Innovative Maize-legume Intercropping Results in Above- and Below-ground Competitive Advantages for Understorey Legumes

P.L. Woomer[1*], M. Lan'gat[2] and J.O. Tungani[1]
[1]Sustainable Agriculture Centre for Research, Extension and Development (SACRED Africa), PO Box 79, The Village Market, Nairobi, Kenya and [2]Tea Research Foundation, Karicho, Kenya.

*Corresponding author

Abstract

Maize–bean intercropping (*Zea mays* with *Phaseolus vulgaris*) offers advantages to smallholder farmers in terms of crop diversity and risk avoidance, but continued reliance upon this practice has resulted in poor yields and widespread pests and diseases of bean in the smallhold growing areas of western Kenya. We are attempting to modify intercropping in a manner that will allow for a legume maize–legume–intercrop rotation as a means of disrupting pest cycles and improving the opportunities for symbiotic nitrogen fixation. The system, known as MBILI, is based upon staggering every other maize row by 25 cm, and growing legumes in the resultantly wider inter-row, holding constant population of maize (44,444 plants ha^{-1}) and legume (88,888 plants ha^{-1}). This adjustment allows for intercropping legumes other than bean, particularly green gram (*Vigna aureus*) and groundnut (*Arachis hypogaea*), both of which have higher light requirements and greater capacity for symbiotic N-fixation than beans. MBILI was compared to conventional intercropping during a series of on-farm experiments conducted over four growing seasons (2000 to 2002) in Western Kenya. MBILI resulted in greater Land Equivalency Ratios than conventional intercropping, 2.0 vs. 1.7 ($P < 0.001$), (2000 short rains, calculated from crop value). Combined results from the 2000 and 2001 short rains were KSh 48 752 $crop^{-1}$ ha^{-1} for MBILI and KSh 28 661 $crop^{-1}$ ha^{-1} for conventional intercropping, at the otherwise same management. MBILI with groundnut increased crop value during three growing seasons between 2000 and 2001 to KSh 62 072 $crop^{-1}$ ha^{-1} compared to conventional maize–bean intercropping (KSh 41 810), again under the same pairwise management. Some of these benefits are attributable to 54% greater light penetration to the legume understorey observed with MBILI (+20 934 LUX averaged throughout the day), an obvious aboveground advantage. MBILI also resulted in greater Fertilizer Use Efficiency (FUE), particularly by maize, because side-dressing applications may be more strategically placed. FUE of maize was increased by 46% (+7 kg maize kg N and P^{-1}) when conventional and MBILI yields are compared (short rains 2000 and long rains 2002). Furthermore, unexpected benefits to MBILI were observed during cropping seasons experiencing mid- and late-season drought, where overall maize yield under MBILI was 25% greater (+ 370 kg ha^{-1}), suggesting advantageous root distribution (2000 and 2001 short rains). Clearly, the benefits from MBILI include more than readily "meets the eye".

Introduction

Smallholders in East Africa are undergoing a profound transition from cereal-based subsistence farming to mixed-enterprise, market-oriented agriculture. The most common subsistence farming activity in the semiarid and subhumid climatic zones is maize–bean intercropping, a system that is intended to reduce household risks during poor growing seasons and produce modest surpluses during favorable seasons (Woomer *et al.*, 1997). The risk avoidance features of this system are sound in that bean leaves and green pods may be consumed early in the growing season, and dry beans mature rapidly. In addition, Maize is drought tolerant and responds to scarcely applied external inputs. During more productive seasons the system seldom fulfills farmer expectations, however, because crop surpluses are generally widespread causing commodity prices to fall to levels where applied inputs, particularly mineral fertilizers, are no longer profitable (Nyangito *et al.*, 1997). Complicating this situation is the accumulation of pests and diseases during continuous intercropping, particularly for bean (Abate and Ampofo, 1996). Basically, the shortcoming of maize-bean intercropping is a lack of diversity that would otherwise allow for wider market penetration and reduce biotic pressures. Farmers cannot abandon maize production because of the food security risk to their households but during the best years they benefit insufficiently to meet their expectations for better livelihoods and herein resides their dilemma.

For the past several cropping seasons, the Sustainable Agricultural Centre for Research Extension and Development in Africa (SACRED-Africa) has worked closely with smallholders in Bungoma District of western Kenya to develop a maize–legume intercrop rotation that maintains risk aversion while at the same time improving the productive capacity and marketing potential of their system. The conventional intercropping system is to plant alternate rows of maize and bean at 37.5 cm or to plant maize and beans together in 75 cm rows, a strategy that apparently provides greater competitive advantage to the taller-statured maize. The entry point for this work was to provide better growing conditions for the understorey legume, allowing for the introduction of additional higher-value pulses, such as groundnut, green gram, and soybean, as intercrops with maize. Farmers were unwilling to lower their maize populations to facilitate legumes so we devised a staggered, paired row arrangement with twin rows of maize 50 cm apart adjacent to a 1 m strip reserved for the legume intercrop (Tungani *et al.*, 2002).

Materials and methods

Research focused upon improving smallholders' maize-based intercrops was conducted over four growing seasons in Bungoma and Teso Districts of western Kenya. This area is dominated by Acrisols and Ferralsols formed on acid igneous rock (Sombroek, 1982) and has a subhumid climate. Teso District tends to receive less precipitation and has sandier soils than Bungoma. The average annual precipitation and temperature patterns, and typical smallholder maize intercropping operations are presented in Fig. 1. A chemical analysis of soils collected from 40 farms in Bungoma and Teso Districts was performed using methods described in Okalebo *et al.* 2002. These soils were pH 5.6 (SD=0.8) and contained 1.0% (0.5) total organic carbon, 0.13% (0.05) total nitrogen and 5.7 mg kg^{-1} (4.0) extractable phosphorus, suggesting that these soils are very low in nitrogen.

Our research program was based upon the following principles. All work was conducted on-farm through collaboration with registered farmers', women's, and self-help groups. Trials were farmer-installed and farmer-managed, based upon instructions and materials provided by SACRED-Africa and local training arranged through the cooperator. The number of treatments was kept to a minimum and each farm contained only one set of treatments (one replicate), to allow for analysis of data collected from each cooperator as a randomized complete block design. Data collection was kept to a minimum and often consisted only of economic yield but

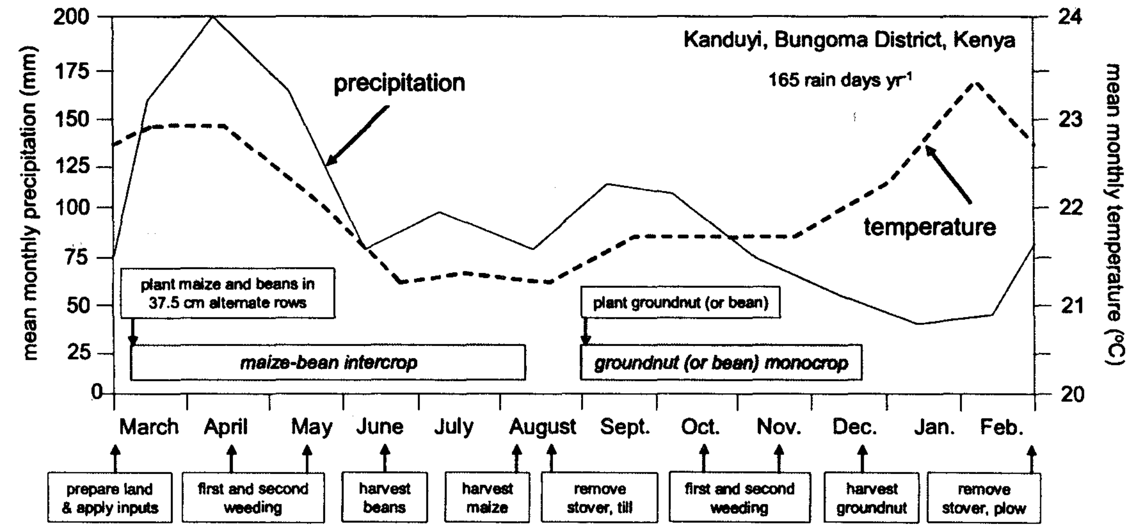

Fig. 1. Climate, temperature and typical smallhold operations in Bungoma, Kenya.

careful records of costs and local prices were maintained. Farmers' impressions of different intercropping options were collected through a series of field days that were organized by the local cooperators. These cooperators included Matunda Women's Group, Bukoli, SACRED Self-Help Group, Siritanyi Farmers' Field School, Chililila Women's Group, Kandui, and St. Marks Women's Group, Amagoro.

A maize–legume intercrop rotation was devised as follows. Site visits were taken to local cooperators and current difficulties with intercropping were discussed and noted; arrangements were made to obtain field areas for trials the following season. Special attention was paid to the maize varieties currently in use by farmers. A list of alternate legumes as candidates for intercropping with maize was prepared and seeds of these crops were obtained. An intercropping row arrangement was devised that would provide greater opportunity to understorey legumes by reducing their competition with maize by staggering every other maize row by 25 cm and planting maize and legumes as paired rows. This approach, referred to as MBILI (*kiswahili* for "two") resulted in the same plant populations (44 444 maize and 88 888 legumes ha^{-1}) while permitting legumes to grow in a 100 cm "gap" between sets of maize rows (Fig. 2).

It is not the intention to provide a complete account of the MBILI research and development process in this paper, but rather to summarize the yield data during four seasons of MBILI on-farm trials and to provide evidence that MBILI offers both above- and below-ground competitive advantage to legumes without adversely affecting maize yield. Yield data were obtained by collecting and air drying legume seed and maize kernels. Solar radiation was measured at three positions (above maize, above legume, and above soil) using a LICOR hand-held light meter and recording radiation as LUX throughout the day at maize tasseling. Fertilizer Use Efficiency (FUE) was estimated by comparing paired fertilized and unfertilized crops, subtracting their difference and dividing by the amount of nitrogen and phosphorus fertilizers applied, an approach that is likely to be

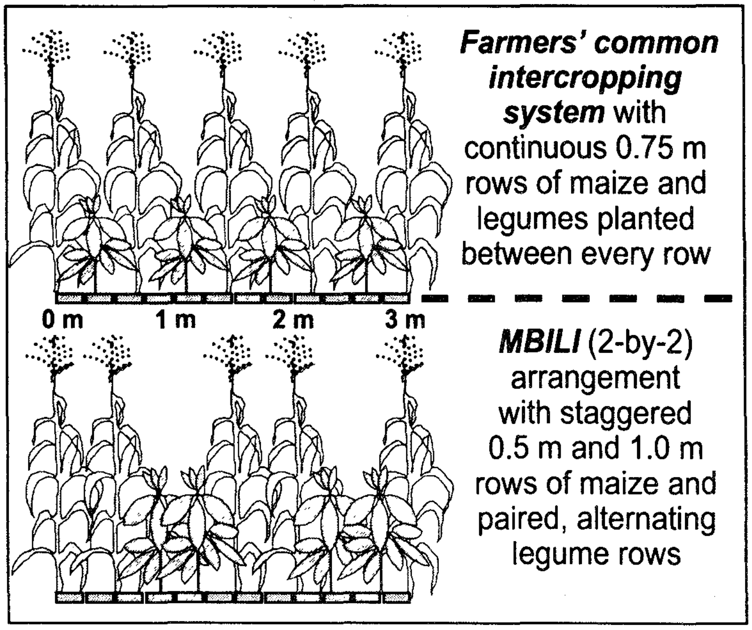

Fig. 2. Comparison of farmers' current intercropping row arrangement with MBILI, a system that is intended to permit better growth conditions for the understorey legume.

less precise than values based upon nutrient analysis of crop tissues. Only the 2000 short-rains and 2002 long-rains studies contained the necessary 2x2 factoral treatment arrangement (MBILI vs Conventional and ± fertilizer) that allowed for FUE to be calculated. Total economic returns were calculated based upon crop yield and commodity prices immediately following each harvest. Data were compiled onto a computer spreadsheet, inspected, and statistical analyses performed (mean, SEM, ANOVA, and linear regression). Mean comparisons were made by the Least Significant Difference.

Farmers' observations concerning MBILI were assessed by a short, formal, open- and closed-ended survey instrument delivered to 96 households. Responses were coded, entered onto a computer spreadsheet, and inspected. One household was excluded due to inconsistent information (a maize operation larger than total farm area) resulting in 95 sets of responses from which summary statistics were calculated.

Results

The paired, staggered row intercropping arrangement (MBILI, Fig. 2) repeatedly outperformed the more common alternating rows in terms of legume yield and total crop returns over three cropping seasons of on-farm trials (Table 1). Maize yields were either unaffected (2001 trials) or slightly improved (2000 short rains). In pair-wise comparisons, the MBILI arrangement increased total returns to intercropping by 26% (2001 short rains) 7% (2001 long rains) and 37% (2001 short rains). The largest legume intercrop response was observed with groundnut (101%), although significant increases were also noted for soybean (52%) and bean (15%) but not green gram (1%). The Land Equivalency Ratios, based upon total crop value in the intercrops during 2000 and their respective monocrops, were 1.67 in

TABLE 1
Maize and legume yields from conventional intercropping and MBILI row arrangements in Bingoma and Teso Districts, Kenya, over several growing seasons.

Arrangement	Intercrop	Fertilization (kg ha^{-1})	Yield: Maize (kg ha^{-1})	Yield: Legume (kg ha^{-1})	Total Return (KSh ha^{-1})
2000 short rains (n = 6)					
Conventional	bean	unfertilized	1196	775	32630
MBILI	bean	unfertilized	1264	878	35810
Conventional	bean	+9 kg N, 10 kg P	1439	940	39444
MBILI	bean	+9 kg N, 10 kg P	1640	1152	46870
Conventional	groundnut	+9 kg N, 10 kg P	1495	307	33780
MBILI	groundnut	+9 kg N, 10 kg P	1706	743	57100
Conventional	g'gram	+9 kg N, 10 kg P	1551	1367	69290
MBILI	g'gram	+9 kg N, 10 kg P	1799	1384	73190
$LSD_{0.05}$			*154*[a]	*177*	*5733*
2001 long rains (n = 17)					
Conventional	bean	+31 kg N, 20 kg P	5245	848	60353
MBILI	bean	+31 kg N, 20 kg P	5469	1002	64516
MBILI	groundnut	+31 kg N, 20 kg P	5344	1203	87912
$LSD_{0.05}$			*ns*	*295*	*10532*
2001 short rains (n = 4 or 8)					
Conventional	bean[b]	unfertilized	1353	755	25635
MBILI	bean	unfertilized	1830	808	30385
Conventional	groundnut	unfertilized	1508	389	27283
MBILI	groundnut	unfertilized	2095	624	41206
Conventional	soybean	unfertilized	1993	440	28653
MBILI	soybean	unfertilized	2687	670	40935
$LSD_{0.05}$			*ns*	*131*	*10571*

[a] $LSD_{0.05}$ for 2000 Short rains compares system within legume intercrop only. [b] bean and soybean n = 4, groundnut n = 8.
ns = not significant

the conventional intercrop arrangement and 2.05 in the staggered (MBILI) arrangement (data not presented).

Part of the legume response can be attributed to improved availability of solar radiation (Table 2). Solar radiation available to the legume understorey increased by 54% (from 38 403 to 59 327 LUX) resulting in a 41% increase in bean yield (from 760 to 1075 kg ha^{-1}) and an additional KSh 3359 return. Again, maize yields in the staggered and alternating row arrangements were not significantly different but tended to be higher within the staggered (MBILI) rows. These findings suggest that part of MBILI's advantage is related to aboveground competition for light between the maize and understorey legume intercrops.

Fertilizer use efficiency (FUE) was also greater in the MBILI system (Table 3). In this case, FUE was estimated by comparing paired

TABLE 2
Average daily light penetration and crop productivity in alternate (conventional) and staggered (MBILI) intercropping row arrangements.

Row arrangement	Solar radiation above		Crop yield		net
	maize	beans	maize	beans	return
	(LUX)		(kg ha^{-1})		(KSh ha^{-1})
Conventional	91 560	38 403	4835	760	26 333
MBILI	91 823	59 327	4900	1075	31 689
$LSD_{0.05}$	ns	20448	ns	207	3359

ns: not significant

fertilized and unfertilized crops, subtracting their difference and dividing by the amount of nitrogen and phosphorus fertilizers applied. Overall, FUE for maize was 21 kg per kg N and P fertilizer in MBILI compared to 14 kg kg^{-1} in the conventional intercrop, an increase of 46%. Legume FUE was 13 kg kg^{-1} N, and P in MBILI compared to 8 kg per kg^{-1} in the conventional intercrop, an increase of 46%. These benefits averaged KSh 245 per kg N and P fertilizer and tended to be greater for groundnut than bean and green gram, and when rock phosphate fertilizers were applied. These findings suggest that part of MBILI's advantage is related to a more efficient use of applied fertilizers.

Farmers' impressions of MBILI are presented in Table 4. Farmers' average field area committed to MBILI is rather small in both absolute terms (0.05 ha) and relative terms (0.1 of their maize production area) but the area of MBILI cultivation was significantly correlated to the number of seasons experience with MBILI ($r = 0.58$, $P > 0.001$), years of farming experience ($r = 0.28$, $P = 0.006$) and the size of maize operations ($r = 0.20$, $p = 0.05$). Technical compliance with MBILI recommendations was strongest with row spacing and pre-plant fertilization, and least in terms for substituting groundnut for bean. Many farmers' practices suggest that MBILI is being readily adapted to local conditions, particularly through the substitution of manure and urea for recommended fertilizers, and replacement of groundnut with soybean and other intercrops.

Discussion

MBILI is an attractive approach to maize–legume intercropping among smallholders in western Kenya. It is based upon their principal food production enterprise and includes adjustments for their most pressing crop production constraints (Fig. 1). It does not rely upon complicated innovation or the introduction of exotic or non-market plants (Fig. 2). It offers material gain during a single season rather than short-term losses for residual benefits. MBILI was developed entirely through farmer-managed on-farm experimentation over several years with careful attention directed toward flexibly adjusting labor and cash requirements to household abilities (Table 1). In these ways, the development and popularization are more consistent with the "Farmer First" paradigm (Chambers *et al.*, 1989) than more top-down "Induced Innovation" approaches (Lacy, 1996). The approach employed in the development of MBILI was described as Assess-Involve-Resolve (Woomer *et al.*, 2002) where farmers serve as full partners in problem identification and resolution. At the same time, it should be noted that SACRED-

TABLE 3
Fertilizer use efficiency in conventional and MBILI intercropping arrangements.

Row arrangement	Fertilizer		Crop		Return	
	Rate	Form	Maize	Bean	Total	Increase
	— (kg ha^{-1}) —		—(kg kg^{-1} N and P)—		—(KSh kg^{-1} N and P)—	
2000 short rains						
Conventional w/bean	9 N, 10 P	DAP	12.7	8.7	359	na
MBILI w/bean	9 N, 10 P	DAP	19.7	14.4	582	+223
Conventional w/g'nut	9 N, 10 P	DAP	13.5	5.0	412	na
MBILI w/g'nut	9 N, 10 P	DAP	14.7	20.7	1171	+759
Conventional w/g'gram	9 N, 10 P	DAP	16.7	10.6	603	na
MBILI w/g'gram	9 N, 10 P	DAP	28.3	3.4	501	-102
2002 long rains						
MBILI w/g'nut	31 N, 20 P	DAP CAN	8.9	1.0	112	+69
MBILI w/g'nut	31 N, 20 P	RP urea	23.3	4.0	352	+309
MBILI w/g'nut	31 N, 20 P	RP CAN	23.3	1.3	254	+211

Africa is a nongovernmental organization that lacks on-station capacities so that any work it conducts must occur on its cooperators' farms. Despite our more extensive, on-farm approach, some very important underlying mechanisms that affect intercrop performance, both above- (Table 2) and below-ground (Table 3), were documented.

Ottman and Welch (1989) assert that the upper leaves of maize tend to be radiation saturated but the lower leaves, which serve as the main source for the energy requirements of nutrient uptake, are radiation deficient. In their study, the lower maize leaves (0–99 cm height) of "twin" row spacing received 10% more solar radiation than did conventional 76 cm rows. Similarly, Zaffaroni and Schneiter (1991) reported that "twin" row spacing, similar to the staggered maize rows of MBILI, did not affect the yield of two sunflower hybrids when compared to the conventional 76 cm rows. In our study, staggered row spacing of maize within MBILI also resulted in greater light penetration within the canopy (Table 2) and this effect may have contributed to the greater nutrient use efficiency of applied fertilizers (Table 3). Furthermore, this perspective suggests that above and below ground competition should be regarded as interacting, not independent, phenomena.

Maize and groundnut are reported to be intercropped and multiple cropped in several tropical areas (Papendick *et al.*, 1976) although this combination experiences difficulties because of differences in crop architecture (Wahua *et al.*, 1981) and the relatively high light requirement of groundnut during critical stages of its reproductive development (Misbahulmunir *et al.*, 1989). Shaded groundnut tends to develop upward reaching stems that are poorly positioned to deposit penetration pegs into the soil. For example, groundnut intercropped with maize in the southern US experienced as much as 67% reduction in yield compared to monocropped groundnut (4178 kg ha^{-1}), but this loss was reduced slightly by delaying maize planting by up to 3 weeks after sowing groundnut (Misbahulmunir *et al.*, 1989). This sort of manipulation is similar to MBILI intercropping in that it

TABLE 4
Summary of MBILI intercropping adoption in Bungoma, Kenya.

Setting	
Respondents	95 farmers (47 women, 48 men)
Farmer's age	35 years (15 to 74)
Farmer's experience	13.3 years (2 to 58, n = 94)
Monthly income	KSh 3080 (1000 to 7000, n = 91)
Farm size	0.95 ha (0.1 – 4.9, SEM = 0.08)
Maize area	0.49 ha (0.1 to 2.0, SEM = 0.04)
MBILI adoption	
MBILI area	0.05 ha (0.01 to 0.61, SEM = 0.01)
MBILI:Maize areas	0.10 (0.01 to 0.75, SEM = 0.01)
First planted MBILI	2000 (1999 to 2002, 1.7 cropping seasons)
MBILI "visitors"	14.8 persons (0 to 200, SEM = 2.5)
Plan to continue MBILI	100%
MBILI technical "compliance"	
Row spacing	90.5%
Pre-plant DAP	85.3% (alternatives: manure = 10.5%, rock P = 1.1%)
Side dressed CAN	66.3% (alternative: urea = 14.7%)
Short statured maize	65.3% (alternative: H600 series = 34.7%)
Fertilizer "package"	64.2% (DAP pre-plant and CAN side dressing)
Groundnut intercrop	53.6% (bean = 25.4%, soybean = 14.7%, others = 6.3%)

reduced the adverse competitiveness of upper-storey maize on the legume intercrop, in this case, groundnut. Mwanga *et al.* (2002) reported similar light interception patterns in staggered rows of sorghum and cowpea or groundnut in intercropping studies in eastern Uganda.

Twin row spacing of soybean was shown to yield less than evenly spaced and zigzag planting patterns (Ikeda, 1992) but this observation was made in soybean monoculture and its relevance within intercropping systems may be questioned. Furthermore, it should not be construed that soybean yield best at lower densities (Johnson and Harris, 1967), rather soybean performs well at plant densities of 250 000 plants ha^{-1} but produces the most uniform yield characteristic with even row distribution (Ikeda, 1992). In the MBILI system, legumes occupy 50% of the land area and are planted at a rate of 88 888 plants ha^{-1} (equivalent to 177 776 plants ha^{-1}), a rate that studies by others indicate as slightly sub-optimal (Ethredge *et al.*, 1989). Indeed, planting legume densities within the MBILI system may require further examination.

Fertilizer Use Efficiency (FUE) is greater within MBILI but at first impression, the data presented in Table 3 may appear unorthodox because nutrient use efficiencies are more commonly expressed as "percentage uptake" (Goyal *et al.*, 1992). In our on-farm studies, we did not measure crop nutrients and were unable to calculate total crop nutrient uptake, rather FUE is expressed as the increase in yield resulting from each kg of applied mineral nitrogen and phosphorus (kg crop kg^{-1} N and P). Yield increases for maize and beans are presented separately (Table 3) allowing for total crop value resulting from fertilizer addition to be calculated, based on their respective prices. Similarly, the cost per unit fertilizer nutrient (N and P) may also be calculated from fertilizer prices (e.g. KSh 74 kg^{-1} for DAP). These valuations then allow for the calculation of Value Cost Ratio (VCR), the incremental value of production divided by the incremental cost of fertilizer use.

VCR for the maize groundnut intercrop during 2000 increased from 5.5 to 15.8 (+ 10.3) due to staggering the crop arrangement (data not presented). The responses in other intercrops and during another year (2002) were less spectacular (e.g., bean intercrop + 3.0) but generally exceeding 2.0, a value regarded as a threshold for investment (Gerner and Harris, 1993). Furthermore, total returns per unit fertilizer were always greater for bean and groundnut intercrops grown in the MBILI row arrangement, a strong suggestion that FUE is being improved through more strategic positioning of fertilizers, particularly the N side-dressing. Mwaura and Woomer (1999) reported that DAP and CAN were the most commonly marketed fertilizers in western Kenya and were available for sale in even the smallest marketing centers. These are the two fertilizers that are recommended within the "MBILI package" (Table 4).

While it is important that agricultural scientists understand the mechanisms that underlie the productivity of different intercropping systems, it is more important to see that better systems are being adopted and adapted by farmers. MBILI is being readily adopted in western Kenya (Table 4) although some of its components meet greater acceptance among farmers than others. Within a few seasons of developing MBILI, large numbers of farmers are examining MBILI within 10% of their maize operations and this proportion increases with time (r = 0.58, *P* 0.001). Farmers consider MBILI more productive than conventional intercropping (70%) but express concerns that it requires new skills (38%) and more labor (25%) and have asked that the technology be more simply packaged (25%) and that specialized training and tools be developed (21%) (data not presented). Furthermore, the MBILI approach is being tested in Uganda in different crop combinations with promising initial results (Owour *et al.*, 2002; Tenywa *et al.*, 2002). Clearly the next phase of MBILI research will involve wider introduction of this intercropping approach and closer documentation of farmers' innovations, but this will be done with the knowledge that the technology offers both above and below-ground competitive advantages to understorey legumes.

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