EFFECT OF SPATIAL PATTERN ON ABUNDANCE OF INSECT PESTS IN A CEREAL-COWPEA MIXTURE

BY

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DECLARATION

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DEDICATION

I dedicate this work to my Father and Mother.

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ABSTRACT

Sorghun was intercropped with a relay crop of millet and cowpea in two experiments during the 1985 and 1986 wet seasons at Samaru to determine the influence of plant spatial patterns on the abundance of the insect pests of each crop.

During the first year, inter-row, intra-row and peripheral crop arrangements at the 1:1 sorghum:millet/cowpea plant ratio as well as inter-row cropping at 1:2, 1:3 and 1:4 plant density ratios were compared with pure stands for each crop. Populations of Contarinia sorghicola and stem borers on sorghum, Geromyia penniseti, stem borers, Meligethes heteropus, Melyris sp., Mylabris sp. Agonosceles sp. and Rhaguva graminivora on millet and Octheca mutabilis, Aphis craccivora, Megalurothrips sjostedti, coreids, Maruca testulalis and Callosobruchus maculatus on cowpea were significantly reduced on at least one intercrop treatment compared with the monocrops. Increasing the row ratio of millet/cowpea to sorghum resulted in corresponding reductions in damage by sorghum shootfly (significant) and increases in populations of Coryna hermaniae on sorghum and Octheca mutabilis, Megalurothrips sjostedti, and Piezotrachelus varium (not significant except in O. mutabilis).

The 1986 experiment consisted of 1:1, 1:2 and 1:3 sorghum to millet/cowpea plant density ratios each of intra-and inter-row cropping compared with pure stands of each crop. Pest infestations at each plant ratio of inter-and intra-row cropping were statistically similar in general except the sorghum and millet stem borers which were more abundant at the intra-row sorghum:millet/cowpea ratios of 1:3 and 1:2, respectively, than the corresponding levels of inter-row cropping. There were significantly fewer Contarinia sorghicola, and stem borers on sorghum and O. mutabilis on cowpea in at least one of the intercrop treatments compared with the monocrop treatments. Increasing densities of millet/cowpea relative to sorghum had a variable effect on populations of the different insects. Among the inter-row cropping treatments it led to corresponding decreases in damage by shootflies and increases in populations of M. heteropus and G. penniseti. Among the inta-row crop treatments it led to corresponding decreases in populations of millet shootfly and O. mutabilis and increases in populations of C. sorghicola.

1. INTRODUCTION

Multiple cropping is the general term for all cropping patterns where more than one crop is cultivated on a field in a year. In American literature, however, polyculture is used. The various patterns of multiple cropping reflect essentially two underlying principles, that of growing crops simultaneously on a given piece of land, that is intercropping, and that of growing individual crops in sequence during one growing season on the same piece of land (Andrews and Kassam, 1976). In this context growing crops "simultaneously" means that crops are grown together for most of the growing period. This does not require that the crops are sown or harvested at the same time.

Food in Nigeria is produced both on commercial farms (generally solecrops) and on smaller peasant farms (generally intercrops). About 90% of cultivated land in Nigeria, however, is cropped in units smaller than 5 hectares on which crops are generally grown as intercrops (Okigbo and Greenland, 1976). Between 70 and 90% of the population in developing countries is either indirectly engaged in or is directly dependent on intercrop farming.

It cannot be denied therefore that the peasant farmers who mostly grow their crops in mixtures, feed a majority of both the rural and urban populations. In the Sudan and Guinea savanna zones of West Africa, where sorghum and millet are the major cereal crops (Keay, 1969), they are rarely grown alone. Often these crops are grown in mixtures with legumes, particularly cowpea and groundnut, Norman (1974) found that the sorghum/millet/cowpea mixture was one of the seven most practiced crop mixtures in Zaria province, northern Nigeria. It was the fifth in order of importance and constituted about 3.9% of cultivated land in the area studied. Sorghum is the major staple food in northern Nigeria followed closely by millet. Cowpea was once second only to groundnut as a cultivated legume in Nigeria, but now stands as the major source of plant protein in the country (Awoyemi, 1985).

One of the major constraints to the realisation of the full production potential of any of these crops is, without doubt, the depredation by pests and the inadequate attention being paid to crop protection, particularly insect control by both the government and the farming community. Despite the importance of these crops in satisfying the household

demands and as raw materials for agro-based industries, there is hardly any information on the insect pest situation in mixtures involving these crops.

Information on the entomology of all component crops of specific intercrop systems, and in particular in the small farmer situation is scant. This is because researchers have tended generally to give low priority to these crops within intercrop systems and to concentrate on research on their monocrops (Adesiyun, 1975; 1978; Adesiyun and Ajayi, 1980; Caswell, 1978; Deeming 1971; Harris, 1961; on sorghum, Ajayi, 1978; 1981; 1985; 1986; Coutin and Harris, 1969 on millet and Booker, 1965; 1967; Ezueh, 1980; Raheja, 1973; 1975; Raheja and Apeji, 1979; Taylor, 1964; 1965; 1967; 1968; 1969; Uvah, 1978, 1983 on cowpea). Acquiring quantitative information about the intercrops, with equal emphasis being given to all components, is a preliminary phase of any basic or applied work in insect-plant interactions within intercrops. Information on pest complexes of intercrops could form a basis for the development of effective pest management strategies in these systems thereby combating one of the major constraints to food production.

The importance of sorghum, millet, cowpea and their predominant production as a three-crop mixture underline the need for studies on the ecology of their insect pests. The objective of this study was to investigate:-

1. Effect of intercropping or intra-cropping on the abundance of the major insect pests of the crops.
2. Effect of different cropping patterns on insect abundance.
3. Effect of increasing ratios of millet/cowpea stands to sorghum on insect population trends on each crop.

2. REVIEW OF LITERATURE

2.1 SORGHUM

2:1.1 NOMENCLATURE AND ORIGIN

Sorghum bicolor L Moench belongs to the family: Gramineae, subfamily Panicoideae and tribe Andropogoneae (Purseglove, 1972). The beginning of sorghum culture, as that of many crops, is shrouded in mystery. Much evidence indicates that sorghum originated in Ethiopia (Damon, 1962) or the Sudan (Evelyn, 1951) in prehistoric times, perhaps 5,000 to 7,000 or more years ago. The first known record of cultivated sorghum was its occurrence in a carving in the Palace of Sennacherib at Ninevah, Assyria about 750 BC (deCandolle, 1886; Anderson and Martin, 1949).

2:1:2 GEOGRAPHICAL DISTRIBUTION AND PRODUCTION

Sorghum is the fourth most important crop in the world behind wheat, rice and maize (Purseglove, 1972). It is extensively cultivated in most parts of Africa, Asia and North, Central and South America. It is also grown in some parts of Europe and the Soviet Union. It is the most important cereal in Nigeria accounting for about 46% of the total land area devoted to the growing of cereals and for

about 50% of the total cereal production in the country (Egharevba, 1979). It is cultivated in all the savannas of the country covering as far as latitude 6°N in the south to 14°N in the north.

Statistics on world production of sorghum is meagre because the bulk of the grain is often consumed locally and is rarely important in international trade. However, Martin and Leonard (1963) estimated that the total area devoted to sorghum production worldwide from 1959 to 1961 exceeded 120 million acres (approx. 48.6 million hectares). Estimated total production in West Africa for the year 1971 was about 5.8 million tonnes from an estimated area of 9.7 million hectares corresponding to a yield of about 500 kg/ha (Kassam and Andrews, 1976).

The area devoted to sorghum production in Nigeria has increased by about 25% over the last two decades from an estimated 4.6 million hectares in 1959 to an estimated 6.1 million hectares in 1979 (Egharevba, 1979). Just as the land area devoted to growing of sorghum has increased over the years so also has the production. Production has gone from a low of 2.5 million tonnes in 1960 to a high of 4.8 million tonnes in 1978 (Egharevba, 1979). Within different ecological zones of the country, yield may vary from 300-1500 kg/ha due to variation

in cultivars, maturity periods, soil fertility and moisture conditions (Kassam and Andrews 1976). Awoyemi (1985) estimated that the projected demand and domestic production of sorghum for the year 1985 were 4.5 and 4.0 million tonnes, respectively.

In Nigeria sorghum is produced both in the dry and rainy seasons. The rainy season sorghum is more important and two types are grown. These are the long rainy season type usually Farafara and the short rainy season type usually Kaura. In both types, seeds are directly sown into the field early in the rainy season. The long rainy season sorghum flowers towards the end of the rainy season, and is harvested after the rains. This sorghum therefore, enjoys the long rainy season which lasts from May/June to October/November. The maturity period of this type ranges between 120 and 125 days in the northern Guinea savanna zone to as long as 240 days in the south. The short rainy season variety on the other hand, matures earlier and is harvested during the rainy season. Dry season sorghum, often called masakwa of Firgi sorghum, is first sown in nurseries towards the end of the rainy season in July/August. The seedlings are later transplanted onto farms in September/October and harvested from late December to early January.

It involves drought and cold tolerant sorghum and is usually grown on residual moisture within the Chad Basin in northeastern Nigeria (Ogunlela and Obilana, 1983).

Although sorghum is tropical in origin and best suited to the tropics, it has been adapted by breeding for growing in the temperate regions provided temperatures are sufficiently high and the growing season long. It can be grown during summer in the temperate region and throughout the year in the tropics. The minimum temperature ranges from 7 to 10°C for germination and 15°C for growth The optimum temperature for growth is 27 to 30°C (Quinby & Martin, 1954). Sorghum is a short-day plant. Its main importance as a crop has been in areas that are too dry and hot for the production of other cereals, particularly maize. The ability of sorghum to produce good yields under conditions of low soil fertility and high temperatures that are unfavourable for other crops, for example maize, makes it a favourable crop under semi arid conditions with a minimum annual precipitation of 350 to 400 mm. The drought - resistance of sorghum has been attributed to its extensive root system and the profusion of rootlets as well as the morphological characteristics

of leaves and stalks which effectively reduce the rate of transpiration (Martin, 1941).

Sorghum grows on a wide variety of soil types but does best on heavy types of soil, provided they are sufficiently fertile, well aerated, well drained and in good tilth (Egharevba, 1979).

2:1:3 USES

In Nigeria, as elsewhere, sorghum is used primarily for human consumption, either in the form of food or as beer. Some grain is fed to horses but rarely do other animals receive any part of the grain other than the bran. Occasionally the grain is used in medicine.

Many kinds of food are prepared from sorghum, the most common being Tuwo (Hausa). This is made by pounding the grain into flour which is then stirred into hot water to form a paste. This thick paste is then allowed to cool and gel. The resultant preparation is referred to as Tuwo.

It is eaten with stew or other vegetable soup preparations. Kunu (Hausa) is another delicacy. This is a thin gruel prepared by pouring the ground sordhum flour into hot water and stirring it.

Kunu is then flavoured by adding sourmilk, tamarind, groundnut and sugar. Other preparations are Koko (Hausa), another form of gruel, Masa (Hausa), a thick pancake prepared by frying sorghum flour paste in groundnut oil and tsatsaffa (Hausa), a criss-crossed shaped pancake.

Stems of the tall sorghum cultivar are used for a variety of building purposes in the house, as fencing materials and as fuel for cooking. Small toys are also made from the dry pith. Leaves and succulent parts of the stem are fed to cattle, goats and sheep after harvest. Sweet stemmed varieties are chewed in some localities.

2:1:4 MAJOR INSECT PESTS

Insects and other pests are major limiting factors to the production of sorghum. Insects cause damage from sowing through harvest and in the store. A wide range of insects attack the sorghum plant at various stages of its growth. Some among them cause considerable damage every year not only in Nigeria, but throughout the sabelian region, while others cause important damage only occasionally. The most important insect pests of sorghum, in order of their time of infestation are the shootfly, the stem borer, the sorghum midge the headworm and headbugs.

2:1:4:1 The Sorghum Shootfly.

These pests occur in practically all sorghum growing areas in the Semi-arid tropics.

During investigation into shootfly damage to sorghum and maize in the rain-grown plots at Samaru during 1966 by Deeming (1971), it became obvious that attack is not attributable to the single species Atherigona varia soccata as was previously believed. Asesiyun (1981) also reared 25 dipteran species from sorghum at Samaru in 1978 and 1979 belonging to the following families; Muscidae, Chloropidae, Diopsidae, Lonchoidae, Milichiidae, Drosephilidae, Phoridae and Scatopsidae. Only members of the first two are phytophagous, the remaining being scavengers.

Damage - Sorghum shootflies are dipterous insects whose larvae feed on the central axil of young shoots and cause deadhearts. Atherigona soccata Rond (Diptera: Muscidae).

This is the single most important species of shootfly in Africa and Asia (Barry, 1972).

Biology - White, cigar-shaped eggs are laid on the under-side of preferably 3rd or 4th leaves (Adesiyun, 1981). Eggs hatch two days later and young larvae crawl down into the sheath and bore down horizontally

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into the base of the young shoot. Mature larvae are yellow and about 6mm long. The larval stage lasts 8 - 10 days. Pupation takes place either in the plant or more rarely in the soil, and lasts about 7 days. During unfavourable conditions however the pupa may aestivate (Teetes et al., 1983).

Control - The most promising control measures are planting early, use of high-yielding shootfly resistant cultivars and the use of systemic insecticides for example carbofuran (Teetes et al., 1983).

2:1:4:2 The Sorghum Stem Borers - These borers consist of the Maize Stalk Borer, Busseola fusca Fuller (Lepidoptera: Noctuidae); the Pink Stalk Borer, Sesamia calamistis Hamps. (Lepidoptera: Noctuidae) and on rare occasions the Sugarcane Borer, Eldana saccharina WLK. (Lepidoptera: Pyralidae).

Distribution - These borers are important pests of sorghum in all sorghum growing regions of Africa.

Damage - Early larval instars of the maize stalk borer scarify the tissues of young leaves resulting in the appearance of "window panes" characteristic of their activity (Teetes et al., 1983). The activity of early instars of the pink stalk borer, on the other hand, is a subject of debate. While Harris (1962)

and Hill (1975) state that the larvae do not feed on young leaves, Teetes et al., (1983) state that the larvae feed on the newly emerging leaves. However, mature larvae of all borers bore into the stem and cause deadhearts. In severe cases of infestation, plant growth is retarded and flowering and grain production seriously reduced. This is because the larvae interfere with the translocation of water and mineral salts. Their feeding activity inside the stem may also cause stem breakage. The tunnelling provides entrance for disease-causing organisms.

Biology - Busseola fusca - Globular cream yellow eggs are laid in groups of 30 - 150 on the inner surface of the leaf sheath by the female inserting her ovipositor between the leaf sheath and the stem. Loose fitting leaf sheaths near the base of the stem are generally preferred. About 400-1000 eggs are laid by a female during 5-6 days of her life. The eggs hatch 6 or 7 days after laying. On hatching the first instar larvae are blackish, and remain in clusters under the leaf sheath and later crawl up the plant into the funnel where they feed on the leaf tissues, leaving only the epidermal layer on the outer surface, that is, "window panes". After sometime they either move to another plant or bore down the

funnel into the stem. where they undergo 6 - 7 instars and measure 35-45mm when fully grown. They have a buff to purple-brown bodies and a brown head. The larval period is about 24-36 days.

The larva cuts an exit hole for the adult and then pupates in the stem. The resulting pupa is brown and about 2.5mm long. The adult emerges in 9-12 days and exhibits a brown colour. Usually 3 generations are produced per year. The 3rd generation larvae enter into diapause with the onset of the dry season and only pupate with the onset of the rainy season thereby completing their life cycle in about 5 to 7 months. The adult has a wing span of 35mm.

Sesamia calamistis Hamps. - Yellowish subspherical eggs are laid between the leaf sheath and the stalk in groups of up to 40. They hatch in 4-6 days and the larvae after feeding on leaves bore into the stem where they remain for about 2 weeks (Teetes et al., 1983). According to Harris (1962) and Hill (1975) however, the larvae after hatching bore into the stem without feeding on the leaves. At maturity, larvae are 30mm long and 3.5mm wide with a brown head and a buff body that has pale-pink dorsal markings. Pupation takes place inside the stem and the pupal

stage usually lasts for 10 days. Unlike Busseola fusca, no diapause generation is produced and larvae survive on wild grasses or volunteer sorghum and millet. Eldana saccharina Walker: The female normally lays eggs in batches of 2-200 but on occasion single eggs may be laid. The incubation period is 5-7 days. The newly hatched larvae are about 2mm long and orange, gradually becoming dark as they feed. The larva is very active producing very large quantities of frass. There are 6 to 7 larval instars in males and 7 to 8 in females. The larval period ranges from about 20 to 60 days. Pupation takes place in a tough cocoon inside the stem. The pupa is reddish brown with a prominent dorsal ridge. The adult emerges in about 8 to 13 days. The adult male has a wingspan of 28 - 30mm and the female 39-40mm. They have pale brown forewings, each with two small spots in the centre, and whitish hindwings with a short fringe. The adults live for 3-8 days.

Control - Destruction of dry stalks and stubble by burning or ploughing reduces the density of diapausing larvae (Adesiyun and Ajayi, 1980). Stalks that are meant for building or other fencing purposes should be spread out thinly in the open during

the dry season and not left in stacks under the shade of trees. Early sowing reduces infestation. Removal of volunteer and alternative host plants is also a good control measure. Also careful and prompt weeding would go along way in controlling this pest. Chemical control with endosulfan or carbaryl is effective (Teetes et al., 1983).

2:1:4:3 The sorghum Midge Contarinia sorghicola Coq. (Diptera: Cecidomyiidae).

Distribution:- The sorghum midge is probably the most widely distributed of all sorghum insect pests, It occurs in almost all regions of the world where the crop is grown except Southeast Asia. The main hosts of C. sorghicola in Nigeria are the cultivated varieties of the genus Sorghum. It has also been reared on many occasions from wild members of this genus (Harris, 1961).

Damage - Damage is caused by larvae feeding on the ovary, often one larva per ovary. This feeding prevents normal grain development and results in a blasted panicle. The affected grain head is flattened with tiny shrunken seeds, and the orange coloured larvae may be seen in the head to confirm the infestation diagnosis.

Biology - For oviposition the female chooses heads which have recently flowered and having found a suitable head, begins to lay. During the whole period of egg laying, she maintains a continuous agitated exploration of the spikelet with her long extensible ovipositor. The extended ovipositor is inserted between the glumes, which have been slightly parted by the emergence of the anthers during anthesis, and eggs are laid within the spikelets. While the eggs are being deposited the exploratory movements cease and the midge remains motionless on the selected spikelets. Each female lays about 75 eggs in flowering spikelets during her short 1-day life. Eggs are cylindrical in shape 0.1 x 0.4mm and hatch in 2 to 3 days. Initially, larvae are colourless but turn dark orange when fully mature. The larvae then move down into the ovary where they grow by feeding on the nutrients at the expense of the ovary which then shrivels up and fails to develop. Consequently infected spikelets have a flattened and empty appearance. Many eggs may be laid on one spikelet but usually only one larva develops to maturity. In the main crop variety, Farafara, most eggs are deposited just inside the tip of the spikelet. Larval development takes 9-11 days.

The larva later pupates beneath the glumes. Shortly before adult emergence, the pupa moves up towards the apex of the spikelet until about three-quarters of the pupal length protrudes from the tip. The pupal period lasts for about 3 days. When the adult emerges, the white pupal skin remains at the tip of the spikelet. A generation is completed in 14-17 days. The adults are stout-bodied, little midges, about 2mm long, and the females have a dark orange abdomen. Diapausing larvae remain in cocoons in those heads of the main crop which flower late in the season and are severely attacked by the midge. Because they contain little or no grain they are not harvested but remain on the stalks, which after harvest are gethered into large stacks and kept through the dry season to be used in building huts and fences or as fuel. The insect's rapid developmental cycle permits the occurrence of 9-12 generations during one season and results in the high build up of infestations when sorghum flowering times are extended by a wide range of planting dates or maturities.

Control - Early and uniform planting date of sorghum over large areas is the most widely accepted method of reducing midge damage. The use of midge - resistant

hybrids is another promising control measure. Multiple insecticide application using disulfoton and phosalone directed at adults are used primarly to reduce losses in late plantings (Teetes *et al*., 1983).

2:1:4:4 The Headworm, Heliothis armigera Hubner (Lepidoptera: Noctuidae).

Distribution: This pest is widely distributed in southeast Asia, Africa, Australia, New Zealand, southern Europe and America.

Damage - The larva infests the sorghum head where it feeds on the developing grains and also on the tender leaves of the whorl.

Biology - The spherical yellowish eggs, measuring o.5mm in diameter are laid singly on the young sorghum heads. The eggs later turn brown. The incubation period is about 3-4 days. The young larvae are whitish green but fully mature ones vary from almost black, brown or green to pale yellow or pink with light grey stripes. Fully grown larvae are about 40mm long. The larval period lasts from 18-25 days. It pupates in the soil in an earthen call and emerges in 1-2 weeks. The adult moth is large and brown or grey with specks that form a V - shaped mark on the forewings. The hindwings

are dull-coloured, with a black border. Egg laying starts about four days after emergence and may continue for a further ten days. The adult, like all moths, is nocturnal (Teetes et al., 1983).

Control - Ploughing the field is useful in exposing the pupae to heat and predators, thus preventing the emergence of adults. Rotation with non-host crops is extremely useful. Sorghum varieties with open type panicles are less affected as the larvae on them are exposed to predaceous organisms. Endosulfan and carbaryl are effective insecticides particularly against the young larvae (Teetes et al., 1983).

Sporadic pests of sorghum on the field include the African armyworm Spodoptera exempta Walker (Lepidoptera: Noctuidae), many species of cutworms, wire worms and white grubs. Others are grasshoppers and locust. The most important storage pests are Sitotroga cerealella Oliv, Tribolium confusum Sankal Tribolium castaneum Herbst and Trogoderma granarium Everts (all belong to Coleoptera: Tenebrionidae).

2:2 MILLET

2:2:1 NOMENCLATURE AND ORIGIN

Pearl millet Pennisetum typhoides (Burmf) Stapf and Hubbard belongs to the family Gramineae, subfamily Panicoideae and tribe Paniceae (Purseglove, 1972). Millet exists in about six to seven distinct types out of which the most midely cultivated species in Nigeria is the pearl millet. Three varieties of P. typhoides are grown in Nigeria, namely gero, maiwa and dauro (Hausa). Millet is a native of Africa and probably originated in the West African savanna (Stapf and Hubbard, 1934).

2:2:2 GEOGRAPHICAL DISTRIBUTION AND PRODUCTION

Although millet is not as important as some other cereals when total world production figures are considered (Martin, et al., 1976), it is nevertheless extensively cultivated and serves as the basic daily diet of several million human beings in Africa, Asia, Latin America and also the Soviet Union. Estimated total production of millet in West Africa in 1971 was about 6.7 million tonnes from an area of about 11.5 million hectares corresponding to a yield of about 580 kg/ha (Kassam and Andrews, 1975).

In Nigeria millet production is restricted to the northern savanna where it is second in importance only to sorghum as a major staple food. Over 40% of the annual land sown in the savanna is devoted to millet (Egharevba, 1978). It is usually grown in mixtures involving sorghum, cowpea, groundnut, cotton, etc., except in the drier areas of sudan and sahel savanna where it is grown as a sole crop. The northern limit of millet production in Nigeria is around the 200 - 250mm rainfall belt in the sahel savanna where other crops cannot do well as rainfed crops. There is an average annual production of 2.4 million tonnes and a national average yield of 750kg/ha However, yields of over 2000kg/ha have been obtained on research farms (Egharevba, 1979).

Millet is a hardy crop and as mentioned earlier it can grow in most places where other crops will not. It is known to be better adapted to conditions of lighter and infertile soils, higher temperatures, high solar radiation and in areas of very low rainfall. These are factors which had been misconstrued by many farmers in their choice of land for millet production. The fact that millet can tolerate rocky or sandy soil does not mean that there is no optimum requirement. Millet does best when it is

grown on well drained, light, loamy soil. Yield differences of up to 80% are obtainable between millet grown in well drained and flooded areas thus demonstrating millet's inability to withstand waterlogged condition(Egharevba, 1979).

Generally, the best time for planting is immediately the rain is established. Since the time of the arrival of rain is not the same in different ecological zones one would expect the time of planting to be different. While the last two weeks of May is the most ideal time for sowing in Samaru depending on the onset of rains, the middle of June is the most appropriate time in Kano (Egharevba, 1979). He further stated that regardless of the onset of rain, millet is likely to do well in Samaru and Kano if planted later than mid June and July, respectively. But one advantage of millet is that, once the crop is established it has a marked degree of drought tolerance.

Gero millet is an extensively cultivated nonphotoperiodic and early maturing variety (75-100 days). It constitutes over 80% of all millet grown in Nigeria because of its greater adaptability (Andrews, 1975; Egharevba, 1978). The photoperiodic late-maturing (120 - 150 days) (Egharevba, 1978)

maiwa is the second most extensively cultivated millet in Nigeria. Both gero and maiwa millets are directly sown into fields either on the flat or on ridges. The third variety, dauro, is a late-maturing photoperiodic millet, which is produced in very small quantities compared to the first two. Dauro millet, unlike gero and maiwa is first sown in nursery beds and the seedlings are later transplanted early in the dry season into fields. This millet is common in the flood plains of Lake Chad, Jos Plateau and some parts of Zaria emirate.

2:2:3 USES.

Millet in Nigeria and other West African countries is grown primarily for human consumption. After the removal of the husk, the grain is ground into flour, which is then made into a thick paste tuwo (Hausa). This is then served with stew or soup some grain is malted and brewed into beer. A thick pancake, Waina (Hausa), is prepared by frying millet flour paste in groundnut oil. The husk is fed to poultry and livestock, while the dry stalk is used in building, as fuel and as livestock feed.

2:2:4 MAJOR INSECT PESTS

Extensive surveys have identified up to 161 insect species associated with millet in Nigeria (Ajayi,1985).

The major pests are the millet stem borer, Acigona ignefusalis Hampson, the millet head caterpillar, Rhaguva graminivora laporte, the millet shootfly Delia arambourgi Seguy, the millet midge Geromyia penniseti Gerstacker and many species of grasshoppers and locusts. Pests of occasional importance include Monolepta goldingi Dysdercus superstitiosus, and Zonocerus variegatus. Sitophilus oryzae, Sitotroga cerealella and Rhizopertha dominica have been recognized by Ajayi (1985) as the most important storage pests. Other stroage pests are Tribolium confusum, T. castaneum and Trogoderma granarium.

2:2:4:1 The Millet shootfly Delia arambourgi Seguy (Diptera: Anthomyiidae).

Distribution - The larvae of Delia arambourgi Seguy were first recorded damaging barley in 1953 when Le Pelley (1954) found it attacking the crop near Nakuru, Kenya. In subsequent years, the incidence of the pest increased in Kenya and was also recorded in all millet growing regions of Africa, particularly Nigeria, Zimbabwe (Rhodesia), Kenya, Uganda, Sudan, Ethiopia and South Africa as well as the Saudi Arabian peninsula.

Damage - This pest attacks plants at the early stages of their growth. Attack is generally on the whorl of the plant and the growing point resulting in deadhearts (Ajayi, 1980). The deadheart can be easily pulled out and emits a pungent smell. Attacked plants that survive come out deformed and growth is very much retarded with a subsequent decrease in grain yield (Egharevba, 1978). One larva may destroy three to four shoots (Hill, 1975).

Biology - The life history is very short and the adult population builds up as the growing season progresses (Ajayi, 1980). Eggs are usually laid on the ground within 2cm of the plant and occasionally on the tips of young leaves (Hill, 1975). According to Ajayi (1980), however, they are exclusively laid on the leaves of seedling plants. The egg hatches after 3-4 days and the larva makes its way over the soil surface, climbs the plant to a position above the first leaf sheath and makes its way down through the tissues to the growing point. In cases where the egg is laid on a leaf the larva makes its way down the leaf, occasionally mining it, and eventually attacks the growing point producing a typical deadheart. The larva remains in the shoot during the first two instars but after the second moult, it leaves and attacks another shoot of the same plant, if tillering

has comenced, or another plant if it has not. The larva moves to a third or even a fourth shoot before reaching maturity some 12 days after hatching (Bullock, 1964).

Pupation takes place in the soil, amongst the plant roots, the pupal stage lasts for about seven days, after which the adult emerges. The adult is a medium-sized fly, about 7-8mm long, and looks rather like a small housefly. The female has a pointed abdomen and is grey. The male is blackish and has a rounded abdominal apex.

Control - So far the most effective method of control is early planting. Seed dressing using dieldrin and heptachlor can equally give successful control (Hill, 1975).

Another shootfly infesting millet is Atherigona approximata Mall. (Jotwani and Butani, 1978).

2:2:4:2 The Millet Stem Borer, Acigona ignefualis Hampson (Lepidoptera: Pyralidae).

Distribution - This pest is found wherever millet is grown. Out of the 161 species of insects found in association with the millet plant in Nigeria (Ajayi, 1985), A. ignefusalis is the most widespread and probably the most damaging insect pest.

This pest is widely distributed in northern Nigeria, where it is abundant in the millet-growing areas. In western and eastern Nigeria, its distribution is limited because millet, which is its usual host, is rarely grown. However, in western Nigeria it was recorded at Ibadan (Harris, 1962). Although it is predominantly a millet pest, sorghum may be attacked when intercropped with millet (Ajayi, 1980).

Damage - Small plants, when attacked, may become riddled with larvae and collapse, while larger plants continue to grow if the growing tip has not been killed. However, the larvae may interfere with the translocation of water and mineral salts to the leaves resulting in many heads failing to set seed. Harris (1962) recorded a grain yield loss of 15% due to attack by *A. ignefusalis* Hamps on early maturing (gero) millet in Kano. Late maturing (maiwa) millet suffers higher levels of attack whilst the "dauro" millet may sometimes be totally destroyed in Samaru, Zaria (Ajayi, 1980). Although *A. ignefusalis* is the predominant borer of millet, *Busseola fusca* also attacks millet (Adesiyun, unpublished).

Biology - Cream-yellow eggs are laid between the leaf sheath and the stem in batches of 20 to 50. The greatest number recorded from a single female was 211 (Harris, 1962). The eggs later turn dark between 8 and 11 days after they are laid and larvae hatch after a further 24 hours.

At first, larvae remain clustered under the leaf sheath but within 24 hours they begin to tunnel in the leaf sheath and in the underlying stem. Unlike larvae of the maize stalk borer, Busseola fusca these larvae do not crawl over the exposed surface of the plant, nor do they tend to concentrate in the funnel. Instead they disperse through the plant partly by active tunnelling and partly by passive transportation. Although A. ignefusalis lays fewer eggs than B. fusca, the difference in their larval habit result in the survival of more larvae of the former species and this is reflected in the presence of more larvae of A. ignefusalis in bored stems.

During the wet season, the larva completes its development in 30-40 days with a mean of 34 days but as the dry season begins, they enter a facultative diapause. Larvae pupate within the stem after they cut exit holes. The male pupa develops in 7 to 12 days while the female takes a little longer with a range of 7 to 13 days.

Control - Control methods are early planting (Ajayi, 1983), low rates of nitrogen, mixed cropping (Adesiyun, 1983), the development of stem borer-resistant varieties of millet, the use of good systemic insecticide, for example, carbofuran and the action of natural enemies (Ajayi, 1985).

2:2:4:3 The Millet Head Caterpillar, Rhaguva graminivora Laporte (Lepidoptera: Noctuidae).

Distribution - This pest is endemic in West Africa but was only recognized as a pest during the drought years of 1972-75 (Vercambre, 1978; Deeming, 1978). In Nigeria, it was first recorded at Azare in 1926 (Deeming, 1978). Since then surveys conducted all over the millet growing areas of Nigeria have shown that the insect is restricted to areas between 11° and 13°N within Bauchi, Borno, Kano, Sokoto and Gongola States in the Sudan and Sahel savanna zones (Ajayi, 1984).

Damage - The young caterpillars make holes into the flower and eat out the contents. Larger ones eat away the bases of flowers including the ovaries thereby reducing seed setting and grain yield. Their feeding usually leaves spiral mines in the head in which they lie protected. The worthless flowers may remain attacked to the head but are often blown away by the wind with only the central rachis remaining (Ajayi, 1981).

Biology - Studies in Senegal (Vercambre, 1978) show that there is only one generation in a year, the insect spending the dry season as a pupa buried about 5 - 20cm underground. Adults emerge in the following year about one month after the first rains, emergence spreading over three to four weeks. If adult emergence coincides with ear emergence and flowering, up to 400 eggs per female are laid on the floral parts. The eggs hatch quickly and feed on the

florets and grains. The mature ones later fall to the ground and burrow into the soil where they spend the dry season in pupal diapause.

Control - Trials conducted by Ajayi (1983) at Institute for Agricultural Research, Samaru have shown that the late planted millet suffers higher infestations, because the emergence of the ovipositing female insect coincides with the flowering and heading periods in millet. Early planting and deep ploughing are valuable cultural control methods. Although a resistant variety has not yet been discovered, existing commercial cultivars could be screened for this attribute. Ajayi (1985) identified one hymenopteran parasite, Bracon hebetor say. Ambush EC at the rate of 100g ai/ha applied three times at weekly intervals starting from heading, gave the best control. Decis EC at the rate of 30g ai/ha, Malathion EC 1kg ai/ha and carbaryl 85 WP at 1.68kg ai/ha also gave effective control (Ajayi, 1986).

2:2:4:4 Head Beetles, Meligethes heteropus Gerstaeoker. (Coleoptera: Nitidulidae).

Distribution - Perhaps the most important of the several beetles that infest the millet head in Nigeria is M. heteropus (Ajayi, 1980). Very large adult populations, usually 20-200 per head, were recorded on millet in many locations in 1977 (Ajayi, unpublished date).

Damage - The beetle enters the millet spikelet between the adjacent paleae of the twinned inflorescences and chews a hole through the palea near the base and consumes the sexual parts, both pistils and stamens.

Control - Since these beetles are exposed while feeding, a good contact insecticide would effectively control them.

Other beetles, Monolepta goldingi, Melyris vestita, M. bifasciata, M. abdominalis, four species of Psalydolytta, three of Mylabris, Coryna hermannieae, Rhinyptia infuscata and three species of Anomala occasionally feed as adults in large numbers on millet pollen, but their effects on pollination and subsequent grain yield have not been quantified (Ajayi, 1986).

2:2:4:5 The Millet Midge, Geromyia penniseti Felt (Diptera: Cecidomyiidae).

Distribution - Barnes (1964) first recorded this midge outside India when he reported Cameron's collection from Sudan in 1936, Paullan's from Madagascar in 1950, Sutherland's from Nigeria in 1953 and Bowden's from Ghana in 1954. Since then there had been additional first records from Uganda in 1957 and Senegal in 1966. Despite the pattern of these records, which might suggest that the pest has spread from India into Africa in the recent past, it seems much more likely that it has been present on millet in Africa and India for a long time and has only

been discovered as interest in the crop has increased (Coutin and Harris, 1969).

Damage - The larvae feed on the ovary and cause it to shrivel up without setting seed.

Biology - When ovipositing, the female positions herself between two flowers, bends her abdomen, extends the ovipositor and inserts it either into the space between a spikelet and the involucre of bristles or more usually, between the two spikelets. Female midges in their oviposition show a marked preference for the parts of millet heads where the female flowers are not fully open and the stigmas have not emerged. Thus individual millet heads are in a suitable state for oviposition from the time that they emerge from the protection of the terminal leaf until the female flowers are fully developed, a period of about three to four days. After this, the male flowers develop and egg-laying stops. Eggs hatch in about three days and young larvae crawl over the spikelets and enter the tips of the hermaphrodite flowers through the gaps that are made when the anthers emerge and part the glumes. The larvae then reach the ovary and start to feed on it. Normal development soon ceases, the ovary shrivels and discolours and in six to seven days the larva occupies the whole of the cavity between the glumes. The larva turns around its head towards the natural opening of the floral cavity and then pupates within the flowers.

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The pupal stage lasts for two days and adults start to emerge a little before sunset. Males generally emerge before females and wait for them on the heads. They then mate, the female flies away to lay eggs the same night only to die the following day (Coutin and Harris, 1969).

During the eitht or nine months of the dry season, the larvae of G. penniseti are in diapause. They lie within the damaged grain and are protected by a cocoon. Under natural conditions the first rains wet the heads that have survived in the fields from the previous season and the first adults emerge just as the early milets are coming into flower. This close synchronisation of pest and host guarantees the initial infestation of the new crop. Four or five generations may occur in a season.

Control - An effective cultural control measure is the destruction of all infested heads before the start of the rains to reduce the carry-over of diapausing larvae. Also early planting and the use of a uniform blooming millet variety would minimise attack by the millet midge appreciably. Chemical control is difficult and expensive because several sprays and a complete coverage of the heads would be necessary. Also many beneficial insects, for example, pollinating beetles and natural enemies could be harmed. Furthermore, residual chemicals in harvested heads could be dangerous (Ajayi, 1985).

Other pests of millet are Marasmia trapezalis Gn. The larvae of this pest bind the two edges of a leaf together with silk and form a funnel inside which they feed on the leaves. Keeping the surrounding weed free is a good control measure. Janomina mesundulata Strand (gizaka in Hausa) may completely defoliate plants. Removal of tree host plants within the vicinity of the millet plant effectively controls the pest (Ajayi, 1980).

2.3 COWPEA

2:3:1 NOMENCLATURE AND ORIGIN

Vigna unguiculata L Walp belongs to the family Leguminosae and subfamily Papilionoideae (Purseglove, 1972). The origin of cowpea culture is a subject of debate. Cowpea is believed to have originated from central Africa (Piper, 1913). India (Wright, 1907; Sellschop, 1962) and Ethiopia (Steele, 1972). However, the great variation found in the collections of uncultivated cowpea in West Africa and the widespread and ancient practices associated with its culture and utilisation (Ezedinma, 1961) are evidence of a long history of cowpea in the area.

2:3:2 GEOGRAPHICAL DISTRIBUTION AND PRODUCTION

Cowpea is widely cultivated in Africa, Asia, America and Australia. Previously second only to groundnut, cowpea is now the most important cultivated legume in Nigeria.

The annual production of cowpea in Nigeria for the year 1978 was estimated at 700,000-800,000 tons out of which 80% was produced in the north (Raheja and Apeji, 1979). Recent estimates by Awoyemi (1985) showed that the projected demand and domestic production of cowpea for the year 1985 was 1.3 and 1.1 million tons, respectively Yields of cowpea are generally high, 1500 to 1800kg/ha (Hays and Raheja, 1977) when protected against pests but very low, 150 to 200kg/ha (Raheja, 1976) when no protective measures are taken. For instance, cowpea grown in a mixture gives higher yield than unprotected cowpea (Andrews, 1974; Hays and Raheja, 1977).

Cowpea is rarely grown as a monocrop in indigenous practice. It is generally grown in mixtures involving two to six crops including sorghum, millet, groundnut, cotton and root crops (Norman, 1972). Cowpea is either grown on ridges or on the flat. In northern Nigeria, Farinwake, the local cowpea variety is sown in mid-July to early August and harvested in October/November. A less common dry season crop of cowpea is sown in December and harvested in March/April in the "fadama" (wet low land) areas under residual moisture or irrigation. In southern Nigeria, however, cowpea is planted in September.

Cowpea is a hardy crop adapted to a wide range of soils. It does best on well drained sandy loam soils, but can do fairly well on sandy or loamy clay soils.

However, very fertile soil induces excessive vegetative growth and poor pod production. It requires only a moderate amount of rainfall for good production. If rainfall is heavy, the plant tends to be leafy and few pods are produced. Moreover, under heavy rainfall, the severity of leaf diseases tends to increase (Onwueme, 1978). Cowpea is a warm weather crop and does best where temperatures are high. Cowpea in Nigeria is mostly produced without fertilizer application, although superphosphate is applied occasionally.

2:3:3 USES

This legume, in the West African savanna, serves both as a cash as well as a cash as well as a food crop. It forms a valuable source of protein for human consumption. The young pods and leaves are often eaten raw and the mature seeds boiled and eaten with stew or soup. Akara balls are prepared by soaking cowpea seeds in water to remove the testa, after which they are ground into a paste and then fried in oil. Cowpea is also a valuable cover crop for controlling erosion (Stanton, 1966) and also for manuring, grazing and canning.

2:3:4 MAJOR INSECT PESTS

In Africa, insect pests constitute a great threat to cowpea production (Booker, 1965). If not controlled, damage by insects limits yields to 150 - 200kg/ha

(Raheja, 1976) or 300 kg/ha (Singh and Jackai, 1985) and may even lead to virtually no marketable yield (Taylor and Ezedinma, 1964). The incidence of cowpea pests appears to be in synchrony with the pattern of rainfall and almost every part of the crop from seedling to harvest is attacked by one insect species or another. Booker (1965) listed 85 species of insects found in association with cowpea at Samaru, Zaria. Not all pests are found at all locations, however, some are consistently found in large numbers and are therefore considered to be major ones. Raheja (1976) constructed a crop life table for sole grown cowpea which estimated losses due to insect attack at various stages of the crop's growth. Insects are responsible for loss of potential yield during the two very important stages, flowering and pod formation.

2:3:4:1 The Foliage Beetle, Ootheca mutabilis Sahlberg (Coleoptera: chrysomelidae).

Distribution - This beetle is widely distributed in Africa. It is reputed to be the most damaging of all the foliage feeding beetles that attack cowpea in East and West Africa (Booker, 1965; van Halteren, 1971). A related species, O. bennigseni Weise, has been reported in East Africa (Le Pelley, 1959).

Damage - The damage is done by the adults, feeding on the leaves between veins. Dense population can totally

defoliate cowpea seedlings, resulting in their death. The adults also causes indirect damage by transmitting Cowpea Yellow Mosaic Virus (Bock, 1971) which is characterized by an inconspicous green mottle to severe mosaic, leaf distortion and blistering (Singh and Allen, 1979). The larvae feed on the roots but seldom cause serious damage (Singh and Taylor, 1978).

Biology - About 60 eggs per egg mass are laid in the soil and the total number of eggs laid by a single female varies from 200 to 500. The eggs which are elliptical, light yellow and translucent, are held together in a mass by a sticky substance secreted by the female. They hatch in about 13 days. The larva develops in the soil and passes through three larval instars, The first and second instars last for about 6 days each, and the third lasts for about 18 days followed by a prepupal stage, which lasts for about 15 days. The pupal stage lasts for about 16 days. The duration of the life cycle of this pest is greatly affected by the length of the rainy season and ranges from 60 to 250 days. After emergence the adult remains inactive in the soil for almost 60 days while their reproductive parts are not fully developed and are incapable of flight. Adult beetles are about 6 mm long and are normally shiny light brown or orange in colour. However, black or brown adults may be found.

Control - Insecticides such as endosulfan, methomyl and chlorpyrifos are effective against these pests, and a single application is often sufficient (Singh and Jackai, 1985).

2:3:4:2 The striped Bean Weevil, Alcidodes leucogrammus Elrich. (Coleoptera: Curculionidae).

A sporadic pest of cowpea in East and West Africa, the dark-brown adults chew the leaves while destructive larvae girdle the stem (Singh and Jackai, 1985).

2:3:4:3. Aphis craccivora Koch. (Homoptera: Aphididae).

Distribution - There are two Aphis spp. reported as cowpea pests in Africa, Aphis craccivora the main aphid infesting cowpeas throughout Africa and Asia and A. fabae Scopoli, which has been reported as a minor pest in East Africa (Singh and van Emden, 1979).

Damage - Aphis craccivora primarily infests seedlings, although it may also infest the pods in large numbers. They cause direct damage to the plant by removal of its sap. Small populations may have little impact on the plant but large populations can cause distortion of leaves, stunting of plants and poor nodulation of the root system. Yield is reduced and the plant may die (Singh and van Emden, 1979). Indirect, and often more serious, damage is through transmission of viruses,

particularly Cowpea Aphid-Borne Mosaic Virus (CAMV) (Bock and Conti, 1974).

Biology - Mostly females are found and they reproduce parthenogenetically. If food is abundant and climatic conditions are optimal, apterous forms are produced. Alates are produced only when crowding occurs and food is in short supply as well as during adverse climatic conditions. The biology of A. craccivora varies a great deal with the host plant, soil fertility, soil moisture and temperature. The adults live from 5 to 15 days and have a fecundity of over 100. Daily progeny production may vary from 2 to 20 days and there are four nymphal instars (Singh, 1980).

Control - Several insecticides such as phosphamidon and dimethoate are effective against aphids, but pirimicarb is probably the best (Singh and Allen, 1980). In nature, aphid populations are often kept under control by natural enemies and adverse climatic conditions. Furthermore, cowpea varieties resistant to aphids have been developed. For example, TVu 36, TVu 5408, TVu 410, TVu 801 and TVu 3000 by IITA (Singh 1977, 1980). Cowpea intercropped with sorghum is virtually free from attack by this aphid (Uvah and Raheja, 1984).

2:3:4:4: Legume Bud Thrips, Megalurothrips sjostedti Trybom. (Thysanoptera: Thripidae).

Distribution - These thrips are among the most important pests of cowpea. In West Africa, they are frequently responsible for total crop loss.

Damage - The nymphs and adults feed on the flower buds and flowers. The racemes of severely infested plants do not have any flower buds and existing flowers may either appear diseased or get aborted (Singh, 1978). They often cause up to 60% damage to the crop (Singh and Taylor, 1978).

Biology - The biology of this pest is not completely understood. Eggs are laid in the flowers, and hatch into larvae that do extensive damage to the flower buds. Pupation takes place in soil, Adults are shiny black and are easily noticed on the flowers.

Control - Methomyl, monocrotophos and cypermethrin are effective insecticides. Thrips-resistant varieties TVu's 1509, 2870, 6507 and 7133 have been developed by the IITA (Singh and Allen, 1979). In Ibadan, Jackai (1983) showed that intercropping two rows of cowpea with one of cassava reduced the populations of thrips. Numbers of thrips on cowpea intercropped with sorghum and millet were reduced by 35% (Uvah, 1978).

Two other species of thrips are found on cowpea (Singh and Allen, 1979). These are, Sericothrips occipitalis, which is a minor foliage pest; the adults

are pale in colour with a black band across the abdomen, and Frankliniella schultzei found on the flower. The adult is brown with a yellowish head.

2:3:4:5 The Pod Borer, Maruca testulalis Geyer. (Lepidoptera: Pyralidae).

Distribution - This pest is widely distributed throughout the tropics and subtropics and can cause serious losses in cowpea yield (Singh and van Emden, 1979). It is a major pest of cowpea particularly in Africa and Southeast Asia.

Damage - Early in the growth of the crop, larvae feed on young tender shoots and peducles. Later, when flower buds and flowers are formed, they prefer to feed on the floral parts and then move into green pods. The characteristic signs of larval feeding are webbing of flowers, pods and leaves and the production of frass on pods. This pest is responsible for 20-60% yield loss (Singh and Allen, 1980).

Biology - The female moth lays up to 200 eggs on flower buds, flowers and tender leaves (Jackai, 1981a;b). Eggs hatch in 2 to 3 days and there are five larval instars. Larval development takes about 8 - 14 days (Jackai, 1981a;b). The late larval instars have black dots on the body (Usua and Singh, 1978). The larval period is followed by a 2 - day prepupal period during

which feeding ceases, The pupal stage lasts for 6 - 9 days. The pupae are initially green but they later turn dark or greyish-brown. Pupation takes place in the soil in a doublewalled pupal cell and dull white adults with light-brown markings on the forewings and the edges of the hindwings, emerge after 5-10 days and live for 5-15 days (Taylor, 1967).

Control - The electrodyn formulation, Cymbush super ED (Cypermethrin/dimethoate), has been found to be the most effective broad spectrum insecticide against this pest (Jackai et al., 1985). Others are endosulfan, fenitrothion and dimethoate. Taylor (1977) showed that intra-row association with maize resulted in less Maruca damage to cowpea flowers than either monocrop or inter-row associations and Karel et al., (1982) reported a higher incidence of Maruca in cowpea monocrop than when intercropped with maize. Other studies where Maruca populations were suppressed by intercropping were those of Uvah (1978), Aidar and Kluthcouki (1983) and Ezueh and Taylor (1983). Jackai (1983) reported the potential of Crotalaria juncea as a trap crop to divert Maruca from attacking cowpea.

2:3:4:6 Blister Beetles, Mylabris spp. (Coleoptera: Meloidae). These pests are found on cowpea throughout Asia and Africa. They feed on the flower and thereby cause considerable crop damage. Populations are usually

low. Large numbers of beetles in a field however, result in total crop loss.

2:3:4:7 Pod sucking bugs.

Among the major pod sucking bugs are Clavigralla tomentosicollis Stal. (formerly Acanthomia tomentosicollis), C. shadabi Dolling (formerly A.horrida Signoret and Anoplocemis curvipes Fabricius, all belong to Hemiptera: Coreidae. Others are Riptortus dentipes Fabricius (Heteroptera: Alydidae) and Nezara viridula L. and Aspavia armigera Fabricius (both Heteroptera: Pentatomidae).

Distribution - Clavigralla tomentosicollis is found in East and West Africa and C. shadabi in West Africa; C. elongata is found in East Africa, while Anoplocnemis curvipes is found in East, Central and West Africa. Several species of Riptortus are found on grain legumes throughout the tropics (Singh and van Emden, 1979) out of which R. dentipes is the most commonly found on cowpea (Singh and Jackai, 1985). The remaining bugs are found wherever cowpea is grown.

Damage - Pod sucking bugs generally attack and suck the sap from green pods causing them to shrivel and dry prematurely with resultant loss in yield.

Biology - Clavigralla tomentosicollis - Eggs are laid on cowpea leaves and stems in batches of 10-70 and on average 200 eggs are laid by each female. Each instar lasts for 2 days, the last instar taking as long as 6 days. The total nymphal period lasts for 14 days (Singh and Taylor, 1978). Nymphs form large colonies on cowpea pods and peduncles and not easily disturbed. The adults are medium - sized, hairy and grey and live for 100 to 150 days. However, they are not great fliers.

C. shadabi and C . elongata are smaller than C. tomentosicollis and have similar biology. However, the former has a spiny dorsal thorax, and the latter is distinguished by its longcylindrical body. Adult longevity in both lasts 40 to 80 days. Eggs are laid singly, about 250 eggs per female, and hatch in about 6 days. There are five nymphal instars and the total nymphal period is about 20 days (Singh and Taylor, 1978).

Anoplocnemis curvipes - The adults are strong fliers, black and fairly large. They live for 24 to 84 days, but unmated males and females survive for upto 150 days. Eggs are laid in batches, normally in chains and are dark grey. They are laid on leguminous trees and wild host plants rather than on cowpea. Each batch contains 10 to 40 eggs and a single female normally lays 6 - 12 batches. The eggs hatch in 7 to 11 days. There are five

nymphal instars and the early instars resemble ants. The total nymphal period is about 30 to 60 days, depending on the host plant and climatic conditions (Singh and Jackai, 1985).

Riptortus dentipes - The adult is light brown with whitish yellow lines on the sides of the body. Fertilized females have a large black abdomen. The adults are strong fliers and live for 10 - 20 days. Eggs are laid in small batches, with an average of 50 eggs per female. They hatch in 6 days. There are five nymphal instars, the first few lasting for about 3 days each and the last about 6 days (Singh and Jackai, 1985).

Nezara viridula - This is a minor pest of cowpea with a wide host range, the adults are green in colour.

Aspavia armigera - This is a darkbrown insect with large scutellum and three white angular spots.

Control - For Clavigralla spp., the use of endosulfan and dimethoate offers a great solution. And for Anoplocnemis curvipes and Riptortus dentipes, endosulfan, dimethoate and fenitrothion are effective (Singh and Jackai, 1985). However, because of constant invasion from adjacent areas, control is often difficult. Reports on the influence of intercropping on pod sucking pests of cowpea have been mixed. Perfect et al. (1978) and Matteson (1982) indicated a decrease in

number of pod sucking bugs in cowpea - maize plots in some locations in southwestern Nigeria, whereas at other locations increased numbers have been associated with cowpea/maize and cowpea/sorghum intercrops (Kayumbo, 1976; Ochieng, 1977; Perfect et al., 1978; Mateson, 1982). Studies by Uvah (1978) showed that the numbers of pod sucking bugs on cowpea intercropped with sorghum and millet were reduced by 90%.

2:4:4:8 Cowpea Seed Moth, Cydia ptychora Meyrick. (Lepidoptera: Tertricidae). This pest is found in the humid tropies of Africa, infesting the green pods of cowpea. A characteristic appearance in the infested pod is produced by pellets of frass embedded in a web of silken threads (Taylor, 1964). This is a serious pest of cowpea in southern Nigeria, but has not yet been recorded in the north where the bulk of the cowpea is produced.

2:3:4:9 Pod Weevil, Piezotrachelus varium Wagner (Coleoptera: Curculionidae).

Distribution - They are found throughout Nigeria but seem to be more serious in the drier parts of northern Nigeria.

Damage - The larvae feed inside the pods thereby destroying the seeds. Pods may have adult emergence holes of about 1mm in diameter (Prevett, 1961).

Biology - The adult is a tiny black weevil about 3mm long. It has a long and slender protruding snout. The female lays its eggs within the flower buds and green pods. The larvae develop and pupate within the seed and adults emerge when pods are dry.

Control - Many broad-spectrum insecticide formulations such as Sherpa Plus and Cymbush Super ED (both containing Cypermethrin/dimecthoate) have been found to be effective.

2:3:4:10 Bruchids

Most important ones are Callosobruchus maculatus Fab. and C. chinensis L.

Distribution - C. maculatus is of worldwide importance while the other is of rare occurence.

Control - Use of fumigants, for example, phostoxin.

2:4 INTERCROPPING AND PLANT-TO-PLANT INTERACTION

2:4:1 INTERCROPPING

Intercropping (see definition in Chapter 1) is a characteristic of small holder subsistence agriculture in many developing nations. The primary objective of the subsistence farmer is to produce for domestic needs and then market the surplus.

About 80 - 90% of the farms in West Africa have an average size of 1-2 hectaras (Kurt, 1982). High population density areas have small farms. Farms in forest are also small due to difficulty involved in land clearing. However, in the sparsely populated drier sudan savanna zone of Nigeria, farm sizes tend to be large.

Rainfall in West Africa generally decreases from the south to the north. Thus climatic zones correspond to vegetational or agro-ecological zones (FAO, 1978). In each of these zones are characteristic cropping systems based on one or more crops typical for that environment. For example, sorghum based cropping systems are typical of the northern Guinea and Sudan savanna zones of Nigeria. Major crops in the system are millet, maize, groundnut, cowpea and cotton (Norman, 1973). Withdecreasing rainfall, the drought resistant crops such as millet become predominant, particularly in the northern Sudan and Sahel savanna zones. The choice of crop in these regions is rather limited because of uncertain rainfall distribution and short duration of the grwoing season. Millet/ cowpea and millet/ groundnut are the most important combinations in these regions.

Intercropping is generally more prevalent in the forest than the savanna areas, because the fields are smaller and there is a greater number of crop species in the former than in the latter. Okogbo (1978) counted as many as 11 different species on individual yam mounds in south-eastern Nigeria. Furthermore, crop diversity on farms in the forest areas is increased by the presence of perennial crops such as cocoa, palm oil and rubber. Unlike the forest areas, the savanna zones generally have fewer cultivated crops because perennial crops are less commonly grown and land is less limiting.

Crop mixtures can be classified by the number of component crops as 2-crop mixtures, 3-crop mixtures and so on. Whereas in the forest areas 3 to 5-crop mixtures dominate, 2-crop mixtures such as millet/sorghum, sorghum/groundnut, and cotton/sorghum dominate in northern Nigeria (Norman, 1974).

As the distance from the farmer's habitation increases the number of crops grown together in a mixture decreases. Highest diversity of crops is found on farms near compounds while remote bush farms are less diverse. In eastern Nigeria, Lagemann (1977) counted about 62 different useful plants on a single farm about half a kilometre away from human habitation.

The number of species in intercropping systems usually rises with an incerease in soil fertility. The more fertile the land is, the greater the number of crops that may be grown together on it.

Social and cultural conditions may also influence cropping systems. For example, farmers may decide to grow a particular set of crops, even if some of the crops are not well adapted to the local conditions. This was the case in Ghana where Baoute immigrants from Ivory Coast brought with them and insisted on extensive cultivation of yam in cocoa growing areas despite a campaigh by the government to discourage this practice.

Cropping patterns could also be influenced by the nature of the terrain. In forest areas, regular spacing is rarely achieved due to the presence of living and fallen trees and stumps as well as the common practice of zero tillage. Plants are, therefore, grown in patches of different size and form. This kind of planting is called patchwork, as crops are not mixed regularly. In the savanna, on the other hand where these constraints are minimal, ridge cultivation and spacing is quite systematic.

In a period when many developing nations are struggling to increase food production, crop depredation by pests is an increasingly important problem, which needs

a l sting solution. Through basic ignorance of cropping systems and the infrastructure which supports it, there have been many inappropriate attempts by researchers and extension agents to accelerate rural development by encouraging monocultures accompanied by large scale importation of modern technology. These systems were developed under conditions of farming in North America and Europe and require sophisticated and highly advanced supportive technologies. The environmental disaster which followed in the wake of the "Green Revolution" whereby widespread introduction of high yielding cultivars created monocultures with a very narrow genetic base leading to increased losses to pests, exemplify the hazards of drastically disturbing the delicate ecological balance of subsistence farming in the tropics (Frankel, 1971; Smith, 1973).

2:4:2 PLANT TO PLANT INTERACTIONS IN INTERCROPS

Plant interference is the response of an individual plant or species to its environment as modified by the presence of another plant or species (Hall, 1974a; 1974b; Trenbath, 1974). Such interference may be non-competitive, competitive or complementary. The factors for which interference may occur among plants are water, soil-based nutrients, light, oxygen and carbon dioxide. During the reproductive phase, agents of pollination and dispersal may be added. Factors not

in finite supply such as temperature and humidity may also be competed for, though they do not constitute an important subject of competition. Water, nutrients and light are factors most competed for but in repidly photosynthesing crops, carbon dioxide may also be competed for. Roots may also compete for space in stony or hard layers of soil.

Non-competitive interference occurs when a growth factor, for example light, is available in sufficient quantity so that it is not limiting. Plant yields are not affected by this kind of interference. Competitive interference or competition, occurs when one or more growth factors are limiting. Here the plant which is better equipped to utilise a factor, referred to as the dominant species, benefits and increases its yield at the expense of the dominated species. Complementary interference or complementarity, on the other hand, occurs when one plant benefits from another, as in the case of legumes supplying nitrogen to cereals via fixation by symbiotic bacteria (Agboola and Fayemi, 1972; Andrews, 1972; Nnadi, 1978).

In conclusion, further understanding of intereference among plants requires almost by definition a greater knowledge of the response of plants to their environment and especially the response of those environmental stresses

caused by neighbours. Willey (1979) stated that maximising intercropping advantages is therefore a matter of maximising the degree of complementarity between the components and minimising inter- and intra-crop competition. On this basis, intercropping advantages are more likely to occur where requirements of the component crops are different. Therefore, work on the improvement of intercropping systems should aim at better utilization of these resources. However, where the limiting factor is entomological rather than agronomic, the intercropping system should be manipulated towards minimisation of depredation by insect pests.

2:5 THE DIVERSITY-STABILITY HYPOTHESIS AND INTERCROPPING

2:5:1 INTRODUCTION

It is widely accepted that the stability of a community of plants and animals in an ecosystem and that of populations of its constituent species is positively related to its diversity (Southwood and Way, 1970). Diversity was defined by van Emden and Williams (1974) as the number of species per unit of individuals, by Murdoch (1975) as the number of species and by Way (1976) as the species richness of plants and animals in a community. Way (1976) considers diversity as a fundamental ecological concept. Diversity is widely thought to promote stability which is said to keep pest outbreaks scarce in many natural ecosystems. Diversity is therefore desirable in agriculture. Stability

as a lack of change has been considered as elusive (van Emden and Williams, 1974) and as an abstraction in nature (Way, 1976). More realistically it may be defined as the maintenance of a fairly constant mean state, either of a particular mix of species in a community (community stability) or of a particular species population size (species stability) irrespective of periodic displacements from the mean (MacArthur, 1965; van Emden and Williams, 1974; Way, 1976; 1977). A population may, however, be classified as more or less stable depending upon the amplitude and the frequency of fluctuations in its numbers. The time scale for stability may vary from a few months' lifetime of an annual crop to hundreds or thousands of years for a natural tropical forest community.

There has been considerable discussion among ecologists about the relationship between the complexity of the food web in an ecosystem and the stability of the community. Elton (1958) demonstrated that the balance of a relatively simple community of plants and animals is more easily upset than that of richer ones. Margalef (1968) states that the greater the number of avenues by which energy may flow through a complex system, the more stable it is.

Pierson (1922) and MacArthur (1955) were among the first to demonstrate the theoretical validity of the diversity/stability concept by comparing pest outbreaks between relatively simple habitats, for example agro-ecosystems, and more complex habitats, for example natural forests.

2:5:2 INSECT-PLANT INTERACTIONS IN DIVERSE SYSTEMS

As a consequence of agriculture aimed at providing enough food and raw materials for the expanding human population, man deliberately interferes with nature by removing or radically changing the natural vegetation to create agro-ecosystems. This alteration of a given ecosystem is meant to increase the flow of energy to man. These agro-ecosystems and particularly monocultures are extreme examples of environmental simplification and specialized management. This process of alteration therefore destroys the natural fauna and flora and disrupts the complex inter-relationship that had been established over a long period between various species of animals and plants. Natural community of plants on the other hand are self-perpetuating and are of diverse age and type which had co-evolved for years. As a result of the above characteristic Schneider (1939), Graham (1956) and Gibson and Jones (1977) proposed that insect outbreaks do not occur in such natural communities as virgin tropical rain forests.

Theoretical and empirical evidence abounds in favour of the diversity/stability concept testifying to the greater incidence of specialist herbivores in simple compared with diverse communities (Pierson, 1922; Graham, 1956; MacLoney, 1930). It is significant that field observations supporting the diversity/stability concept come overwhelmingly from forests ecosystems. This is no doubt partly because the forest have provided obvious long-term comparisons between the more diverse natural systems and the less diverse plantation monocultures. It is envisaged that the mixture of very many different plant species and their associated animals in tropical forests comprises a complex web of interacting species where tendencies for any particular species to become relatively abundant or scarce are delicately countered by complex Web adjustments (MacArthur, 1955; Pimentel, 1961). This was the widely accepted explanation for the apparent absence of pest outbreaks in tropical forests. However, this does not imply that insects and other phytophagous species are completely harmless in tropical forests. Janzen (1971) reported that intense destruction by specific fruit and seed-eating beetles gave rise to widely spaced trees of certain species in Central American forests. A similar situation was reported by Way (1977) in Africa where trees such as mahogany are kept dispersed by the activity of specific

herbivores. Uvah (1983) believes that at higher host density, destruction by herbivores increases resulting in the death of many host trees which then become too widely spaced for successful dispersal by herbivores whose population is forced to fall. He concludes that stability is achieved by mutual density dependent action of the herbivores and their host trees, a mechanism that emphasizes the relative importance of habitat permanence in the mechanics of the diversity/ stability concept.

Some studies indicate that diversity does not always lead to stability. For example, Watt (1964; 1965) showed that the more competitors a herbivore had the less stable the population. Also Zwolfer (1963) found that simple parasite complexes of lepidoptera increased stability more efficiently than larger complexes. Both citations above clearly showed a negative correlation between diversity and stability. Murdoch (1975) and Goodman (1975) agree that correlation alone between diversity and stability is not a significant proof that the apparent stability is due to diversity or causes of it. In this respect, van Emden and Williams (1974) suggested that the relationship between diversity and stability is parallel rather than causative and that the correlation may be a community over time, thereby explaining why natural systems are much more

stable than most agro-ecosystem. Southwood and Way (1970) state that the role of diversity in the stability of populations is unclear and difficult to predict without adequate knowledge of the responses of the various links in the system. However, they accept that, generally the greater the diversity, the greater the chance of attaining stability. Diversity is a broad term which covers a wide range of relationships which should first be defined before the relationship between diversity and ecosystem stability can be considered (van Emden and Williams, 1974; Southwood and Way, 1970).

With regard to agro-ecosystems, available evidence suggests that the "green revolution" technology has intensified losses to pests (Pradhan, 1971). The reasons for this include the cultivation of large areas of land to a uniform variety and the increased susceptibility of the new high yielding varieties to pests. In the past, farmers often selected seeds from individual plants that survived best under native cultural conditions. The plants that yielded best under these conditions were genotypes that also naturally harboured resistance alleles to local insects and pathogens. With the failure of the government to convince farmers to adopt the cultivation of these high-yielding varieties, there

had been an increasing research activity in the area of diversification of agroecosystems as a means of controlling insect pests ranging from investigations on the effects of the presence of non-crop species to those of mixed or intercropping.

Examples abound where intercropping has been found to reduce incidence of insect pests. In Nigeria, unsprayed cowpea is less vulnerable to attack by insects when intercropped with sorghum than when sole cropped (Raheja, 1976; Uvah, 1978) and a similar situation prevails in maize/cowpea intercropping in Tanzania (Kayumbo, 1975). Similarly okra appears to be a useful diversionary crop for flea beetles (Podagrica sp.) attacking cotton which is usually the major crop in some intercropping systems in Nigeria (Usenbo, 1976). Less flower damage due to Maruca testulalis Geyer occurred when cowpea was intra-row rather than inter-row cropped with maize in Nigeria (Taylor, 1977). Amoako-Atta (1983) observed fewer stem girdlers, Alcidodes leucogrammus on cowpea in a sorghum/cowpea dicrop than on cowpea in pure stands, maize/cowpea dicrop, sorghum/maize/cowpea tricrop in alternate rows and sorghum/maize/cowpea tricrop of no definite pattern. Coaker (1980) obtained reductions of 80% and 70% in Brevicoryue brassicae and P. radicum infestations respectively, on sprouts by undersowing with clover. Bach (1980a,

1980b, 1981) intercropped cucumber with maize, tomato and broccoli in field experiments and found consistently higher densities of the specialist cuourbit herbivore Acalymma inuba Fab. in monocrop fields. She also found fewer beetles on the cucumber growing horizontally than vertically and that tomato was more effective than maize in decreasing beetle numbers on cucumber.

However, not all crop associations reduce the number of their respective pest species. Maize which is sometimes a valuable diversionary host for the cotton bollworm Heliothis armigera, can be a damaging source of the pest if the period of tasselling in maize and boll formation in cotton are not synchronized. Robinson (1960) found higher numbers of pea aphids on peas intercropped with oats than when alone. In Nigeria, the cropping pattern of maize, tomatoes and cotton establishes a favourable host plant sequence for Heliothis armigera and Cryptophlebia leucotreta leading to severe infestations on cotton (Beeden and Hayward, 1972).

2:5:3 STABILISING MECHANISMS

Mechanisms suggested by various authors to be responsible for lower abundance of insect herbivores in mixed crop systems can be categorized into four: natural enemy action, visual effects, chemical effects and diversionary and physical barrier effects.

2:5:3:1 Natural Enemy Action

In the more diverse environment created by intercropping the numbers and/or diversity of natural enemies may be increased, Price and Waldbauer (1975) or perhaps less commonly, decreased (Pimentel, 1961; Root, 1973). Apparently, mixed crop systems offer a greater variety of prey and hosts for active natural enemy stages, and more suitable micro-environments or refuges (Dempster and Coaker, 1974) as well as sources of food such as nectar and pollen for other stages, thereby maintaining higher densities of natural enemies (Smith, 1969; Horn, 1981). Raros (1973) found more predatory wolf spiders in maize/groundnut mixtures in the Philliphines than in sole cropped maize which contributed further to the control of the stem borer achieved by wider spacing of maize in the intercrop. This may be partly due to improved supply of soil microfauna in the mixed planting to support early instar spiderlings (Gavarra and Raros, 1975). Dempster and Coaker (1974) showed that increased number of predators particularly Harpalus rufipes Deg. were responsible for increased early Pieris rapae L. Larval mortality on sprouts undersown with clover. However, increased numbers of predators do not always lead to increased predation of target species (Theunissen et al., 1980; Tukahirwa and Coaker, 1982). In the Solomon Islands and Tanzania, O'Connor (1950) and Way (1953)

found that coconut was attacked by the coconut bug Pseudotheraptus wayi. A predaceous bug, Oecophylla smaragdena could control the bug. But where coconuts were under clean culture the colonies of Oecophylla were eliminated by another ant, Pheidole sp. Only undergrowth provides a favourable habitat for Oecophylla as well as a means for it to avoid Pheidole while moving from tree to tree. Therefore, cover crop was recommended and this permitted effective control of the coconut bug.

Entomogenous fungi generally benefit from high relative humidity beneath dense foliar canopies and this probably explains reduced mite abundance on areca nut grown beneath banana in India (Khader and Anatoly, 1968).

2:5:3:2 Visual Effects

The colour and contrast of the host with its background influence host finding by some insect pest species. A mixture of crop types may affect the visual stimuli which attract insect pests to their suitable host plants and, in extreme cases, one crop becomes totally camouflaged by another to flying insects. This is particularly so, for young plants in a relay system. Smith (1969) found that growing Brussels sprouts sparsely so that the plants were strikingly silhouetted against bare soil attracted

host-seeking aphids. Improved ground cover using a weedy background to break this pattern in Brussels sprouts not only made the crop less attractive to aphids but also more attractive to many natural enemy species (Smith 1969; 1976). Also maize in a maize/groundnut intercrop is less attacked by the maize borer, Ostrinia furnacalis because the moth prefers a background with a brownish hue to a solid green background (Raros, 1973).

Host finding by certain species may also be influenced by attraction to particular colours, for example, yellow is attractive to many species of aphids (Moericke, 1950; 1969) and also to certain species of Diptera (Finch and Skinner, 1974a, Hawkes, 1969), flower-dwelling thrips (Lewis, 1959) and the apple bug (Prokopy et al., 1979) are attracted to white, whilst adults of the apple maggot flies are attracted to red (Prokopy and Hauschild, 1979). Aphid numbers were reduced when ground cover was increased by growing groundnuts (A'Brook, 1964; 1968), field beans (Way and Heathcote, 1966) and sugar beet (Heathcote, 1970) at higher densities.

Since complete ground cover may result in intense intra- and inter-crop competition for growth factors amongst the crops in the intercrop (Tukahirwa and

Coaker, 1982), a compromise has to be struck to achieve low pest build-up without undue yield loss to competition from cover plants.

2:5:3:3 Chemical Effect

Many phytophagous insects locate their host plants using olfactory mechanisms (Kennedy, 1965; Kennedy and Moorhouse, 1969; Hawkes and Coaker, 1979; Finch, 1980). Thorsteinson (1960) also states that odours are significant in food plant recognition in the final host finding stages. For example, the odours of apple was reported to attract the apple maggot flies Rhagoletis pomonella Walsh (Prokopy et al., 1973). Similarly, Tahvanainen and Root (1972) recorded reduced colonisation and subsequent reproduction of the flea beetle Phyllotreta cruciferae when crotalaria were interplanted with tomato and tobacco. This was due to the presence of aromatic odours.

Hills (1972) found that carrots intercropped with onions were protected from damage by Psila rosae because the onions "jammed carrot scent". Latheef and Irwin (1980) found significantly lower abundance of the Mexican bean beetle, Epilachna sp. on snap bean, Phaseolus vulgariis L. bordered by French marigold Tagetes patula L. than on non-bordered beans. Many other insect pests of vegetable crops have been found

to be repelled by a host of aromatic herbs (Cox, 1974). Altieri et al. (1978) and Risch (1980) suggest that adverse or confusing chemical stimuli are responsible for lowered herbivore abundance in some tropical multiple cropping systems. However, Latheef and Irwin (1980) on the other hand, found that higher numbers of Heliothis zea Boddie occured on beans bordered with pot marigold, Calendula officinalis L., and sumer savory, Satureja hortensis L, than in monoculture. They suggested that the pest was attracted by these non-hosts.

It emerges from the above examples that most insects tested are capable of perceiving host plant odour and are influenced in their host finding and host discrimination behaviour by either a few key host specific chemicals or by characteristics ratios of several non-specific host volatiles. It is therefore possible for odour from an associated non-host plant to mingle with that of the host and thereby interfere with the host finding process.

2:5:3:4 Diversionary and Physical Barrier Effect.

Litsinger and Moody (1975) ascribed physical interference (protection from wind, hiding, shading

significantly longer periods on monoculture host plants. Interplanted non-host plants may exert a 'fly paper effect' (Trenbath, 1976) causing a loss of the dispersing individuals which settle on the non-host component of the intercrop. Where the search for a suitable host is prolonged due to the presence of the non-host, the mortality of the pest may be increased leading to reduced infestation of host plants.

The dispersal of both the adult and larval stages of insect pests may be impeded where host and non-host are grown together. The non-host plants may offer a barrier to dispersal of insect into and/or within the host habitat. For example, thrips attack on cowpea is reduced by interplanted maize (Rosingh, 1980). Taylor (1977) also observed that Maruca testulalis attacked cowpea flowers less when cowpea was intra-row mixed with maize. An outer guard row of a highly preferred crop may prevent widespread dispersal of crawling insects which invade from adjacent uncultivated areas. For example, in a soyabean/pigeon pea intercrop, an outer row of the preferred soyabean may just be as efficient a barrier to immigrating hairy caterpillars, Amsacta sp., as a BHC filled trench (Krantz et al., 1975). At Zaria, northern Nigeria,

Uvah (1978) intercropped sorghum, with a relay crop of millet and cowpea and found that the abundance of the cowpea herbivores, Aphis craccivora Koch, Maruca testulalis Geyer, Megalurothrips sjostedti Trybom and the pod sucking bugs, was lowered by 92%, 45%, 35% and 90% respectively, compared with their numbers on monocrop cowpea. He suggested that the sorghum afforded partial protection to the cowpea by acting as a non-host physical barrier which confused landing potential insect invaders of cowpea at the canopy level and also created an unsuitable microclimate about the cowpea below. Way (1977) regards diversionary effects, physical barriers and hazards to insect dispersal as 'outstanding and fundamental components of insect pest control'. An example of physical hazard was given by Farrel (1976) who observed in Malawi that the hooked hairs of intercropped Phaseolus beans trapped dispersing individuals of Aphis craccivora and effectively reduced rosette virus infection in groundnut.

2:5:4: CONCLUSION

The ultimate aim of pest control is to decrease the loss in crop yield and quality and therefore a reduction in pest abundance per se is not necessarily

of great value. The available techniques for controlling individual pests are almost inexhaustible and involve a wide range of applied science and technology. They can be conveniently categorized, in increasing order of complexity as cultural, mechanical, physical, biological, chemical, genetic and regulatory methods (Metcalf et al., 1951). It can not be argued that cultural and chemical methods of control are currently the most practiced methods employed in pest management. Despite their impressive credentials, the use of chemicals have often not been ecologically sound, leading to such disadvantages as pest resistance, outbreaks of secondary pests, toxicity and environmental pollution. There is a need to look for and develop alternative methods that will ultimately reduce the current level of reliance on chemicals. It is clear from the literature that a greater abundance of some specialist herbivores occurs on host crops grown alone than in diverse communities. However, enough evidence exists to indicate that this is not universal.

A more profound understanding of the natural control mechanisms operating in mixed or multiple systems is a top priority for tropical research. This does not however preclude the use of resistant varieties or chemicals in controlling pests.

In this respect, diversity, in the form of barrier or diversionary crops or crop association which enhance natural enemy activity, is crucially important in reducing pest damage. The right kind of diversity is fundamental in insect pest control. The fact that only a few factors are often responsible for creating or ameliorating pest problems in agro-ecosystems makes population ecology a vital part of any successful and practical pest control strategy.

3 GENERAL MATERIALS AND METHODS

3.1 AGRONOMY

3.1.1 Experimental site - Two experiments were carried out on the Research Farm of the Institute for Agricultural Research (IAR), Samaru (11°10'N, 07°38'E 686m above sea level) in the northern Guinea savanna zone of Nigeria during the 1985 and 1986 rainy seasons.

3.1.2 Land preparation - The fields for both experiments were ploughed using a tractor-mounted disc plough, to destroy weeds and encourage proper drainage. The fields were then harrowed using a tractor-mounted disc harrow to pulverize the soil and break down large soil particles. Finally, the fields were ridged to provide rows which were 0.75m apart. Ridging created suitable beds for seed germination and also reduced water logging.

3.1.3 Seed type and rates - A late-maturing sorghum variety (cv Farafara) was intercropped with an early gero millet (cv Ex-Borno) and a local indeterminate cowpea (cv Farinwake). Five to eight seeds of sorghum or millet and two cowpea seeds were separately sown per 2-3m hole. Sorghum and millet were later thinned to two plants per stand at two weeks after sowing.

3.1.4 Field sanitation - Hoe weeding was done whenever necessary, often a day or two after heavy rain to ease the process.

3.1.5 Fertilizer - Compound fertilizer 15:15:15) was applied during harrowing at the rate of 100 kg/h. Five weeks later, 50kg of single-superphosphate (SUPA) and 50kg of calcium ammonium nitrate (CAN) were thoroughly mixed and applied onto sorghum and millet by side placement.

3.1.6 Pesticides - These were not used in any of the experiments.

3.2 SAMPLING OF INSECT PESTS

In sampling populations of insect pests associated with these crops, the crop's developmental stage which provided the highest densities of individuals on the crop was selected to enhance accuracy of the estimates. Pest populations were expressed in terms of damage to plants or numbers of larvae/adults per plot. In each plot plants were chosen randomly and no plant was sampled twice for a single pest. Adult insects were identified at the Insect Museum, Department of Crop Protection, A.B.U., Zaria.

The same sampling procedure was employed for both 1985 and 1986 as is described in subsections (3.2.1 to 3.2.3) Except where specified, all insects were sampled in both experiments.

3.2.1 Sorghum pests

3.2.1.1 Sorghum shootflies (see section 2:1:4:1)

Although larvae were not reared to adults, the percentage of sorghum plants with deadhearts was used as an index of abundance of shootflies after Jotwani et al., (1970). Shootfly damage was assessed by counts of shoots with and without deadhearts. A shoot was considered to be infested (deadhearts) if a gentle pull of the shoot caused it to come away revealing the typical damage (pungent smell and decaying at the base). Deadheart counts were made at 3,4,5,6,7 and 8 weeks after sowing. On each occasion, the total numbers of shoots per plot were recorded, deadhearts were removed and their numbers recorded. Finally, shootfly damage was expressed as the percentage of total shoots with deadhearts.

3.2.1.2 Sorghum midge, Contarinia sorghicola

Sorghum heads were sampled at 77, 80, 83, and 85 days after sowing. On each occasion, twenty seeds each from five heads per plot were removed and pressed between the thumb and the forefinger. Seeds that produced an orange-exudate were considered to be infested.

3.2.1.3 Sorghum stem borers (see section 2:1:4:2).

Five stalks per plot were removed at 3,5,7 and 9 weeks after sowing. The stalks were dissected and the number of larvae were recorded. The larvae were not reared to adults.

3.2.1.4 Sorghum headworm, Heliothis armigera

At 80, 85 and 90 days after sowing, five randomly selected heads were thoroughly checked per plot and the numbers of larvae were recorded.

3.2.2 Millet pests

3.2.2.1 Millet shootfly, (see section 2:2:4:1).

Shoots with deadhearts per plot counted at 3,4,5,6,7 snf 8 weeks after sowing. On each occasion, the total numbers of shoots including the tillers were also counted. Deadhearts were expressed as a percentage of all the shoots. Larvae were not reared to adults.

3.2.2.2 Millet midge, Geromyia penniseti.

At 51, 53 and 55 days after sowing, five heads per plot were removed and kept in a jar. The numbers of emerging adults were then recorded.

3.2.2.3 Millet headbeetles, Meligethes heteropus

The numbers of adult beetles that emerged from heads used for sampling G. penniseti were recorded.

3.2.2.4 Millet stem borer, Acigona ignefusalis

Five stalks per plot were removed at 30, 40,50 and 60 days after sowing. The stalks were dissected and the numbers of larvae were recorded. The larvae were not reared to adults.

3.2.2.5 Millet headworm, Rhaguva graminivora.

In 1985, 50 heads per plot were sampled and those with cut-off spikelets which characterize Rhaguva activity were recorded at harvest. This was not sampled for in 1986 due to the depredation of cereal heads by birds.

3.2.2.6 Other head insects

Populations of the meloids, Mylabris sp, Melyris sp, and Coryna hermanniae, and the

shield bug, Agonosceles versicolor were recorded on five heads per plot at 7 and 8 weeks after sowing. This was done in 1985 only.

3.2.3 Cowpea pests

3.2.3.1 Cowpea foliage beetle, Ootheca mutabilis.

Populations of adult beetles on five plants per plot were recorded at 3,4 and 5 weeks after sowing.

The remaining cowpea pests were not sampled in 1986 due to fungal attack which prevented flowering thereby precluding sampling of its flower and pod insects. However, they were sampled in 1985.

3.2.3.2 Thrips, Megalurothrips sjostedti

Ten fallen flowers per plot were collected and immersed in water. The flowers were later dissected and the numbers of thrips were recorded. This was done at 39, 42, and 45 days after sowing.

3.2.3.3 Aphids, Aphis craccivora

Ten pods each from five randomly selected plants per plot were removed at 59,63 and 67 days after sowing and placed in plastic bags. The pods were later washed in detergent (omo)

solution in water (1g/I) and aphids were strained on a piece of cloth and the numbers recorded.

3.2.3.4 Cowpea podborer, Maruca testulalis.

Numbers of adult emergence holes (often covered by frass) were recorded on 50 pods (10 pods/plant) per plot.

3.2.3.5 Pod sucking bugs (sse section 2.3.4.7)

Commencing at 60 days after sowing, a sample of 100pods/plot was removed from ten randomly selected plants per plot, on each of the three occasions at five-day intervals. Out of these, the numbers of shrivelled and dry pods which reflected damage by these bugs were recorded. Populations of coreid bugs could not be assessed by direct count because the bugs tended to fly away or drop to the ground when approached.

3.2.3.6 Cowpea weevil, Piezotrachelus varium.

At harvest, seeds from 50 pods/plot were placed in a jar and the numbers of emerging adult weevils were recorded at 7,14,21 and 40 days. All weevils were removed and then destroyed after each sampling.

3.2.3.7 Bruchids (see section 2.3.4.10)

Seeds used in sampling for weevils were also used for sampling these pests on the same days as in section 3.2.3.6.

3.2.4 ANLYSIS OF DATA

The data was subjected to analysis of variance (ANOVA) and the differences between means were assessed using the least significance difference test at the 5% probability level. Cumulative curves were also drawn for the following insects for both experiments: shootflies and stem borers of sorghum and millet and sorghum midge. The standard errors of difference for individual sampling dates are shown in Appendices for purposes of comparison of treatments.

4. FIELD EXPERIMENTS

4.1 THE 1985 EXPERIMENT

4.1.1. Methods

This experiment was conducted during the 1985 rainy season on IAR Field W_2, which had been fallow during the previous year. In this field, an area mesuring 110m x35m (Fig 1) was marked out for the experiment. From this area, 27 smaller plots, each measuring 10m x 9m, were marked out. Adjacent plots were separated by a 2m-wide strip of bare soil. Peripheral plots were at least 2m-away from the edge of the field. The experiment was laid out in a a randomised block design (Fig. 1) and made up of the following nine treatments (Fig. 2) each replicated three times.

Sorghum: millet/cowpea inter-row ratio of 1 : 1
" " " " " 1 : 2
" " " " " 1 : 3
" " " " " 1 : 4
" " intra-row ratio of 1 : 1

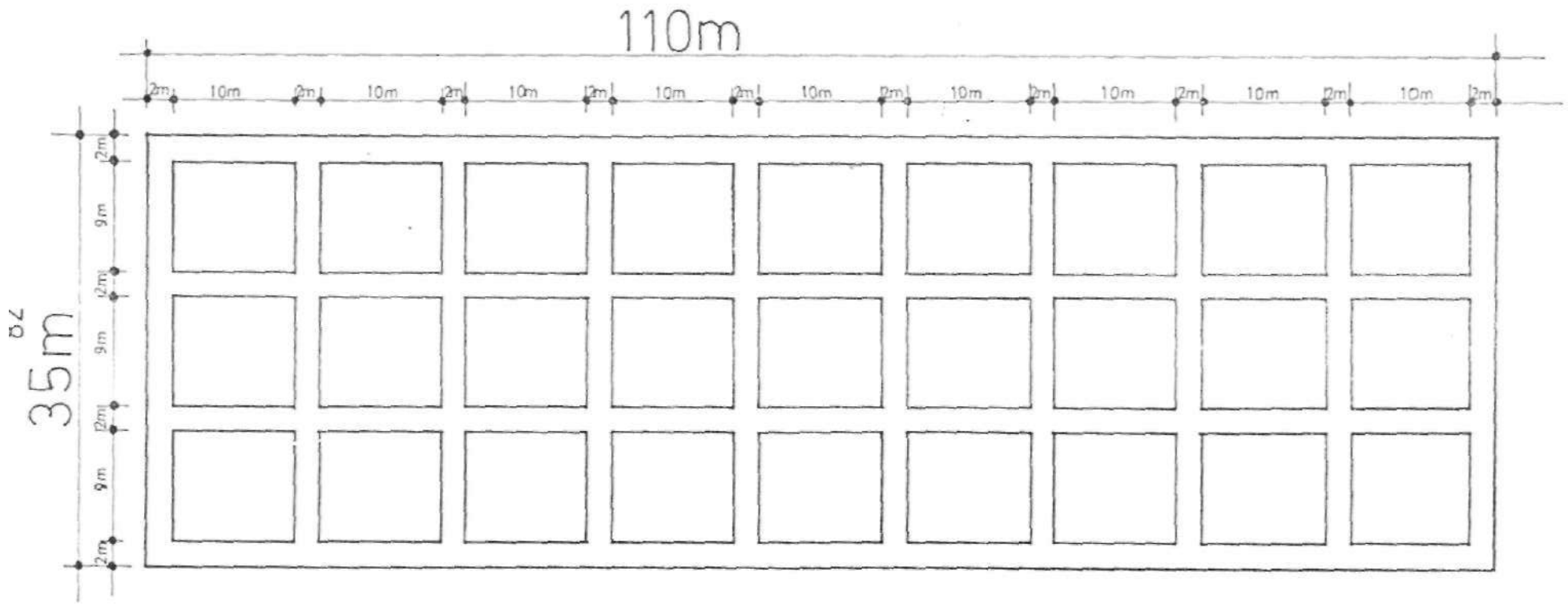
3 sorghum stands peripheral to a core of millet/ cowpea

Monocrop sorghum.

Monocrop millet.

Monocrop cowpea.

FIG.1 Layout Of 1985 Experiment



SCALE: 1:500

FIG. 2 SPATIAL PATTERNS OF CROPS IN THE INTERCROP AND MONOCROP TREATMENTS (1985)

Sorghum and millet were sown on 23 June 1985, most of which germinated three days later. Cowpea, on the other hand, was sown on 2 August germinated two to five days later. Where plants were not visible at the soil surface after five days, gaps were immediately resown. Irrespective of the crop(s) all plant stands were 0.5m apart in all treatments.

4.1.2 Results

In interpreting the data (Tables 1,2 and 3) the following criteria were employed to compare the different treatments.

i) Pest populations on the monocrop treatment on the one hand against those on all treatments on the other.

ii) Populations of insect pests among the different patterns of crop arrangement with similar crop ratio, that is, sorghum: millet/cowpea inter-row ratio of 1:1, sorghum; millet/cowpea intra-row ratio of 1:1 and three sorghum stands peripheral to a millet/cowpea core.

iii) The effects of decreasing row ratio of sorghum to millet/cowpea on abundance of each of the insect pests of the crops.

iv) Insect population trends with increasing or decreasing relative densities of the host plants.

4.2.1 : Sorghum Pests

Cumulative curves in Fig. 3 show that at the beginning of sampling, there was no appreciable effect of the treatments on shootfly damage. Subsequently, however, shootfly damage increased more rapidly on monocrop than on intercrop sorghum. The cumulative percentage of shootfly-infested sorghum plants (i.e, those with deadhearts)(Table 1) in the monocrop sorghum was significantly higher than those on all the intercrops. The intra-row pattern had the lowest percentage of plant with deadhearts which was also significantly lower than those in the remaining two patterns with similar crop ratio. The latter two treatments had statistically similar infestations of shootfly. There was a consistent decrease in numbers of damaged plants with decreasing populations of sorghum relative to millet/cowpea within the inter-row crop treatments.

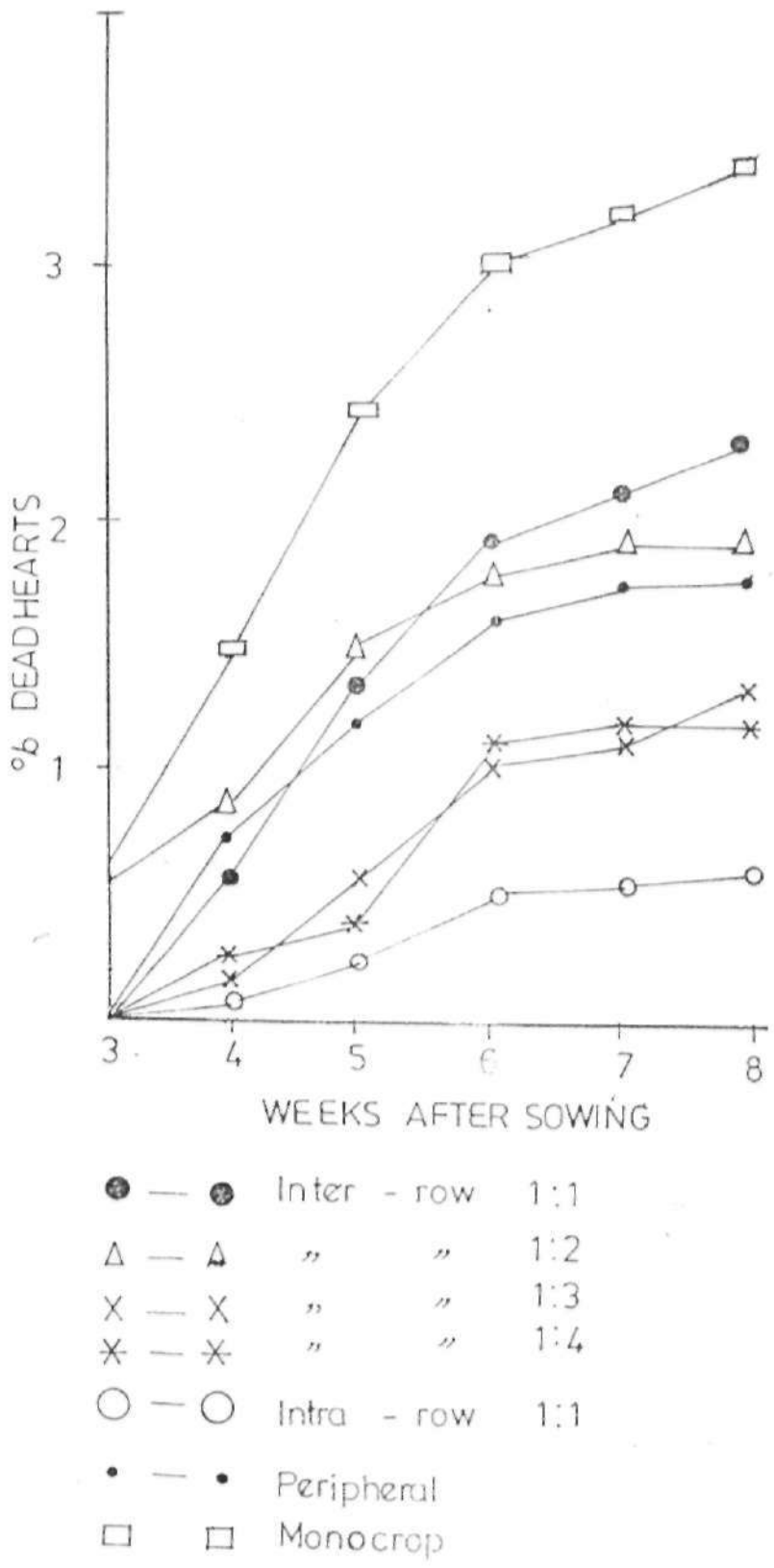


Fig. 3: Effect of intercropping pattern on the incidence of the sorghum shootfly at Samaru, 1985.

All intercrop treatments had statistically lower populations of the sorghum midge, Contarinia sorghicola than those of the monocrop treatment (Table 1). Decreasing row ratio of sorghum to millet/cowpea did not significantly affect the size of sorghum midge infestations. Furthermore, similar populations of C.sorghicola were recorded on the three cropping patterns studied. Increasing the row density of sorghum did not affect the level of infestation by the sorghum midge. Cumulative curves for C. sorghicola (Fig.4) indicate that its population build-up on the monocrop was more rapid than on other treatments. Curves for intercrop threatments are bunched showing that they had similar midge populations throughout the sampling period.

Cumulative populations of sorghum stem borers (Table 1) on monocrop sorghum were similar to those on sorghum: millet/cowpea inter-row ratio of 1:4, the peripheral and the intra-row crop arrangements but significantly higher ($P<0.05$) than those on the remaining treatments.

TABLE 1. 1985 EXPERIMENT. Mean cumulative populations of sorghum insect pest.

TREATMENTS	% deadhearts (*A. soccata*)	No of *C. sorghicola*/ 100 seeds	No of stem borers/5 stalks	No of *Heliothis*/ 10 heads
Sorghum:millet/cowpea inter-row ratio of 1:1	2.4d	13.0a	39.0a	5.3a
Sorghum:millet/cowpea inter-row ratio of 1:2	2.0d	10.0a	34.3a	3.3a
Sorghum:millet/cowpea inter-row ratio of11:3	1.4bc	17.7a	38.0ab	4.7a
Sorghum:millet/cowpea inter-row ratio of 1:4	1.3b	13.3a	44.0abc	4.7a
Sorghum:millet/cowpea inter-row ratio of 1:1	0.6a	16.7a	43.abc	3.3a
3 sorghum stands peripheral to a core area of millet/cowpea	1.9cd	12.3a	54.7bc	2.0a
Monocrop sorghum	3.4e	35.7b	59.3c	2.7a
± SED	.25	6.19	9.29	1.89

Within a column, values followed by the same letter are not significantly different at 5% level using the LSD test.

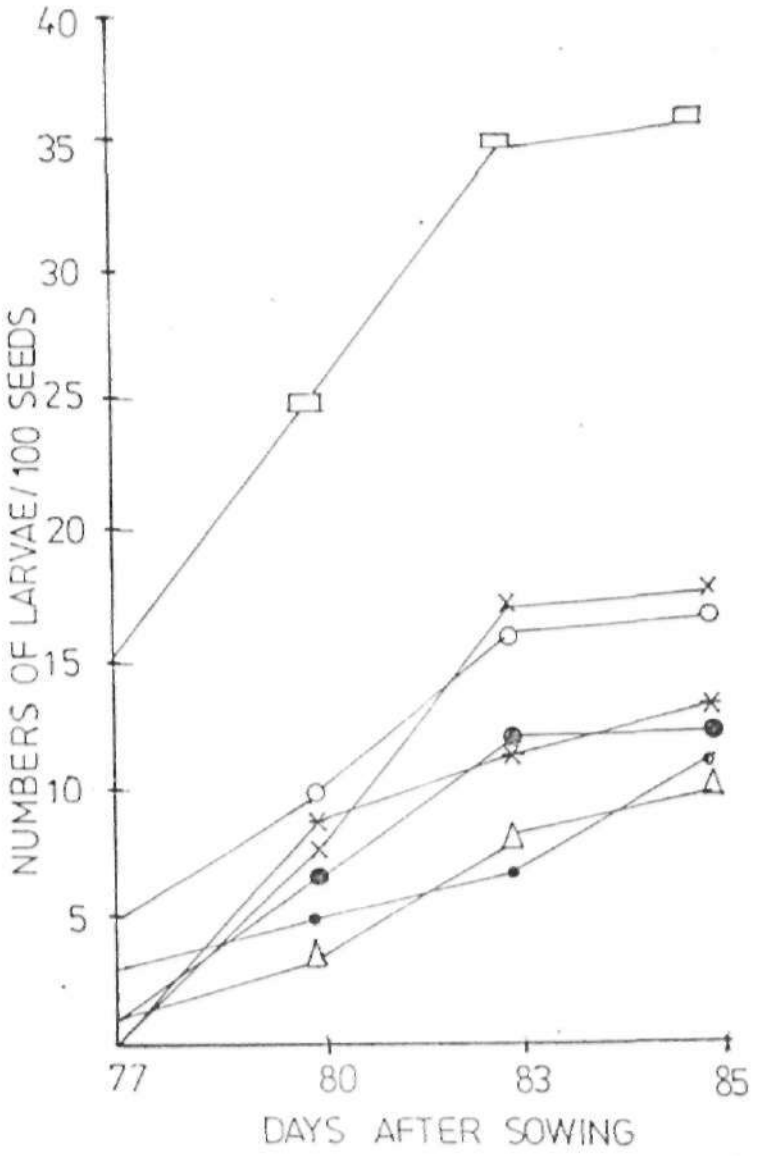


Fig. 4: The effect of intercropping pattern on the incidence of the sorghum midge at Samaru, 1985.

Among the different cropping patterns, sorghum: millet/cowpea inter-row ratio of 1:1 had similar borer population to those on the intra-row treatment which were lower than those on the peripheral intercrop treatment. Borer populations among the inter-row treatments were not significantly different and did not decrease or increase consistently with decreasing row ratio of the host plant. Populations of stem borers (Fig. 5) on the peripheral treatment were higher than those on the monocrop treatment for most of the sampling period. The population build-up was generally similar on all treatments.

Populations of sorghum headworm, Heliothis armigera were similar ($P > 0.05$) in all the treatments (Table 1). Thus different intercropping patterns had no effect on the abundance of this insect on sorghum.

4.1.2.2 Millet pests

Percentages of millet plants with deadhearts in monocrop millet were similar ($P > 0.05$) to those in all other treatments except sorghum: millet/cowpea inter-row ratio of 1:4 (Table 2). The three cropping patterns (inter-row 1:1, intra-row 1:1 and peripheral) also had similar

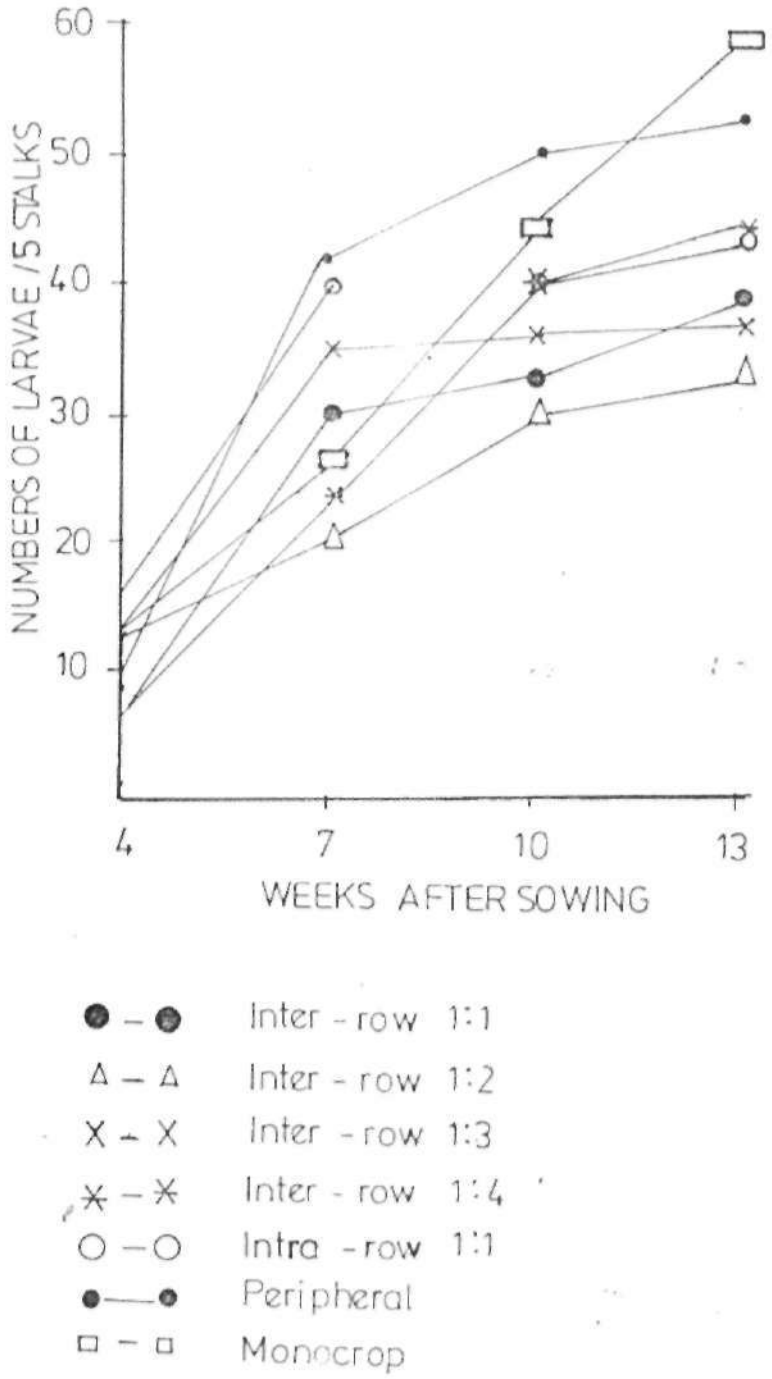


Fig. 5: Effect of intercropping pattern on the incidence of sorghum stemborers at Samaru, 1985.

TABLE 2. 1985 Experiment. Mean cumulative populations of millet insect pests.

TREATMENTS	% deadheart *D. arambourgi*	No. of *G. penniseti*/ 5 heads	No. of stem borers/ 5 stalks	No. of *Meligethes*/ 5 heads	No. of *Melyris*/ 5 heads	No. of *Mylabris*/ 5 heads	No. of *Coryna*/ 5 head	No. of *Agonosceles*/ 5 heads	No. of *Rhaguva* infested heads/ 50 heads
Sorghum: millet/cowpea inter-row ratio of 1:1	1.8ab	19.0a	31.3a	187.0ab	6.0ab	5.3a	34.3a	30.0a	1.0a
Sorghum: millet/cowpea inter-row ratio of 1:2	1.6ab	18.3a	34.7a	153.7a	3.0a	5.0a	39.3a	25.7a	2.0b
Sorghum: millet/cowpea inter-row ratio of 1:3	1.8ab	35.7b	29.0a	199.3ab	7.7ab	7.3ab	43.7a	22.7a	1.3ab
Sorghum: millet/cowpea inter-row ratio of 1:4	1.0a	33.3b	34.3a	175.3ab	16.7c	18.0bc	48.7a	61.3b	2.3b
Sorghum: millet/cowpea inter-row ratio of 1:1	2.3b	23.0a	33.7a	171.0a	6.3ab	14.0abc	49.0a	29.0a	1.3ab
3 sorghum stands peripheral to a core area of millet/ cowpea	2.0ab	22.0a	26.0a	169.3a	8.0ab	8.7ab	51.3a	27.0a	1.3ab
Monocrop millet	2.6b	63.0c	65.0b	269.7b	14.0bc	20.7c	69.7a	47.3ab	3.0b
± SED	0.51	3.79	9.83	44.78	3.86	5.20	25.20	12.73	0.96

Within a column, values followed by the same letter are not significantly different at 5% level using the LSD test.

percentages of infested plants. The proportion of plant with deadhearts was also smilar among all the inter-row crop treatments. Thus, increasing row ratio of the host plant had no effect on millet shootfly incidence. Cumulative curves for millet shootflies (Fig. 6) show that the monocrop treatment experienced a steeper rise in populations of this pest than any other treatment. The cummulative increase in millet shootfly activity among the intercrop treatments was generally similar except for the inter-row 1:3 treatment which had a higher rate of increase.

All intercrops had significantly lower populations ($P<0.05$) of the adult millet midge, Geromyia penniseti, than that of the monocrop treatment. The incidence of this pest was similar among the three cropping patterns studied. Sorghum: millet/cowpea inter-row ratios of 1:3 and 1:4 had similar populations of G.penniseti. However, these treatments harboured higher populations than the other two inter-row crop treatments. Increasing row ratios of millet/cowpea to sorghum resulted in an irregular trend in populations of this pest.

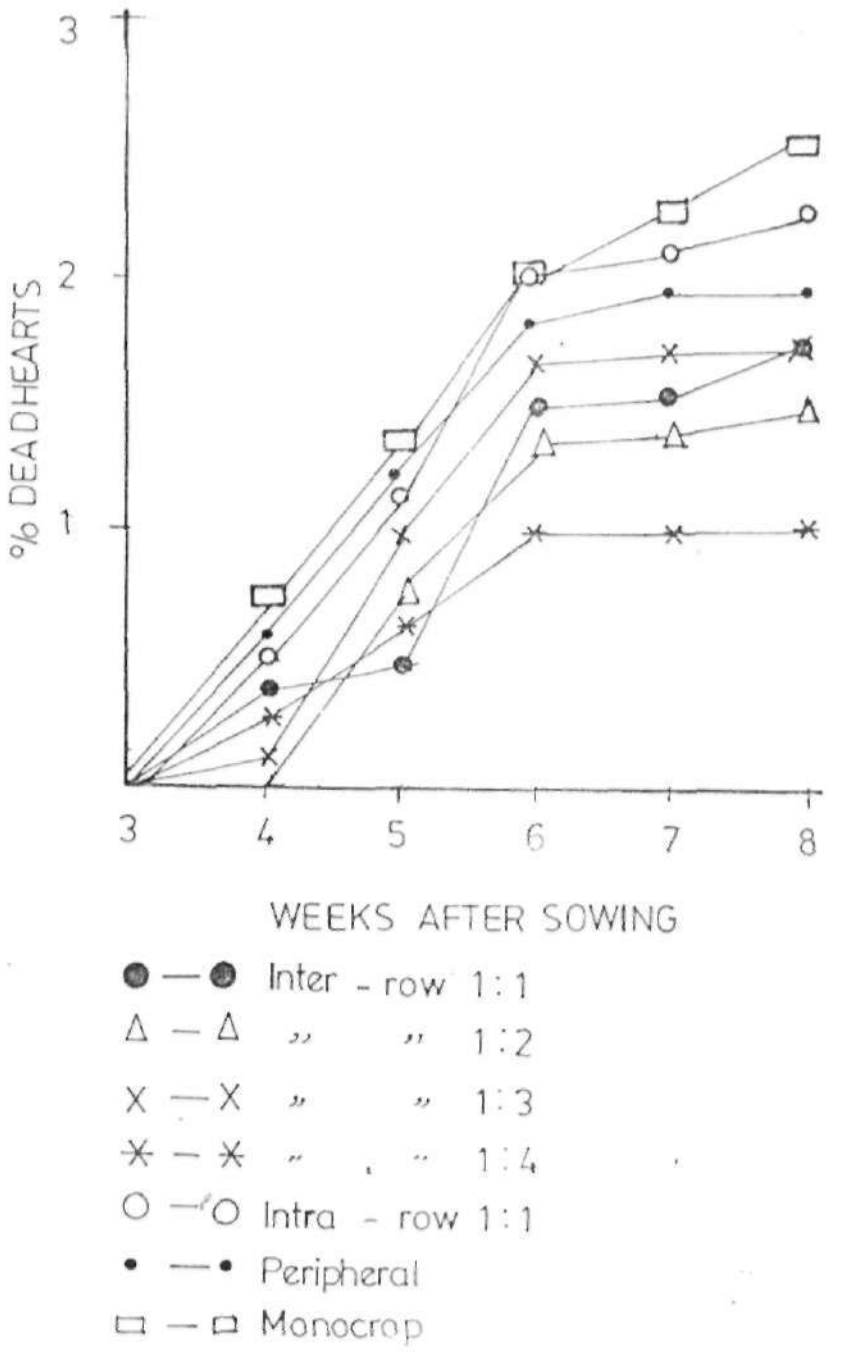


Fig. 6: Effect of intercropping pattern on the incidence of the millet shootfly at Samaru, 1985.

Monocrop millet harboured significantly higher populations ($P < 0.05$) of millet stem borers than intercropped millet (Table 2). The three cropping patterns harboured similar populations of millet stem borers. Increasing row ratio of millet/cowpea to sorghum among the inter-row treatments had no significant effect on the populations of the stem borers. Similarly the population of these did not reflect changes in the densities of the host plant relative to sorghum in the inter-row crop treatments. Fig. 7 shows that while cumulative populations of stem borers of millet on all intercrop treatments were low, similar and rose gradually, those on the monocrop millet were initially low but rose more steeply.

Adult headbeetle, Meligethes heteropus, populations on millet (Table 2) were lower ($P < 0.05$) on the peripheral, intra-row and 1:2 inter-row sorghum: millet/cowpea treatments than on the monorop. Populations of Meligethes on millet in the three remaining treatments were, however, similar to those on monocrop millet. Similar populations of this pest were recorded on the three cropping patterns. Headbeetle populations were similar on millet in all inter-row crop and an increase in the

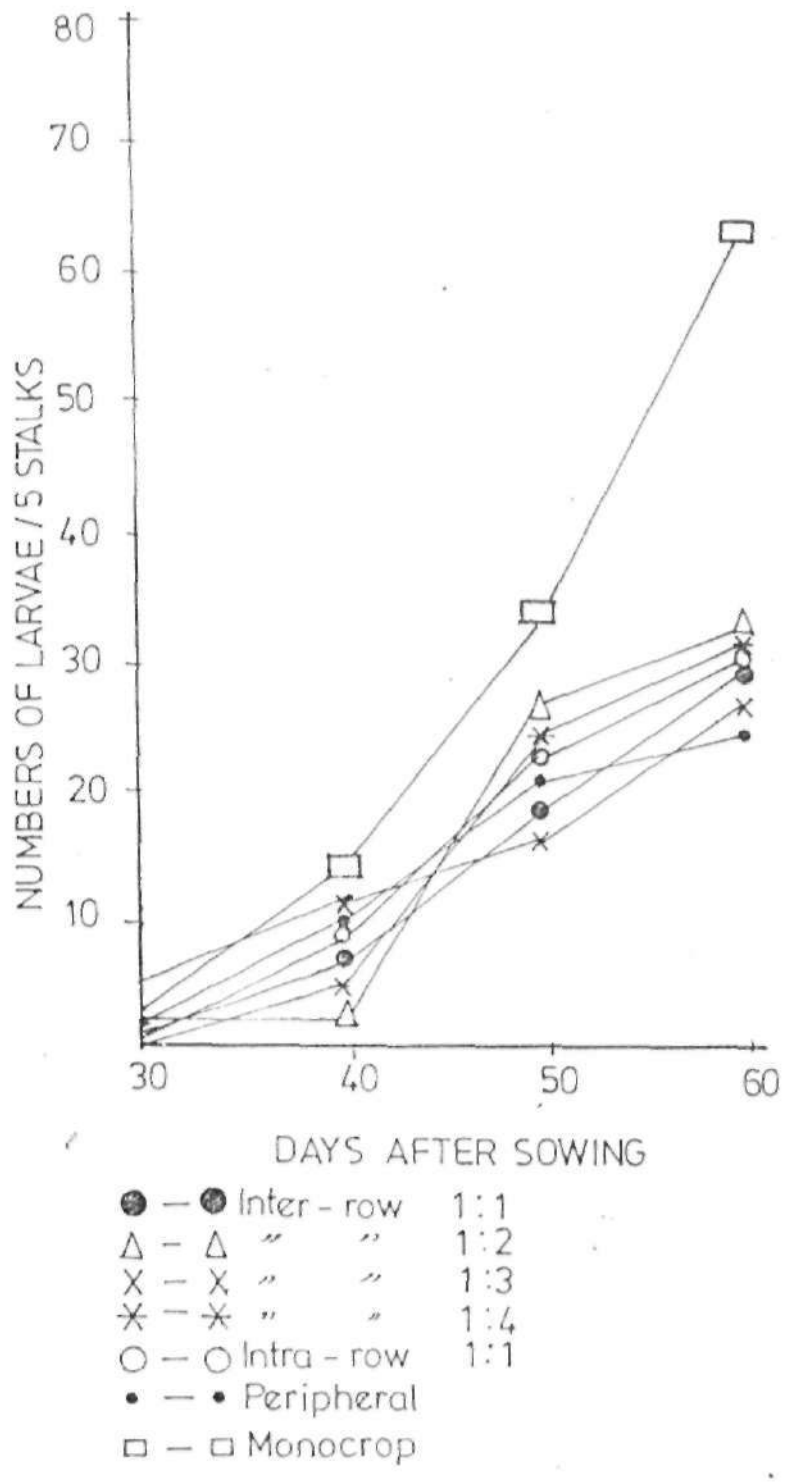


Fig. 7: Effect of intercropping pattern on the incidence of millet stem borer at Samaru, 1985.

population of the host crop relative to sorghum therefore had no measurable effect.

Table 2 shows that the treatment with sorghum: millet/cowpea row ratio of 1:2 harboured lower populations ($P < 0.05$) of the meloid, Melyris sp., than those on the monocrop treatment. However, the remaining treatments had similar Melyris populations to those on the monocrop. The three different cropping patterms also had similar populations of this pest. Sorghum: millet/cowpea inter-row ratio of 1:1, 1:2 and 1:3 harboured similar populations of this pest which were lower than those on 1:4. Melyris population trend among inter-row crop treatments was irregular with increasing proportion of millet rows relative to sorghum.

Sorghum: millet/cowpea inter-row ratio of 1:4 and the intra-row treatment (Table 2) had similar populations of Mylabris sp. on millet to those on the monocrop treatment. The remaining treatments carried lower populations of this pest than the monocrop. Similar populations of Mylabris were also recorded on the three cropping patterns. Among the inter-row crop treatments, while the 1:4 treatment had similar populations of Mylabris to those on 1:3, it had significantly higher humbers than those on 1:1 and 1:2 treatments. There was no consistent trend in

populations of this pest with increasing relative density of millet in the inter-row crop treatments.

Populations of adult Coryna hermaniae on millet (Table 2) were similar ($P > 0.05$) in all the treatments. However, among the inter-row crop treatments there was a consistent increase in populations of this pest as host density increased relative to sorghum.

Populations of the shield bug, Agonosceles versicolor, on monocrop millet were similar to the 1:4 inter-row ratio but higher than the remaining intercrop treatments (Table 2). Similar populations (P 0.05) of this pest were recorded on millet in all the three cropping patterns studied. Sorghum: millet/cowpea inter-row ratio 1:4 had significantly higher populations ($P < 0.05$) of this pest than the remaining inter-row crop treatments. When the general trend within the inter-row crop treatments is considered, changes in population of A. versicolor appeared to be inconsistent with increasing ratios of millet/cowpea rows to those of sorghum.

The population of Rhaguva sp in monocrop millet was significantly higher ($P < 0.05$) than 1:1 row ratio of sorghum: millet/cowpea but was similar to those on all other intercrops (Table 2).

Head caterpillar populations on all cropping patterns were similar. Although the 1:1 inter-row treatment had similar populations of this pest to the 1:2, it had significantly lower populations than the 1:3 and 1:4. Increasing densities of millet in the inter-row crop treatment did not result in a corresponding increase or decrease in populations of this pest.

4.1.2.3 Cowpea pests (Table 3)

Monocrop cowpea harboured statistically similar populations of the foliage beetle, Ootheca mutabilis, to those on the treatments with 1:3 and 1:4 row ratios of sorghum:millet/cowpea which were higher ($P < 0.05$) than those on the remaining treatments. O. mutabilis populations were also similar to those in the 1:2 and 1:3 but statistically lower ($P < 0.05$) than those on the 1:4 treatment. Populations of O. mutabilis increased with increase in density of cowpea among the inter-row treatments.

The populations of the cowpea thrips, M. sjostedti, on the sorghum:millet/cowpea row ratio of 1:4, the intra-row and the peripheral treatments were similar to those on monocrop cowpea. Population of thrips on cowpea in the peripheral treatment was similar to intra-row 1:1 but not inter-row 1:1. Although M. sjostedti populations were statistically similar among

TABLE 3. 1985 Experiment. Mean cumulative populations of cowpea insect pests.

TREATMENT	No of Ootheca/ 5 plants	No of Megalurothrips/ 10 flowers	No of A. craccivora/ 10 pods	Maruca emergence holes/ 50 pods	No of pods damaged by sucking bugs/50 pods	No of P. varium/ 50 pods	No of bruchids / 50 pods
Sorghum:millet/cowpea inter-row ratio of 1:1	20.3a	57.0a	176.0abc	69.0ab	27.0ab	37.7a	45.3abc
Sorghum:millet/cowpea inter-row ratio of 1:2	27.0ab	59.0ab	111.6ab	61.0ab	26.7ab	41.3a	39.6ab
Sorghum:millet/cowpea inter-row ratio of 1:3	32.0abc	60.3ab	173.6abc	59.5ab	27.7ab	42.2a	52.0abc
Sorghum:millet/cowpea inter-row ratio of 1:4	39.7bc	78.7abc	176.6bc	73.3ab	26.0ab	46.0a	52.0abc
Sorghum:millet/cowpea intra-row ratio of 1:1	31.3ab	88.3abc	97.6a	51.3a	20.3a	38.7a	33.0a
3 sorghum stands peripheral to a core area of millet/ cowpea	24.7a	92.0 bc	191.6cd	59.7ab	29.0ab	39.7a	62.0bc
Monocrop cowpea	45.7c	110.0c	263.3d	106.0b	33.0b	52.7a	63.0c
± SED	6.41	15.77	36.14	21.92	4.43	10.64	9.75

Within a column, values followed by the same alphabet are not different at the 5% level of significance using the LSD test.

the inter-row crop treatments, there was a gradual increase in populations of this pest with increasing relative densities of the host plant.

The population of the cowpea aphid on the monocrop was significantly higher ($P<0.05$) than in all the inter-row and the intra-row crop arrangements but was similar to that in the peripheral treatment. Among the three cropping patterns studied, the intra-row treatment had similar aphid populations to those of the sorghum:millet/cowpea row ratio of 1:1 but lower than the peripheral treatment. Increasing the ratio of millet/cowpea to sorghum in the inter-row crop arrangement had no significant effect on aphid populations.

All intercrops except the intra-row crop treatment had similar populations ($P>0.05$) of adult emergence holes of the cowpea pod borer, Maruca testulalis, to those on the monocrop treatment. Increasing the row ratio of cowpea had no corresponding effect on the populations of the pod borer. Similar numbers of emergence holes were recorded on all three cropping patterns.

Besides the intra-row crop treatment which had fewer ($P<0.05$) shrivelled pods (evidence of pod sucking damage), all the remaining treatments had similar populations of damaged pods to those on monocrop cowpea. There was no significant change in damage caused by these pests among the three cropping patterns with similar crop ratio. Among the inter-row

crop treatments, differences in damage caused by bugs with increased relative density of cowpea were neither significant nor regular.

All treatments had similar populations ($P > 0.05$) of the cowpea weevil, C. varium, on cowpea. Thus intercropping had no significant effect on the abundance of this pest. However, numbers of the weevil increased with relative increase in cowpea rows amongst the inter-row crop treatments.

Among intercrops, only the intra-row and 1:2 sorghum: millet/cowpea inter-row treatments had lower ($P < 0.05$) populations of bruchids than those on the monocrop treatment. All others recorded populations similar to those on monocrop cowpea. Among the three cropping patterns with similar relative plant densities, the intra-row treatment had similar populations of bruchids to those on the 1:1 row ratio of sorghum:millet/cowpea but statistically lower than those on the peripheral treatment. Populations of bruchids were not statistically different among the inter-row crop treatments and did not exhibit a consistent trend with increase in relative densities of cowpea plants.

4.1.3 Discussion

The shootflies, midge and stem borers on sorghum (Table 1); shootflies, stem borers, Rhaguva, midge, the

moloids (Melyris and Mylabris) and headbeetles on millet (Table 2) and beetles, thrips, aphids, podborers, pod sucking bugs and bruchids on cowpea (Table 3) had significantly lower populations on one or more of the intercrops than the corresponding monocrop treatments. Among these, the populations of shootflies and midge on sorghum and midge and stem borers on millet were significantly higher on the monocrops than on all the intercrops. The monocrop treatments harboured higher pest populations as a consequence of the large concentration of their single host species which made it possible for the pests to invade and multiply rapidly in the absence of non-host crops Root, (1973). Such monocrop stands were more prone to discovery, that is, they were more apparent to invading pest populations (Feeny, 1976) than the intercrops. In addition to these, lower abundance of cowpea pests on the intercrops could have been due to the presence of sorghum acting as a non-host physical barrier which could confuse landing potential insect invaders of intercrop cowpea at the canopy level, impede the dispersal of these pests within the cowpea and create an unsuitable microclimate that would discourage colonisation and intensify the activity of mortality factors.

The headworm on sorghum, meloids (Coryna sp.) and shield bugs on millet and E. varium on cowpea had similar

populations in all the treatments. The headworm on sorghum may also feed on the cowpea which therefore, could not have discouraged it from colonizing intercrop sorghum. The presence of cotton and maize in nearby fields possibly attracted more headworm to the neighbourhood and therefore increased the number of individuals available to infest sorghum. Furthermore, sorghum being the tallest crop, their heads in all treatments were equally in an exposed position above the canopy. These factors were possibly responsible for similar numbers of H. armigera on sorghum in all treatments. The meloid, Caryna hermanniae, and the shield bug, A. versicolor, fed on the foliage of millet and sorghum initially and later switched on to millet heads. Here too, the great variety of food plants ensured similar populations of the meloid and shield bugs on millet in all treatments. It is possible in the case of P. varium that the ageing sorghum crop with its drooping leaves was neither able to camouflage pods from invading weevils nor limit their dispersal within the cowpea.

The populations of most of the insects were statistically similar on all the three intercrop patterns with the same crop ratios. However, the intra-row cropping pattern had significantly lower infestations of sorghum shootfly than the remaining patterns, and of aphids and field infestations of

bruchids on cowpea than the peripheral pattern. Furthermore, significantly lower numbers of stemborers were found on the inter-row than on the peripheral cropping pattern. Thus it was not possible to rank the performance of the cropping patterns by this criterion. It is however clear from Tables 1-3 that the inter-row and intra-row patterns each had 10 insect pests and the peripheral pattern had 7 insect pest species whose populations were significantly lower than those on the monocrop treatments. On this basis, the intra-row and inter-row patterns may be considered to have performed better by lowering the numbers of more insect species from the control than the peripheral intercrop pattern. This could be because the peripheral intercrop pattern approximates more closely to a monocrop situation.

The effect of sorghum shootfly declined with decreasing density of the host plant among the inter-row crop treatments. This was probably so because as the sorghum plant density decreased, the adult shootfly and their emerging progenies found it increasingly difficult to locate a host on which to feed and oviposit. For Coryna on millet and O. mutabilis, thrips and P. varium on cowpea, populations increased with increasing row ratio of their host plants. This was so because the crops became more apparent, both visually and olfactorily, to their pests. This observation conforms with the "plant apparency theory"

of Feeny (1976), the "resource concentration theory" Of Root (1973) and Tahvanainen and Root's (1972) "associational resistance theory". The remaining pests which did not exhibit a particular pattern of abundance and others like pod sucking bugs on cowpea, which showed no apparent change in numbers did not fall in line with these theories. The reasons for this are not clear.

It is clear from Fig. 3-7 that the activity or populations of shootflies and midge on sorghum and shootflies and stem borers on millet increased much more rapidly on the monocrop treatments probably because the pure stands were easier to find and feed on than mixed stands where the possibility of visual and/or olfactory confusion was high. However, while the incidence of deadhearts (sorghum and millet) declined in the last threesamples probably because most of the plants had grown beyond the stage susceptible to these pests, the incidence of sorghum midge declined probably because later in their development the grains became unsuitable sites for oviposition resulting in lower midge populations. It is likely that the monocrop situation created at the periphery led to the build-up of sorghum stemborers on the peripheral treatment.

4.2 1986 EXPERIMENT

4.2.1 Methods

The experiment was carried out on IAR Field S_5B. Cotton had been grown on this field in 1985. An area measuring 85m x 30.5m (Fig. 8) was marked out and later divided into 27 equal plots, each measuring 7m x 7.5m. The plots were separated from each other and from the sorrounding uncultivated land by a 2m unplanted discard. The experiment was a randomised block design (Fig. 8) made up of the following nine treatments (Fig. 9) each replicated three times:

Sorghum:millet/cowpea inter-row ratio of 1:1
" " " " " 1:2
" " " " " 1:3
" " intra-row " " 1:1
" " " " " 1:2
" " " " " 1:3

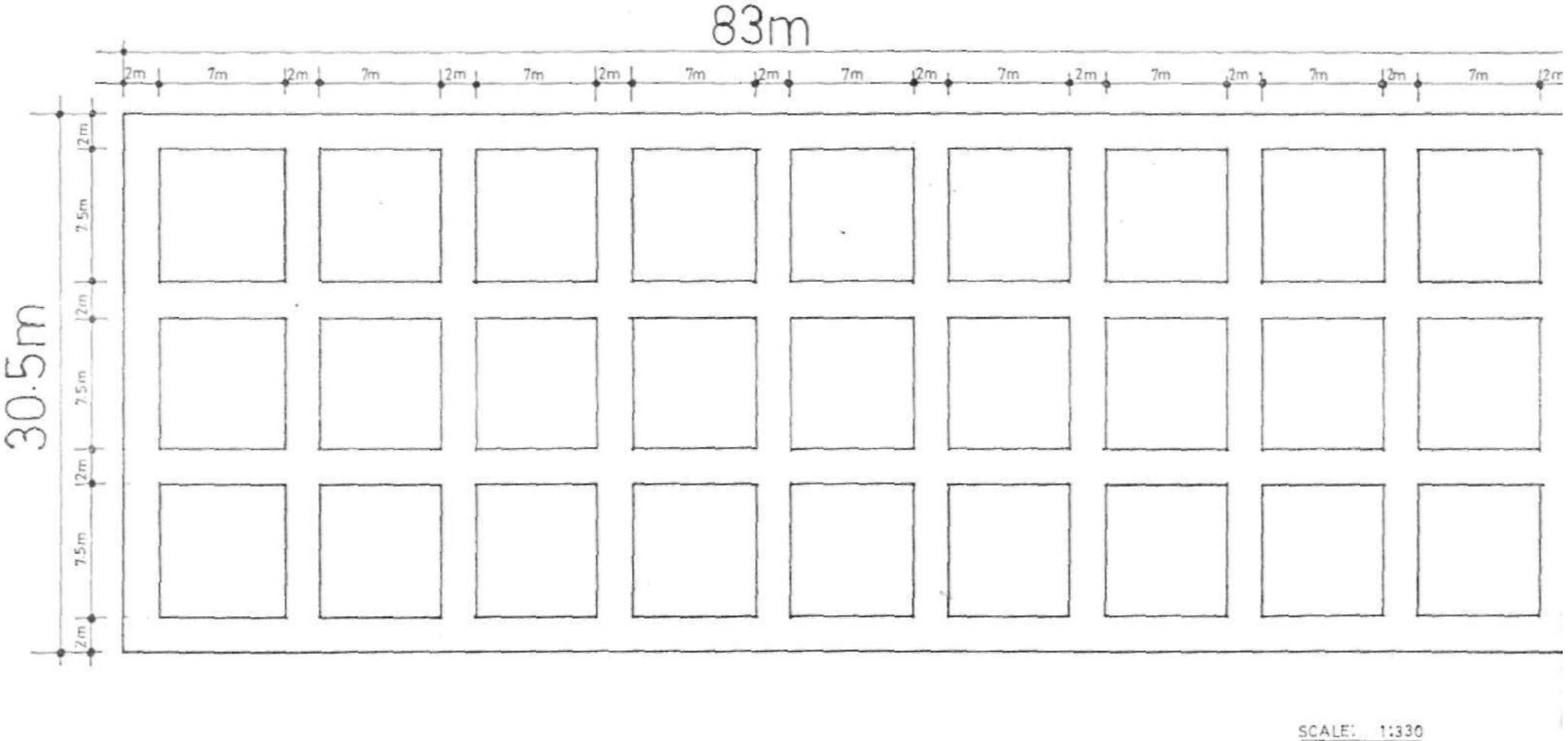
Monocrop sorghum.

Monocrop millet.

Monocrop cowpea.

Sorghum and millet on the one hand and cowpea on the other were sown on 7th June and 28th July, 1986, respectively. All crops were sown on ridges spaced 0.75m apart. In the intra-row crop treatments (Fig. 9) one, two or three millet/cowpea stands,

FIG.8. LAYOUT OF 1986 EXPERIMENT.



SCALE: 1:330

6.) SPATIAL PATTERNS OF CROPS IN THE INTERCROP AND



respectively, were sown within the row between two sorghum stands spaced 1m apart. In the inter-row crop treatments, millet/cowpea stands were sown on one, two or three rows, respectively between two adjacent rows of sorghum. All crops were spaced 0.5m apart in all monocrop and inter-row treatments.

4.2.2 RESULTS

The 1986 results are presented with particular emphasis on the following aspects:

i) Populations of insect species on the intercrops are compared with those on their respective monocrops.

ii) Pest populations are compared between intra-row and inter-row treatments at each level.

iii) Levels of plant ratio within intra-row treatments are compared for significance.

iv) Levels of plant ratio within the inter-row treatments are compared for significance.

v) The influence of densities of the host plant relative to other crops on insect populations is stated.

4.2.2.1 Sorghum pests

There was no significant difference between the treatments in the percentage of sorghum plants infested

by the sorghum shootflies (Table 4). Therefore neither intra-row cropping no inter-row cropping significantly influenced the incidence of the shootflies on sorghum. The incidence of deadhearts within the inter-row treatments did not follow a consistent trend with increasing row ratio of sorghum to millet/ cowpea. A similar situation obtained among the three intra-row cropping treatments. Percentages of shoots with deadhearts in all treatments rose steeply at the beginning of sampling but declined as the plants increased in size with age (Fig.10). Inter-row 1:3 experienced the most rapid increase in percentage of deadhearts.

At P = 0.05 the incidence of sorghum midge, Contarinia sorghicola, on monocrop sorghum was similar to that on all other treatments except sorghum: millet/cowpea inter-row 1:2 and intra-row 1:1 ratios (Table 4). Populations of this pest on inter-row and intra-row treatments with the same sorghum: millet/cowpea plant ratios were similar. Decreasing ratio of sorghum to millet/cowpea rows in the inter-row crop treatments did not significantly alter the infestation by this pest. Similar populations of C. sorghicola were also recorded on all intra-row crop treatments. Furthermore, although

TABLE 4. 1986 Experiment. Mean cumulative populations of sorghum insect pests.

TREATMENTS	% deadhearts (A. soccata)	No of C. sorghicola/ 100 seeds	No of stem borers/ 5 stalks	No of Heliothis/ 10 heads
Sorghum:millet/cowpea inter-row ratio of 1:1	4.6a	18.3abc	13.3b	4.3a
Sorghum:millet/cowpea inter-row ratio of 1:2	4.3a	10.0a	2.3a	5.7a
Sorghum:millet/cowpea inter-row ratio of 1:3	5.5a	18.0abc	7.0ab	5.0a
Sorghum:millet/cowpea intra-row ratio of 1:1	5.0a	12.3ab	14.0b	13.3a
Sorghum:millet/cowpea intra-row ratio of 1:2	3.1a	14.3abc	8.0ab	9.0a
Sorghum:millet/cowpea intra-row ratio of 1:3	4.2a	21.7bc	24.3c	11.7a
Monocrop sorghum	3.1a	23.3c	15.7bc	8.3a
± SED	1.23	4.41	4.57	4.25

Within a column, values followed by the same letter are not significantly different at 5% level using the LSD test.

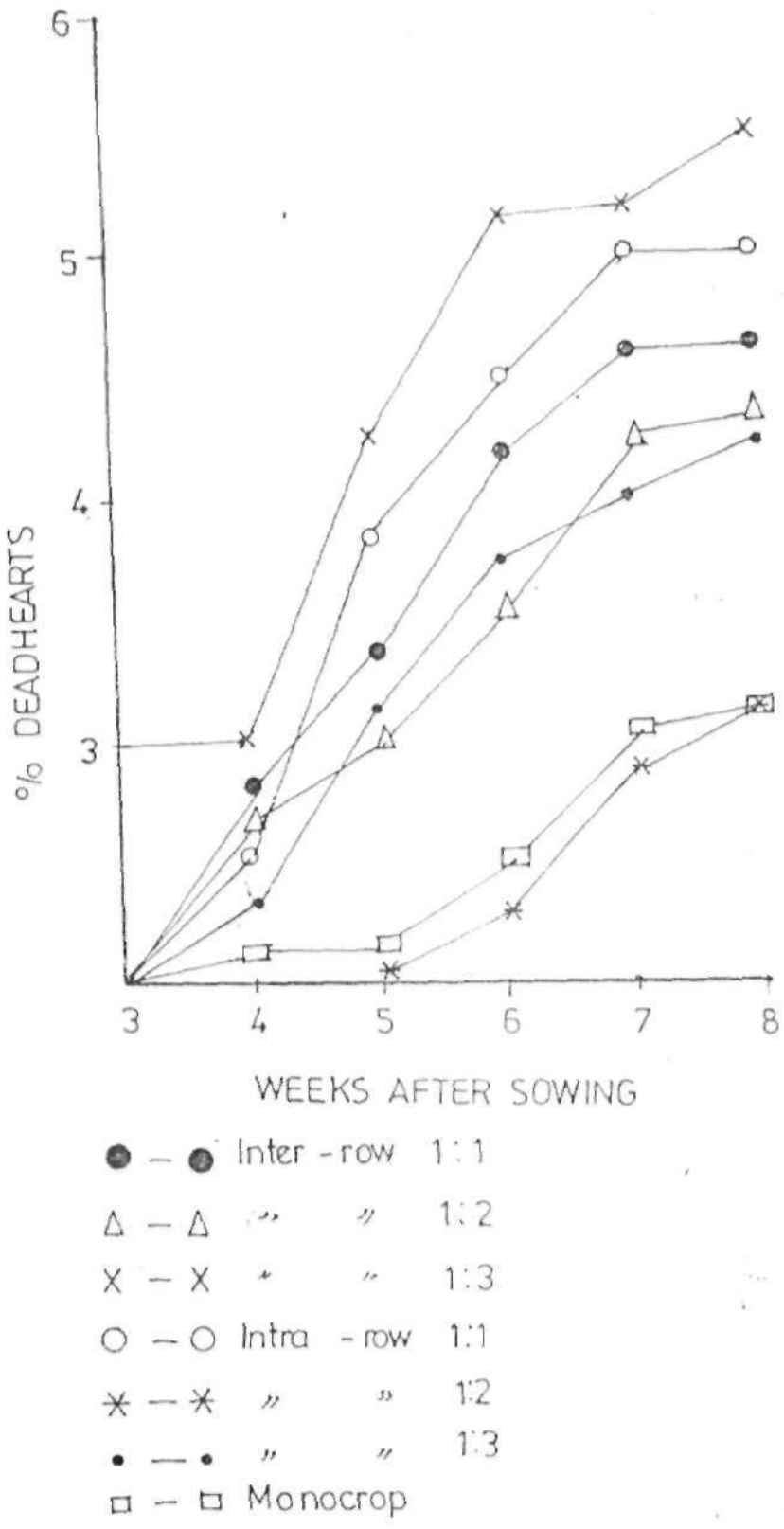


Fig. 10 : Effect of intercropping pattern on the incidence of sorghum shootfly at Samaru, 1986.

C. sorghicola populations changed irregularly amongst the inter-row crop treatments, they increased in the intra-row crop treatments with decreasing ratio of sorghum to millet/cowpea densities. Fig. 11 shows that cumulative numbers of C. sorghicola increased rapidly for the first three samples but the increment declined in the last sample for most treatments.

The treatment with sorghum: millet/cowpea row ratio of 1:2 had fewer ($P<0.05$) sorghum stem borers than monocrop sorghum (Table 4). All other treatments, however, however, had similar stem borer populations to those on the monocrop. Except at sorghum:millet/cowpea plant ratio of 1:3 where the intra-row treatment had higher populations of stem borers than the inter-row arrangement similar populations of stem borers were recorded at each plant ratio in the intra-row and inter-row and inter-row treatments. Witin the intra-row treatments, the sorghum: millet/cowpea row ratio of 1:1 and 1:2 had similar populations of the stem borers, which were significantly lower ($P<0.05$) than those of the 1:3 ratio. The pest population did not change in a consistent direction with decreasing relative densities of the host plant. The intra-row 1:3 treatment not only had

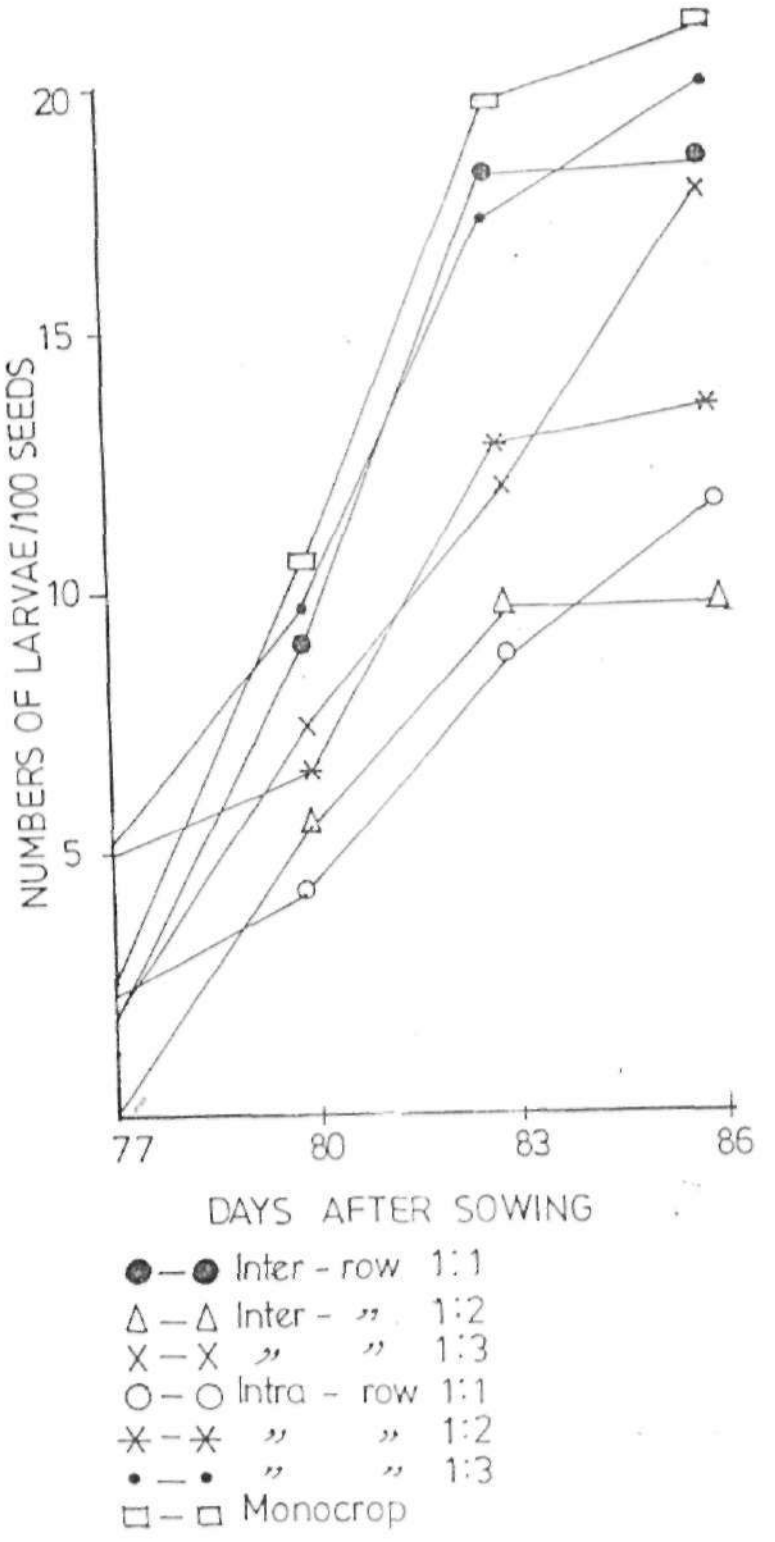


Fig. 11: Effect of intercropping pattern on the incidence of sorghum midge at Samaru, 1986.

about the highest populations of stem borers at the beginning of sampling but also maintained this situation throughout the sampling period (Fig. 12).

Populations of the sorghum headworm, Heliothis armigera (Table 4), were similar in all treatments. There was no effect of intercropping on populations of this pest whether its host was mix-cropped within or between rows. Numbers of H. armigera did not change in a consistent direction with decreasing ratio of sorghum in both the inter-row and intra-row treatments.

4.2.2.2. Millet pests

Only sorghum to millet/cowpea intra-row and inter-row ratios of 1:1 had significantly higher ($P < 0.05$) incidence of millet deadhearts (caused by shootflies) than those on the monocrop treatment (Table 5). Percentages of millet deadhearts were also similar on all sorghum: millet/cowpea intra-row and inter-row treatments with similar plant ratios. Among the intra-row treatments, similar populations ($P > 0.05$) of deadhearts were recorded on sorghum: millet/cowpea intra-row 1;2 and 1:3 ratios which had fewer deadhearts than those on the 1:1 ratio. Although percentages of deadhearts were statistically similar among the inter-row crop treatments,

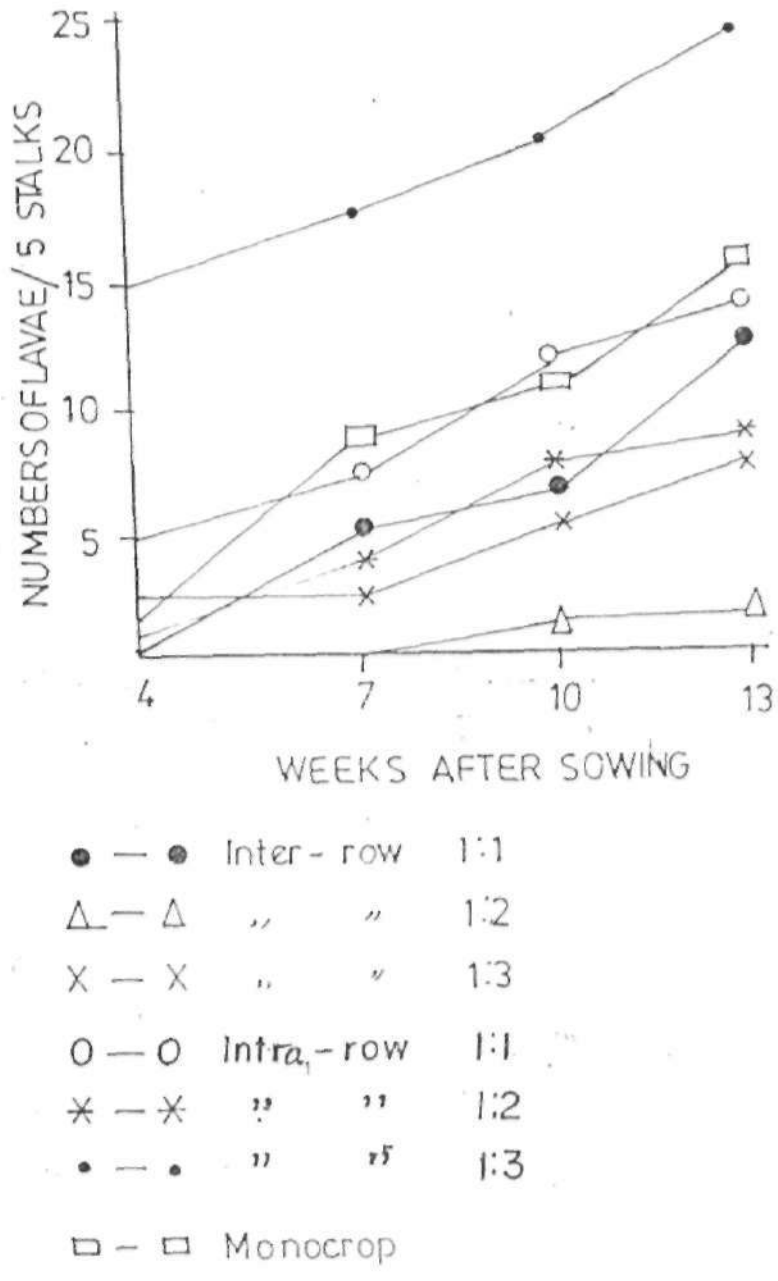


Fig. 12: Effect of intercropping pattern on the incidence of sorghum stem borer at Samaru, 1986.

TABLE 5. 1986 Experiment. Mean cumulative populations of millet insect pests.

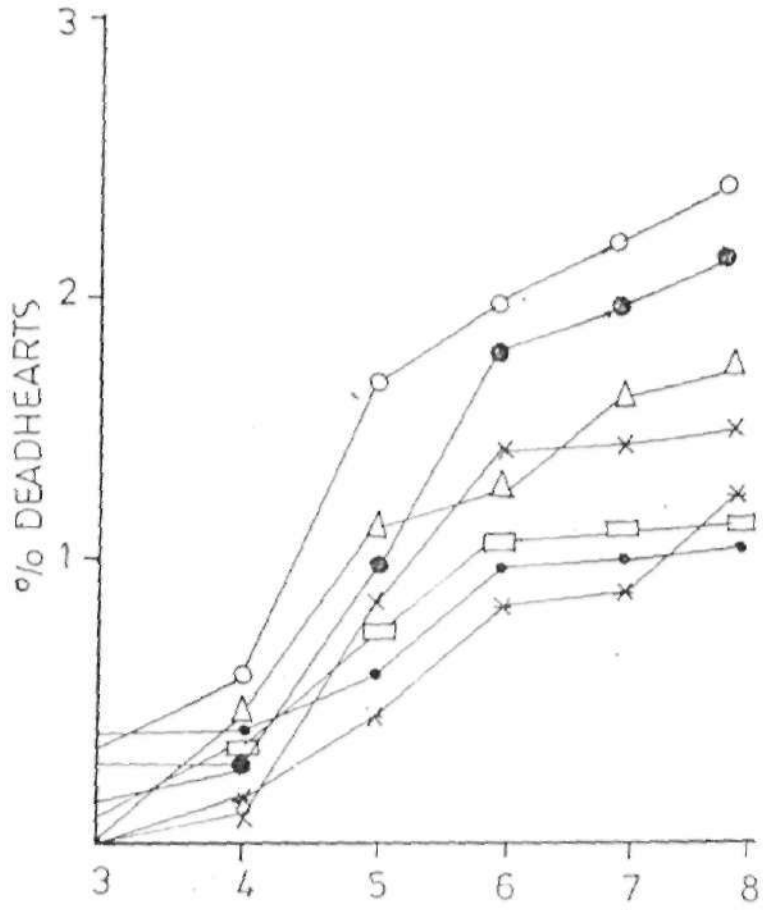
TREATMENTS	% deadhearts D. arambourgi	No of G. penniseti/ 5 heads	No of stemborers/ 5 stalks	No of Meligethes/ 5 heads
Sorghum:millet/cowpea inter-row ratio of 1:1	2.2bc	32.7a	8.0a	40.0ab
" " " " " " 1:2	1.8abc	46.3a	6.7a	50.7ab
" " " " " " 1:3	1.6abc	63.3a	11.0ab	78.7ab
" " " intra-row " " 1:1	2.4c	25.0a	6.4a	46.7ab
" " " " " " 1:2	1.3ab	52.3a	19.7b	32.0a
" " " " " " 1:3	1.1a	39.3a	13.3ab	94.3b
Monocrop millet	1.2a	50.7a	12.7ab	73.3ab
± SED	0.44	28.35	4.70	26.35

Within a column, values followed by the same letter are not significantly different at 5% level using the LSD test.

increasing relative densities of the host resulted in decreasing percentage of millet deadhearts. In the intra-row treatments, numbers of deadhearts decreased with increasing relative densities of the millet plant. Cumulative percentages of millet deadhearts (Fig. 13) increased rapidly during the first three weeks of sampling. Thereafter, the rate of increase declined probably because most of the plants had grown beyond the stage susceptible to these insects. Although rates of increase were generally similar, the intra-row 1:1 treatment maintained the highest shootfly infestations throughout the sampling period.

Populations of adult millet midge, Geromyia penniseti, on millet on all treatments were similar (Table 5). Thus neither inter-row nor intra-row cropping significantly changed the incidence of millet midge from those on the monocrop. G. penniseti numbers on millet increased with increasing rows of millet/cowpea relative to sorghum among the inter-row treatments. However, among the intra-row treatments, the incidence of this pest changed irregularly with increasing plant ratio of its host plants.

Millet stem borer populations on the monocrop treatment were not different ($P > 0.05$) from those on millet in the remaining treatments. The two cropping



●—● Inter - row 1 : 1
Δ—Δ " " 1 : 2
X—X 1 : 3
o— o Intra - row 1 : 1
✳—✳ " " 1 : 2
•—• " " 1 : 3
▭—▭ Monocrop

Fig. 13: Effect of intercropping patterr. on the incidence of millet shootfly at Samaru, 1986.

patterns supported similar populations of this pest at all levels except 1:2 where the inter-row treatment had significantly fewer borers than the intra-row one. The sorghum: millet/cowpea intra-row ratio of 1:2 had similar populations ($P > 0.05$) of this pest compared with those on 1:3 which were higher than those on 1:1. Similar borer populations were, however, recorded on all inter-row treatments. Increasing ratio of millet/cowpea to sorghum within the inter-row crop treatments did not cause a consistent increase or decrease in numbers of millet borers. Fig 14 shows that numbers of millet stem borers increased most rapidly on the intra-row 1:2 treatment and least so on the intra-row 1:1 treatment. The remaining treatments had similar increase. The final build-up of populations of this pest falls into three distinct groupings.

All treatments supported similar populations ($P > 0.05$) of the millet headbeetles, Meligethes heteriopus. The two cropping patterns studied had similar populations of this pest at each crop ratio. Population of M. heteropus were similar in all inter-row treatments. However, sorghum to millet/ cowpea intra-row ratio of 1:2 had statistically similar headbeetle populations to the 1:1 ratio but

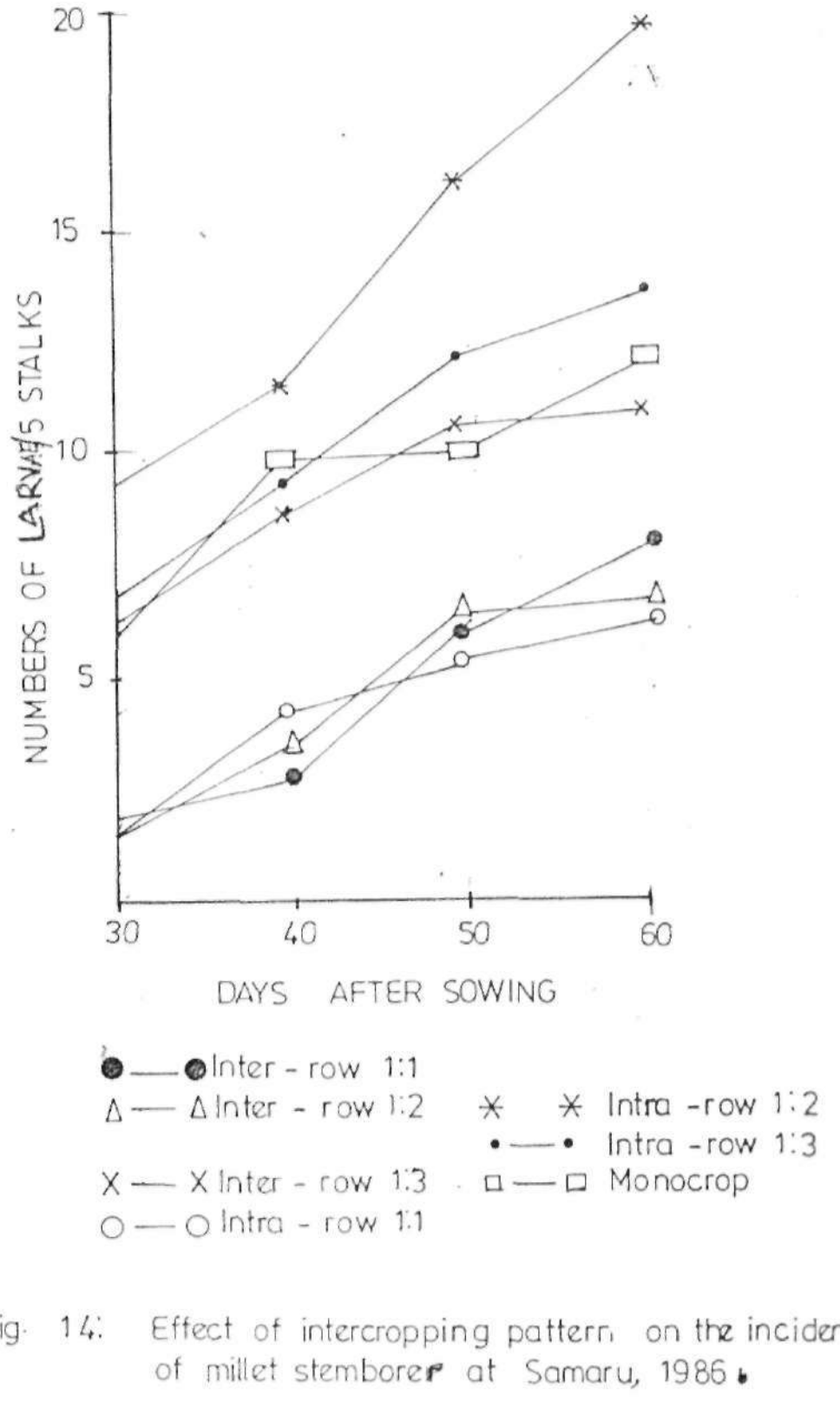


Fig. 14: Effect of intercropping pattern on the incidence of millet stemborer at Samaru, 1986.

TABLE 6.

1986 Experiment. Mean cumulative populations of Ootheca mutabilis on cowpea.

TREATMENT		No. of beetles/ 5 plants
Sorghum:millet/cowpea inter-row ratio of	1:1	30.7ab
" " " " " " "	1:2	9.0a
" " " " " " "	1:3	36.0ab
" " " intra-row " "	1:1	23.0ab
" " " " " " "	1:2	17.7ab
" " " " " " "	1:3	13.0a
Monocrop cowpea		46.3b
± SED		13.25

Within a column, values followed by the same letter are not significantly different at 5% level using the LSD test.

lower than the 1:3 ratio. Numbers of Meligethes sp. increased with increasing populations of millet/cowpea to sorghum among the inter-row crop treatments. However, their numbers in the intra-row crop treatments did not show a regular trend with increased density of millet/cowpea to sorghum.

4.2.2.3 Cowpea pests (Table 6)

Significantly higher populations ($P < 0.05$) of the cowpea foliage beetle, Cotheca mutabilis, were recorded on monocrop cowpea than on the sorghum to millet/cowpea intra-row 1:3 and inter-row 1:2 treatments, populations of this pest on the remaining treatments were similar to those on the control. Similar populations of this beetle were recorded at all levels for each of the two cropping patterns. The two intercropping patterns also had similar populations of this pest between themselves at each level. Although populations of cowpea beetles in the three intra-row crop treatments was statistically similar, their numbers decreased with increasing relative densities of the host plant. Among inter-row treatments, however, numbers of this pest were statistically similar and did not increase or decrease consistently with increasing relative densities of the host plant.

4.2.3 Discussion

It is clear from the 1986 experiment (Tables 4-6) that the monocrop treatments had statistically similar populations of shootflies and headworm on sorghum and headbeetles, midge and stem borers on millet to those on all the intercrop treatments. The monocrop treatment, however, had higher populations of midge and stem borers on sorghum and leaf beetles on cowpea than at least one of the intercrop treatments. Populations of headworm on sorghum on all treatments were similar due probably to its polyphagous feeding habit; the variety of food plants in the area was further enriched by the presence of cotton, tomato and maize near the field. The way this could affect H. armigera, the sorghum headworm, has been described in section 5:1 No. precise reason could be found for the behaviour of the other species which maintained similar activity (or population) on all the treatments.

The population of the stem borers of millet and sorghum were higher on the intra-row 1:2 and 1:3 than their corresponding inter-row levels. This contradicts a similar work carried out by (Adesiyun, 1983) who showed that infestation of sorghum by Busseola fusca was reduced when interplanted with millet in alternate stands within the same row. The reason for this contradiction is not clear. It may, however,

be attributable to differences in sampling procedure employed in these two studies. Each of the remaining pests on all three crops had statistically similar populations on inter-row and intra-row cropping patterns at each crop ratio.

With increasing density of millet/cowpea relative to a similar population of sorghum in the intra-row crop treatments, numbers of sorghum midge (Table 4) increased while those of millet shootflies (Table 5) and cowpea beetles (Table 6) decreased. In the inter-row crop treatments, however, increasing densities of millet cowpea in relation to sorghum led to declining activity of millet shootfly and increasing populations of millet midge and headbeetles (Table 5). It would appear that with increasing ratio of millet/cowpea to sorghum rows, the treatments tended towards monoculture and thereby enabled some of these pests (head beetles and midge on millet among the inter-row treatments) to locate and utilize their host plants more easily as there was relatively less disturbance from the non-host sorghum. However, no precise reason could be advanced for the apparent consistent trend in populations of the sorghum midge, the millet shootflies and the cowpea leaf beetle among the intra-row crop treatments and in those of millet shootflies among the inter-row treatments.

The build-up of some insect pests of these crops (Figs. 10-14) could be explained in the same light as those of 1985 (4.1.3) except that the monocrop treatments harboured lower populations of pests than some intercrops. No precise reason could be advanced for this situation.

GENERAL DISCUSSION

It is clear from these experiments that the abundance of some of the more important insects of each component of this three-crop system was reduced due to growing these crops in mixture. While it is apparent from the 1985 experiment that the intra-row and inter-row treatments had an edge over the peripheral, the inter-row did better than intra-row in 1986. The principle that species diversity can be important in the control of pest population outbreaks (Graham, 1975; MacArthur, 1955; Murdoch, 1975; Way, 1976; 1977) has some application in these experiments. This, therefore, supports the idea that intercrop systems can promote mutual protection of their component crops from pests (Adesiyun, 1983; Amoaka-Atta, 1983; Azueh, 1980; Uvah, 1978; Uvah and Raheja, 1984; Taylor, 1977, where possible, diversity of both fauna and flora should be encouraged. It is acknowledge, however, that although reductions in insect pest abundance such as were obtained here could have significant impact on production in capital-scarce, low input subsistence agriculture, it is not likely to provide the high levels of control required in capital-intensive agriculture.

Since it appears that intercropping will undoubtedly persist for some considerable time on the subsistence farms which produce the bulk of the food consumed in this country, and in view of the fact that elements of natural pest control exist in these cropping patterns, investigations to elucidate the likely factors responsible for pest reductions will be useful in efforts to improve the effectiveness of crop diversity in pest management. Crop diversity could then be integrated with low doses of other ecologically and financially more costly insect control measures.

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APPENDIX A (1985)

1. Cumulative means percentages of sorghum deadhearts.

TREATMENTS	WEEKS AFTER SOWING					
	3	4	5	6	7	8
S:M/C inter-row 1:1	0.0	0.65	1.35	2.0	2.2	2.4
" " " 1:2	0.6	1.0	1.55	1.9	2.0	2.0
" " " 1:3	0.0	0.15	0.55	1.25	1.3	1.4
" " " 1:4	0.0	0.2	0.4	1.2	1.3	1.3
S:M/C intra-row 1:1	0.0	0.0	0.2	0.5	0.6	0.6
Peripheral	0.0	0.8	1.3	1.8	1.9	1.9
Monocrop	0.7	1.5	2.5	3.1	3.2	3.4
± SED	0.23	0.62	0.25	0.42	9.1	0.12

2. Cumulative mean populations of sorghum midge.

TREATMENTS	DAYS AFTER SOWING			
	77	88	83	86
S:M/C inter-row 1:1	1.5	6.5	12.5	13.0
" " " 1:2	1.5	4.0	7.5	10.0
" " " 1:3	0.0	7.0	16.5	17.7
" " " 1:4	0.0	9.0	11.0	13.3
S:M/C intra-row 1:1	0.5	10.0	15.5	15.7
Peripheral	3.5	5.0	6.5	12.3
Monocrop	15.0	25.0	35.0	35.7
± SED	1.7	4.8	4.1	2.4

3. Cumulative mean populations of sorghum stem borers.

TREATMENTS	WEEKS AFTER SOWING			
	4	7	10	13
S:M/C inter-row 1:1	8.5	30.0	33.0	39.0
" " " 1:2	14.0	20.0	30.0	34.3
" " " 1:3	13.5	36.0	37.5	38.0
" " " 1:4	8.0	22;0	40.0	44.0
S:M/C intra-row 1:1	17.0	40.0	40.0	43.3
Peripheral	10.0	41.5	51.0	54.7
Monocrop	14.0	26.0	44.0	59.3
± SED	8.9	4.8	2.9	6.9

4. Cumulative mean percentage of millet deadhearts.

TREATMENT	WEEKS AFTER SOWING					
	3	4	5	6	7	8
S:M/C inter-row 1:1	0.0	0.4	0.5	1.6	1.6	1.8
" " " 1:2	0.0	0.0	0.75	1.45	1.45	1.6
" " " 1:3	0.0	0.1	1.0	1.8	1.8	1.8
" " " 1:4	0.0	0.35	0.6	1.0	1.0	1.0
S:M/C intra-row 1:1	0.0	0.5	1.1	2.0	2.1	2.3
Peripheral	0.0	0.6	1.2	1.9	2.0	2.0
Monocrop	0.0	0.7	1.3	2.0	2.35	2.6
± SED	0.48	0.36	0.47	0.17	0.15	2.8

5. Cumulative mean populations of millet stem borers.

TREATMENT	DAYS AFTER SOWING			
	30	40	50	60
S:M/C inter-row 1:1	0.0	7.0	20.0	31.3
" " " 1:2	0.3	3.0	28.0	34.7
" " " 1:3	0.5	11.5	17.0	29.0
" " " 1:4	0.0	4.5	16.0	34.3
S:M/C intra-row 1:1	0.0	9.5	23.5	33.7
Peripheral	1.5	10.0	22.0	26.0
Monocrop	3.0	15.0	35.0	65.0
± SED	3.3	6.7	7.1	1.6

APPENDIX B (1986)

1. Cumulative mean percentages of sorghum deadhearts.

TREATMENT	WEEKS AFTER SOWING					
	3	4	5	6	7	8
S:M/C inter-row 1:1	2.0	2.85	3.4	4.15	4.6	4.6
" " " 1:2	2.0	2.65	3.0	3.55	4.1	4.3
" " " 1:3	3.0	3.05	4.2	5.05	5.1	5.5
S:M/C intra-row 1:1	2.0	2.5	4.9	4.45	5.0	5.0
" " " 1:2	2.0	2.0	2.05	2.25	2.9	3.1
" " " 1:3	2.0	2.4	3.2	3.08	4.0	4.2
Monocrop	2.0	2.1	2.15	2.45	3.05	3.1
± SED	0.25	0.48	1.0	0.49	0.26	3.0

2. Cumulative mean populations of sorghum midge.

TREATMENT	DAYS AFTER SOWING			
	77	80	83	87
S:M/C inter-row 1:1	2.5	8.5	18.1	18.3
" " " 1:2	0.0	5.1	10.0	10.0
" " " 1:3	2.5	7.2	13.5	18.0
S:M/C intra-row 1:1	3.0	4.1	8.3	12.3
" " " 1:2	5.1	6.6	13.5	14.3
" " " 1:3	5.5	9.6	17.5	21.7
Monocrop	3.0	11.2	19.5	23.3
± SED	7.4	6.9	5.7	2.0

3. Cumulative mean populations of sorghum stem borers.

TREATMENT	WEEKS AFTER SOWING			
	4	7	10	13
S:M/C inter-row 1:1	0.0	5.0	6.0	13.3
" " " 1:2	0.0	0.0	2.0	2.3
" " " 1:3	2.5	2.5	5.0	7.0
S:M/C intra-row 1:1	5.0	7.0	11.0	14.0
" " " 1:2	1.5	4.0	7.5	8.0
" " " 1:3	15.0	17.0	20.0	24.3
Monocrop	2.0	8.0	10.5	15.7
± SED	1.7	4.1	7.8	5.9

4. Cumulative mean percentages of millet deadhearts.

TREATMENT	WEEKS AFTER SOWING					
	3	4	5	6	7	8
S:M/C inter-row 1:1	0.0	0.25	1.0	1.8	1.95	2.2
" " " 1:2	0.0	0.41	1.05	1.2	1.7	1.8
" " " 1:3	0.0	0.12	0.85	1.3	1.5	1.6
S:M/C Intra-row 1:1	0.3	0.55	1.75	2.0	2.2	2.4
" " " 1:2	0.0	0.15	0.45	0.9	0.95	1.3
" " " 1:3	0.43	0.35	0.6	1.0	1.0	1.1
Monocrop	0.15	0.3	0.75	1.15	1.15	1.2
±	2.0	0.28	0.25	0.38	0.22	0.64