Agroforest Syst (2011) 83:361–372
DOI 10.1007/s10457-011-9415-2

Effect of organic fertilizer on the growth and fruit yield of six paprika (*Capsicum annum* L.) cultivars in Malawi

Gudeta W. Sileshi · Festus K. Akinnifesi · France M. Gondwe · Oluyede C. Ajayi · Simon Mng'omba · Konisaga Mwafongo

Received: 20 January 2011 / Accepted: 4 July 2011 / Published online: 15 July 2011

Abstract The production of paprika (*Capsicum annum* L.) under small-scale farm conditions in southern Africa is constrained by low soil fertility and lack of appropriate cultivars. The objective of this study was to determine the growth responses and fruit yields of six cultivars of paprika to organic and inorganic nutrient sources. The study was conducted in 2007 and 2008 at Chitedze Agricultural Research Station in Malawi. A combination of six paprika cultivars and four nutrient sources, namely (1) organic input from Gliricidia, (*Gliricidia sepium*) biomass, (2) inorganic fertilizer, (3) integrated nutrient input (Gliricidia biomass + inorganic fertilizer), and (4) control (no nutrient input) were compared. Each combination was replicated five times. A split-plot design was used where nutrient sources formed the main plot and cultivars the sub-plots. Plant height differed due to nutrient source in 2007 and 2008, while differences due to cultivar were minor. The control plots produced the shortest plants (height < 50 cm), while plots receiving the integrated nutrient input produced the tallest plants (height > 60 cm). Numbers of branches and fruits per plant differed due to nutrient source and cultivar during most of the study period. Plants receiving either organic inputs (Gliricidia biomass) alone or the integrated nutrient input alone had significantly higher stem, leaf and fruit weight compared with the control. Average fruit yield was lower in control plots than in plots receiving the organic input alone or the integrated nutrient input. Among cultivars, Papri-King, Papri-Supreme and Papri-Queen produced higher dry fruit yield. The ASTA and RAL colour rating was within the internationally accepted range for fruit from the treatments.

Keywords Biomass transfer · Inorganic fertilizer · *Gliricidia sepium* · Integrated nutrient management

Introduction

Pepper (*Capsicum annum* L.) is an important horticultural crop of major economic significance globally. International spice traders use the term 'paprika' for non-pungent red pepper, whose powder is widely used as colorant in the food and pharmaceutical industries. Paprika accounts for 20% of the volume and 15% of the value of total spice imports into the European Union (EU), while global demand for paprika is estimated at 120,000 Mt for bulk paprika (Keyser 2002). Given a world-wide move to the use of natural products and proposed EU ban on the use

G. W. Sileshi (✉) · F. K. Akinnifesi · O. C. Ajayi · S. Mng'omba · K. Mwafongo
World Agroforestry Centre, Southern Africa Regional Agroforestry Programme, Chitedze Agricultural Research Station, P.O. Box 30798, Lilongwe, Malawi
e-mail: sgwelde@yahoo.com

F. M. Gondwe
Department of Agricultural Economics, Bunda College of Agriculture, P.O. Box 219, Lilongwe, Malawi

of synthetic dyes in the pharmaceutical, cosmetic, textile, beverages, meat and poultry, food and confectionery sectors, it is expected that demand for paprika-based products will increase by about 20% per annum. Paprika has emerged as a major export crop in southern Africa, and production is estimated at 12,000 t year^{-1} in Zimbabwe and 6,350 t in Malawi, which is mostly exported to South Africa and EU countries (Langmead 2005; Mavengahama et al. 2008; Ogunlela and Koomen 2005). Since paprika is used as a colouring agent, its market value depends partly on the red colour. The genuine high quality powder needs to be brilliantly red. In southern Africa, paprika quality is usually assessed at the farm level in terms of grade ranging from A to D (Langmead 2005). In Malawi, paprika is graded A (best) to D (average) by Cheetah Malawi Limited and prices for full dry fruit vary from $1.32 per kg for grade A to $0.36 per kg for grade D (Anon 2009).

Paprika is a source of income and a profitable activity for small-scale farmers in southern Africa (Keyser 2002). Langmead (2005) estimated that on average, a small-scale farmer makes a profit of US$ 236 ha^{-1} in Zambia. However, paprika production in smallholder farms is constrained by low yields, with the median yield estimated at 800 kg ha^{-1} in Zambia (Langmead 2005). However, successful production of paprika is contingent upon good field establishment (Mavengahama et al. 2008), fertilization, choice of appropriate cultivars and irrigation under the dry-land conditions of southern Africa. Fertilization is especially important because firstly most of the land in southern Africa is exhausted and secondly paprika requires appropriate fertilizations (De-Viloria et al. 2002; Guertal 2000; Yodpetch 1997). While many soils in southern Africa have moderate to high inherent fertility, low nutrient status is widespread because of exhaustion due to prolonged cultivation, nutrient mining (especially in tobacco growing areas) and soil erosion. The use of fertilizer averages 8 kg ha^{-1}, which is only 10% of the world average. Small-scale farmers also have limited access to fertilizer (Denning et al. 2008). This is due to the lack of credit facilities or unwillingness of agencies to provide credit for fertilizer because of the well known risk of farmers applying the fertilizer to their maize than paprika (Giné et al. 2010; Langmead 2005). Even when fertilizer is available, farmers may not apply at recommended rates because of cost and the perceived risk of poor performance particularly under dry land conditions. In the past attempts have been made to develop alternative soil fertility management technologies appropriate for small-scale farm conditions.

Recently, emphasis has been placed on integrated soil fertility management (ISFM), which makes best use of inherent soil nutrient stocks, locally available organic nutrient sources and inorganic fertilizers (Vanlauwe 2004). Integrated nutrient management (INM) is the technical backbone of ISFM (Chianu and Tsujii 2005; Vanlauwe 2004). This involves judicious use of combinations of organic inputs and inorganic fertilizer (Chianu and Tsujii 2005) with the aim of restoring organic matter in the soil, enhancing nutrient use efficiency and maintaining soil physical, chemical and biological properties. Among the organic nutrient sources, biomass from leguminous trees has been demonstrated to improve soil fertility under smallholder farm conditions in sub-Saharan Africa (Kuntashula et al. 2004; Sileshi et al. 2008; Snapp et al. 1998). This is achieved through a practice called “biomass transfer”, which involves harvesting legume biomass (leaves and twigs) from tree stands, and applying it to crop fields (Kuntashula et al. 2004; Rao and Mathuva 2000). The legume biomass can be applied alone or combined with small amounts of inorganic fertilizer. However, the effect of integrated nutrient management in general and legume biomass in particular, on growth and yield of paprika has so far not been studied. In the present investigation it was hypothesized that use of organic inputs from legume biomass alone or in combination with inorganic fertilizer will improve growth and yield of paprika. Therefore, the objective of this study was to determine the growth responses and fruit yields of six cultivars of paprika to organic and inorganic nutrient sources.

Materials and methods

Study site

The experiment was conducted for 2 years (2007 and 2008) at the Kandiani site (latitude 13°58′S; longitude 33°58′E; elevation 1,151 m) of Chitedze Agricultural Research Station in Malawi. The site receives adequate rainfall for rain-fed agriculture with a long-term mean annual precipitation of 892 mm. About 85% of the total annual precipitation is received in November–April. The mean annual temperature is 20°C. The soils at the study site are medium texture sandy clay loam belonging to the Lilongwe series. According to the FAO soil classification, they belong to Ferruginous Latosols (Sakala et al. 2003).

Experimental design and management

The study tested a combination of four fertilization regimes involving organic input from Gliricidia (*Gliricidia sepium*) biomass, inorganic fertilizer and six paprika cultivars. The fertilization regimes (here after called "nutrient source") were: (1) control (no external nutrient input), (2) inorganic fertilizer, (3) Gliricidia biomass, and (4) integrated nutrient input (Gliricidia biomass + half of the recommended dose of fertilizer for paprika). The inorganic fertilizer treatment involved the recommended basal dressing of 23–2–0 (23N–21P_2O_5–0K_2O + 4S) and top-dressing with calcium ammonium nitrate at 27N–0P_2O_5–0K_2O. The Gliricidia biomass was applied at the rate of 8 t ha^{-1} on dry matter basis, which was chosen on the basis that it provides about 3.0–4.5% N and 0.2–0.3% P (Mwinga et al. 1994), and experience indicating that 8 t ha^{-1} of biomass provides sufficient N to vegetable crops (Kuntashula et al. 2006). Gliricidia biomass was incorporated in the plots manually during land preparation within 1 week before transplanting in well prepared plots.

The cultivars were (1) Papri-King, (2) Papri-Queen, (3) Papri-Excel, (4) Papri-Supreme, (5) Papri-Ace, and (6) PX1140 4601. The first four cultivars are open-pollinated; Papri Ace and PX1140 4601 are F1 hybrids. Prior to field establishment, paprika seedlings were raised in flat trays in a greenhouse at Chitedze Agricultural Research Station. Compound D fertilizer (8N–18P_2O_5–15K_2O) was applied at a rate of 250 g per tray. The seedlings were transplanted in field plots at 6–8 weeks after sowing, and field management and data collection continued for an additional 20–25 weeks. Within-row and between-row spacing was 0.15 and 0.50 m, respectively. Each plot measured 9.0 m^2 with a width of 1.20 m and length of 7.50 m.

Each treatment combination was replicated five times. A split-plot design was used where nutrient sources were randomly assigned to the main plots, and cultivars were randomly assigned to the sub plots within each main plot. Overhead irrigation was applied using a watering can in all treatments once every day to maintain soil moisture. Copper oxychloride and Diathane were applied at the recommended rate on all plants to control fungal diseases. Cypermethrin was applied from early flowering onwards to control aphids and other insect infestations. All plots were kept weed-free at all times through hand-weeding.

Data collection

Plant height (from root collar to top of each plant) was recorded every week for ten plants randomly selected (and tagged) per replicate in each fertilization regime and cultivar. The number of branches and fruit per plant were recorded for the ten plants used for height measurement every week. Ten randomly selected plants were uprooted from each replicate of every treatment, and the fresh weight of leaves, fruits, stems and roots recorded. Samples were then taken from each plant part and oven-dried. This was used to calculate dry weight of leaves, fruit, stems and roots. Total plant biomass was obtained by adding the weight of these components together.

Fruits were harvested from each plot as they matured, and weights of fruits per treatment recorded on successive harvests were added up to assess total fruit yield. Dry weight of fruit (10–12% moisture) was computed per plot (9 m^2). Each fruit was also assigned to a grade (A, B, C, and D), and the proportion (ratio of number of fruits in each grade to the total number of fruits in each treatment) of high and low quality fruit (unmarketable and reject) calculated. Fruit colour was recorded using the RAL colour chart for Grade A and B separately. RAL is a matching system for professional users of colour in industry, trade, architecture and design. In addition, current procedures for measuring extractable colour in paprika follows the standards set by the American Spice Trade Association (ASTA 1984). Extractable colour is measured using a spectrophotometer and expressed in ASTA units. The ASTA value for samples of fruits from each treatment was determined at Cheetah, a major paprika company based in Malawi.

Data analysis

The stem, leaf, fruit and dry weight data were analyzed using the linear mixed model (PROC MIXED) to examine nutrient input and cultivar effects. A traditional analysis of data from split-plot designs requires the construction of the whole plot error to test effect of the nutrient source and the pooled residual error to test cultivar and interaction effects. To carry out this analysis one has to obtain the correct F-test for the nutrient source (main-plot). However, PROC MIXED eliminates the need for the error term construction as it estimates variance components for the block, nutrient source × block, and the residual, and automatically incorporates the correct error terms into the test statistics (SAS 2003).

Plant height growth was used to assess vegetative varietal response to different nutrient sources. Data on height measurements made on successive occasions were subjected to growth modelling. For this analysis there were a total of 50 plants per cultivar (10 plants × 5 replicates) or 300 plants per nutrient source (10 plants × 5 replicates × 6 cultivars) on every measurement occasion except under certain specific circumstances. Plant growth (length, total mass or dry matter) over time is known to follow a definite pattern, which conforms to a general mathematical form of the sigmoid curve (Chen and Nelson 2006; Damgaard and Weiner 2008; Zeide 1993). Several sigmoid growth models with biologically interpretable parameters have been proposed to describe the growth of individual plants. In most of the models, initial growth is exponential, and a negative term reduces the relative growth rate as size increases, resulting in an asymptotic maximum size (Zeide 1993). One of the common sigmoid models is the logistic growth curve described by three parameters (A, B and R):

$$Y = \frac{A}{(1 + e^{(B - \mathrm{R} \times T)}) + \varepsilon}$$

where A is the asymptotic value, B is the shape parameter, R is the growth rate constant, T is time (in weeks after transplanting) and ε is the random error. The asymptotic value (A) thus estimated gives the maximum height possible. Estimation of the inflection point (I), the size at which the plant experiences its maximum absolute growth rate (Damgaard and Weiner 2008) is very important for sigmoid growth models. This is the point where the shape of the curve changes from concave upwards to concave downwards. In a simple curve this point occurs at or near the centre of the curve, and the whole curve is symmetrical in nature. However, deviations occur in the symmetry of the curve, particularly with the position of the point of inflection. Estimating the inflection point as a free parameter is biologically reasonable since there is no general theory that predicts at what growth stage plants experience their maximum growth rate (Birch 1999). For accurate estimation of the inflection point as a free parameter, the equation was specified in the non-linear procedure (PROC NLIN) of SAS (SAS 2003) as follows:

$$Y = \frac{A}{(1 + e^{(-\mathrm{R}(T - I))})}$$

The 95% confidence intervals of these estimates were compared to see if differences exist among cultivars or nutrient sources. This is because confidence intervals provide a more powerful test of differences in parameters than significance tests. However, biases in the parameter estimation can render inferences using the confidence limits invalid. Therefore, Hougaard's measure of skewness (g) was used to assess whether or not a parameter contains considerable nonlinearity and thus biased. The estimator of a parameter was considered unbiased if $|g| < 0.25$ (EL-Shehawy 2009).

In order to assess whether or not the model used accurately describes the data, the pseudo-R^2 was computed. The traditional R^2 (coefficient of determination) definition requires the presence of an intercept, which nonlinear models do not have. A measure relatively closely corresponding to R^2 in the nonlinear case is the pseudo-R^2 calculated from the residual sum of squares and corrected total sum of squares.

Data on ASTA values and RAL colour were analyzed using the normal probability and kernel density distributions. For ease of presentation the 2007 and 2008 RAL colour data were combined. The sizes of samples used for Grade A paprika fruit were 1,527 from the control, 1,432 from plants receiving inorganic fertilizer alone, 1,418 from plots receiving Gliricidia biomass alone and 1,492 from plots receiving the integrated nutrient input. The sample sizes for Grade B paprika fruits were 1,058 in the control plot, 1,020 in the inorganic fertilizer plots, 997 in the Gliricidia biomass plots and 1,084 in the integrated nutrient input.

Results

Height growth

The effect of nutrient source on height was statistically significant, whereas cultivar differences were not significant in most cases. The final plant height differed significantly due to nutrient source (Table 1) in both 2007 ($P = 0.0043$) and 2008 ($P = 0.0096$). In 2007 plants in control plots were shortest while plants receiving the integrated nutrient input were tallest. Cultivars differed ($P = 0.048$) in their final height in 2007, with cv. PX1140 4601 being taller than all others. In 2008, cultivars significantly differed ($P = 0.026$) in height, where Papri-Excel plants were taller than those of Papri-Queen.

The logistic growth model fitted plant growth very well (Pseudo-$R^2 > 0.900$; $P < 0.001$) with respect to nutrient source and cultivar (Fig. 1; Table 1). The only exception was in the case of cv. PX1140 4601 in 2007 where the $R^2 = 0.792$; $P < 0.001$). The model parameters (Table 1) were unbiased ($|g| < 0.100$) for nutrient sources and cultivars except for the growth rate constant ($|g| = 0.350$) and asymptotic height ($|g| = 0.229$) of cv. PX1140 4601 in 2007. Examination of the 95% confidence intervals (Table 1) in 2007 indicates that the asymptotic height and inflection point in the control were significantly lower than in other treatments. Plants receiving the integrated nutrient input attained asymptotic height of 66.3 cm, which was significantly higher than for plants

Table 1 Variation in measured and asymptotic plant height (cm), and growth parameters of paprika with cultivar and nutrient sources in 2007 and 2008

Year	Factor	Level	Measured height	Asymptotic height (A)	Inflection point (I)	Growth rate (R)	Pseudo R^2
2007	Nutrient source	Control	48.3 b	45.3 (44.8–45.8)	4.4 (4.2–4.5)	0.35 (0.33–0.37)	0.935
		Fertilizer	63.7 a	61.5 (60.8–62.2)	5.0 (4.8–5.2)	0.37 (0.35–0.39)	0.955
		Gliricidia	64.7 a	62.0 (61.4–62.6)	6.0 (5.9–6.2)	0.35 (0.33–0.36)	0.929
		Gliricidia + Fertilizer	67.3 a	66.3 (65.9–66.8)	6.1 (5.9–6.2)	0.33 (0.32–0.34)	0.973
	Cultivar	Papri-King	60.2	59.1 (58.4–59.7)	5.7 (5.5–5.8)	0.34 (0.32–0.36)	0.940
		Papri-Queen	61.4	60.2 (59.5–60.8)	5.3 (5.1–5.4)	0.33 (0.31–0.34)	0.953
		Papri-Excel	59.9	58.0 (57.2–58.9)	5.7 (5.6–5.9)	0.34 (0.32–0.36)	0.934
		Papri-Supreme	59.6	57.8 (57.2–58.5)	5.3 (5.2–5.5)	0.35 (0.33–0.36)	0.947
		Papri-Ace	59.9	58.9 (58.2–59.5)	5.4 (5.2–5.5)	0.35 (0.33–0.37)	0.945
		PX1140 4601	65.0	65.5 (61.9–69.2)	5.9 (5.1–6.7)	0.32 (0.24–0.40)	0.792
2008	Nutrient source	Control	50.3 b	50.7 (50.1–51.4)	4.7 (4.5–4.8)	0.41 (0.38–0.43)	0.920
		Fertilizer	52.3 b	52.5 (51.8–53.2)	5.0 (4.9–5.2)	0.36 (0.34–0.38)	0.951
		Gliricidia	61.7 a	61.4 (60.8–61.9)	4.4 (4.3–4.5)	0.49 (0.47–0.51)	0.925
		Gliricidia + Fertilizer	61.4 a	61.4 (60.7–62.0)	4.5 (4.4–4.6)	0.47 (0.45–0.49)	0.947
	Cultivar	Papri-King	57.8	58.0 (57.2–58.8)	4.6 (4.4–4.7)	0.47 (0.44–0.50)	0.932
		Papri-Queen	53.7	53.8 (53.1–54.6)	4.3 (4.2–4.5)	0.40 (0.37–0.43)	0.932
		Papri-Excel	58.1	57.6 (56.9–58.3)	5.0 (4.9–5.2)	0.51 (0.48–0.54)	0.940
		Papri-Supreme	55.9	57.0 (56.0–57.9)	4.5 (4.3–4.7)	0.38 (0.35–0.41)	0.919
		Papri-Ace	55.6	55.9 (55.1–56.7)	4.6 (4.4–4.7)	0.48 (0.45–0.52)	0.919
		PX1140 4601	55.9	57.2 (56.3–58.0)	4.6 (4.5–4.8)	0.39 (0.36–0.41)	0.934

Means with the same letter in each year and factor are not significantly different according to Tukey's studentized range (HSD) test

Figures in parenthesis represent the 95% confidence intervals of growth parameters. Overlap in the 95% confidence intervals of asymptotes and inflection points indicate lack of significant differences

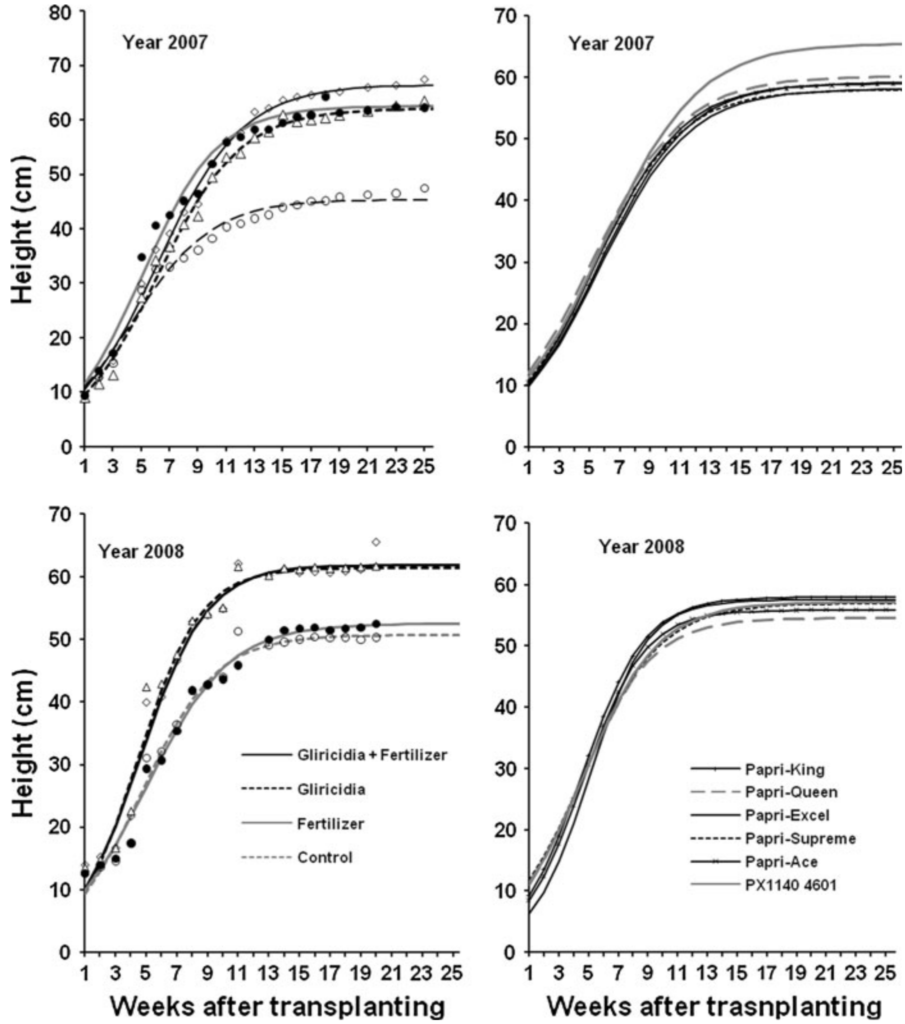

Fig. 1 Variation of the predicted (P) and observed (O) growth of plant with nutrient source (*left panel*) and cultivar (*right panel*) in 2007 (*top*) and 2008 (*bottom*). To avoid clutter in the cultivar charts only predicted curves were presented

receiving either inorganic fertilizer (61.5 cm) or Gliricidia biomass alone (62.0 cm). The inflection point (Table 1) indicated that slowing of growth occurred at 4.4 weeks in the control compared to the other nutrient sources (5–6 weeks after transplanting). The growth rate (*R*) did not significantly vary with nutrient source. Among cultivars, the highest asymptotic height was recorded in cv. PX1140 4601, which was taller than all other cultivars (Table 1). The inflection points and growth rate did not vary among cultivars.

In 2008, growth rate was slower in the control and plants receiving the recommended fertilizer compared with plants receiving Gliricidia biomass alone or the integrated nutrient input (Table 1; Fig. 1). The asymptotic heights were significantly higher in plants receiving the integrated nutrient input and Gliricidia biomass than in plants receiving inorganic fertilizer alone or in control plots. The 95% confidence limits of inflection points indicated that slowing of growth occurred much later in plots that received inorganic fertilizer compared to the other nutrient sources. The cultivar Papri-Queen had the smallest asymptotic height compared to the other cultivars (Table 1).

Plant biomass (dry weight)

In both 2007 and 2008, stem, leaf, fruit and total dry weights significantly ($P < 0.05$) varied with nutrient source. In almost all cases plants receiving the integrated nutrient input or Gliricidia biomass alone had significantly higher stem, leaf and fruit weights

Table 2 Variation in stem, leaf, fruit and root dry weight (mg $plot^{-1}$) of paprika with cultivar and nutrient sources in 2008

Year	Factor	Level	Stem	Leaf	Fruit	Root	Total
2007	Nutrient source	Control	33.7 b	25.9 b	89.7 b	11.7 b	150.5 b
		Fertilizer	72.6 a	57.9 a	97.4 ab	27.9 ab	241.6 a
		Gliricidia	82.7 a	61.0 a	124.7 a	35.7 a	281.0 a
		Gliricidia + Fertilizer	94.6 a	77.2 a	96.3 ab	40.3 a	295.6 a
		P value	0.009	0.002	0.014	0.015	0.005
	Cultivar	Papri-King	72.1	57.5	100.0	25.7	233.8
		Papri-Queen	76.5	55.6	108.9	27.0	244.3
		Papri-Excel	65.6	49.8	110.1	22.9	240.2
		Papri-Supreme	73.4	57.1	97.7	28.7	240.8
		Papri-Ace	65.9	56.5	95.9	35.9	254.3
		PX1140 4601	68.5	53.7	95.1	42.4	235.9
		P value	0.661	0.887	0.547	0.231	0.939
2008	Nutrient source	Control	80.1 b	50.6 b	202.2 b	20.1	353.6 b
		Fertilizer	78.4 b	47.0 b	221.7 ab	18.9	366.0 b
		Gliricidia	124.5 a	58.2 ab	289.7 ab	24.3	497.5 ab
		Gliricidia + Fertilizer	134.5 a	76.1 a	372.1 a	22.6	539.6 a
		P value	0.002	0.028	0.047	0.254	0.011
	Cultivar	Papri-King	106.0	61.1	257.1	20.4	448.2
		Papri-Queen	97.3	55.8	342.4	20.6	416.2
		Papri-Excel	105.6	58.5	259.8	21.7	445.6
		Papri-Supreme	113.8	58.6	270.3	18.0	460.7
		Papri-Ace	103.5	53.2	255.9	23.9	436.5
		PX1140 4601	100.2	60.7	243.0	24.0	427.9
		P value	0.573	0.662	0.670	0.475	0.810

Data for 2007 were not presented because maximum likelihood estimates were not reliable for some treatments

Means with the same letter in each year and factor are not significantly different according to Tukey's studentized range (HSD) test

compared to the control. Root dry weight was not significantly influenced by nutrient source in 2008 (Table 2). Cultivar differences in stem, leaf, root and fruit dry weights were not statistically significant.

Number of branches and fruits per plant

The number of branches per plant differed significantly ($P < 0.05$) due to nutrient source and cultivar from week 5 after transplanting in 2007; in 2008 significant differences were noted only between 5 and 9 weeks after transplanting (Table 3). In both years, the number of branches per plant was lower in control plots compared to the other treatments (Fig. 2). Among cultivars Papri-King, Papri-Queen and Papri-Excel produced larger number of branches per plant compared with cv. PX1140 4601 (Fig. 2).

Nutrient source and cultivar significantly affected ($P < 0.05$) the number of fruits per plant from 5 weeks after transplanting in 2007 (Table 3). In 2008, nutrient source significantly ($P < 0.05$) affected number of fruits per plant on most sampling dates, while cultivar did not (Table 3). Between weeks 5 and 21 after transplanting in 2007, the number of fruits per plant was significantly lower in the control compared to all other treatments. In 2008, the control and plants receiving inorganic fertilizer did not significantly differ. Plants receiving either Gliricidia biomass alone or the integrated nutrient input produced significantly more fruits per plant compared to the control (Fig. 3). Among cultivars, Papri-King and Papri-Excel consistently produced more fruits per plant compared with cv. PX1140 4601. Cultivar did not affect the number of fruits per

Table 3 Significance (*P value*) of fertilization and cultivar effects with respect to the number of branches and fruits per plant of paprika in 2007 and 2008

Year	Week	Branches			Fruits		
		Nutrient source	Cultivar	Interaction	Nutrient source	Cultivar	Interaction
2007	5	0.632	<0.001	<0.001	0.147	0.062	0.683
	7	0.076	0.007	0.016	0.017	<0.001	0.042
	9	0.056	<0.001	0.262	0.013	<0.001	0.026
	11	0.008	0.021	0.557	<0.001	<0.001	0.315
	13	0.090	0.010	0.215	<0.001	0.005	0.760
	15	0.028	0.008	0.063	<0.001	0.003	0.006
	17	0.045	0.005	0.050	0.004	<0.001	0.003
	19	0.064	0.005	0.089	0.012	<0.001	0.034
	21	0.033	0.015	0.089	0.025	<0.001	0.147
	23	0.038	0.015	0.055	0.078	<0.001	0.010
	25	0.046	0.059	0.090	0.082	0.190	0.003
2008	5	0.013	0.002	0.438	0.001	0.051	0.291
	7	0.011	0.046	0.216	0.079	0.765	0.005
	9	0.005	0.258	0.784	0.011	0.915	0.159
	11	0.505	0.173	0.796	0.039	0.263	0.577
	13	0.349	0.074	0.062	0.964	0.010	0.394
	15	0.649	0.267	0.862	0.012	0.691	0.181
	17	0.857	0.686	0.743	0.771	0.423	0.672
	19	0.104	0.823	0.456	0.399	0.243	0.752

plant on all of the occasions in 2008 except at 13 weeks after transplanting (Fig. 3).

Total fruit yield (dry weight)

In 2007, fruit yield did not significantly differ with nutrient source ($P = 0.255$), while it did with cultivar ($P < 0.001$). Among cultivars Papri-King, Papri-Supreme and Papri-Queen had higher fruit dry weight compared with Papri-Ace and PX1140 4601 (Fig. 4). In 2008, nutrient source significantly ($P < 0.010$) affected fruit dry weight; plants receiving Gliricidia biomass alone or the integrated nutrient input out-yielded the control. For the data combined over years, nutrient source ($P < 0.001$) and cultivar ($P = 0.002$) effects were significant (Fig. 4).

Fruit quality

The distribution of ASTA values was not affected by nutrient source. Examination of the means and their 95% confidence limits revealed that ASTA values in the control (336.9) were not significantly different from plots that received inorganic fertilizer (327.6), Gliricidia biomass (336.7) and the integrated nutrient input (330.0) were not significantly different. On the RAL scale, colour of Grade A paprika ranged from flame red (3,000) to traffic red (3,020). Kernel density distributions revealed that the modal colour is black red (3,007). The probability of the colour of Grade A paprika falling between 3,004 (purple red) and 3,009 (oxide red) was 0.79, 0.88, 0.78 and 0.79 in the control, inorganic fertilizer, Gliricidia biomass and the integrated nutrient input, respectively. The majority of Grade B paprika fruits fell between flame red (3,000) to raspberry red (3,024). Examination of the kernel density distributions of Grade B paprika fruit indicated that the modal value was 3,005 (wine red). The probability of the colour falling between 3,004 (purple red) and 3,009 (oxide red) was 0.55, 0.48, 0.53 and 0.55 in the control, inorganic fertilizer, Gliricidia biomass and the integrated nutrient input, respectively.

The proportion unmarketable fruit was higher (>30%) in 2007 than in 2008 (<10%). In 2007,

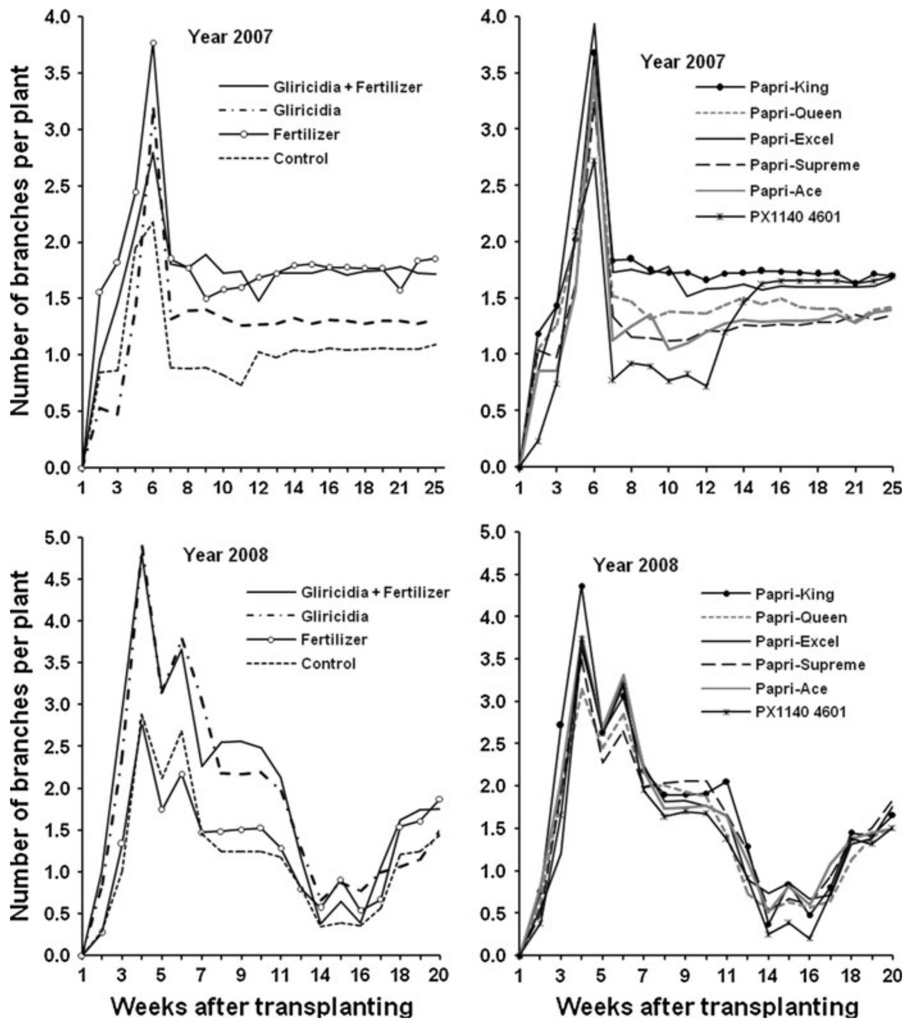

Fig. 2 Variation of the number of branches per plant with nutrient source (*left panel*) and cultivar (*right panel*) in 2007 (*top*) and 2008 (*bottom*)

nutrient sources did not significantly influence the proportion of unmarketable fruit, but cultivar did (Table 4). Papri-Supreme had the lowest while PX1140 4601 had the highest proportion of unmarketable fruit. In 2008 nutrient source and cultivar did not affect the proportion of unmarketable fruit (Table 4).

Discussion

The study indicated clear effects of nutrient source on height growth, number of branches, fruits per plant and dry weight of fruits. The effect of Gliricidia biomass was comparable to that of the recommended rate of inorganic fertilizer, while the integrated nutrient input was superior to all other treatments. If soluble fertilizers are used under irrigated conditions, there is a possibility of N loss and reduced crop yield. Faster growth, larger number of branches and fruits per plant, and the higher fruit yield recorded in plants receiving the integrated nutrient input could be attributed to the synergistic effect of organic and inorganic resources. This is consistent with the findings from earlier studies on maize crops in Malawi (Akinnifesi et al. 2007) and vegetable crops in Zambia (Kuntashula et al. 2006). The combination of organic and inorganic inputs may extend N availability over the growing season and increase P availability from the Gliricidia biomass and the fertilizers. Gliricidia biomass has been shown to be a very good N source for crops (Akinnifesi et al. 2007; Kuntashula et al. 2006; Mwinga et al. 1994). Studies on farmer fields in eastern Zambia indicate

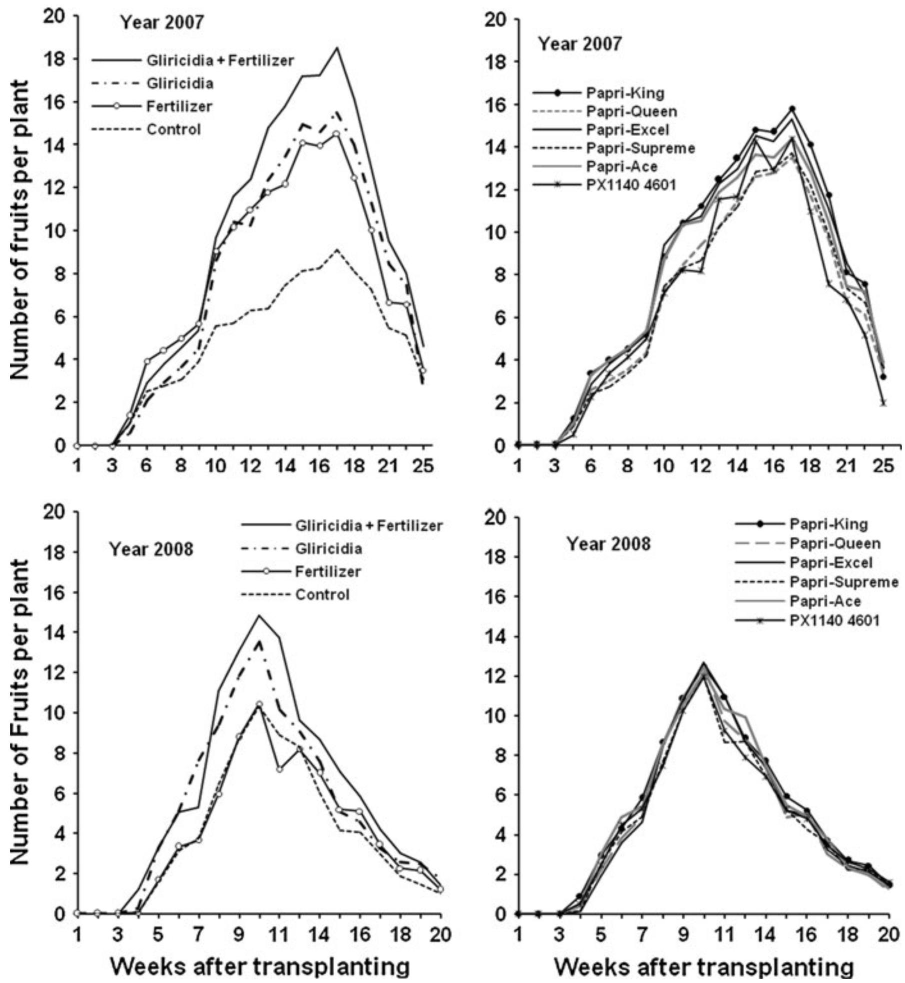

Fig. 3 Variation of the number of fruit per plant with nutrient source (*left panel*) and cultivar (*right panel*) in 2007 (*top*) and 2008 (*bottom*)

that application of Gliricidia biomass (8–12 t ha^{-1}) give cabbage and onion yields comparable with the recommended fertilizer rate application, while requiring lower cash inputs (Kuntashula et al. 2006). Gliricidia biomass has high nitrogen content but low polyphenol and lignin contents that makes it a very high quality organic input. Its biomass when applied to the soil decomposes quickly, releasing nutrients quickly in the early stages of plant growth, thereby contributing more to the initial supply of plant nutrients (Mafongoya et al. 1998).

Cultivar differences in response to fertilization have been reported to reflect on yield and yield components of paprika (Yodpetch 1997). Papri-King, Papri-Queen and Papri-Supreme had higher fruit yields than the other cultivars. The cultivar Papri-King is a high yielding cultivar and the most popular in Zimbabwe and Zambia (Langmead 2005). Papri-King and Papri-Queen are also considered to be of high quality and return relatively high prices under good management in Zambia. Papri-Queen is more disease resistant, but lower-yielding than Papri-King (Langmead 2005).

The colour of powder from all treatments was of high quality relative to the minimum required indicating that treatments did not compromise market quality of fruit. Comparison of ASTA colour rating of fruit from the different treatments indicated that the quality was within the acceptable range. The lower limit required for international markets is 250 ASTA units. Generally, the higher the ASTA colour value, the greater is its effect on brightness or richness of the final product. The ASTA colour value is the most important factor determining the value of the final product since

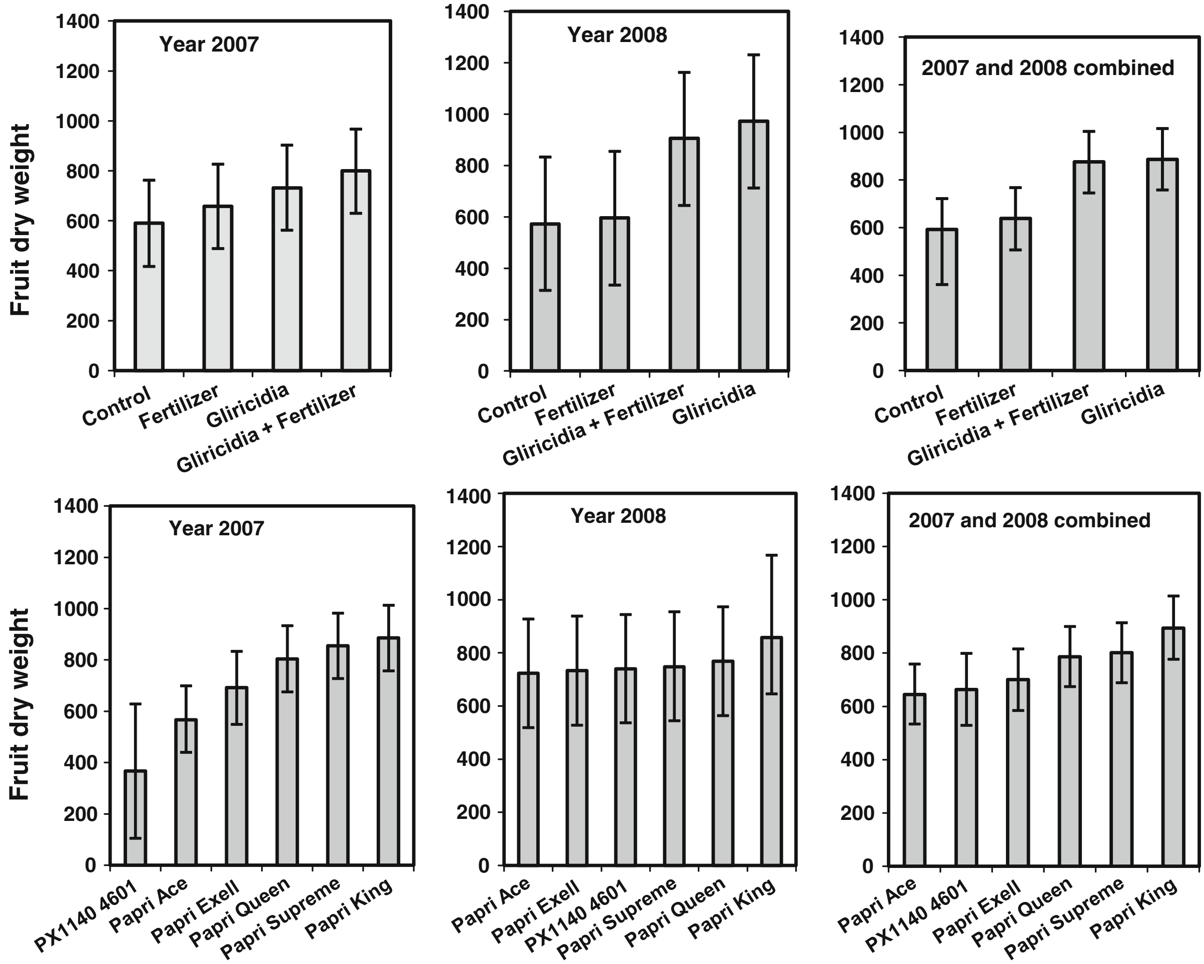

Fig. 4 Variation of total fruit yield (mg per plot) with nutrient source (*top*) and cultivars (*bottom*) in 2007 and 2008. *Vertical bars* represent the 95% confidence limits of estimates

Table 4 Proportion of low quality fruits (unmarketable and rejects) of paprika in each treatment and variety in 2007 and 2008

Factor	Level	2007	2008
Nutrient source	Control	0.33	0.07
	Fertilizer	0.36	0.07
	Gliricidia	0.34	0.07
	Gliricidia + Fertilizer	0.35	0.10
	P value	0.742	0.174
Cultivar	Papri-King	0.32 ab	0.09
	Papri-Queen	0.33 ab	0.08
	Papri-Excel	0.32 ab	0.08
	Papri-Supreme	0.30 b	0.06
	Papri-Ace	0.43 ab	0.07
	PX1140 4601	0.44 a	0.08
	P value	0.036	0.642

paprika fruit or powder is bought and sold on the principle of price per ASTA unit per kilogram.

We concluded that Gliricidia biomass alone or the integrated use of Gliricidia biomass and half of the recommended dose of inorganic fertilizer improve paprika yields on small-scale farms in southern Africa where climatic and soil conditions are comparable with the study site. Paprika customers show considerable interest in the environmental aspects of crop production. With the increasing interest in reduced use of synthetic inputs, food markets are becoming increasingly conscious of chemical additives. Customers are likely to place high premium on food produced with less inorganic fertilizer. Creating and maintaining market opportunities for paprika growers requires more research in alternative sources of nutrient inputs such as legume biomass.

References

Akinnifesi FK, Makumba W, Sileshi G, Ajayi OC, Mweta D (2007) Synergistic effect of inorganic N and P fertilizers and organic inputs from *Gliricidia sepium* on productivity of intercropped maize in Southern Malawi. Plant Soil 294:203–217

Anon (2009) http://qodebreaker.blogspot.com/2009/11/140kg-paprika-farming-in-malawi.html. Accessed 20 Jan 2011

ASTA (American Spice Trade Association) (1985) Official Analytical Methods. ASTA, New Jersey

Birch CPD (1999) A new generalized logistic sigmoid growth equation compared with the Richards growth equation. Ann Bot 83:713–723

Chen Y, Nelson RL (2006) Variation in early plant height in wild soybean. Crop Sci 46:865–869

Chianu JN, Tsujii H (2005) Integrated nutrient management in farming systems of the savannas of northern Nigeria: what future? Outlook Agric 34:197–202

Damgaard C, Weiner J (2008) Modelling the growth of individuals in crowded plant populations. J Plant Ecol 1:111–116

Denning G, Kabambe P, Sanchez P, Malik A, Flor R, Harawa R, Nkhoma P, Zamba C, Banda C, Magombo C, Keating M, Wangila J, Sachs J (2009) Input subsidies to improve smallholder maize productivity in Malawi: toward an African green revolution. PLoS Biol 7:e1000023

De-Viloria ZA, De-Arteaga R, Torrealba LTD (2002) Growing of pepper (*Capsicum annum*) in response to different levels of NPK and sowing density. J Hortsci 72:1062–1066

EL-Shehawy SA (2009) On calculating the Hougaard measure of skewness in a nonlinear regression model with two parameters. J Math Stat 5:360–364

Giné X, Goldberg J, Yang D (2010) Identification strategy: a field experiment on dynamic incentives in rural credit markets. Bureau for Research and Economic Analysis of Development (BREAD) working paper no. 263: 37

Guertal EA (2000) Preplant slow-release nitrogen fertilizers produce similar bell pepper yields as split applications of soluble fertilizer. Agron J 92:388–393

Keyser JC (2002) The costs and profitability of tobacco compared to other crops in Zimbabwe. Economics of tobacco control paper no 1. The World Bank, Washington DC

Kuntashula E, Mafongoya PL, Sileshi G, Lungu S (2004) Potential of biomass transfer technologies in sustaining vegetable production in the wetlands (dambos) of eastern Zambia. Expl Agric 40:37–51

Kuntashula E, Sileshi G, Mafongoya PL, Banda J (2006) Farmer participatory evaluation of the potential for organic vegetable production in the wetlands of Zambia. Outlook Agric 35:299–305

Langmead P (2005) Appraisal of diversification opportunities: the Zambian paprika case study. Agricultural management, marketing and finance service (AGSF) working document 1. FAO, Rome

Mafongoya PL, Nair PKR, Dzowela BH (1998) Mineralisation of nitrogen from decomposing leaves of multipurpose trees as affected by their chemical composition. Biol Fertil Soils 27:143–148

Mavengahama S, Ogunlela VB, Mariga IK (2008) Effective hardening of paprika (*Capsicum annuum* L.) seedlings for good field establishment and fruit yield in the smallholder system. Agric Trop Subtrop 41:110–116

Mwinga D, Kwesiga FR, Kamara CS (1994) Decomposition of leaves of six multipurpose tree species in Chipata, Zambia. Forest Ecol Manage 64:209–216

Ogunlela VB, Koomen I (2005) Paprika (*Capsicum annuum* L.) field establishment and crop productivity under varying planting density and ammonium nitrate topdressing. J Food Agric Environ 3:185–189

Rao MR, Mathuva MN (2000) Legumes for improving maize yields and income in semi-arid Kenya. Agric Ecosyst Environ 78:123–137

Sakala AR, Rao PSC, Sakala WD (2003) Evaluating soil physical and chemical characteristics for describing nutrient leaching in agricultural soils. Malawi J Agric Sci 2:8–20

SAS (2003) SAS/STAT, Release 9.1. SAS Institute Inc, Cary

Sileshi G, Akinnifesi FK, Ajayi OC, Place F (2008) Meta-analysis of maize yield response to planted fallow and green manure legumes in sub-Saharan Africa. Plant Soil 307:1–19

Snapp SS, Mafongoya PL, Waddington S (1998) Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. Agric Ecosyst Environ 71:185–200

Vanlauwe B (2004) Integrated soil fertility management research at TSBF: the framework, the principles and their application. In: Bationo A (ed) Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy Science, Nairobi

Yodpetch C (1997) Study on the optimum fertilizer rates on yield and quality of three long cayene peppers (*Capsicum annuum* L.). Kasetsart J 32:37–45

Zeide B (1993) Analysis of growth equations. Forest Sci 39:594–616