp.	Hymenoptera: Bethlidae	Groundnut- intercropping	0.60	0.54	Bhaskaran and Thangavelu, 1990
3	Micraspis hirashimai	Coleoptera: Coccinellidae	Maize intercropping	-1.42	-1.23	Litsinger *et al*., 1991
4	*Solenopsis geminata*	Hymenoptera: Formicidae	Maize-bean, biculture	2.98	2.69	Perfecto and Sediles, 1992
5	*Coccinella septempunctata**	Coleoptera: Coccinellidae	Cotton, relay intercropping	1.92	1.77	Parajulee *et al*., 1997
6	*Coccinella septempunctata*	Coleoptera: Coccinellidae	Rice bean, intercropping	1.65	1.32	Satyanarayana *et al*., 1998
7	*Menochilus sexmaculatus*	Coleoptera: Coccinellidae	Pigeonpea, intercropping	5.97	4.77	Srinivasa Rao, 2001

* Indicates the dominant species when several species were sampled.

Table 5. Summary of the data included in the meta analysis and corresponding effect sizes (*d*)-**Damage**

S.No	Species	Family	Crop / treatment	*g*	*d*	Study
1	*Maruca testulalis*	Lepidoptera: Pyralidae	Maize, cowpea, intercropping	-2.14	-2.11	Amoako-Atta *et al*, 1983
2	*Maruca testulalis*	Lepidoptera: Pyralidae	Maize, cowpea, intercropping	0.66	0.57	Ezueh and Taylor, 1984
3	*Helicoverpa zea*	Lepidoptera: Noctuidae	Soyabean, weed densities	-4.49	-4.06	Alston *et al*, 1991
4	*Clavigralla tomentoscollis**	Hemiptera: Coreidae	Cowpea, maize intercropping	1.12	1.01	Gethi and Khaemba, 1991
5	*Melanogromyza obtusa*	Diptera: Agromyzidae	Pigeonpea, intercropping	-10.25	-8.20	Yadav *et al*., 1992
7	*Maruca testulalis*	Lepidoptera: Pyralidae	Maize-common bean, intercropping	-1.48	-1.29	Karel, 1993
8	*Exelastis atomosa*	Lepidoptera: Pterophoridae	Pigeonpea, intercropping	-1.97	-1.82	Sharma and Pandey, 1993
9	*Helicoverpa armigera*	Lepidoptera: Noctuidae	Pigeonpea, intercropping	-4.71	-3.77	Srinivasa Rao, 2001
10	*Trichoplusia ni*	Lepidoptera: Noctuidae	Broccoli, intercropping	-6.19	-5.38	Hooks and Johnson, 2002

* Indicates the dominant species when several species were sampled.

planting density and plant physical obstruction account for 22.5% reduction of pest population. Predators and parasites account for only 15 and 10%respectively. Masking, camouflage and repellency account for 12.5% each. Overall natural enemy action controlled about 30% of crop pests and the remaining known cases were controlled by other factors (Baliddawa, 1985).

As mentioned, one of the reasons for reduced pest incidence in polycultures compared to the monocultures is the abundance of natural enemies of insect pests. A meta analysis of studies on occurrence of natural enemies found an effect size of 0.71, which was statistically significant. Though such a finding is in tune with other evidences, an unequivocal statement is not made, as only seven studies were included in the analysis.

5.0 Limitations of Meta analysis

Meta analysis is a useful tool to integrate research results from different studies. There are however certain limitations that need to be considered. First, critics say that integrating studies that differ widely with respect to the experimental design and statistical analysis, as meta analysis does, may not be appropriate. However, by carefully defining the selection criteria, as we attempted here, one can minimize the consequences of inappropriate integration. Second, only the published results are considered leaving the unpublished results out of the analysis. Since it is the non-significant results that usually do not get published the effect sizes may be, in reality, overestimates of the population effect sizes. The 'fail-safe N' addresses this problem to some extent. Another limitation arises when a single study reports more than one effect size as they study the behaviour of different pests in different situations and at different points of time, including all the results from a single study may result in bias as the sample size gets artificially inflated. Selecting one effect size from a given study is one option to overcome with this limitation but the choice of the one effect remains a subjective question. It is to be mentioned here that these limitations are also relevant to the subjective literature reviews and meta analysis as a tool is prone to be misused, as is the case with any other statistical tool. It is therefore helpful to be aware of these limitations while conducting meta analysis or while accepting results of a meta analysis.

6.0 Conclusions

Considering the potential role of crop diversity in managing the pest populations, several studies looked into the relationship between crop diversity and pest incidence. In order to consolidate the understanding, attempts were made to synthesize such information. Qualitative literature reviews have been the most popular means of putting together research results to draw some generalizations on the research question at hand. These qualitative reviews suffer from the fact that they do not consider the quantitative information contained in the individual studies and hence the generalizations or conclusions that emerge cannot be given any statistical validity. We have attempted here a quantitative synthesis, also called meta analysis, of studies dealing with pest incidence in different situations of crop diversity. Results based on the effect size, one of the frequently used measures in meta analysis, showed that the effect of crop diversity on the incidence of insect pests was significant and relatively large. The effect size was negative meaning that the insect populations were less in diversified crop situations compared to the corresponding monocultures. It was also observed that the effect size was more with lepidopteran insects than with non-lepidopteran insects. Further, a positively significant effect size for the natural enemy populations in crop diversified situations corroborate the 'natural enemy hypothesis' as one of the pest reducing factors. The studies included in the meta analysis were also observed to differ in terms of crops and pests dealt with, experimental methods, etc which was reflected in the range of effect sizes for different studies. It can be concluded that meta analysis can be most useful for drawing quantitative inferences especially when confronted with conflicting evidences.

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