Intercropping—what are the advantages?

R. Fordham

Wye College, University of London, Ashford, Kent, TN25 5AH, U.K.

Intercropping is defined as the growing of two or more crops simultaneously on the same area of land. Although widely practised, particularly in tropical regions, it has often been considered to be a primitive form of farming that would in time be replaced by sole cropping. However, in spite of the emphasis of research and development on the intensification of monocrop systems, the practice of intercropping remains widespread and evidence is accumulating to indicate that in many situations it may represent a more efficient use of natural resources.

Adoption of any system of agricultural production will be ultimately determined by underlying social and economic factors. Farm size, labour inputs, level of management, and available technology will all have important bearing on the type of agriculture adopted by farmers. The risk component will also play an important role, particularly in the case of the subsistence farmer whose very survival may depend on growing a range of crops. Within this social and economic context there exist, however, the basic limitations imposed by the physical environment in which the crop species are competing for resources. Factors such as light, carbon dioxide, water, and nutrients will ultimately determine how a crop system performs and the success of any particular method of production, whether it be based on a single species or a combination of several, will depend on how effectively these resources are shared between the component plants.

Light as a resource

Unlike water and nutrients, light is a resource that cannot be stored for later use. If it is not intercepted by chloroplasts in the leaves or other green parts of a plant it is effectively lost. In situations where water and nutrients are not limiting factors, the rate of dry matter production by a crop is primarily determined by the amount of light intercepted by its foliage [1]. A. F. Hawkins [2] has recently reviewed methods for maximising light interception which include modification of the canopy structure. Increasing plant populations and transplanting are, for example, common agronomic techniques for increasing yields through more complete interception of available light. In terms of total light intercepted there are unlikely to be any significant differences between closed monocrop canopies and those consisting of mixtures of crops; in both instances interception is likely to be in excess of 95 per cent of incident values. However, the photosynthetic response of individual leaves to light is asymptotic, with saturation to light intensity occurring at a fraction of that available on a bright day. Light intercepted in excess of saturation is wasted and there is thus scope for not only maximising interception but also modifying leaf architecture to ensure that light is distributed uniformly through the crop canopy. G. E. Blackman [3] has discussed the theoretical background to this approach in relation to a monocrop, and proposed an idealized canopy structure having its upper leaves increasingly angled to avoid wasteful interception of light above saturation values.

By increasing the number of component species making up a crop canopy the possibilities for improving the efficiency of light interception are increased significantly. The upper leaves can consist of species adapted to high light intensities whereas more shade tolerant ones can utilise light transmitted deeper into the canopy. Fast-growing annuals may also be planted between widely spaced perennials during their early establishment phase prior to canopy closure. By skilful timing and choice of species and varieties, the loss of production resulting from light reaching the soil surface can thus be reduced to a minimum.

Water and nutrients

For plants fully to utilise intercepted light they must be adequately supplied with water and mineral nutrition. The overall demand for water is primarily determined by climatic factors and will be little affected by the species composition of a complete canopy. However, as soil water reserves are depleted, interplant competition will develop; the effect this has in a mixed species situation will depend largely on the distribution and efficiency of the different root systems. In practice the compound rooting profile of an interplanted stand is unlikely to be as well organised as the crop canopy but it is possible to envisage combinations of crops where deep-rooting species exploit water reserves beneath those in which more shallow-rooting plants are growing.

To a large extent nutrient uptake will be influenced by rooting pattern in a similar way to water uptake, although the situation may be complicated by differential distribution of individual ions in the soil profile. Nutrient requirements of different species also vary and this is particularly exemplified by the nitrogen-fixing legumes. It is not surprising that legumes are frequently used as intercrops, a practice which takes on particular significance with the recent increases in fertiliser prices.

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An important side effect of maximising light interception is the physical protection of the soil surface afforded by the crop canopy, irrespective of its composition. The resultant improvement in infiltration and reduction of soil erosion will have important bearing on the availability of both water and nutrient resources in areas of intense rainfall.

Shelter and support

In temperate regions of the world, the provision of shelter and support is common practice in the intensive production of many horticultural crops. Shelter-breaks may be inert structures or living species such as poplar (*Populus spp.*) and alder (*Alnus spp.*) of little direct commercial value. Physical support of trees by stakes and of climbing plants with canes and string is a common but costly requirement for maximising the production of crops such as apple (*Malus spp.*) and runner bean (*Phaseolus multiflorus*). In tropical areas, combinations of crops are frequently selected to provide mutual shelter and support.

Pests and diseases

Many pests and diseases are host specific and are likely to spread rapidly through densely planted monocultures. The practice of crop rotation is an effective method for reducing the build-up of soil-borne problems from one growing season to the next but interplanting has the advantage of reducing contact between different crop species, which in many instances may slow down the rate of spread of certain pests. Depending on the stage of attack in an intercropped situation, it is also possible that additional resources will become available to the unaffected crop species which can thus compensate in part for any overall losses in yield.

In the past, pest control technology has centred largely on the application of chemical pesticides. However, it is now apparent that many intercrop combinations can also significantly decrease the incidence of certain pest problems. In the Philippines, for example, the intercropping of maize (*Zea mays*) and groundnut (*Arachis hypogaea*) has proved effective in reducing the incidence of the maize borer (*Ostrinia furnacalis*) [4]. Intercropping is, however, just one facet of the desirability of introducing integrated pest control programmes including both chemical and biological control techniques.

Wherever agriculture is practised, weed competition is invariably responsible for significant losses in productivity. Weed species are in effect unwanted interplants and their presence is an indication of an ecological niche that could be exploited by a more useful intercrop. Intercropping is potentially an efficient method for suppressing weed growth.

In most instances the adverse effects of weed growth on production can be attributed to competition for light, water; and nutrients. However, allelopathy (the harmful effect that plants may have on each other through the release of toxic chemicals) may sometimes contribute to the success of weeds. Research in Nigeria [5] has demonstrated that leachate from the roots of weeds can significantly reduce the growth of yam (*Dioscorea rotunda*) and as much as one third of the total yield loss brought about by presence of weeds amongst yams could be attributable to allelopathy. It is conceivable that the phenomenom may also be present in some crop species where it would affect their suitability as intercrops.

Land equivalent ratios

From the foregoing account it is possible to envisage situations where intercropping of two or more species could lead to an increase in productivity compared to a situation built up from the same species grown as sole crops on the same total area. How do intercropped systems compare with monocrop systems in practice? This is not an easy question to answer: farmers do not make such comparisons and rigorous experimentation on intercropping systems is a recent development. There is an almost infinite range of possibilities for combining two or more crops. Differences in species and cultivars, population density, spatial arrangements, sowing or planting dates, harvesting dates, and other agronomic practices each add to the complexity. The objectives of farmers will also vary. In some instances the aim may be to maximise the yield of the primary crop and accept any additional production from interplanted crops as a net gain. A more common situation is the one in which a farmer, for one reason or another, needs to grow more than one crop. In this instance his objective may be to achieve higher yields from intercropping than can be obtained from growing the component crops separately.

Comparisons of yield data have been a major obstacle in the evaluation of intercropping farming systems. How can one effectively summarise results from, for example, experiments where the component crop yields differ as greatly as those from maize and beans (*Phaseolus vulgaris*). It is now common practice to base comparisons on an estimate of the Land Equivalent Ratio (LER) defined as the relative land area under sole crops that is required to produce yields achieved by intercropping. Maize is frequently intercropped with various other species in many parts of the world. The maize/bean combination for example, has achieved LER values approaching 2 but, as can be seen from the summary of values presented in Table 1, LER values in the range 1.1 to 1.5 are more typical.

TABLE 1: LAND EQUIVALENT RATIOS (LER) OF MAIZE (*Zea mays*) INTERCROPPED WITH VARIOUS LEGUME CROPS AT DIFFERENT LOCATIONS

Intercrop grown with Maize	Country	LER*	Ref.
Bean (*Phaseolus vulgaris*)	Columbia	1.47	(6)
Soyabean (*Glycine max*)	Columbia	1.44	(6)
Cowpea (*Vigna sinensis*)	Nigeria	1.44	(7)
Bean (*Phaseolus vulgaris*)	Costa Rica	1.20	(8)
Bean (*Phaseolus vulgaris*)	Kenya	1.20	(9)
Soyabean (*Glycine max*)	USA	1.08	(10)

*Where possible the LER has been based on the mean value for a number of trials

R. W. Willey [11, 12] has reviewed the methodology and interpretation of intercropping experiments in detail. One problem of interpretation, for example, stems from differences in planting density. Calculation of LER should therefore be based on 'optimum' plant population density, itself a difficult parameter to define and one which may vary between seasons. An important outcome of recent studies on intercropping is that the optimum plant population of a crop mixture may be significantly higher than those of the individual crop components [13, 14].

The following descriptions illustrate examples of the diversity of intercropping systems in current practice:

Multi-storeyed cropping

Multi-storeyed cropping is in many ways analogous to naturally evolved systems such as a rain forest. A rain forest is built up from a multi-layered canopy in which each species of plant is adapted to its own ecological niche between the surface of the forest and its floor. Multi-storeyed cropping differs in that the species are selected on the basis of their economic value and are usually formally interplanted to facilitate management. Such systems are particularly applicable to plantation crops such as coconut (*Cocos nucifera*) which benefit from high light intensities yet let sufficient light between their fronds to permit significant growth in a range of species better adapted to more shaded conditions. Depending on the variety of coconut planted it may be anything from four to seven years before cropping begins and revenue from an intercrop is particularly desirable during this period. In Malaysia, for example, coconut occupies a substantial percentage of the country's cultivated land, most of which is managed by smallholders who could benefit by the adoption of intercropping. Perennials such as cocoa (*Cacao theobroma*), banana (*Musa sapientum*), pineapple (*Ananas comosus*), coffee (*Coffea spp.*), and cloves (*Eugenia caryophyllata*), have been studied for this purpose along with short-term crops including maize (*Zea mays*), chilli (*Capsicum spp.*), cabbage (*Brassica oleracea*), cauliflower (*B. oleracea var. botrytis*), tomato (*Lycopersicon esculentum*), and shallot (*Allium cepa*) [15]. Such practice is not, of course, confined to the tropics: in the South of England, for example, strawberry (*Fragaria elatior*) is frequently interplanted between apples during the establishment of new orchards.

The choice and arrangement of crops is large. E. V. Nelliat *et al.* [16] have described a number of species combinations tested at the Central Plantation Crops Research Institute at Kasaragod in India. One such complex combination, illustrated in figure 1, consisted of coconut, black pepper (*Piper nigrum*), cocoa, cinnamon (*Cinnamon zeylanicum*), and pineapple. The coconut in this instance provided not only the upper storey but also supported the pepper, which developed a second storey canopy on the trunk of the coconut to a height of about 8m. A combination of cocoa and cinnamon formed the first floor and pineapple provided the ground floor. Light transmission through a coconut canopy initially decreases with age as the palms grow larger, reaching a minimum at around 10 years, but increasing again (at least near the edge of the plantation) as the trunks increase in height, permitting more lateral lighting to reach the soil surface. During the first year following planting as much as 50 per cent of the incident light in a normal plantation may be available for an intercrop. Nelliat *et al.* also estimated that the coconut roots themselves were exploiting only approximately 12 per cent of the available land area within the plantation thus leaving considerable scope for introducing a range of intercrops.

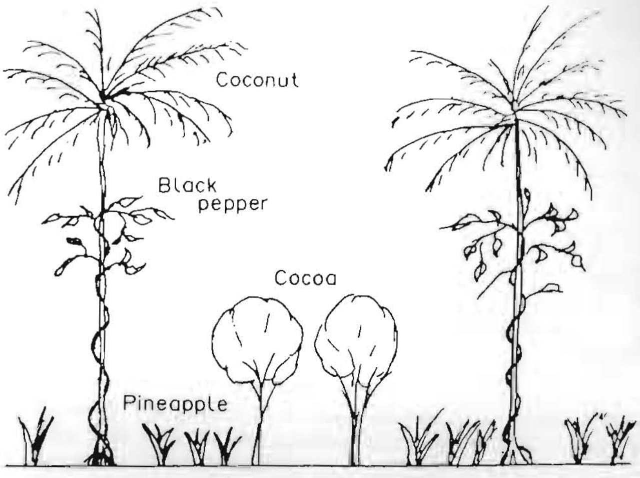

Figure 1 Cross-section through a multi-storeyed crop combination of coconut, black pepper, cocoa, and pineapple. (after Nelliat *et al.* [16])

Similar systems are under test at the International Institute of Tropical Agriculture in Nigeria [17] where, for example, the leguminous tree species *Leucaena leucocephala* provides not only nitrogen and leaf mulch to interplanted maize and cassava (*Manioc esculenta*) but also physical support for yam vines (*Dioscorea spp.*).

The stimulant crops tea (*Camellia sinensis*), coffee, and cocoa have been traditionally established beneath shade trees in an attempt to simulate the conditions of their natural habitat. Although it has been demonstrated that, given adequate nutrition, these species will in most instances yield higher in unshaded conditions [18] they still benefit from some shade and shelter during their establishment phase. In the case of cocoa, banana and plantain (*Musa spp.*) are commonly used to provide shade, shelter, and income during the years following planting and prior to canopy closure.

Intercropping with shorter-term crops

The above examples of multi-storeyed cropping, involving long-term perennials, permit maximum use of light and other resources particularly during the initial phase of canopy development which may spread over a number of years. However, all crops pass through an initial phase when they are building up their leaf area prior to achieving maximum growth rates. In sole crop systems considerable effort has been directed towards reducing the duration of this period when there is insufficient leaf area to utilise incident light fully. Increasing plant populations and transplanting techniques are common approaches to intensifying the production of field vegetables. An alternative is to interplant fast growing, early maturing crops between slower growing longer term crops, thus exploiting the resources available during the start-up period of the latter. There are numerous examples of this overlapping of growing periods throughout the world. For example, sugar cane (*Saccharum officinarum*), a perennial which is completely defoliated at each harvest, is frequently interplanted with relatively shorter term crops such as maize, soyabeans, tomato, cucumber, and melon (*Cucumis spp.*) etc. When the earlier crop has matured, competition between the component species is removed and conditions become more favourable for the remaining crop. This form of intercropping is particularly prevalent in regions having a single wet season too short to accommodate two crop cycles in succession.

One common association is the maize/bean system of Central America [8] where maize is grown through the wet season and beans are planted as the corn approaches physiological maturity. The bean crop then completes its growth cycle during a period of dry weather.

Choice of planting dates can be critical in determining yields of the intercrop. In one study on the maize/bean system. C. A. Francis *et al.* [6] obtained LER values ranging from 1.1 to 1.6 depending on the relative dates of establishing the two species.

In areas where the growing season is sufficiently long it may be possible to combine successional plantings of two fast-growing species with a long season crop of a third species. D. J. Andrews [19] described a system tried in Nigeria in which a long season cereal (*Sorghum vulgare*) was interplanted with a quick maturing cereal, such as *Pennistum* millet or maize, followed by a quick maturing, later-planted legume (cowpea) (figure 2).

Ditch and ridge system

A series of alternating furrows and ridges, depending on their size, will provide different soil environments for a wide range of crops. In a similar way in parts of Nigeria [20] a range of conditions is provided by planting crops on large mounds with, for example, yams (*Dioscorea spp.*) at the top and rice (*Oryza sativa*) near the bottom in close proximity to the water table. In South and Central China, where rainfall is high and large areas of hydromorphic soils are found, highly labour-intensive systems of intercropping have been developed around various forms of ditch and furrow systems [21]. These are based on a range of soil profiles from flat beds separated by ridges through to high-raised beds separated by deep drainage ditches. Further complexity has been introduced by providing bamboo trellises for supporting crops, over both ditches and beds (figure 3). Taro (*Colocasia esculenta*) is widely grown in such systems, where it is well adapted to conditions at the edge of the ditches. At maturity its leaves form an almost closed canopy above the water-filled ditches. Yam bean (*Pacyrrhizus erosus*) trained on trellises can be used to provide shelter or, for example, *Luffa spp.* can be grown on tent shaped trellies to provide protection for underplanted crops such as Chinese cabbage (*Brassica chinensis*).

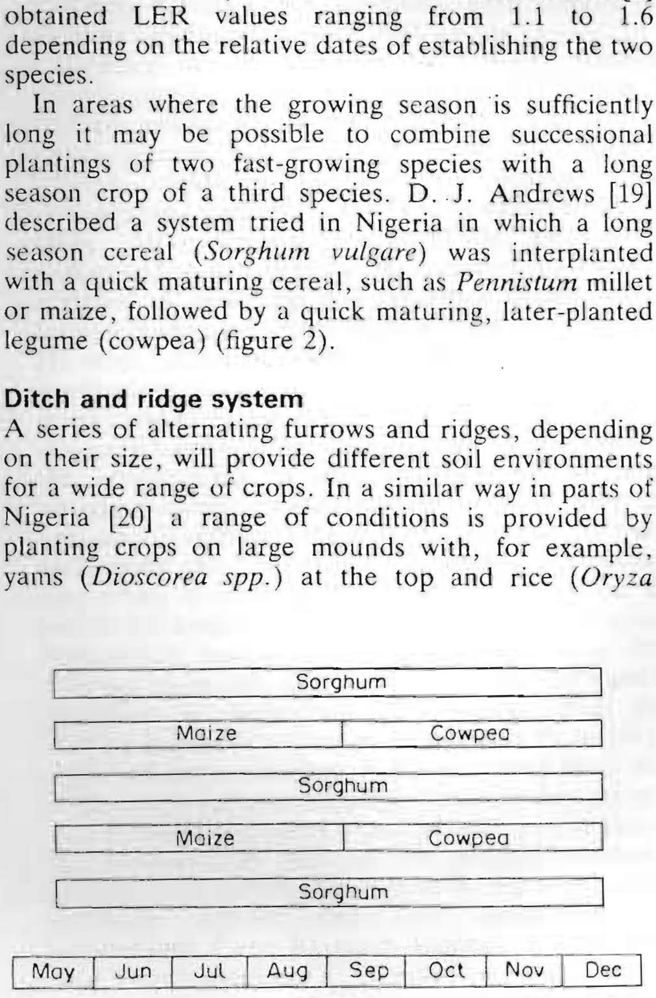

Figure 2 Diagramatic representation of a three-crop system of intercropping based on Guinea zone dwarf sorghum with a short-season cereal followed by a late-planted legume. (after Andrews [19])

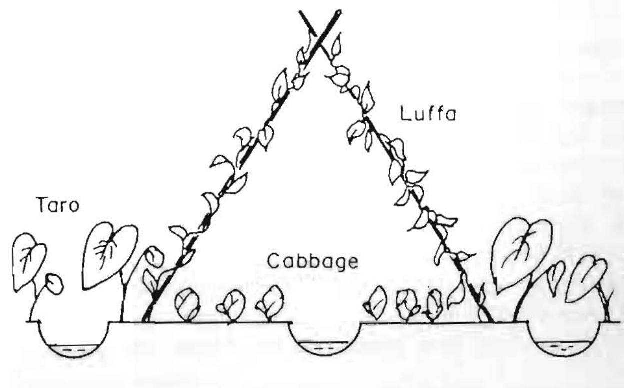

Figure 3 Cross-section through an intercrop combination of taro, luffa, and Chinese cabbage growing on a ditch and bed system in China. (after Harwood and Plucknett [21])

Strip intercropping

In the previous examples the component intercrops have been grown in close association with each other. Strip or lane cropping, however, involves growing different species in separate but adjacent blocks. This is, in effect, well on the way to sole cropping but the blocks are close enough to influence each other significantly. This practice is particularly beneficial where tall crops are planted in strips at right angles to the prevailing wind to provide shelter. The method has received considerable attention in the United States of America where, for example, maize has been used to shelter sugar beet (*Beta vulgaris*) and soyabeans, and oats (*Avena sativa*) to shelter tomatoes. J. K. Radke and R. T. Hagstrom [10] have reviewed these studies and concluded that strip intercropping has promise as an economical alternative to sold cropping. The method is certainly more flexible than the practice of providing permanent shelter breaks, although the two techniques can, of course, be used in conjunction.

The use of fast-growing woody and herbaceous legumes in strip cropping systems is being studied intensively at the International Institute of Tropical Agriculture in Nigeria [5]. In addition to being useful crops in their own right, many species have also demonstrated their value in sustaining soil productivity by their role in restoring soil fertility and organic levels.

What are the problems?

On the evidence available, it is apparent that in many areas intercropping is capable of making a more efficient and sustainable use of natural resources than is possible by sole cropping. However, the available techniques have a number of inherent disadvantages that should not be ignored. Drought, for example, has often resulted in loss of productivity in an intercropped situation although this is more likely to be due to the early development of a full crop cover, and consequently maximum water use, rather than the presence of mixed species canopy in itself.

Intercropping is usually characterised by high labour inputs although it should be recognised that its practice can lead to more efficient weed supression, thus releasing a significant amount of labour from hoeing and hand weeding. In a small holder context herbicides are not always a realistic, or even desirable, alternative. Where appropriate, a reduction in labour inputs can be achieved using suitably designed machinery and the International Rice Research Institute, for example, have carried out valuable development work in this area.

A more serious problem than either technical considerations of water and labour requirements is the inherent complexity of intercropped systems. In the past, research has been almost entirely directed towards improving the simpler situation where different crop species are grown in isolation from each other. More recently, considerable progress in understanding and developing intercropping has been achieved by observing and recording details of how farmers traditionally grow their various crop mixtures. However, although tradition and conservatism have justifiably resisted past attempts to substitute a variety of multiple cropping techniques by sole cropping, they should not prevent the development of innovation in the interplanting of new combinations of crops, including underexploited species of both trees and annuals. To achieve such changes it may be necessary to broaden the education of our future 'agricultural' researchers to cover a wider range of disciplines. The traditional boundaries between forestry, agriculture, horticulture, and ecology may need breaking down although there will, of course, always be the need for specialists in multidisciplinary teams. The plant breeder in particular has an important role to play as almost all plant selections in the past have been made in the context of solecropping. Varieties that are to be used in an intercropping situation must be evaluated in that situation. In view of the possible number of combinations, variety assessment in this way becomes extremely difficult and time consuming. The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) is, however, adding a cereal between the rows of pigeon pea (*Cajanus cajan*) genotypes as part of their selection programme on this species.

The objective of variety selection for intercropping systems are primarily to minimise intercrop competition and maximise complementary aspects. Much of the research conducted in this area has been directed towards changes in the leaf canopy; the distribution and activity of root systems have been largely neglected. Computer simulations may also have a role to play in evaluating some of the potential crop combinations where they could be particularly valuable in highlighting potential problems and reducing the need for extensive and long term field experimentation.

Through the important efforts of the International Research Institutes and other organisations, problems of intercropping, along with other forms of multiple cropping, are now receiving their long-awaited attention. It is to be hoped that the outcome of present research will shift the balance from the previous over-emphasis on solecropping towards a more rational integration of the many approaches to intensifying crop production.

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