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The alley farming index: Preliminary steps towards a more realistic model

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Abstract. This paper presents the Alley Farming Index (AFI), a modification of the replacement value of the intercrop (RVI) index. The RVI index is used to assist in determining the ecological and economic benefits of a polyculture system and is potentially useful in intercropping situations where only annual crops are utilized. Alley farming is a modification of the alley cropping system where food crops are planted in between, regularly pruned, widely spaced trees. Unlike the RVI index the modified equation, presented here, accommodates alley farming where perennials and the amount of tree prunings used as green manure are important parameters. The AFI is presented in two forms, one that assumes a linear relationship between the quantity of tree prunings applied as green manure and annual crop yield, and a second more generalized form which accommodates other relationships between green manure application and crop yield (e.g., logarithmic or parabolic). Although designed specifically for alley farming the modified index can also accommodate alley cropping systems.

Introduction

It has been common to use the Land Equivalent Ratio (LER) (Mead and Willey, 1980) or the replacement value of the intercrop (RVI) (Vandermeer, 1989) to indicate potential gains and losses of an intercropping situation. Among other indices that have been proposed, some look solely at production while others incorporate cost components (Vandermeer, 1989). The indices provide useful information in discerning beneficial crop combinations from those that may not be as ideal. A difficulty arises, however, with regard to the type of polyculture that these indices are able to incorporate as they were derived for evaluating annual crops and not perennials. While these indices can also be used to evaluate agroforestry systems, they are often unrealistic due to the unique relationships between annual crops and trees.

This paper presents a modification of one index, the replacement value of the intercrop (RVI) (Vandermeer, 1989), specifically with reference to alley farming. This form of agroforestry is a variant of alley cropping which incorporates rows of widely spaced tree hedges with crops planted within the resulting alleys (Kang et al., 1981). In both systems the trees are pruned. In alley cropping foliar prunings are used solely as green manure for annual crops. However, in alley farming these prunings are used either as green manure for crops or as fodder for livestock (Kang et al., 1990).

Measures of intercropping performance

There have been two major generalized models used to evaluate intercropping performance: the land equivalent ratio (LER) and the relative value total (RVT) (Vandermeer, 1989). These two models take two fundamentally different approaches, i.e.,

$$\text{LER} = (P_1/M_1) + (P_2/M_2),$$

and

$$\text{RVT} = (aP_1 + bP_2)/aM_1;$$

where M_c is monoculture yield and P_c is polyculture yield for crops (c) 1 and 2, a and b are the prices for crops 1 and 2, respectively and $aM_1 > bM_2$.

The LER evaluates production in terms of relative land requirements for intercrops versus monocultures. The RVT considers the quantity of output and the price of commodities produced where the resulting comparison is between potential gross revenues of the two crops, a characteristic more relevant to the farmer's economic decision making process (Schultz et al., 1982). Both equations are structured to yield a value of one when the polyculture land requirement (LER) or gross revenue (RVT) is equal to that of the monoculture. A LER greater than one indicates the polyculture land requirement for a given output is proportionately less than in the monoculture. A RVT greater than one indicates the gross revenue of the polyculture is greater than that of a monoculture of the most valuable crop (M_1)

A close relative to the RVT equation, the replacement value of the intercrop (RVI), changes the value of monoculture revenue by the net difference in costs (c_n) of external inputs between the monoculture (c_m) and polyculture (c_p). It is defined as follows,

$$\text{RVI} = (aP_1 + bP_2)/(aM_1 - c_n);$$

where $c_n = c_m - c_p$. The RVI equation is a useful modification when: the system being studied uses extra inputs such as fertilizers or insecticides but in varying quantities depending on whether a monoculture or polyculture is being used; or intercrop comparisons are to be made with the highest theoretical monoculture output.

Additional parameters in agroforestry

Agroforestry is a distinct type of polyculture where trees are utilized in combination with annual crops. A variety of potential benefits have been documented in these systems, including: improved soil fertility, higher yields, soil conservation and economic benefits to farmers (Kang et al., 1990; Ong et al., 1991; Wiersum, 1991; Current and Scherr, 1995; Ong, 1996). While the mechanisms that provide these results are often similar between agroforestry and other types of polyculture, trees present additional parameters that are not common in a purely annual intercropping system. These include strong negative effects on perennial crops which are competitively at a disadvantage for light and soil resources and potential fertilization by the trees' net foliar biomass production. These two additional parameters vary greatly depending on the agroforestry system examined. The focus of this paper is the effects of tree biomass production in alley farming systems. Due to the structured nature of this type of agriculture, it provides a good starting point for interpreting the unique situations that trees present.

The original intention of alley cropping was to create a system of agriculture that could improve soil fertility and therefore reduce or eliminate the need for fallow between cropping cycles. In this system the tree species are regularly pruned to reduce competition with the annual crops. The foliar component of the periodic prunings is added to the crops as green manure, assuring that crops get sufficient sunlight and that nutrients are made available to them (Kang et al., 1984), while the woody portions can be used as fuelwood. As originally conceived, the crops are used for consumption or sale, while the trees make plant nutrients available that are deep within the soil or through biological nitrogen fixation. These nutrients would be normally unavailable to annual crops. Ideally, beneficial interactions between the trees and annual crops will result. Often, however, alley cropping is not done in this manner and instead a portion of the prunings are not utilized as green manure but are used as fodder for livestock (Weischet and Caviedes, 1989, Ong et al., 1991). Although a reduction in crop output undoubtedly results from this practice of alley farming, tree litter under some circumstances is too valuable as fodder to be used as green manure (Ong et al., 1991).

The alley farming index

The replacement value of the intercrop (RVI) is potentially useful for alley farming, where one crop is a perennial woody species instead of an annual. However, difficulty arises because perennial crops have different properties than annual crops. Within the RVI equation, if net biomass production is used for fodder it can be priced at the cost of forgone, unneeded animal feed. In this situation, fodder is treated as any other seasonal crop and no modifications to the RVI are necessary. However, if part or all of the tree prunings are used as green manure for the annual crop(s), increased yield cannot be evaluated in the original formulation. A significant change must be made to the RVI.

Here a modification of the RVI to take into account this tree pruning allocation problem is proposed. The initial modified version, the ‘alley farming index’ (AFI) is similar to the original RVI equation,

$$\mathrm{AFI} = [a(P + P^*(T - fT - wT)) + bfT] + dwT/(aM - c_n);$$

where T is the tree biomass production per year; P is the yield of the annual crop in polyculture without green manure; P^* is the increased yield response of the annual crop in polyculture per kilogram of green manure applied; M is the yield of the annual crop in monoculture; a, b and d are the prices of the annual crop (a), fodder (b) and fuelwood (d) respectively; w and f are the fractions of woody prunings (w) and prunings used as fodder (f); and c_n is the net difference in extra costs between the monoculture and polyculture.

The first difference is the slight change in terminology. In the RVI equation, P_1 and P_2 represented different polyculture yields for the two crops. Yield of the annual crop component in polyculture, in AFI, is divided into two parts, P and P^*. Tree production (T) has replaced the second crop’s polyculture yield (P_2). This term has been used instead of P_t or other terms emphasizing intercrop interactions because the tree component of the alley farming system, due to its dominant position, will not be significantly affected by the annual crop component.

The next change involves the manner in which AFI expresses polyculture crop yield. This index includes the possibility that the farmer will be required to provide fodder for livestock or that there is a market for fodder in the area. Further, it assumes that the woody portion of the prunings will be used or sold as fuelwood. Thus, within this equation, a price has been put on tree prunings when they are used as fodder. This represents a net savings or revenue (if sold) for the farmer. When used as green manure, prunings are incorporated into the equation as increased yield.

Total annual crop yield (P_t) is a linear function which may be written as,

$$P_t = P + P^*(T - fT - wT);$$

where the slope is determined by the polyculture yield with no green manure application (P) and the maximum yield ($P_{\max}$) when full mulch is used ($P + P^*(T - wT)$). Here the amount of tree prunings used as green manure on the seasonal crop is represented by ($T - fT - wT$). Theoretically, when more green manure is applied crop production should increase if the green manure contains limiting nutrients or other attributes that the crop requires for improved growth. This relationship between green manure application and crop yield has been confirmed by many studies (Atta-Krah and Sumberg, 1988; Jabbar et al., 1992; Larbi et al., 1993). The numerator of the AFI equation looks at green manure application in this manner. In the simplest situation the fraction of tree prunings used as fodder is equal to one (this assumes no woody fraction). Here AFI reduces to $(aP + bT)/(aM - c_n)$, which is equivalent to $(aP_1 + bP_2)/(aM_1 - c_n)$, the original RVI equation. If all of the prunings are used as green manure seasonal crop output will increase by P^*T and the new numerator will be $(a(P + P^*T))$. Revenue now depends solely on the production of the seasonal crop. In order for the intercrop to be favorable here, polyculture crop revenue must be greater than monoculture crop revenue, $a(P + P^*T) > (aM - c_n)$.

A serious drawback of the AFI equation is that it assumes a linear relationship between green manure application and yield. Crop yield will not increase with greater green manure application if the nutrients supplied are not limiting, as shown in Figure 1a. At low levels of green manure there is a high but decreasing marginal return to additional application. At some point m^* marginal return to green manure is reduced to zero and increased crop yield cannot be obtained through increased application. At extremely high levels ($< m^*$) crop yield begins to decline.

While this is a realistic scenario and suggests the general shape of the curve (approximately parabolic) the precise shape of the curve is usually unknown. Also, since the amount of green manure is limited it is impossible to tell exactly what part of the curve will be represented in a real-world situation. Several possibilities can be seen in Figure 1. If output changes quickly in response to low levels of green manure application, or if large quantities of green manure can be obtained, theoretically it is possible to encompass the entire, previously described curve (Figure 1a). In this situation minimum yield is at point P where no green manure is used. The maximum yield ($P_{\max}$) is obtained quickly and negative effects occur before all of the prunings are used. Here P^* results in less than maximum yield. For yield maximization the farmer should apply foliar prunings as green manure to the level of m^* and allocate the remainder of the foliar prunings to livestock (if present) in the form of fodder. In part b, yield increases more gradually and maximum yield is obtained when all of prunings are used as green manure. However, maximum yield can be obtained if less green manure is applied suggesting again that excess prunings over m^* should be allocated to fodder. Finally, in part c the response to increased green manure application is linear as suggested in the definition of AFI above. Here, the optimal scenario for crop yield is to apply all of the foliar prunings as green manure to the crops.

Since it is unlikely that one yield curve can accurately reflect all real world situations a more generalized model can be constructed,

$$\text{AFI}' = [a(P + f(P_i)) + bfT] + dwT/(aM - c_n);$$

where $f(P_i)$ is the increased yield of annual crop in polyculture. Instead of defining the polyculture yield curve, AFI′ uses the more generalized $f(P_i)$. This function makes no assumptions about crop response to green manure

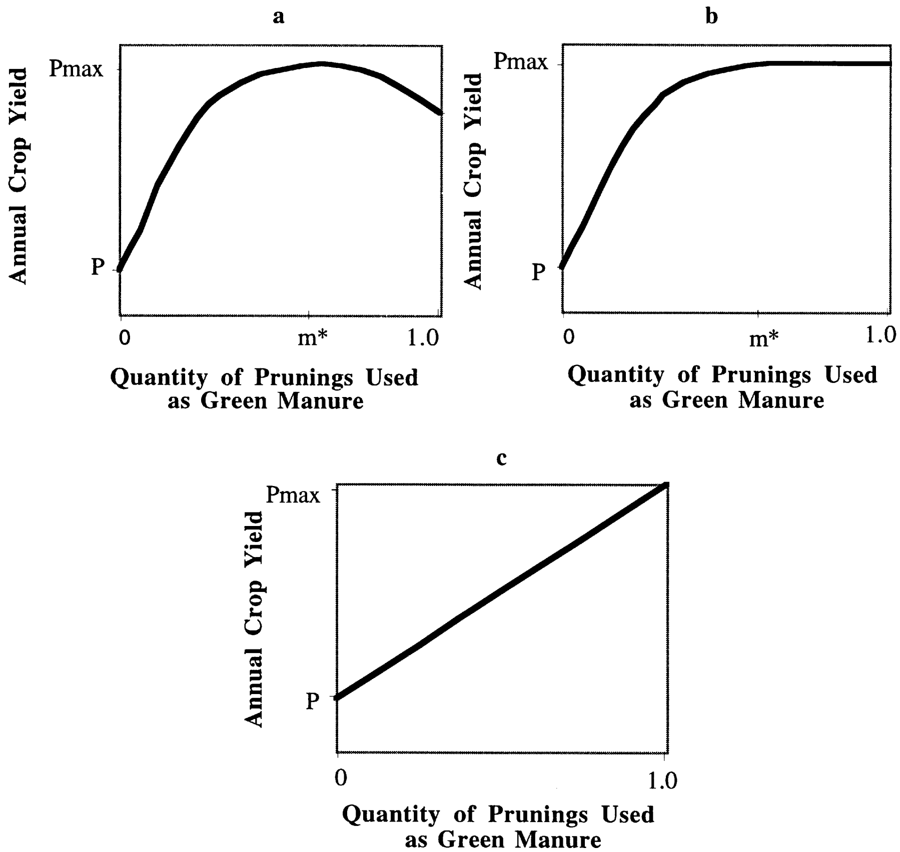

Figure 1. Three possible annual crop yield response curves to increasing green manure additions (a = parabolic; b = logarithmic; c = linear). Where: m^* represents the point at which marginal return to additional green manure equals zero P represents yield of annual crop without green manure additions; and P_{max} represents maximum possible yield.

application and will be determined by the shape of the yield curve for a particular alley farming situation. The yield curve will be a function of many components, including: site quality, litter quality and decomposition rate, quantity of litter used, and crop nutrient demand. In a region with relatively homogeneous soil characteristics, it should be possible to obtain a species specific (tree and crop) yield curve as defined by $f(P_i)$.

Using averaged data from a three year study (1985–1987) conducted in southwest Nigeria by Jabbar et al. (1992), Table 1 shows two possibilities: maize grown with *Leucaena leucocephala* and maize grown with *Gliricidia sepium*. In each case there are four levels of mulch application representing 25, 50, 75, and 100 percent of total foliar prunings. While the same percentages of prunings were applied in each case, it should be noted that *Leucaena* produced slightly more than half of the amount of foliar prunings as *Gliricidia*.

Table 1. Maize yield response to variable foliar pruning additions using *Leucaena* and *Gliricidia* *in south-western Nigeria*.

Percent of available foliar prunings applied	Quantity of foliar prunings applied (t DM/ha)	Maize grain yield (t DM/ha)	Yield increase (%) over green manure-free treatment
Leucaena			
0	–	2.65	–
25	1.86	3.41	29
50	3.69	3.94	49
75	5.54	4.00	51
100	7.41	4.46	68
Gliricidia			
0	–	1.79	–
25	0.91	2.57	44
50	1.82	2.59	45
75	2.72	2.94	64
100	3.64	3.33	86

Source: Jabbar et al., 1992.

In the case of *Leucaena*, maize yield increased by 49% when 50% (3.69 tDM/ha) of the prunings were applied as green manure. But, when the remaining 50% of the prunings were applied yield increased by only 19%. Here, the marginal return to foliar prunings declines as its application increases. In the case of *Gliricidia*, maize yield increased by 45% when 50% (2.72 tDM/ha) of the prunings were applied as green manure. However, in contrast to the previous example, when the remaining 50% of the prunings were applied yield increased by an additional 41%. At the given levels of green manure application, it appears that for the *Leucaena* example there is a logarithmic relationship between green manure application and maize yield while the *Gliricidia* example suggests a linear relationship. The most likely reason for this is the large difference in the available amount of foliar prunings. If more *Gliricidia* prunings had been available a more logarithmic relationship probably would have developed.

The optimal allocation of prunings, within the context of AFI, will depend not only upon the yield curve but also on the economic value of fodder. If the value of fodder is high in comparison to maize then the optimal allocation of prunings to fodder will be higher than if the value of fodder is low.

While analysis may reveal that maximum and minimum yields are quite variable between sites, it is highly likely that the limited amount of prunings available to a farmer will not be able to push yields to their theoretical maximum (where marginal returns are at or near zero), as they could if an unlimited green manure supply was available. Yield curves should vary in two ways: the difference between crop yield with full green manure application and yield without mulch (P), represented by $P^*(T - wT)$ in AFI; and whether the curve is flat resembling the original AFI equation or a logarithmic function. Holding crop type constant, soil conditions, and the quantity and quality of green manure should be the predominate factors affecting the shape of the yield curve. Although there is not enough empirical data to conclude the precise effects of these parameters some general predictions can be made: (1) nutrient poor soils should increase $P^*(T - wT)$ and flatten the yield curve; (2) trees producing larger quantities of mulch should increase $P^*(T - wT)$, while making the yield curve logarithmic in nature; and (3) trees producing nutrient rich mulch should increase $P^*(T - wT)$ and create a flatter yield curve (Table 2). The actual site specific yield curve, of course, will be the product of the interaction of these and perhaps other parameters.

Table 2. Effect on crop yield curve by soil conditions, green manure quantity, and quality.

	P*(T-wT)		Curve Shape	
	High value	Low value	Flat	Logarithmic
Soil quality	Nutrient poor	Nutrient rich	Nutrient poor	Nutrient rich
Green manure quantity	Large quantity	Small quantity	Small quantity	Large quantity
Green manure quality	Nutrient rich	Nutrient poor	Nutrient poor	Nutrient rich

P^* represents increased yield of annual crop in alley farming when all foliar prunings are applied.

It is important to remember that the AFI indices are used to measure polyculture performance. Much of this paper focused on the yield component of AFI due to its differences with past models. But, it should be noted that economic decisions by the farmer will be based on revenue considerations and not solely on crop yield. Significant variation in the allocation of trees, crops, and mulch will depend on a multitude of factors (e.g. the crop/fodder price ratio; crop yield when mulch-free and under full mulch; and the shape of the $f(P_i)$ curve). The AFI indices account for these factors and can provide a potentially more accurate model for determining alley farming performance than can the RVI or LER indices.

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References

Atta-krah A and Sumberg J (1988) Studies with *Gliricidia sepium* for crop/livestock production systems in West Africa. Agroforestry Systems 6: 97–118

Current D and Scherr S (1995) Farmer costs and benefits from agroforestry and farm forestry projects in Central America and the Caribbean: implications for policy. Agroforestry Systems 30: 87–103

Jabbar M, Cobbina J and Reynolds L (1992) Optimum fodder-mulch allocation of tree foliage under alley farming in southwest Nigeria. Agroforestry Systems 20: 187–198

Kang B, Reynolds L and Atta-Krah A (1990) Alley farming. Advances in Agronomy 43: 315–359

Kang B, Wilson G and Lawson T (1984) Alleycropping: a stable alternative to shifting cultivation. International Institute of Tropical Agriculture, Ibadan, Nigeria

Kang B, Wilson G and Sipkens L (1981) Alley cropping maize and *Leucaena leucocephala* Lam. in Southern Nigeria. Plant and Soil 63: 165–179

Larbi A, Jabbar M, Atta-Krah A and Cobbina J (1993) Effect of taking a fodder crop on maize grain yield and soil chemical properties in *Leucaena* and *Gliricidia* alley farming systems in western Nigeria. Experimental Agriculture 29: 317–321

Mead R and Willey R (1980) The concept of a ‘Land Equivalent Ratio’ and advantages in yields from intercropping. Experimental Agriculture 16: 217–228

Ong C (1996) A framework for quantifying the various effects of tree-crop interactions. In: Ong C and Huxley P (eds) Tree-Crop Interactions. CAB International, Wallingford, UK

Ong C, Corlett J, Singh R and Black C (1991) Above ground interactions in agroforestry systems. In: Jarvis P (ed) Agroforestry: Principles and Practice, pp 45–56. Elvier, Amsterdam

Schultz B, Phillips C, Rosset P and Vandermeer J (1982) An experiment in intercropping tomatoes and cucumbers in southern Michigan, USA. Scientia Horticulturae 18: 1–8

Vandermeer J (1989) The Ecology Intercropping. Cambridge University Press, New York

Weischet W and Caviedes C (1989) The Persisting Ecological Constraints of Tropical Agriculture. John Wiley and Sons, New York

Wiersum K (1991) Soil erosion and conservation in agroforestry systems. In: Avery M, Cannell M and Ong C (eds) Biophysical Research in Asian Agroforestry, pp 209–230. Winrock International, USA