Agroforestry Systems **23**: 157—176, 1993.

Fertilizers in agroforestry systems

L. T. SZOTT[1] and D. C. L. KASS[2]

[1] *Latin American Agroforestry Network, IRDC, CATIE, Turrialba, Costa Rica;* [2] *Program in Sustained Agricultural Production, CATIE, Turrialba, Costa Rica*

Key words: alley cropping, fertilization, home gardens, nutrient cycling, organic fertilizer, shaded perennials

Abstract. This review encompasses results of fertilization experiments on several agroforestry systems — alley cropping, perennial shade systems, home gardens — in which fertilizer use is a likely management alternative. Fertilizer response was found to be most common in alley cropping, variable in perennial shade systems, and rarely reported in home gardens. Level of nutrient removal in harvested products is probably the overriding factor in determining fertilizer response; greater accumulation of organic residues, slower growth under shade, and longer periods of nutrient uptake probably also contribute to the relatively smaller fertilizer response of the perennial shade systems and home gardens. Considerable knowledge gaps exist regarding the breakdown of organic residues, and interactions between mineral and organic amendments. Systems based on annual crops (e.g., alley cropping) are likely to be less nutrient-efficient and sustainable than systems based on perennial crops, due to reduced fixation and transfer of N to the crops, the tendency of the trees to compete for and sequester nutrients, relatively high P requirements of the crops, and the high labor cost of tree management. The possible benefits of fertilization of specific components in home gardens, and relative advantages of including low-value tree legumes, high-value shade trees, and fertilization in shaded perennial systems are only beginning to receive research attention.

Introduction

Agroforestry systems in which large quantities of nutrients are removed in harvested products are unlikely to be sustainable without fertilization. This is especially true on acidic, infertile tropical soils where system performance has often been less successful than expected. On these soils, the ability of agroforestry systems to significantly increase nutrients through enhanced nutrient recycling or nitrogen fixation appears to be limited, mainly due to the low levels of available nutrients and high levels of elements toxic to plant growth [Sanchez, 1987; Hawkins et al., 1990; Palm et al., 1991; Szott et al., 1991b]. On fertile soils, nutrient deficiencies may also occur under high levels of nutrient removal. A balance between nutrient removals and additions can be achieved by reducing the quantity of nutrients (and products) exported or, as is more likely, by increasing nutrient inputs via fertilization. This paper focuses on the latter. We intend to indicate the types of agroforestry systems in which fertilizers might be, or are, used and review the results of fertilizer use in these systems. We discuss the management of organic and inorganic fertilizers in tree-based systems, and finally, we examine some economic considerations of fertilizer use in agroforestry.

Relevance of fertilizers in agroforestry

Fertilizers are defined as any organic or inorganic material which is added to a soil to supply certain elements essential to the growth of plants [Soil Science Society of America, 1987]. Although fertilizer use is theoretically possible in almost all agroforestry systems, the greater labor or capital costs associated with fertilizer application would tend to limit its use to systems where cash cropping is an important feature [Raintree, 1987]. These systems would likely include alley cropping and mixed tree-crop systems (e.g., home gardens and shaded perennial crops) due to the high level of nutrient removal and the high value of products produced in these systems. The use of organic fertilizers would likely predominate where agricultural and market infrastructure are less developed; the use of organic fertilizers, inorganic fertilizers, or mixtures of the two types would predominate where relatively low-cost commercial fertilizers are available, and where a high return is expected from fertilizer applications.

Review of results

Alley cropping

In alley cropping, the annual removal of nutrients is usually greater than in most perennial tree-crop systems [Szott et al., 1991b; Palm et al., 1991; Wood and Lass, 1985], resulting in greater demand on the system to supply and/or recycle nutrients. Much of the research on alley cropping during the past decade has addressed the ability of this system to maintain productivity with or without mineral fertilizers [Hawkins et al., 1990; Kang et al., 1985; Kass et al., 1989; Salazar, 1990, 1991; Sanchez, 1987]. In many studies, however, interpretation of the response of alley cropping to fertilization is difficult due to: (1) a lack of a true control treatment in which trees and prunings are absent; (2) the importation of mulch from off-site; (3) fertilization of plots with P and K, effectively limiting the scope of many studies to examinations of the effect of nitrogen; and (4) the relatively short duration of the studies [Hawkins et al., 1990].

Crop and tree yields

Most studies address the ability of leguminous species to substitute for nitrogen fertilization. The results usually show that the application of inorganic nitrogen fertilizers considerably increases (up to 1000 kg ha^{-1})

yields of maize alley cropped with *Leucaena leucocephala*, but gives much smaller increases with *Gliricidia sepium*, *Flemingia macrophylla*, or other alley cropping species. A more limited database suggests that additions of inorganic N also increase grain legume yields in these systems (Table 1).

Levels of other nutrients are rarely varied in alley cropping studies but here, too, responses are apparent. Yamoah and Burleigh [1990] reported a considerable increase in pole bean (*Phaseolus vulgaris*) production when 30 and 60 kg ha^{-1} of P were applied to N-fertilized *Sesbania sesban* alley cropping systems, but results of only one harvest were presented. Other studies have shown that beneficial effects of fertilization are often delayed. Salazar [1991] observed a response to low levels of P (25 kg ha^{-1} year^{-1}) — in otherwise unfertilized *Inga edulis*, *Cassia reticulata*, or *G. sepium* alley cropping systems on an Ultisol (Acrisol) — only in the seventh (cowpea), tenth (cowpea), and eleventh (rice) crops of an eleven-crop-long sequence (Fig. 1). Fertilizer additions (50 kg N, 25 kg P, 20 kg K, 35 kg Ca, and 16 kg Mg ha^{-1} crop^{-1}) to rice and cowpeas alley cropped with *I. edulis* on an Ultisol resulted in significantly greater grain yields in the fertilized, as compared to the unfertilized, treatment in the fourth through the seventh crops of a seven-crop-long sequence [Fernandes, 1990]. Balances of P additions and removals in alley cropping systems on infertile and acidic, or fertile (but low in P) soils suggest that P may eventually limit the productivity of these systems [Salazar, 1990, 1991; Palm et al., 1991]. This would tend to support the argument that prunings alone, especially on infertile soils, cannot sustain the productivity of continuous alley cropping [Palm et al., 1991; Szott et al., 1991a, b].

Although few studies report the effect of direct fertilization on pruning production by alley cropping species, limited results suggest that many respond to nitrogen. It should be noted, however, that nitrogen fertilization may decrease N_2 fixation, as observed by Sanginga et al. [1989] for *L. leucocephala*. Hill [1970] and Stewart and Gwaze [1988] observed that *L. leucocephala* and *Faidherbia albida* (syn. *Acacia albida*), respectively, respond to nitrogen. On an acidic soil in Rwanda, Yamoah et al. [1989] observed that, in the first four months after transplanting, growth of *S. sesban*, *Calliandra calothyrsus*, *L. leucocephala*, and *Markhamia lutea* increased with manure additions of up to 5 Mg ha^{-1}, but that by eight months, there was no response to manure. They also noted that lime increased the growth of all trees. On an acidic, infertile Ultisol, Szott [1987] found little response in pruning production of *I. edulis*, *Erythrina* sp., or *Codariocalyx gyroides* to lime or lime + P applied to the hedges at transplanting, but production of *Cajanus cajan* responded to lime. Tissue P contents of these species, however, did increase with P addition, and the Ca and Mg contents of *C. cajan* increased with lime. Responses of *C. cajan* to K and P additions to an Oxisol (Ferralsol) were also noted by De Lucena-Costa and Paulino [1992] and De Lucena-Costa et al. [1992]. Netera et al. [1992]