Original Research Article

Determination of Production Efficiency of Crop Mixtures: the Relevance of the Agronomic Efficiency Method

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Abstract

The paper looks at estimation of the agronomic efficiency (AE) for various crop mixtures at varying levels of fertility management. To evaluate the concept, three trials using different cropping patterns and fertility rates were reviewed by calculating and comparing the relative yield and agronomic efficiency of the main crop. AE was higher in the mixtures compared to the sole crop in all the trials, and in the mixtures while efficiency between the control and the fertility levels employed were high, those between the fertility levels were not as high and increased at a reducing rate, sometimes tending to be constant. These responses gave rise to situations similar to a quadratic response and could therefore permit for optimum fertility levels for crop mixtures to be predicted. This therefore means that sustainable intensification is possible under small scale production systems as increase in efficiency was higher at lower fertilizer rates compared to the higher rates. Assessment of AE for crop mixture could also result in staggered recommended production practices, thus discouraging the excessive use of fertilizers – chemical or organic – and cut cost of production, reduce the pollution of the environment with its attendant consequences while production costs could be within reach of the small scale farmers. Small scale family farmers seeking alternative methods of soil fertility management could be encouraged to undertake the clipping/thinning management of companion leguminous crops as such measures could enhance their productivity as the estimation of AE has shown in these investigations. The practice of either clipping or thinning of the leguminous companion crop is similar or close to current production practices employed by these farmers and therefore should not be difficult to adapt and adopt.

Key words: Agronomic efficiency; staggered production practices; replacement and additive mixtures; expected yield; green manure.

INTRODUCTION

Current agricultural production systems place great strains on biodiversity, soils, water and the atmosphere, and if current population growth, meat and energy consumption, and food waste continues, the situation will be exacerbated (Ponisio et al., 2015). Farming systems that are both highly productive and minimize environmental harms are therefore critically needed (Garnett et al., 2013; Bennett et al., 2014; Loos et al., 2014). Advocates of sustainable intensification have focused on increasing production efficiency while minimizing economic and environmental costs; stipulating that emphasis on efficiency may not necessarily lead to development of sustainable, resilient productive systems that can buffer unexpected changes resulting from the complex socio-ecological interactions that influence agriculture. They therefore suggested that food must be grown in a manner that protects, uses and regenerates ecosystem services (e.g. favours natural pests control over the use of synthetic pesticides) rather than replacing them. Also according to Ho (2011), there is an emerging scientific consensus that a shift to small scale sustainable agriculture and localized

food systems will address most, if not all the underlying causes of deteriorating agricultural productivity as well as the conservation of natural soil and water resources while saving the climate.

Fertilizer use among smallholder farmers in Africa, Asia and Latin America have shown that additional yields achievable through mineral fertilizers are often marginal; due to widespread low fertility of the soils and perhaps the poor ability to make nutrients from fertilizers available to plants and to create beneficial growing conditions is often minimal (Henao and Baanante, 1999; Tittonel and Giller, 2013). Yet very often recommendations for optimum production of a crop cultivar in monoculture is extrapolated to other production systems without proper considerations to prevailing conditions for production - like the soil type or varietal differences and for crops in mixtures, their performance at different stand arrangements or crop proportions and perhaps allelopathic properties. These factors can in addition also affect nutrient use efficiency of crops and their interaction in crop mixtures will determine the performance of a crop mixture. Interaction between crops in mixtures could be complementary,

compensatory or competitive and thus how nutrients are used can be influenced by the type of interaction that occurs between the crops in the mixtures. On account of this, nutrients are often applied to crop mixtures to mitigate the effect of such interactions on the component crops. In addition, organic manures are frequently used in small-scale family farming to produce crops and its application could impart nutrient usage in the soil, as it could modify nutrient availability to the crops through the modification of the soil's physical, chemical and biological properties (Lee and Wani, 1988; Lal et al., 1979; IITA, 1992). Our hypothesis therefore is that an estimation of agronomic efficiency (AE) of production systems under small scale producers will remove the ambiguity surrounding their production systems as well as save the natural resources.

Crop performance in mixtures has been assessed using various methods, e.g. the relative yield total - RYT (de Wit and van den Bergh, 1965), land equivalent ratio - LER (Mead and Willey, 1980), area harvests equivalency ratio - AHER (Balasubramania and Sekayange, 1990), area-X-time equivalency ratio - ATER (Hiebsch and McCollum, 1978), bivariate analysis (Pearce and Gilliver, 1978) etc., which are often aimed at comparing their performance among themselves as well as their sole crops. While these parameters measure performance of the crops against their various sole crops, often the efficiency of the crop mixture in utilizing environmental factors *vis-à-vis* one crop mixture against another, is down-played. Also while RYT and LER will give the best crop combination that could be recommended for optimum production to the farmer, the efficiency of such recommendation is not often determined i.e. does the highest RYT or LER value represent the most efficient level of production? In their estimation, sole crop yields are taken as 1.0 while mixtures are adjudged as superior when they perform better than their expected value; their proportion in the mixture (Willey, 1979). While crop mixtures are sometimes subjected to different treatment levels, the sole crop is often subjected to recommended level of production for optimum yield; thus making the efficient use of resources important for the recommendation of cropping pattern and nutrient use efficiency. Unlike in mono-cropping trials, the processing of data using the regression and correlation analysis is cumbersome and adds very little to information available (Dear and Mead, 1983; Mead and Riley, 1981). Thus the agronomic efficiency (AE) is a simple method that can determine the performance of crop mixtures at various fertility levels to enable recommendation of the best combination for the crop and fertility level for possible optimum production of the mixtures.

MATERIALS AND METHODS

Nutrient use efficiency in field studies are either calculated based on differences in crop yield and/or nutrient uptake between fertilized plots and an unfertilized control – ‘*difference method*’. Using the same principles, the production (*agronomic*) efficiency of crop mixtures (i.e. of different cropping patterns, proportions, or arrangements) can be calculated based on the differences between the yield of crops in mixtures and their respective sole crops. Sole crop yields are considered as yields obtainable at the recommended practices for optimum production.

Three crop mixtures were used to illustrate the validity of the AE concept. The first mixture was a maize/soyabean trial conducted in 2004 and 2005 at Samaru (11°11'N, 07°38'E and 686 m above sea level), in the northern Guinea savanna ecology of Nigeria. It estimated the responses of maize (*Zea mays* L.) and soyabean (*Glycine max* (L.) Merr.) mixtures to green manure from the soyabean companion crop at various nitrogen fertility levels. Treatments were a factorial combination of four maize/soyabean mixtures (2 replacement - [2:2 and 3:3] and 2 additive - [1²:2 and 1³:3] mixtures) as well as sole crops of maize and soyabean and four nitrogen (0, 30, 60 and 90 kg N ha⁻¹) rates arranged in randomized complete block (RCBD) in three replicates. The second mixture was that of sorghum (*Sorghum bicolor* (L.) Moench) and soyabean (*Glycine max*, L., Merrill) trial conducted during the wet seasons of 2011 and, 2012; also at the Research farm of the Institute for Agricultural Research, Samaru and at Saye, Zaria (Lat. 11° 11'N, long 10° and 694 m above sea level) in the northern Guinea savanna ecological zone of Nigeria. Treatments consisted of three N rates (0, 30, and 60 kg ha⁻¹), four cropping patterns (as indicated in the maize/soyabean mixture above); with or without application of green manure as well as sole crops of sorghum and soyabean. The treatments were laid in a split plot design and replicated three times. The third mixture was that of popcorn (*Zea mays everta* L.) and cowpea (*Vigna unguiculata* (L.) Walp) trial also carried out at the Institute for Agricultural Research farm in 2013 and 2014 rainy seasons to assess the productivity of the mixtures. Treatments consisted of four poultry manure (0, 2, 4 and 6 t ha⁻¹) rates, two cowpea varieties (a local and an improved type), two times of cowpea introduction (mid-June and mid July) and clipped and no-clipping (the clipped cowpea was used to further manure the popcorn). The treatments were laid out in a split plot design and replicated three times. Sole crops of both crops were included using recommended production practices.

The ‘*difference method*’ compares the mixture performance (**actual yield**) with the sole crop equivalent

(expected yield) at the various crop proportions and therefore estimates efficiency in the production of a particular crop at that cropping pattern under the prevailing experimental conditions. It can be calculated as follows:

$$\text{Agronomic Efficiency (AE)} = [(\text{actual yield} - \text{expected yield}) / \text{expected yield}] \times 100$$

When values are negative, it signifies an inefficient system, i.e. performing lower than the expected yield; while a positive value signifies an efficient system. Recommendation can therefore be based on the most efficient method of production, i.e. the value with the highest rate of increase.

Results from these field trials were therefore subjected to relative yields and agronomic efficiency calculations and the results used to explain the value of agronomic efficiency in the determination of production efficiency in crop mixtures.

RESULTS

Trial 1: Maize/soyabean mixture:

This trial evaluated the productivity of maize and soyabean in mixtures at reduced rates of nitrogen application to the maize crop with added green manure from the soyabean companion crop.

From the estimation of the relative yields, the relative yield (RY) for the maize crop among the cropping patterns, was highest at the 1²:2(A) cropping pattern followed by the replacement mixtures and the 1³:3(A) cropping pattern performed poorest. Among the nitrogen rates, the RY increased with increase in the rate of nitrogen applied and was highest at the application of 90 kg Nha⁻¹ (Table 1). However, from the estimation of the agronomic efficiency (AE) for the maize crop, values indicated that for the cropping patterns (just like for RY)

the 1²:2(A) also gave the highest value, followed by the replacement mixtures and the 1³:3(A) gave the least value. For the N-rates however, unlike for the RY, AE decreased with increase in the N-rate and was least with the sole crop (Table 2). This conflicting behavior necessitated looking at both the RY and AE values at the interaction of cropping pattern by nitrogen rates for the maize grain. While RY was highest at the 3:3(R) for the control and application of 30 kg Nha⁻¹, the 1²:2(A) cropping pattern gave the highest RY value for the application of 60 and 90 kg Nha⁻¹ (Table 3). AE at the control was negative but was highest at the 3:3(R) cropping pattern in the application of 30 kg Nha⁻¹, while the 1²:2(A) cropping pattern gave the highest values for the 60 and 90 kg Nha⁻¹ application. AE at 60 kg Nha⁻¹ was over fivefold that of the 30 kg Nha⁻¹ while at 90 kg Nha⁻¹ it was about twice that at 60 kg Nha⁻¹ (Table 3).

Trial 2: Sorghum/soyabean mixture:

This trial was conceived to evaluate the productivity of sorghum/soyabean mixture at different cropping patterns and rates of N application, with or without green manure (GM) supplement at two experimental sites.

Results from the calculation of the relative yield (RY) for the treatments showed that additive mixtures gave higher RY values than the replacement mixtures in both sites, with the 1²:2 (A) having the highest value; while among the N-rates the RY values increased with increased application rate in both sites. Estimation of the AE showed that the application of 30 kg Nha⁻¹ had the highest value at both locations and that the 1²:2(A) cropping pattern also had the highest value at Samaru, and was similar to the 1³:3(A) and negative at Saye (Table 4). Thus both RY and AE estimations are again varied at the N-rates though similar at cropping patterns necessitating further analysis. When the RY and AE were estimated for the interaction of N-rates by cropping pattern on sorghum

Table 1. Grain and seed relative yield (RY) for maize and soyabean mixtures in 2004 and 2005 seasons, and RYT for the average of both seasons at Samaru

Treatment	MAIZE RY				SOYABEAN RY				RYT
	Expected	2004	2005	Average	Expected	2004	2005	Average	
Patterns (M.SB)									
2:2 (R)	0.50	0.79	0.81	0.80	0.50	0.78	0.77	0.78	1.58
3:3 (R)	0.50	0.88	0.90	0.89	0.50	0.88	0.90	0.89	1.78
1 ² :2 (A)	0.50	0.91	0.98	0.95	0.67	0.85	0.84	0.84	1.79
1 ³ :3(A)	0.50	0.60	0.63	0.61	0.75	0.92	0.93	0.92	1.53
Fertility: (kg/Nha ⁻¹)									
0	0.50	0.15	0.19	0.17	0.50	0.74	0.76	0.75	0.92
30	0.50	0.64	0.67	0.65	0.50	0.83	0.81	0.82	1.47
60	0.50	1.04	1.06	1.05	0.50	0.92	0.94	0.93	1.98
90	0.50	1.35	1.40	1.37	0.50	0.95	0.93	0.94	2.32

Table 2. Effects of cropping patterns and nitrogen levels on grain yield (kg ha⁻¹) of maize and soyabean 2004 and 2005 raining season and the agronomic efficiency of the maize crop at Samaru

Treatment	Maize				Soyabean		
	2004	2005	Combined		2004	2005	Combined
Patterns (M:SB)							
2:2 (R)	1486.2 ^b	1518.9 ^c	1502.5 ^b	(44.0)	657.1 ^c	701.0 ^c	679.1 ^c (56.0)
3:3 (R)	1656.8 ^a	1700.5 ^b	1678.6 ^a	(60.0)	746.7 ^{ab}	831.6 ^a	789.1 ^a (81.0)
1 ² :2 (A)	1714.8 ^a	1879.7 ^a	1797.3 ^a	(70.0)	717.4 ^b	774.3 ^b	745.8 ^b (71.0)
1 ³ :3 (A)	1076.1 ^c	1133.5 ^d	1104.8 ^c	(6.0)	782.3 ^a	855.0 ^a	818.6 ^a (88.0)
SE±	58.0	61.2	54.1	12.48	18.50	10.39	
Fertilizers (kg Nha⁻¹)							
0	159.7 ^d	195.8 ^d	177.8 ^d		621.8 ^c	678.0 ^c	649.9 ^c
30	1297.9 ^c	1371.4 ^c	1334.6 ^c	(38.6)	698.6 ^b	771.7 ^b	735.1 ^b (2.8)
60	1968.0 ^b	2041.5 ^b	2004.7 ^b	(30.5)	774.6 ^a	843.6 ^a	809.1 ^a (2.7)
90	2508.3 ^a	2623.8 ^a	2566.0 ^a	(26.4)	808.5 ^a	868.5 ^a	838.5 ^a (2.1)
SE±	58.0	61.2	54.11		12.48	18.50	10.39
Sole crop	2058.0	2125.9	2091.9	(16.0)	852.4	892.0	872.2

Agronomic efficiency in parentheses

Table 3. Grain yield (kg ha⁻¹), agronomic efficiency (AE) and relative yield (RY) of maize as affected by cropping pattern in mixture with soyabean in 2005 raining season

Treatment		Nitrogen levels (kg N ha ⁻¹)										
		0		30		60		90				
		AE	RY	AE	RY	AE	RY	AE	RY			
Patterns M:SB												
2:2(R)	313.6 ^h	-70	0.15	1496.8 ^c	41	0.70	1867.2 ^d	76	0.88	2397.6 ^c	126	1.13
3:3(R)	336.4	-68	0.16	1654.4	56	0.78	2105.2	98	1.0	2706.0	155	1.27
1 ² :2 (A)	80.8 ^a	-92	0.04	1346.8 ^f	27	0.63	2608.4 ^b	145	1.23	3482.8 ^a	228	1.64
1 ³ :3(A)	52.4 ^a	-95	0.02	987.6 ^g	-7	0.46	1585.2 ^e	49	0.75	1908.4 ^d	80	0.9
SE± 84.74												

Means followed by the same letters within the same treatment group are not significantly different at 5% level of probability using DMRT.

Table 4. Grain yield (kg ha⁻¹), relative yield (RY), and agronomic efficiency (AE) of sorghum as affected by nitrogen fertilizer rate, planting pattern and thinned soyabean biomass at Samaru and Saye in 2011 and 2012 wet seasons

Treatment	Grain yield (kg ha ⁻¹)									
	Samaru					Saye				
	2011	2012	Combined	RY	AE	2011	2012	combined	RY	AE
Nitrogen (kg N ha⁻¹)										
0	1288.3 ^b	2985.4 ^b	2294.6 ^b	0.65		945.3 ^b	1554.0 ^b	1249.2 ^b	0.40	
30	3486.5 ^a	4526.8 ^a	3946.6 ^a	1.11	(55.9)	1486.5 ^a	3246.0 ^a	2366.2 ^b	0.75	(37.2)
60	3316.5 ^a	4576.7 ^a	4049.2 ^a	1.14	(29.7)	2316.5 ^a	3533.8 ^a	2924.3 ^a	0.93	(27.9)
SE+	89.5	74.10	80.70			189.48	104.12	146.30		
Sole crop	3643	3457	3550		(19.3)	3287	2984	3136		(29.0)
Pattern (P)										
2:2	2597.3 ^{ab}	3727.3	3229.9 ^b	0.97	(-3.4)	2397.3 ^{ab}	2737.7	2667.6 ^{ab}	0.85	(-14.9)
3:3	2244.9 ^b	3674.1	3052.2 ^b	0.86	(-14.0)	2034.9 ^b	2544.0	2394.5 ^b	0.76	(-23.6)
1 ² :2	2961.7 ^a	4752.4	3909.9 ^a	1.10	(10.1)	2564.7 ^a	2866.4	2914.1 ^a	0.93	(-7.1)
1 ³ :3	2984.2 ^a	3965.2	3528.4 ^{ab}	0.99	(-0.6)	2578.3 ^a	2963.5	2913.0 ^a	0.93	(-7.1)
SE+	218.93	418.63	113.23			218.90	146.10	182.41		

Agronomic efficiency in parentheses

Table 5. Grain yield of sorghum (kg ha⁻¹) in mixture with soyabean and the agronomic efficiency (AE)* and relative yield (RY) as affected by the different cropping pattern and application of green manure at Samaru and Saye

	Samaru						Saye					
	0	RY	30	RY	60	RY	0	RY	30	RY	60	RY
Cropping pattern with green manure												
2:2(R)	23740(33)	0.71	3695.3(108)	1.11	4036.0(127)	1.21	1452.8(-9)	0.46	3035.1(91)	0.95	3256.3(104)	1.02
3:3(R)	2411.3(35)	0.72	3766.3(112)	1.13	4053.3(128)	1.22	1654.0(4)	0.52	3220.4(102)	1.01	3378.5(112)	1.06
1 ² :2(A)	2980.8(67)	0.89	4697.7(164)	1.41	4908.7(176)	1.47	1501.7(-6)	0.47	4154.2(161)	1.30	4335.3(172)	1.36
1 ³ :3(A)	2957.7(66)	0.89	4483.3(152)	1.35	4746.7(170)	1.43	1593.6(0)	0.50	4179.5(162)	1.31	4474.3(181)	1.40
SE±												
Cropping pattern without green manure												
2:2(R)	1269.0(6)	0.38	3213.7(81)	0.96	3088.7(74)	0.93	1357.0(-17)	0.43	3057.7(92)	0.96	3206.7(109)	1.01
3:3(R)	1395.0(15)	0.42	3374.7(90)	1.01	3450.7(74)	1.04	1579.3(-7.8)	0.50	2697.7(69)	0.85	2985.7(89)	0.94
1 ² :2(A)	2282.3(28)	0.69	4438.3(149)	1.33	4451.3(150)	1.34	1308.7(-18)	0.41	3495.3(119)	1.10	3615.1(127)	1.13
1 ³ :3(A)	2257.7(27)	0.68	4321.3(143)	1.30	4562.0(156)	1.37	1328.0(-17)	0.42	3304.4(109)	1.04	3724.7(134)	1.17
SE±												

* The Agronomic Efficiencies (A/E) of the mixtures in parentheses

grain yields, the results showed that at both locations the RY and AE values increased with increase in the rate of N applied (Table 5). However, the rate of increase between the application of 30 kg and 60 kg N ha⁻¹ was much lower than the increase between the control and 30 kg N ha⁻¹; suggesting reduced efficiency rate. In plots that did not receive GM, the both RY and AE followed the same pattern though the efficiency between 30 kg and 60 kg N ha⁻¹ was lower, suggesting superiority of the 30 kg N ha⁻¹ application.

Trial 3: Popcorn/cowpea mixture:

The third trial is an organic manure management trial to investigate the productivity of popcorn and cowpea mixtures when cowpea varieties are introduced at different times and either clipped or unclipped and the fodder obtained used as green manure for the popcorn.

In this trial the relative yield (RY) for the popcorn increased with increases in the rate of poultry manure in both seasons (Table 6); however, when the agronomic efficiency (AE) for the poultry manure rate was

Table 6. Effect of poultry manure rates and fodder from cowpea companion crop on the grain yield (kg ha⁻¹), agronomic efficiency (AE) and relative yield (RY) of popcorn intercropped with cowpea varieties

Treatments	2013			2014		
	Yield	AE (%)	RY	Yield	AE (%)	RY
Poultry manure (tha⁻¹) (P)						
0	1160.44c		0.575	1786.91b		1.064
2	1647.33b	24.7	0.816	2225.62a	21.9	1.326
4	1851.78a	17.3	0.917	2278.82a	12.3	1.357
6	1916.00a	12.6	0.949	2289.58a	8.4	1.364
SE±	92.340			59.07		
Variety (V)						
SAMPEA 6	1605.67	59.01	0.795	2102.07	150.40	1.252
Kananado	1682.11	66.58	0.833	2188.40	160.69	1.303
SE±	65.30			41.77		
Time of introduction (T)						
At planting	1487.67b	47.33	0.737	2171.44	158.67	1.293
6WAS	1800.11a	78.27	0.891	2119.02	152.42	1.262
SE±	43.874			38.60		
Clipping (C)						
Clipped	1696.56	68.01	0.891	2191.32	161.04	1.305
Not clipped	1591.22	57.58	0.788	2099.14	150.06	1.250
SE±	43.874			38.60		
Sole Crop Yield	2019.56	7.16		1678.93	0.90	

Table 7. Grain yield (kg ha⁻¹), relative yield (RY) and agronomic efficiency (AE) of popcorn under various organic management practices in a popcorn/cowpea mixture at Samaru

Treatments	Poultry Manure Rates (tha ⁻¹)											
	0			2			4			6		
	YIELD	RY	AE	YIELD	RY	AE	YIELD	RY	AE	YIELD	RY	AE
Cowpea Varieties												
SAMPEA 6	1570.71	0.78	55.7	2204.09	1.09	118.4	2299.33	1.14	127.9	2334.13	1.16	131.3
Kananado	2003.11	0.99	98.5	2247.16	1.11	122.7	2258.31	1.12	123.8	2245.02	1.11	122.5
Clipping												
Clipped	1773.07	0.88	75.7	2281.91	1.13	126.2	2343.73	1.16	132.3	2366.58	1.17	134.5
Not Clipped	1800.76	0.89	78.5	2169.33	1.07	115.0	2213.91	1.10	119.4	2212.58	1.10	119.3
Cowpea Introduction												
At Planting	1883.06	0.93	86.6	2244.58	1.11	122.5	2247.9	1.11	122.8	2310.22	1.14	129.0
6WAS	1690.76	0.94	67.6	2206.67	1.09	118.7	2309.67	1.14	128.9	2268.93	1.12	124.9

calculated, the lowest rate of 2 t had the highest value in both seasons though values for 2013 were higher than those for 2014. In the other treatments – the mixture with the late maturing cowpea variety (Kananado) gave higher RY and AE values among the cowpea varieties in both seasons, while the late introduction of cowpea into the mixture had higher RY and AE than the introduction at planting in 2013 but not in 2014 and the clipping and application of the cowpea green manure obtained to the popcorn had higher RY and AE values than where the cowpea was not clipped and thus green manure was not applied to the popcorn (Table 6). When RY and AE were estimated for the interaction between poultry manure rate and other production factors, results showed that both RY and AE increased with increases in the poultry manure rate up to 4 t ha⁻¹ for all the production factors and thereafter either declined or varied very slightly (Table 7). The rate of increase between the application of 2 t and 4 t ha⁻¹ of poultry manure was very low compared to that between the application of 2 t ha⁻¹ and the control, suggesting reduction in the efficiency rate. Mixtures with Kananado (local cowpea variety) had higher RY and AE values at lower fertility levels while those with SAMPEA 6 (improved cowpea variety) had higher values at the higher fertility levels.

DISCUSSION

In the trials considered above the AE for nitrogen usage in the crop mixtures were always higher than for the sole crop except at Saye, supporting the view that production packages extrapolated from sole crop requirements and recommended for crop mixtures could often be exaggerated because of interactions within the crop mixtures. However, the nutrient status of the soil was

important in the assessment as where soil fertility was low as at Saye, AE for the sorghum sole crop was better due to high value obtained and the corresponding low values of the mixtures in 2011. Thus nutrient recommendation for crop mixtures should not be assessed independently from sole crop requirement and perhaps could be staggered, based on the farmer's capability as well as on the return to investment.

In the crop mixtures, estimation of the agronomic efficiency (AE) of the cropping patterns is a way to get round the difficulty posed to determine the optimum requirement by crops in the mixtures as it shows that the demand by the crops decreases with increasing rate of the applied nutrient. Agronomists often look for linear or quadratic responses to make recommendations for optimum production levels; this procedure affords them this opportunity as situations similar to quadratic responses can be achieved through the estimation of agronomic efficiency (AE). In Trial 1 considered above, the response of maize to the rates of fertilizer applied was different for both the additive and the replacement mixtures. The difference between the control and the 30 kg N ha⁻¹ was high but the response of the 1²:2(A) at 60 kg N ha⁻¹ exceeded those of the replacement mixtures. So for recommendation of production packages it will be easy to recommend low rates of nitrogen application for single plants of maize and higher rates for when more than one plant/stand is employed. It would seem therefore that the very high nitrogen rates usually recommended for maize production and the recommendation of one plant per stand are highly exaggerated and recommendation should be staggered based on farmers' capabilities. In Trial 2 the agronomic efficiency for the sorghum crop increased about threefold between the control and the application of 30 kg N ha⁻¹ and much less between 30 kg and 60 kg N ha⁻¹ at both sites and for both with and without green

manure application. The cropping patterns also responded differently to the rates of nitrogen application, with the additive mixtures performing better than the replacement mixtures. However, unlike the maize crop the sorghum crop was able to perform well even without nitrogen application probably because of its ability to tiller and because the sorghum crop is an indigenous crop of the region. Thus it will be easier to recommend a production package based on these findings for the production of sorghum in these mixtures. Also the high fertility rates and thinning to one plant per stand recommended for sorghum production seem to be exaggerated as was observed for maize above. In Trial 3, which is an organic manure management trial, the agronomic efficiency for the popcorn almost doubled between the control and the application of 2 t ha⁻¹ of poultry manure, depending on the cowpea companion crop. With the improved cowpea variety, the AE continued to increase albeit at a reduced rate between the control and the application of 6 t ha⁻¹ of poultry manure; while with the local variety all the application of poultry manure had similar AE values but were higher than that of the control. Thus the cowpea varieties interacted differently with the popcorn *vis-à-vis* in nutrient usage. This situation is similar to the responses exhibited by maize and sorghum to nitrogen application earlier stated, thus where fertility is low indigenous crops/varieties will perform better than those bred under high fertility conditions and vice versa. The AE for the other treatment followed the trend of the cowpea varieties, thus recommending a package for use by the farmer will also not be too difficult.

The RY for crops in the mixtures was similar to the AE estimated for the crops, however unlike RY that would credit sole crops with 1.0, AE estimates the nutrient use efficiency of all crops according to the rate of fertilizer applied. Also while RY is adjudged to be positive and can be recommended for crop production when its values are higher than the expected value, AE is able tell the agronomist precisely how efficiently he is producing at various crop combinations and nutrient levels, such that various productions packages can be recommended for different levels of production.

CONCLUSIONS

This investigation was undertaken because of the difficulties often encountered in fertilizer recommendation for use in crop mixtures. Apart from showing that nutrient use efficiency in sole cropping is poorer than in mixtures, it has also been shown that within crop mixtures, efficiency can vary with the level of fertility applied and with the cropping pattern employed. Thus

a blanket recommendation of production practice is not only misleading but a misnomer, as all farmers are put in one category. Through the estimation of AE a staggered package of production can be given so that farmers can choose according to their production capacity as well as the crop varieties adopted for use – local versus improved. Such practices will improve production efficiency, reduce the cost of production through overindulgence/avoidance of unnecessary high inputs levels, minimize the use of external and non-renewable resources, preserve the environment and reduce the adverse effects of these practices on our environment and health. Farmers will therefore be producing at affordable levels which will make sustainability and the intensification of production possible.

REFERENCES

- Balasubramania V., Sekayange L. (1990): Area harvests equivalency ratio for measuring efficiency in multi-season intercropping. *Agronomy Journal* 82: 519-522.
- Bennett E., Carpenter S.R., Gordon L.J., Ramankutty N., Balvanera P., Campbell B., Cramer W., Foley J., Folke C., Karlberg L., Liu J., Lotze-Campen H., Peterson G.D., Polasky S., Rockstrom J., Scholes R.J. and Spierenburg M. (2014): Towards a more resilient agriculture. *Solutions for a Sustainable and Desirable Future* vol. 5 (5): 65-75.
- Dear K.B.G., Mead R. (1983): The use of bivariate analysis techniques for the presentation, analysis and interpretation of data. *Statistics in Intercropping Technical Report No. 1*, Reading University.
- Garnett T., Appleby M.C., Balmford A., Bateman I.J., Benton T.G., Bloomer P., Burligame B., Dawkins M., Dolan L., Fraser D., Harrero M., Hoffmann I., Smith P., Thornton P.K., Toulmin C., Vermeulen S.J., Godfray H.C.J. (2013): Sustainable intensification in agriculture: premises and policies. *Science* 341: 33-34.
- Henao J., Baanante C. (1999): Nutrient Depletion in the Agricultural Soils of Africa 2020 Vision Brief 62. Washington D.C. International Food Policy Research Institute.
- Hiebsch C.K., McCollum R.E. (1978): Area- X -Time Equivalency ratio: A method for evaluating the productivity of intercrops. *Agronomy Journal* 79: 15-22.
- Ho M.W. (2011): Small integrated farms with off-grid renewable energy may be the perfect solution to food and financial crisis while mitigating and adapting to climate change. *ISIS Report* 18/07/11. ISIS contribution to UNCTAD Trade and Environment Review 2011.
- IITA (1992): Sustainable food production in sub-Saharan 1. IITA's contributions resource and crop management, pp. 25-64.

- Kremen C., Iles A., Bacon C. (2012): Diversified farming systems: an agroecological, system-based alternative to modern industrial agriculture. *Ecology and Society* 17: 44.
- Lal R., Wilson G., Okigbo B. (1979): Changes in properties of an Alfisol produced by various grasses and legume crop covers. *Soil Science* 127(6): 377-382.
- Lee K., Wani S. (1988): Soil fertility and fertilizer management in semiarid Tropical India. In: *Proceedings; Colloquium of soil fertility and fertilizer management in semiarid Tropical India*, Hyderabad, India. IFDC-Alabama, USA.
- Loos J., Abson D.J., Chappell M.J., Hanspach J., Mikulcak F., Tichit M., Fischer J. (2014): Putting meaning back into 'sustainable intensification'. *Frontiers in Ecology and the Environment* 12: 356-361.
- Mead R., Willey R.W. (1980): The concept of 'land equivalent ratio' and advantages in yield from intercropping. *Experimental Agriculture* 16: 217-218.
- Mead R., Riley J. (1981): A review of statistical ideas relevant to intercropping research. *Journal of the Royal Statistical Society* 144 (4):462.
- Pearce S.C., Gilliver B. (1978): The statistical analysis of data from intercropping experiments. *Journal of Agricultural Science, Cambridge* 91: 625-632.
- Ponisio L.C., M'Gonigle L.K., Mace K.C., Palomino J., de Valpine P., Kremen C. (2015): Diversification practices reduce organic to conventional yield gap. *Proceedings of the Royal Society B* 282: 20141396.
- Tittonell P., Giller K. (2013): When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research* 143:76-90.
- Willey R.W. (1979): Intercropping – its importance and research needs. *Fields Crop Abstracts* 32(1):73.
- de Wit C.T., van der Bergh J.P. (1965): Competition among herbage plants. *Netherlands Journal of Agricultural Science* 13: 212- 221.

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