Working Papers are made available in limited numbers for comment and discussion and to inform interested colleagues about work in progress at the International Council for Research in Agroforestry. Comments and suggestions are invited, and they should be directed to the author(s).
INTRODUCTION
The use of mixed systems for agricultural and forestry production is by no means new. In pure agricultural systems the sowing of mixed annual crops has been a common farmer response to risk from climatic uncertainties to the need for diversity of food crops and to pragmatic observations of beneficial interactions between species. In the humid tropics, whether highland or lowland, sophisticated tree-crop mixtures have been developed over centuries using many species and where a wide variety of benefits are obtained. In the drier parts of Africa trees have formed important components of grazing systems, or have been left deliberately for their benefits in cultivated land. A simpler system, the use of agriculture crops for assisting in the establishment of forest plantations (taungya) is widespread, and in Africa as elsewhere shifting agriculture provided, in the past, a sustainable land-use system which is only now breaking down under the pressure of increasing populations.

DEFINITIONS OF MIXED SYSTEMS OF PLANT PRODUCTION
In practical terms this paper considers all multiple cropping systems, including agroforestry, agrisilviculture and taungya as 'mixed systems'. Multiple cropping includes all cropping patterns where more than one crop is grown on a piece of land in a year, and it may not be out of place to compare this with ICRAF's definition of Agroforestry.

Agroforestry is a collective name for land-use systems and technologies where woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals in a spatial arrangement or in temporal sequence. In agroforestry systems there are both ecological and economic interactions between the different components. (Lundgren & Raintree, 1983)
All other terras, e.g. intercropping, relay cropping, taungya (where the ultimate objective of the mixed system is the establishment of a forest plantation) are included in one or other of the above.

BACKGROUND TO MULTIPLE CROPPING
Until very recently the most striking advances in agricultural production were mostly obtained through high-input monocrops – the green revolution. The CGIAR- institutes were set up largely to develop and improve single crops, and many forestry programmes were similarly based, e.g. on fast-growing Central American tropical pines for industrial production (see for instance Kemp, 1973).

But the African husbandman has continued to use his traditional multiple cropping systems, improved where possible by the adoption of new crops and techniques, despite the efforts of expensive extension services to induce him to adopt monocropping practices (Steiner, 1982).

It may even be, as suggested by Bowers (1981), that the protracted struggle by the Wachagga of Kilimanjaro to be allowed to grow coffee during the colonial period was really a fight for the recognition of the validity of the multiple cropping, as opposed to the plantation, approach to land use. The recent development of interest in farming systems research (see e.g. Collinson, 1982) is a reflexion of the recognition that major changes away from multiple cropping are unlikely to occur in Africa. The extent of multiple cropping systems continues to be considerable, e.g. in Southern Nigeria in 1970-71 over 80% of areas were reported under this type of system; in Uganda in 1963-64 over half the farming areas were quoted as under multiple cropping. This latter included areas of coffee, maize and groundnuts (Okigbo & Greenland, 1976).

1/ Consultative Group on International Agricultural Research

2/ Although as early as 1934 L.S.B. Leakey (Science and the African) was recommending research on traditional farming systems in East Africa, and deploiring the neglect of them at the time (quoted by Agboola, 1981).
More detail on West African incidence of intercropping is recorded by Steiner (1982) which indicates that both in humid and dry zones the percentage is very high indeed.

Table 1  Percentage of land under multiple cropping

<table>
<thead>
<tr>
<th>Nigeria</th>
<th>Maize</th>
<th>Sorghum</th>
<th>Millet</th>
<th>Rice</th>
<th>Yams</th>
<th>Coco Yams</th>
<th>Cassava</th>
<th>Ground nut</th>
<th>Cowpea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest &amp; derived savannah</td>
<td>91</td>
<td>95</td>
<td>-</td>
<td>64</td>
<td>68</td>
<td>89</td>
<td>23</td>
<td>46</td>
<td>83</td>
</tr>
<tr>
<td>Guinea savannah</td>
<td>79</td>
<td>83</td>
<td>74</td>
<td>92</td>
<td>51</td>
<td>92</td>
<td>66</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>Northern Guinea &amp; Sudan</td>
<td>73</td>
<td>80</td>
<td>92</td>
<td>43</td>
<td>74</td>
<td>59</td>
<td>22</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td>Ghana</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western Rainforest</td>
<td>96</td>
<td>-</td>
<td>-</td>
<td>36</td>
<td>100</td>
<td>100</td>
<td>88</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ashanti Rainforest</td>
<td>87</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td>100</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>-</td>
</tr>
<tr>
<td>South Guinea Savannah</td>
<td>72</td>
<td>100</td>
<td>-</td>
<td>60</td>
<td>89</td>
<td>99</td>
<td>77</td>
<td>62</td>
<td>-</td>
</tr>
<tr>
<td>North Guinea Savannah</td>
<td>98</td>
<td>94</td>
<td>97</td>
<td>24</td>
<td>78</td>
<td>-</td>
<td>93</td>
<td>86</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Steiner, 1982.

Note: Mean of all Ghanaian, S. Guinea & N. Guinea sites taken.
Two factors in particular suggest that these levels are unlikely to fall. These are the increase in population and the fact that small farmers tend to practise multiple cropping more than large farmers.

Steiner (1982) reports that an average of over 70% of farms in Cote d'Ivoire, Ghana & Nigeria, are under 5 ha.

<table>
<thead>
<tr>
<th>Country</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cote d'Ivoire</td>
<td>64%</td>
</tr>
<tr>
<td>Ghana</td>
<td>82% (under 4 ha)</td>
</tr>
<tr>
<td>Nigeria</td>
<td>90%</td>
</tr>
</tbody>
</table>

It seems likely that similar figures apply to other parts of Africa with high or rising populations.

TRADITIONAL AFRICAN MIXED CROPPING SYSTEMS

The literature is rich in references to traditional systems in different parts of the continent, and only a few examples will be discussed. Most of them reveal a thoughtful and sophisticated approach to the problems of sustainable production, whether referring to settled or to shifting agricultural practice.

Taking shifting agriculture first, several examples of farmers' awareness of declining yields following intensive cropping are given by Braun (1973).
Table 2 Examples of crop yield decline in shifting agriculture

<table>
<thead>
<tr>
<th>Country</th>
<th>Mixed or monocropping</th>
<th>Cropping/ fallow (years)</th>
<th>Loss in yield reported during cropping period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congo (Zaire)</td>
<td>2 out of 7 rotations mixed cropping</td>
<td>2-5 / 2-10</td>
<td>20 - 50%</td>
</tr>
<tr>
<td>Benin (North)</td>
<td>Some mixed</td>
<td>2-3 / 3-10</td>
<td>25 - 60%</td>
</tr>
<tr>
<td>Malawi</td>
<td>All monocrops</td>
<td>1-2 / 3-20</td>
<td>&quot;Rapid decline&quot;</td>
</tr>
<tr>
<td>Niger</td>
<td>Mixed</td>
<td>5-6 / 5</td>
<td>50 - 60%</td>
</tr>
<tr>
<td>Uganda</td>
<td>Monocrop followed by mixed cropping</td>
<td>1-2 / 0-10</td>
<td>30 - 50%</td>
</tr>
</tbody>
</table>


Variations in the patterns of shifting agriculture are seen depending on soil fertility. Thus the 'Citimene' systems of Zambia entailed utilising the stored nutrients of a considerably larger area of Miombo woodland than was actually cultivated, on soils of low fertility, whereas at the other end of the scale complex multiple-species gardens were developed by the Wachagga of Kilimanjaro on their eutrophic brown forest soils (Greenland, 1973).
The deep knowledge of the site requirements of many crops is particularly evident in the wetter zones, for instance in SE Nigeria, Zaire, and the East African mountains. Okigbo & Greenland (1976) note that the Medge of Zaire were known to be growing 80 varieties of 30 species of food crops in 1911, and that a close study of the cropping patterns indicated that local topography was cleverly used, with wide crowned trees suitably dispersed to control weeds and erosion, and light-demanding and shade-tolerant plants appropriately located. In Eastern Nigeria great complexity is shown in the placing of large numbers of different crops, sometimes more than 50 species, at various levels on artificial mounds (some 2.5m high) on hydromorphic soils. In Southern Nigeria, also, planted fallowing is practised, using, for instance, *Acioa barteri*, *Anthonotha marcophylla* & *Gliricidia sepium*. Such agroforestry and multiple cropping practices occur in many other parts of Africa, for example the Mango-Cashew-Coconut-Cassava pigeon pea associations of the Kenya Coast and mixed cropping on Ukara Island (Lake Victoria) and in Sukumaland. In the latter the influence of powerful cash markets in influencing cropping patterns is seen, in this case encouraging monocrops of cotton.

In many drier areas also crop mixtures abound, e.g. in the Hausa lands where Agboola (1981) notes that 156 crop mixtures had been recorded. These areas in the Sudan Zone are also notable for the deliberate retention of naturally occurring trees in the arable farming systems. The trees are retained for many purposes - for fruit, soils, medicines, fodder etc.; some of the better known are *Acacia albida* and *Butyrospermum parkii*, but *Tamarindus indica*, *Borassus palm*, Baobab, *Parkia biglobosa* and *Balanites aegyptiaca* are also noted (Yandji, 1981).

Animals are an essential part of many mixed cropping systems involving trees. These silvopastoral systems comprise at one end the traditional nomadic grazing systems of the drier zones throughout Africa, where range management principles are needed for stable production, to more synthetic systems developed from plantation agriculture. Examples of these include cattle under coconuts in Tanzania, and under oil palm in Cote d'Ivoire (Lazier et al, 1981).
Taungya systems for the establishment of planted forests were developed in Burma and India in the nineteenth century, and spread to other parts of the tropics thereafter. Their extent has varied with the need felt by governments to develop 'compensatory'- plantations in the national forest reserves.

Some of the most notable examples of successful taungya schemes, in the context of the national objectives referred to above, are to be found in Nigeria, Kenya, Tanzania, Uganda and Congo. Spears (1980) notes that 160,000 ha of plantations were raised in the forest reserves of the Kenya Highlands under the 'shamba' system where licensed farmers grew maize, beans and potatoes before and after the trees were interplanted for 4-5 years. The conditions in the East African volcanic highlands are unusually favourable however. Ball (1977), notes that in 1975-76 there were over 24,000 'traditional' taungya farmers in 20,000 ha of forest reserves in Southern Nigeria. But he notes that 80% of the population was over 30 years of age, and similar situations where younger people are reluctant to enter into taungya agreements exist elsewhere in Africa.

Taungya is, of course, an imposed system rather than one developed indigenously, although it is an older practice in Africa than many systems developed by peasant farmers. It has undoubtedly depended for its success in some places on land hunger and poverty, and its social aspects have been examined critically by a number of writers, e.g. King (1968), leading to the new term 'agrisilviculture' which was intended to be a kind of 'taungya with a human face'.

1/ i.e. compensating for a lack of natural forests, for a lack of merchantable species in natural forests, or for a lack of expertise to manage exploited natural forests for a sustained yield of merchantable wood.

2/ the Kiswahili word used for the taungya system in East Africa.
Farmers adopt multiple cropping systems for a variety of pragmatic reasons, and Ruthenberg (1980) distinguishes between mixed cropping and phased planting.

Mixed cropping is adopted:

- to increase overall production per unit area
- to reduce the incidence of pests and diseases
- to enable planting to take account of soil variations
  - to exploit the different mature heights of various crops
- to ensure a continued and varied supply of food
- to provide a soil cover against weeds and erosion
- to even out the demand for labour during the year

Phased planting is adopted:

- to even out the demand for labour during the year
- to reduce land preparation costs
- to minimise risk, particularly from climatic uncertainties
  - to provide phased harvests
- to provide ground cover.

The disadvantages of mixed cropping systems indicated below are more apparent to those who wish to change them:

- difficulties of mechanisation
- difficulties in applying inputs, e.g. fertilizers
- more complex experimentation (Okigbo & Greenland, 1976).

Analyses of traditional systems generally show overall increases in crop yields. For dry zone farms incorporating *A. albida* trees (up to about 40 trees/ha) Charreau & Vidal (1965) record striking effects on the yield of millet, for example:
Table 3  Effects of A. albida on millet yield in Senegal

<table>
<thead>
<tr>
<th>Parameter measured</th>
<th>Near tree trunk</th>
<th>Edge of tree canopy</th>
<th>Outside tree canopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield of millet protein kg/ha</td>
<td>180</td>
<td>84</td>
<td>52</td>
</tr>
<tr>
<td>Mean no. of ears per plant</td>
<td>5.4</td>
<td>4.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Weight of grain per ear (g)</td>
<td>29.8</td>
<td>23.3</td>
<td>22.6</td>
</tr>
</tbody>
</table>


Note that not only was the quantity of grain increased; the quality was also improved. Great variations between years were experienced.

Soil analyses in the same cropping zones showed equally interesting results.

Table 4. Soil analyses near A. albida trees in Senegal

<table>
<thead>
<tr>
<th>Parameter measured</th>
<th>Near tree trunk</th>
<th>Edge of tree canopy</th>
<th>Outside tree canopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative values (outside canopy = 100)</td>
<td>84</td>
<td>87</td>
<td>100</td>
</tr>
<tr>
<td>C/N Ratio</td>
<td>142</td>
<td>142</td>
<td>100</td>
</tr>
<tr>
<td>Total humus %</td>
<td>234</td>
<td>127</td>
<td>100</td>
</tr>
<tr>
<td>Available P₂ O₅</td>
<td>200</td>
<td>158</td>
<td>100</td>
</tr>
<tr>
<td>Exchangeable Cations Me/Kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>178</td>
<td>158</td>
<td>100</td>
</tr>
<tr>
<td>Mg</td>
<td>143</td>
<td>114</td>
<td>100</td>
</tr>
<tr>
<td>K</td>
<td>133</td>
<td>144</td>
<td>100</td>
</tr>
</tbody>
</table>

The usual measure of improvement in yield resulting from multiple cropping is the Land Equivalent Ratio (LER). This is the relative land area under sole crops required to produce the same yields from a unit area of intercropping.

Some recent examples quoted from Beets (1982) show very substantial improvements in yield from field studies; such improvements are, of course, very evident to the farmer.

Table 5 Examples of improved yields obtained through intercropping, Land Equivalent Ratios (LER)

<table>
<thead>
<tr>
<th>Crop association</th>
<th>Country</th>
<th>LER</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize/beans</td>
<td>Kenya</td>
<td>1.2</td>
<td>)</td>
</tr>
<tr>
<td>Maize/beans</td>
<td>Colombia</td>
<td>1.5</td>
<td>)</td>
</tr>
<tr>
<td>Maize/Cowpea</td>
<td>Nigeria</td>
<td>1.4</td>
<td>) Quoted in</td>
</tr>
<tr>
<td>Maize/groundnutes</td>
<td></td>
<td>1.3</td>
<td>) Beets (1982)</td>
</tr>
<tr>
<td>Maize/Cowpea/sorghum</td>
<td>Kenya</td>
<td>1.5</td>
<td>)</td>
</tr>
<tr>
<td>Sorghum/soya</td>
<td>Zimbabwe</td>
<td>1.3</td>
<td>)</td>
</tr>
<tr>
<td>Castor/beans/groundnuts</td>
<td>Tanzania</td>
<td>1.8</td>
<td>)</td>
</tr>
<tr>
<td>Pigeonpea/groundnutes</td>
<td>India</td>
<td>1.6</td>
<td>ICRISAT, 1983</td>
</tr>
<tr>
<td>Maize/soya</td>
<td>India</td>
<td>1.5</td>
<td>De, 1980</td>
</tr>
</tbody>
</table>

The benefits of mixed cropping are not only in yields, but there is also mounting evidence of the positive effects on soil conservation, and thus on the sustainability of the systems; (see, for instance, Table 6).
Table 6  
Annual soil loss in tonnes/ha under monocrops at Ibadan Nigeria. Annual and mixed cropping (after Aina et al., 1976)

<table>
<thead>
<tr>
<th>Slope %</th>
<th>Cassava only</th>
<th>Cassava plus Maize</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>87</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>125</td>
<td>86</td>
</tr>
<tr>
<td>15</td>
<td>221</td>
<td>137</td>
</tr>
</tbody>
</table>

The socio-economic basis on which the African farmer makes his decisions has been studied by a number of writers. The small farmer is not particularly impressed by an LER obtained from on-station experiments, however impressive in percentage terms these may be (see Table 5). The actual increase in harvestable yield may, in fact, be very small on a small field or farm. Farmers are more likely to adopt multiple cropping for reasons other than the LER, for instance a more efficient use of labour per unit of output, particularly in intensity of cultivation and weeding. This is despite the fact that the labour input per unit area is often increased.

An equally important reason for traditional intercropping is erratic rainfall. Steiner (1982) records that two-thirds of crop failures in the southern Guinea zone can be attributed to this cause, and the 'contingency mixing' of maize and sorghum in Haute Volta is a good example of a response to this risk.

In some societies there is a traditional division of responsibility for crops between the sexes - women in parts of Cameroun, for instance, plant 'their' crops in their husbands fields. The result inevitably is a complex multicropping system. In many areas near to a powerful market the opposite - the adoption of low-labour monocropping - is the farmers' response.

The economic evaluation of taungya has been studied in both West and East Africa and, from the point of view of the national government generally shows substantial economic advantages for the establishment of plantations. Ball (1977) gives realistically estimated internal rates of return (IRR) for various methods of raising plantations of *Tectona grandis* (teak) and *Gmelina arborea* in southern Nigeria.
Table 7. Costs and IRR of plantations in Nigeria 1975-76. Agricultural crops, maize, yams, cassava, vegetables

<table>
<thead>
<tr>
<th>Type of operation</th>
<th>Comparative cost %</th>
<th>IRR Teak 4/</th>
<th>IRR Gmelina -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taungya, departmental -</td>
<td>100%</td>
<td>7.1%</td>
<td>11.2%</td>
</tr>
<tr>
<td>Taungya, traditional -</td>
<td>180%</td>
<td>5.5%</td>
<td>10.3%</td>
</tr>
<tr>
<td>Direct labour -</td>
<td>450%</td>
<td>3.7%</td>
<td>6.1%</td>
</tr>
</tbody>
</table>

Source: Ball, 1977.

1/ Directly employed labour. Trees and agricultural crops sold by Forest Department.

2/ Farmers own and sell agricultural crops and clear land free.

3/ All labour employed direct. No agricultural crops.

4/ Teak rotation 60 years, Gmelina 15 years.

Note the effect of time on the profitability of Gmelina, a much less valuable crop than teak.

In Congo the raising of Terminalia superba with bananas is an extremely successful taungya system in which the now maturing trees have been underplanted with cocoa (Koyo, 1981). Here, however, the principles of agroforestry mixtures were insufficiently applied, and, although the (unthinned) plantation trees continued to grow reasonably well, the yields of cocoa fell over the years 1970-73, giving 49, 67, 31 and 16 kg/ha respectively.
THE FUTURE OF MIXED CROPPING SYSTEMS

There is no doubt that mixed cropping systems will continue in Africa, and that the complex and expensive external inputs needed to change traditional farming systems will only be available to the few. Thus more research is needed on systems, by both biological and social scientists. The need is for

- an understanding of the current systems and identification of constraints.
- an estimate of the national government's present and future proposals for infrastructure for agricultural development.
- the development of new, adapted cropping systems.
- adaptive, on-farm, research. (Norman, 1976)

There is nothing new in this but it has few resources allocated to it. In the specific situations of agroforestry, ICRAF has developed a 'Diagnosis and Design' methodology with a very similar approach.

'There is no substitute for good design' (Raintree 1983). Farmers have pragmatically designed their own systems, whereas modern agroforestry designs are able to draw on scientific knowledge as well as farmers' experience. Such a system involving *Acacia Senegal* (for gum production) in combination with grazing, cereal and fuelwood production has been described by von Maydell (1978). Another system becoming widely applied is alley cropping, where trees (often nitrogen-fixing leguminous species, e.g. *Leucaena*) are grown in widely spaced rows with agricultural crops between (see, for instance, ter Kuile, 1983).

There is clearly scope for a great deal of site-specific research on such topics as optimum spacing, choice of species and technologies on both these systems and for those in the humid tropics (Watson, 1981). Spears, (1980) has identified the objectives of such research as 'truly sustainable tree and agroforestry cropping systems', and Lundgren (in Budowski, 1981) has said
... economic and nutritional output from land must not only be sustained at the present low levels, but be substantially increased ...

The problem is, of course, how to increase productivity whilst retaining the stability of traditional systems.

Research should thus focus on

- the development of new genetic strains for use in multiple cropping and agroforestry systems (in contrast with most current breeding which is directed towards monocropping). This is especially true for multipurpose trees;
- the development of no-tillage, green manure/mulching systems, incorporating trees;
- the further development of Diagnosis & Design (D&D) methodologies for steady improvements to meet perceived farmer needs;
- the application of agroforestry technology to forest fallows;
- the development of land-use systems in forest reserves that produce a wider variety of products than wood only, and that safeguard soils, water supplies, land ownership and crop ownership.

Lanly (1983) records that 7.2% of the total land area of tropical Africa was under forest fallow at the end of 1980. Perhaps if a single focus for future research effort is needed, this is it.
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