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The Biological Management of Soil Fertility Project

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Abstract

Cover cropping, hedgerow intercropping, additional food-crop cropping and combinations of these with monocropping were studied as whole systems in S.E. Asia. The benefits of each system in terms of nutrient retention or supply, the sustainability of levels of organic matter and fertility were assessed, along with the financial rewards or penalties and the constraints to adoption of each cropping system in terms of extra labour, conflicts with off-farm labour and farmers' attitudes.

Leguminous pre- and post-crops such as groundnut increased the yield of a food crop and provided enough marketable produce itself to increase a farmer's income significantly. The residues also helped maintain levels of soil organic carbon and nitrogen in soil. Analysis suggested a good price for the secondary crop to be key, however, as is sufficient water to grow it and availability of or tenure on the land for a farmer to be willing to invest. Hedgerow intercropping boosted soil fertility but did not increase incomes sufficiently, monocropping was profitable but yields and soil fertility declined rapidly. Monocropping remains popular with farmers with little land or without tenure, however. N_2-fixation was sufficient to match offtake in a moderately yielding food-crop in these systems; more intensive production requires additional input. Overall leguminous secondary cropping has the least against it of the improved cropping systems investigated and probably stands the best chance of being adopted by farmers in the region.

Keywords: legumes, cover cropping, intercropping, hedgerow intercropping, farming systems, economics, soil fertility, South East Asia

Introduction

The Biological Management of Soil Fertility project (BMSF) has evaluated novel cropping systems in S.E. Asia to establish their value to resource-poor farmers in the region. It specifically set out to test scientifically the observations made in previous research that systems with cover crops appeared to yield better than systems without (Van Noordwijk & Sitompul, 1992). Not having the benefit of standardised plots, this earlier work made direct comparisons impossible. The current research has rectified these problems and besides providing a true scientific comparison between

yields in different cropping systems, it sought to address wider issues too. The hypotheses under investigation were as follows:

1) Novel cropping systems can increase yields of food crops. Sufficient N can be fixed by leguminous secondary food crops, cover or intercrops to increase yields significantly and those yield increases can be maintained
2) The use of inter or cover crops can increase soil organic matter in comparison with intensive monocropping and so maintain long-term soil fertility.
3) The yields and profit obtained from improved cropping systems are sufficient to pay for the extra materials and labour.
4) The proposed cropping systems will gain acceptance by the communities that need to adopt them.

It is clear that a satisfactory confirmation of (1) – (4) is essential to the successful adoption and implementation of novel cropping practices. If systems fail at (1) or (2) research scientists will not recommend them. On the other hand, however good a practice may seem during a research project, it will not be adopted unless it provides significant extra income and does not conflict with other demands on labour nor contravene social taboos. For this reason the BMSF project has addressed each of the issues (1) – (4) in an attempt to provide a complete assessment of a series of novel systems within the context in which they might be implemented. This article summarises the results of that assessment based on detailed accounts presented elsewhere in this special issue of the Netherlands Journal of Agricultural Science (Hairiah *et al*, 2000; Vityakon *et al.*, 2000; Toomsan *et al.*, 2000; Gauthier, 2000) and it is an attempt to bring together all of the results, put them in context and present recommendations and conclusions from the whole project. This will be done by treating issues (1) – (4) in turn, detailing the additional results and techniques coming out of the research but also synthesising the results into a single set of conclusions based on judgements of the importance of each factor.

Experiments were carried out at two sites, one at Northern Lampung on Sumatra and the other at Khon Kaen in N. E. Thailand. At Lampung both intercropping, sequential and cover cropping systems were investigated and at Khon Kaen sequential pre-food crop systems. In reviewing these experiments a distinction needs to be made between secondary crops that yield marketable produce, those grown soley to fix N or recycle nutrients and release them during the growth of a food crop (often called green manures in this series of articles) and cover crops, which although used as a generic term for all crops grown outside the main food-crop growing season, strictly should refer to crops grown when the soil would otherwise not be cultivable such as during the dry season. Secondary food crops and cover crops, in this sense were grown at Lampung; green manures (in most instances with marketable produce) were sown at Thailand.

Can novel cropping systems increase yields of food-crops?

Three types of cropping system were evaluated during 1994–7 at Lampung, for full details see Hairiah *et al.* (2000). The systems studied were: cassava, cassava inter-

cropped with rice-maize mixtures, hedgerow intercropping with rice-maize mixtures and leguminous secondary cropping. Yields in cassava-based systems declined linearly with time although intercropping with rice and maize increased the cassava yield by between 5 and 48%. Yields of rice-maize mixtures in rotation were themselves almost doubled (rice, 2.4 t ha^{-1}; maize 0.4 t ha^{-1}) in comparison with yields intercropped with cassava (rice 1.4 t ha^{-1}; maize 0.2 t ha^{-1}). Yields of rice-maize grown between hedgerows generally fell in between these values. Groundnut yielded 0.1–0.2 t ha^{-1} where grown between the hedgerows and 0.15–0.2 t ha^{-1} as a sole crop in rotation.

Rice yields following cover crop green manures at Khon Kaen were of the order of 50% greater than rice in a bare fallow rotation (Toomsan *et al.*, 2000; groundnut-rice, 2.4 t ha^{-1}, fallow-rice, 1.8 t ha^{-1}). Giving 30 kg N ha^{-1} to the rice instead of a green manure raised yields to 2.3 t ha^{-1}. Green manure cover crops such as *Sesbania*, or a mixture of *Sesbania* and cowpea benefited rice to a similar or slightly greater extent but rice following mungbean produced very little extra yield compared with a bare fallow (1.9 t ha^{-1}). The pre-rice crops themselves typically yielded up to 1.3 t ha^{-1} of marketable produce.

Flemingia fixed a similar amount of N to Gliricidia in mixed hedgerows with Peltophorum (35 and 26 kg ha^{-1} yr^{-1} respectively), but a smaller proportion overall (25% and 51%, Hairiah *et al.*, 2000b) of the total N uptake. These amounts are barely enough to replace the N removed by the main food crop and it seems that a legume cover crop will be needed to sustain greater food-crop yields. Results derived with the natural abundance techniques to measure N_2-fixation were comparable with the dilution technique and the simplicity of the method is greatly in its favour for field-work in the region provided a difference of 6‰ N exists between soil and atmosphere (Cadsich *et al.*, 2000)

Secondary cropping and intercropping increased yields significantly at both sites. Most of the additional crops grown were N-fixers and increased the N export of the cropping system as a whole. The results support the hypothesis that improved cropping systems can increase yield in a food-crop. Certain crops performed well, but it is important to ensure that the secondary crop leaves sufficient N behind in residues (see below) and that it does not compete pre-emptively with the subsequent food-crop (Thorup-Kristensen, 1993).

Can improved cropping systems increase the sustainability of farming?

Hedgerow intercropping systems added more N (net) to soil each year (about 50 kg ha^{-1}) than any other system tested, although there is some suggestion that a part of the benefit came from the cover crops (Hairiah *et al.*, 2000b). Secondary cropping in the absence of hedgerows added no net N (i.e. it was in balance), while cassava lost about 50 kg N ha^{-1} yr^{-1}. Hedgerow trees also shade soil during the fallow season helping to prevent the ingress of persistent weeds such as Imperata (Van der Heide *et al.*, 1992) and in some cases help control the weed where already established.

Sitompul *et al.* (2000) showed that a significant portion of the light organic matter

fraction derived from forest remained in soil for at least ten years after forest was cleared to make way for a sugar cane plantation. Although it is possible that some of this material was charcoal derived from fire either long ago or during the clearing process, light fraction OM and simulations of it clearly show promise as a means of monitoring fertility and changes in soil organic matter with time.

Experiments at Khon Kaen tested another form of agroforestry: that of transporting off-site organic matter into the cropped fields. Vityakon *et al.* (2000) found much tree pruning residue still in particulate form in soil 12 months after addition. Over and above this there was a build-up of 10–15% of the (10 t ha^{-1}) applied dry matter (DM) found in soil after 12 months. Assuming 40% C in DM this implies retention of 400–600 kg C ha^{-1} yr^{-1}. Easily decomposable residues such as groundnut released N quickly and because this N was mineralised into the wet season there were large losses, presumably by leaching or denitrification before a food-crop could recover the N. No single residue appeared to be optimal from the point of view of returning nutrients (N) to the following food crop, but mixtures of *Sesbania* and rice stover or groundnut and rice stover did appear to release the most N at the time when the food crop had most need of it (Vityakon *et al.*, 2000). It is possible that such admixtures might be used to fine tune release patterns of N in practice (see e.g. Whitmore & Handayanto, 1996).

Novel cropping systems do appear able to maintain organic C and N in soil, confirming hypothesis (2). Hedgerow intercropping systems increased soil N at Lampung. Importing 10 t ha^{-1} of residues from elsewhere as a mulch increased organic matter in soil at Khon Kaen. The use of hedgerow and extra sequential crops is sustainable in terms of maintaining levels of N in soil. Toomsan *et al.* (2000) stress the need to ensure sufficient P, K, lime and micronutrients are available to maintain soil fertility; Giller *et al.* (1994) stress that sufficient moisture must be available to grow cover crops.

Are the yields obtained from improved cropping systems economically worthwhile?

Hedgerow intercropping provided about US$ 90 ha^{-1} yr^{-1} more profit than cassava monocropping (Whitmore *et al.*, 2000). Sequential cropping benefited farmers by about US$ 440 ha^{-1} yr^{-1} at Lampung relative to cassava (growing on degraded land). Benefits from growing the additional crops were mostly negative in financial terms in Thailand but the *Sesbania*-cowpea mixture was worth US$ 1155 in rotation with rice (Whitmore *et al.*, 2000) but the pioneer nature of the crop makes it unlikely that profits will be sustained at this level in the long-term. Nonetheless net profits of US$ 440 at Lampung by including groundnut in the rotation suggest that significant extra income can be won by growing a crop with an established market. Both at Lampung and Khon Kaen mixtures had advantages over sole crops. At Lampung the intercropped rice-maize-cassava outperformed cassava alone (profit increase of US$ 72).

The additional cost of these novel cropping systems was large, being between two and three times the cost of producing the food crop alone. Obviously growing additional crops entails risks but the costs are mainly labour that has to be set against

wages that could be earned off-farm. Although the lack of immediate income out of season may be a significant problem, this is at least a problem that a farmer can face directly. Fertilizers might increase yields of food crops too but the farmer may need access to credit to buy them. Additional cropping offers more profit for an outlay that is within a farmer's grasp. Nonetheless it is also true that the extra crops required maintenance fertilizer (P and K) to obtain the highest yields.

Hedgerow intercropping was not economically attractive within these experiments but the premise that hedgerow crops decrease labour (and so reduce costs) by shading out weeds that would otherwise have to be removed by hand, was not tested. Although not found to increase profit to attractive levels in the experiments reported on in the BMSF project, hedgerow trees which themselves yield a marketable produce such as fruit, rubber, oil or even timber may make economic sense. Whether the labour needed to grow such trees would compete with food crop production is unclear, however. Hypothesis (3) can be said to have been partly confirmed: it is true in particular instances but not all.

Will the proposed cropping systems gain acceptance?

Only 30–40% of farmers surveyed (Gauthier, 2000) used mulching or green manures with a view to recycling nutrients. Although it can be said that even 40% represents a significant and encouraging proportion of farmers who are prepared to recycle nutrients from crop residues, in most instances this recycling was passive rather than active. Most mulching was reported by farmers who could not or did not want to dispose of weed residues in any other way. The use of chemical fertilizer was a much more popular option with more than 60% of respondents using added mineral nutrients despite the large financial drain on household resources. Green residues left on the surface of land provide shelter for pests, especially rats, and farmers often burn residues rather than risk the propagation of disease or pests. There is a risk of conflict where pests harboured in one farmer's fields plague a neighbour's crops. Ploughing a cover crop or green manure into soil is seen as a time-consuming measure needing much additional effort and there is some evidence that farmers blame the mulches for making the soil more difficult to till (Toomsan *et al.*, 2000). During the recent economic crisis in the region off-farm labour was hard to find but despite this, few farmers turned to cultivating cover crops or green manures (V. Limpinuntana, personal communication). At Khon Kaen green manures were planted before the main rice crop but farmers have difficulty with this strategy because harvest of the pre-rice crops can conflict with planting of the main rice food crop. Also, the variety of rice used is photo-period sensitive and flowers on or about the September equinox each year; any delay in planting will cost yield therefore. Pre-rice crops have been found to delay planting of rice by between two and six weeks. The perception in Thailand, too, is that off-farm work is preferable to the hard field labour needed to raise additional crops. Where lowland rice is grown as the main food crop, preceding crops risk flooding if the rains arrive early so making harvest difficult or impossible. Hence the value of vegetable crops such as cowpea that can continue to

yield beans right up until the crop is removed. If the season is favourable it can also yield grain. Cover crops can be planted after harvest of the rice but drought makes establishment difficult. Giller *et al.* (1994) discuss this point and it seems that cover crops have gained most acceptance where irrigation is available during the dry season. Successes with sesame and kenaf, which are drought-tolerant and can be planted early enough to be harvested in June well before rice transplantation, have also been reported (V. Limpinuntana, personal communication).

Lack of tenure at Lampung discourages farmers from taking measures that cost yield now but might be expected to show a benefit in the future. Tenure rights are so insecure that many farmers do not know if they will still be farming the same land in six months time.

Household finances are also a source of conflict. Although Whitmore *et al.* (2000) tried to cost labour and the time involved in BMSF fairly, off-farm work may be seen as more desirable in that it provides a weekly (i.e. regular) pay packet. It may even convey status. The profit from a secondary crop might be greater than off-farm income but it is less certain and crucially it involves delay until the produce is harvested and sold.

Attitudes are against novel cropping systems because of the additional labour requirement. Hedgerow intercropping is at a further disadvantage and will remain so until tenure problems are solved so that farmers can be persuaded that the additional investment will give returns in the future. Off-farm labour to pay for fertiliser remains an attractive option. Sequential systems have an advantage over hedgerow intercropping systems in that the peak additional labour requirement is outside the main cropping season. Where hedgerows require pruning or other maintenance during the growth of the main food crop there is a potentially serious conflict for labour. There is resistance to these novel systems that must be overcome before they can be widely adopted and hypothesis (4) cannot be said to have been confirmed.

Synthesis, conclusions and recommendations

From the foregoing it is quite clear that the conclusions drawn from a single aspect of the BMSF project alone might differ considerably from those drawn by looking at a different aspect. To sustain yields and soil fertility, hedgerow intercropping is the best system. To provide the most return for the least investment, monocropping (exhaustion cropping) is probably the most attractive strategy and takes account of many of the problems facing farmers who lack tenure. Not surprisingly it is widely adopted. However taking all the research together, it may be possible to draw a different conclusion if prices for leguminous crops can be sustained and Table 1 may help to make this clear. Both at Lampung and Khon Kaen, the inclusion of a legume crop provided not only extra marketable produce with a value in excess of costs, it also supplied enough extra nitrogen to the crop rotation to balance that removed by the main food crop. In other words it was sustainable in terms of maintaining both soil fertility and income. Paradoxically the cover or additional crop may help address the land-tenure issue because it makes full use of land throughout the year and this

Table 1. Comparison of cropping systems.

	Attitude	Tenure	Profit	Sustain-ability	Feasibility	Plus:minus
Exhaustion cropping	++	++	+/–	––	++	6 : 2
Fertilizer	++	++	+	+/–	–	5 : 1
Hedgerow intercropping	––	––	–	++	–	2 : 6
Secondary cropping	–	+	+	+	+	4 : 1

continuous use of the land may help to establish a farmer's claim to that site. The existence of a good, reliable market for the produce is key, however. Secondary cropping, cover cropping and green manures thus score reasonably well on all issues geared to improving farming systems and are not perceived too negatively (Table 1). Although exhaustion cropping is highly feasible and often the preferred option, we know that it is not sustainable. Hedgerow intercropping is highly sustainable but it scores badly on tenure, acceptability and even feasibility. Secondary cropping comes to the fore in Table 1 as the preferred option not so much because of how highly it scores but rather how little there is against it. The same is true of fertiliser use, but if fertilisers are not available or if the farmer has no money to buy them, the option is not feasible.

Farmers should be encouraged to plant leguminous crops between food crops of upland cassava or maize provided sufficient water is available for their growth and provided there is a good market for the produce. Legumes should also be planted before crops of lowland rice provided a good, reliable market exists for the produce, sufficient P and K fertilizer is available and the crops can be harvested in time to plant rice. Farmers' perception of secondary cropping is the greatest obstacle to adoption and this needs to be addressed. If the large benefits of hedgerow intercropping to soil fertility are to be gained in practice, trees that save labour (by e.g. shading weeds) or contribute to farm income may need to be included. Further research needs to be carried out into the benefits of mixtures of crops from the points of view of profit, matching residue quality and timing of nutrient release to subsequent crops and maintaining long-term fertility of soil. Policy makers should try to bring about a climate that allows tenure issues to be resolved as smoothly as possible if they wish to see sustainable farming carried out in S.E. Asia.

The BMSF research project has provided unequivocal evidence for the benefits of additional cropping, intercropping and hedgerow intercropping in the humid tropics. Application of these techniques and in particular matching the appropriate technique to a particular farm, region, social climate or economy is the realm of extension. Those who took part in the research recognise that there is no panacea for the problems faced by the farmers in the region but hope to see the speedy implementation of their general scientific research to the benefit of the communities with whom they have worked. This special issue of Netherlands Journal of Agricultural Science contains much of the data coming from the project and the research scientists who took part hope that it will prove a useful statement of the project results.

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