2. Understory Vegetable Production in Smallholder Agroforestry Systems of West Java – A Viable Option?

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Abstract

Farmers in Nanggung, West Java, traditionally cultivate vegetables under full sunlight. There is opportunity to expand vegetable production in the understory of agroforestry systems, but farmers have limited experience with such practices. An on-farm trial evaluated the production of nine commercial vegetable species (of which seven subsequently survived) under three light levels as the treatment in a nested design, replicated three times. Average light levels for each treatment were 127-603*1000 lux (open area, control), 95-245*1000 lux (medium light) and 75-135*1000 lux (low light). Relationships between a number of site/overstory variables and vegetable growth and yield were explored. Results indicate that in an understory of mixed tree systems with medium light level, the production per plant of amaranth (*Amaranthus* sp.), kangkung[4] (*Ipomoea aquatica* Forsskal), eggplant (*Solanum melongena* L.), chili (*Capsicum annuum* L.), tomato (*Lycopersicon esculentum* Miller), yard-long bean[5] (*Vigna unguiculata* L. Walp.) and katuk (*Sauropus androgynous* L. Merrill) was superior to production under full sunlight (from 98 to 278%). Even in understory of low light levels (heavy shade), those seven vegetables produced 43-139% of the full sunlight plot production. Because the trial was managed with hired labor and at an intensity that exceeded smallholder practices, vegetable production costs representative of smallholder conditions could not be documented. However, illustrative data demonstrate the production costs/kg were lowest under medium light levels for all vegetable species. This study requires replication to address questions of vegetable quality and seasonal variation, cropping rotation, tree-vegetable-site matching, labor input requirements, and overall profitability under varied light levels. Results from those studies will inform the development of efficient and effective practices for understory vegetable production in smallholder agroforestry systems.

Keywords: Vegetable production, tree shade management, vegetable agroforestry systems

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[4]Local name of a morning glory plant widely consumed as vegetable in Indonesia. In the Philippines the same plant is called and written ‘kangkong’. [5]Also named *Vigna sinensis*

1. Introduction

Dudukuhan (talun) is a traditional tree farming system in West Java. This system is distinguished from home gardens (pekarangan) by location – it is located away from the house and with a lower level of management. Dudukuhans are characterized by irregular tree spacing and extractive management, with few inputs (minimal quality germplasm, fertilizers, labor). Farmers favor this management approach because of constraints imposed on them by restricted land tenure, small landholding size, off-farm employment opportunities, limited market access, or their limited experience with intensive tree management.

Dudukuhans are divided into four types: 1) timber systems, 2) mixed fruit-timber-bananas-annual crop systems, 3) mixed fruit-timber systems, and 4) fallow systems (Manurung et al., 2008).

Budidarsono et al. (2004) conducted a farm and household study of dudukuhan systems in Nanggung. They found that the dudukuhan averaged 0.25 ha and received little proactive management. Harvesting was the most common activity, conducted in 35.9% of dudukuhans during the period of analysis. Weeding and maintenance of tree or annual crops was the second most common activity, conducted in 15.1% of the dudukuhan plots. The number of person-days committed to harvesting (30 ps-day/ha) was less than the number of person-days used in weeding and maintenance (95 ps-day/ha). Chemical fertilizer was applied to only 1.4% of dudukuhans, with organic fertilizer applied to 3.1%. The fertilizer application rate was very low, only 30.0 kg/ha of chemical fertilizer and 1.9 ton/ha of organic fertilizers. Most of the labor and fertilizer inputs are committed to annual crop production under mixed fruit-timber-bananas-annual crop and mixed fruit-timber dudukuhan systems. Timber dudukuhan systems are not commonly intercropped because of their dense canopy and location further from the home.

Understory crops (including vegetables) can be integrated with forestry, orchards, or other agroforestry systems. Farmers use understory crops to provide earlier returns, diversify products, and/or to make more efficient use of land and labor (Wilkinson and Elevitch, 2000). Farmers in Nanggung, West Java, have adequate knowledge and experience to grow vegetables under full sunlight. However, household survey results show that while 27% of farmers grow vegetables, only 11% have grown vegetables under dudukuhan systems (Wijaya et al., 2007), primarily under mixed fruit-timber-bananas-annual crop systems. The vegetable species most commonly grown in Nanggung under full sunlight or understories are kucai (*Allium tuberosum*), longbean (*Vigna unguiculata*), cucumber (*Trichosanthes cucumeroides* Maxim), green bean (*Phaseolus vulgaris*), corn (*Zea mays* L.), and chili (*Capsicum frutescens*) (Wijaya et al., 2007). Other vegetable species are commonly cultivated on a small scale for family consumption and are not associated with dudukuhans. Most farmers believe that the growth and production of vegetables would be impeded under dudukuhan systems (Manurung et al., 2008). Farmers expressed interest in understory vegetable production, but they need assistance so that they can evaluate their options.

An on-farm trial was designed to evaluate management practices, production, and viability of vegetable cultivation in the understory of dudukuhan systems. Nine commercial vegetable species (that variously produced leaf products, fruit products and/or were indigenous species) were evaluated for growth and yield under three different light levels: heavy shade, medium shade and no shading (full sunlight).

1.1 Study site

Nanggung subdistrict is located on the western part of West Java province, about 100 km from Jakarta and 45 km south of Bogor. It covers a total area of 9,724 ha with an elevation from 400-1,800 m asl and consists of 10 villages. Land use systems are dominated by agricultural and forestry practices. The dudukuhan systems occupy 1/5 of the subdistrict area, with the same proportion under state forests, and paddy rice on one-sixth of the area. Annual rainfall varies between 3,000 and 4,000 mm and the average annual temperature ranges between 22 and 24°C. Nanggung subdistrict had a population of 74,211 inhabitants in 2003, belonging to 17,187 households. Population growth from 1998 to 2003 was 3.23% per year, higher than the average for West Java province (2.17%). Most residents (73.3%) were engaged in agriculture as a main occupation and considered themselves farmers (Budidarsono et al., 2004). Agricultural activities alone contributed 31.2% to the total household income. Average family income per household was Rp9,211,000 per year (US$1=Rp9000), most of which went towards consumption. A close look at the expenditure items shows that the largest proportion was spent on food (43.4%) with the remainder on non-food consumption items (housing, clothing, schooling, transportation).

2. Materials and Methods

An on-farm trial evaluated the growth and yield of nine commercial vegetables; eventually only seven of them were evaluated (after two failed to adapt to the location) under three levels of light intensity: low light (heavy tree shade), medium light (low tree shade) and full sunlight (no shade). The trial was replicated three times in a nested design. The species planted in the trial were the indigenous species katuk (*Sauropus androgynous* L. Merrill) and kenikir (*Cosmos caudatus* Kunth). Also introduced during the trial were the species kangkung (*Ipomoea aquatica* Forsskal), amaranth (*Amaranthus* sp.), chili (*Capsicum annuum* L.), eggplant (*Solanum melongena* L.), yard-long bean (*Vigna unguiculata* L. Walp.), green bean (*Phaseolus vulgaris* L.) and tomato (*Lycopersicon esculentum* Miller), which produce fruit vegetables as their main product. All the introduced species were commercial varieties bred for production under full sunlight and were available in local markets. Plants of two species, green bean and kenikir, suffered insect attacks in all three treatments 3-5 weeks after planting and failed to establish.

Vegetable cultivation practices and cultivation periods used in this study were based on Susila (2006) and are summarized in Table 1. Fertilizer practices are presented in Table 2.

Table 1. Cultivation practices and cultivation periods for the seven species of vegetables

Activities	Vegetable species						
	Amaranth	**Kangkong**	**Eggplant**	**Chili**	**Tomato**	**Longbean**	**Katuk**
Land preparation	X	X	X	X	X	X	X
Fertilizing	X	X	X	X	X	X	X
Nursery			X	X	X		
Support stakes				X	X	X	
Planting	X	X	X	X	X	X	X
Replanting			X	X		X	
Watering	X	X	X	X	X	X	X
Coppicing				X			
Weeding	X	X	X	X	X	X	X
Harvesting	X	X	X	X	X	X	X
Cultivation period (days)*	**28**	**28**	**77**	**77**	**77**	**77**	**77**

* From planting to harvest

A sites assessment was undertaken before trial establishment to document tree characteristics: light levels and soil physical and chemical characteristics of each plot. Results are presented in Table 2 and Figure 1.

Figure 2 shows that there were only 8 rainy days out of 77 days of the trial period. The vegetables were planted on August 6, 2007 and growth and production data were collected weekly until October 16, 2007. Plot size per species and treatment was 1,000 m^2. Measurements made on five adjacent plants or their vicinity per replicate included: 1) light levels, 2) plant height, 3) stem diameter, 4) yield, 5) plant survival rate, 6) plant damage (due to insects), 7) soil pH and 8) relative soil humidity.

Table 2. Fertilizer application for each vegetable species (kg/ha/planting season)

Age (weeks)	Fertilizer	Ama-Ranth	Kang-kong	Egg-plant	Chili	Tomato	Longbean	Katuk
Preplant	Organic (ton/ha)	15	10	15	20	15	15	30
	Urea	56	187	160	199	199	112	190
	SP36	250	311	311	311	311	250	88
	KCL	90	112	90	90	90	90	88
4 WAP	Urea	56	187	80	75	100	112	
	KCL	90	112	45	34	45	90	

Note: WAP = Week After Planting

The growth and yield data of the nine vegetables were analyzed using multiple regression analysis to quantify how the independent variables affected growth and production of the vegetable species. There were 25 independent variables used in the multiple regression analysis as follows: 1) tree density, 2) tree basal area, 3) tree canopy width, 4) tree canopy height, 5) soil pH, 6) relative soil humidity, 7) light level, 8) plant survival rate, 9) plant damage percentage, and 10) all soil characteristics (sand, silt, clay, C, N, C/N, P_2O_5, K_2O, Ca, Mg, K, Na, KTK, KB, Al^{3+}, H^+).

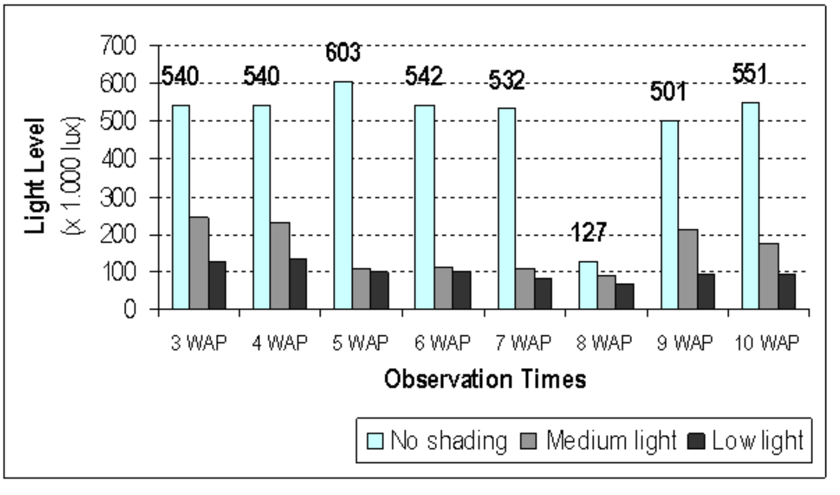

Figure 1. Weekly light levels measurement (*1000 lux)

Multiple regression analysis using SPSS (version 11) software indicated that 19 of the 25 independent variables were redundant due to the multicolinearity with other independent variables. The analysis identified the independent variables which most affected vegetable growth and production as relative soil humidity, light levels, plant survival rate, plant damage percentage, alkaline concentrate (KB), and soil acidity level (H^+).

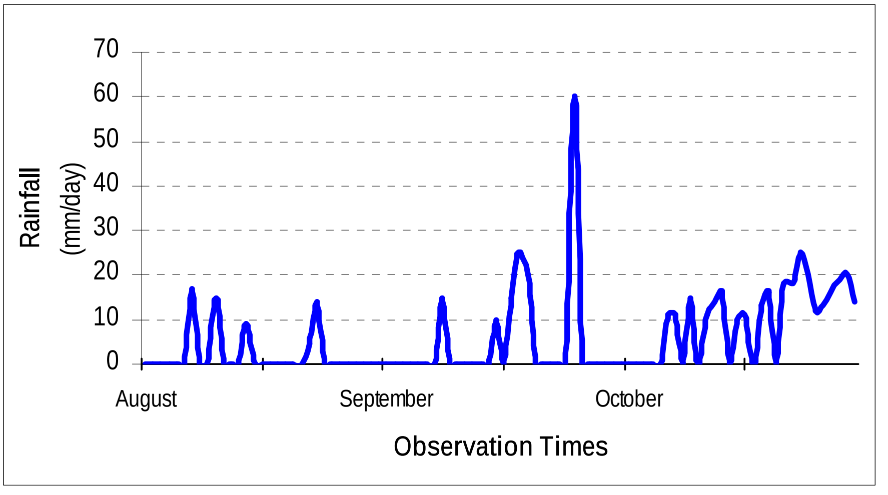

Figure 2. Daily rainfall measurement during the 3-month trial

3. Results

3.1 Amaranth (*Amaranthus* sp.)

Amaranth can be harvested 4 weeks after planting. There was a significant difference between the medium light treatment and both the no shading and low light treatments for height and stem diameter and production of amaranth. There were no significant differences in growth or yield between no shading and low light treatment. In the medium light treatment, the height and diameter of amaranth plants reached 25.2 cm and 0.53 cm, respectively, compared to the no shading treatment (8.6 cm and 0.31 cm) 4 weeks after planting. Height and diameter doubled between the 3rd and 4th week, but increased only slightly in the no shading and low light treatments. Amaranth yields in medium light treatment (15.3 g/plant) were three times those of the no shading treatment (5.5 g/plant) and twice those in the low light treatment (7.0 g/plant).

The multiple regression analysis of the growth and production of amaranth plants are shown in Table 4. The plant damage significantly affected growth and production of amaranth plants at the 1% level. Furthermore, plant survival rate and the alkaline concentrate had a significant effect on the diameter increment of amaranth plants. Light levels affected the production of amaranth plants at the 5% level.

Table 3. Pre-planting site assessment of the three light level treatments

Variables	Light levels treatments		
	Full sunlight (no shading)	Medium light (mixed fruit - timber - banana - annual crop system)	Low light (mixed fruit - timber system)
Number of tree species	0	18	36
Tree density (per Ha)	0	400 (5 m x5 m)	626 (4 m x4 m)
Sum of stem diameter (cm)	0.0	327.8	528.5
Mean of tree height (m)	0.0	10.4	8.0
Sum of canopy width (m^2)	0.0	294.4	380.0
Sum of canopy height (m)	0.0	97.5	154.4
Sand (%)	17	17	16
Silt (%)	48	28	32
Clay (%)	35	55	52
C (%)	1.50	1.54	1.99
N (%)	0.11	0.11	0.15
C/N	14	14	13
P_2O_5 (ppm)	2.1	7.9	14.4
K_2O (ppm)	47	68	63
Ca (cmol (+) / kg)	1.69	7.39	1.92
Mg (cmol (+) / kg)	0.95	2.88	0.59
K (cmol (+) / kg)	0.26	0.15	0.31
Na (cmol (+) / kg)	0.15	0.09	0.15
KTK (cmol (+) / kg)	21.63	21.12	18.74
KB (%)	14	50	16
Al^{3+} (cmol (+) / kg)	8.92	9.14	7.71
H^+ (cmol (+) / kg)	0.41	0.66	1.16

Table 4. Multiple regression analysis results for the growth and production of amaranth

Independent Variables	Dependent Variables		
	Height	Diameter	Production
Constant	56.468	2.087**	23.370
Relative soil humidity	-0.440	-0.019	-0.011
Light levels	-0.024	0.000	-0.027*
Plant survival	0.076	0.002**	0.020
Plant damage	5.282**	0.142**	2.586**
Alkaline concentrate (KB)	0.021	-0.004**	0.006
Soil acidity level (H^+)	-14.270	-0.330	-15.979
R square	**0.903****	**0.929****	**0.840****

Note: *Significant at the 95% level, **Significant at the 99% level

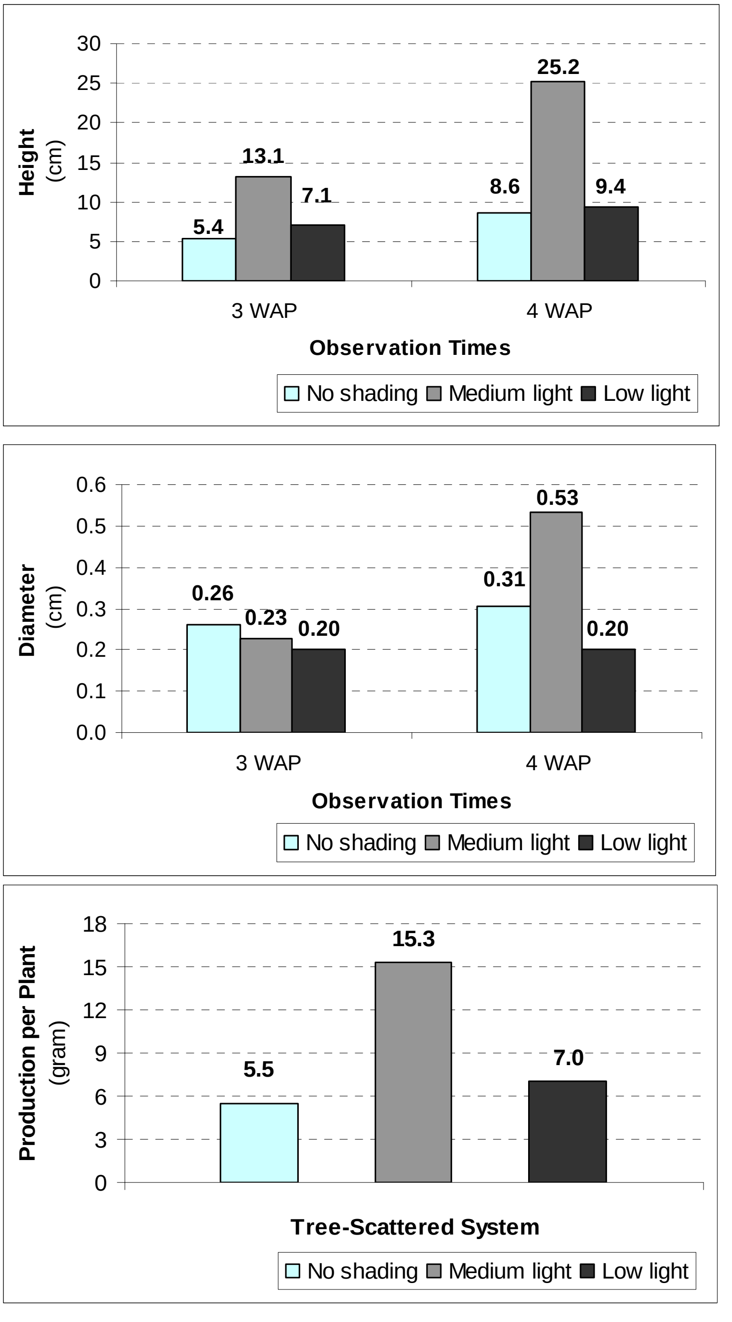

Figure 3. Growth and production of amaranth during 4 weeks of planting season

3.2 Kangkung (*Ipomoea aquatica* Forsskal)

As with amaranth, kangkung can be harvested 4 weeks after planting (Fig. 4). Plant height, stem diameter and production were significantly different between medium light treatment and both the no shading and low light treatments. There was no difference between the latter two treatments. Yield under medium light (30 g/plant) was nearly double that of the no shade treatment (16 g/plant) and 50% greater than that of the low light treatment (19 g/plant). Although the low light treatment had a marginally greater yield than the no shade treatment, the difference was not significant.

Table 5 shows the multiple regression analysis of the growth and production for kangkung plants. Relative soil humidity, plant survival rate, and alkaline concentrate (KB) had a significant effect on height increment growth of kangkung plants. Furthermore, relative soil humidity, plant survival, alkaline concentrate (KB) and soil acidity level (H+) all significantly affected kangkung production at 1% level.

Table 5. Multiple regression analysis results for the growth and production of kangkung

Independent Variables	**Dependent Variables**		
	Height	**Diameter**	**Production**
Constant	8.574	0.409	47.273
Relative soil humidity	-0.315*	-0.012**	-1.194**
Light levels	-0.002	0.000	0.000
Plant survival	0.227**	0.007**	0.603**
Plant damage	0.158	0.046*	0.597
Alkaline concentrate (KB)	0.271**	0.005**	0.497**
Soil acidity level (H+)	5.251	0.187**	16.958**
R square	**0.724****	**0.591****	**0.682****

Note: *Significant at the 95% level, **Significant at the 99% level

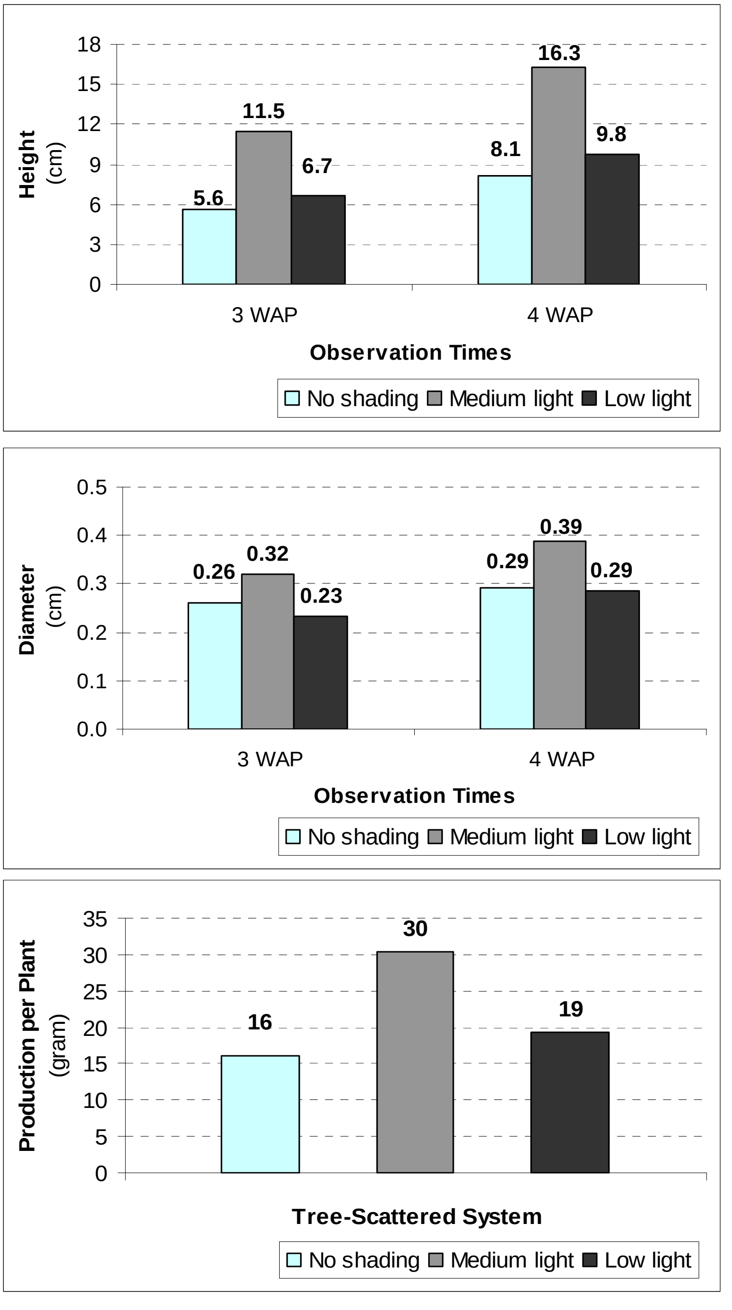

Figure 4. Growth and production of kangkung during 4 weeks of planting season

3.3 Eggplant (*Solanum melongena* L.)

Eggplants were taller and had thicker stems in the medium light treatment. Plant height and stem growth in medium light were approximately twice those of plants in no shade treatment. Low light suppressed height and diameter compared to no shade treatment. Eggplant yields in the medium light treatment were 833 g/plant, 70% greater than in the no shade treatment (488 g/plant). Yields in low light treatment (209 g/plant) were less then half of the no shade treatment, much lower then expected based upon growth data.

Table 6 reports the multiple regression analysis of the growth and production for eggplant. Alkaline concentrate (KB) had a significant negative effect on plant growth increment (height and diameter) and production. Soil acidity level had a significant negative affect on diameter increment and production. Relative soil humidity had a significant effect on plant diameter increment.

Table 6. Multiple regression analysis results for the growth and production of eggplant

Independent Variables	Dependent Variables		
	Height	Diameter	Production
Constant	54.578	-0.041	881.437*
Relative soil humidity	-0.413	0.009*	-5.833
Light levels	0.012	0.000	0.120
Alkaline concentrate (KB)	0.939**	0.014**	14.531**
Soil acidity level (H+)	-7.280	-0.358**	-416.583**
R square	**0.897****	**0.963****	**0.953****

Note: *Significant at the 95% level, **Significant at the 99% level.

3.4 Chili (*Capsicum annuum* L.)

Height and diameter increments of chili plants showed an upward trend in all trial plots (Fig. 6). As with eggplant, height of chili reached a peak at 8 weeks after planting. Stem diameter continued to increase during the sampling period, but at an increasingly slower rate. Height was consistently greatest in the medium light treatment, but diameter of the no shade treatment exceeded that of the medium shade treatment from week 7 onwards. Differences in height growth were not significant. There was no significant difference in chili production between medium light and full sunlight treatments (1,465 g/plant and 1,339 g/plant, respectively), but under low light level chili production (962 g/plant) differed significantly from the other two treatments.

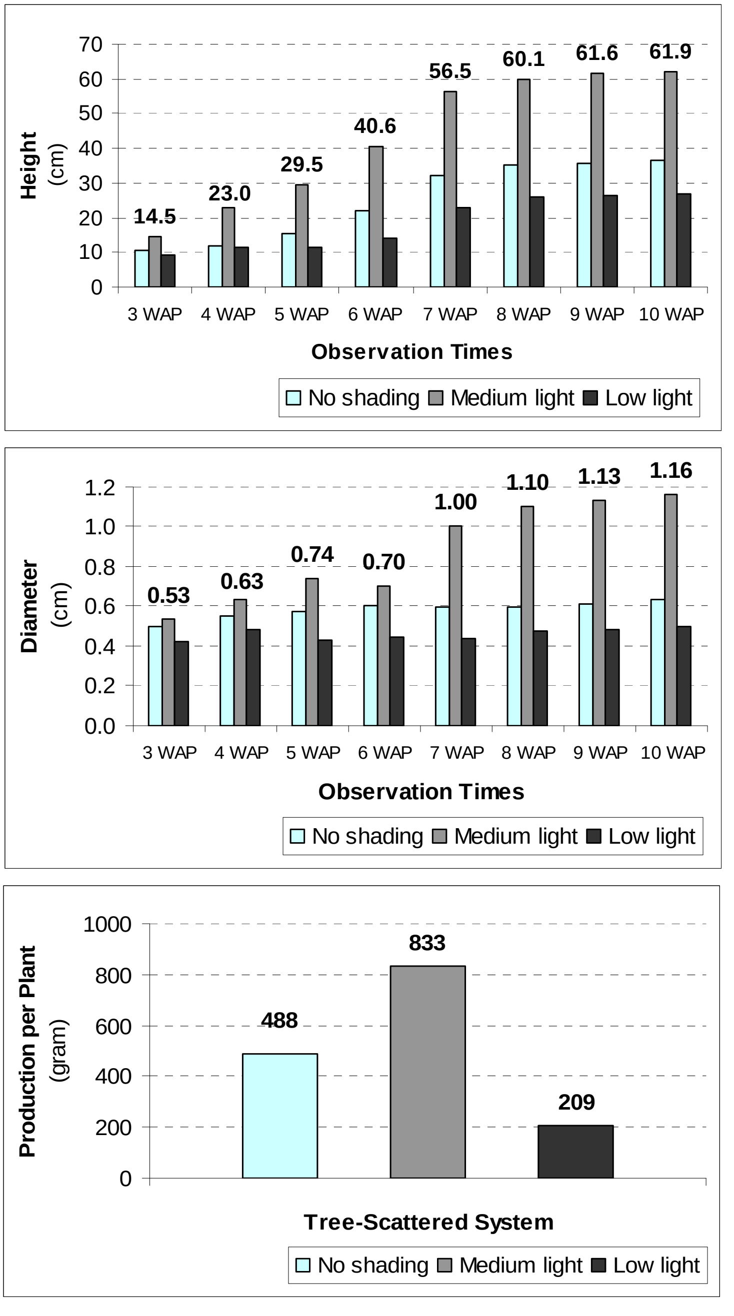

Figure 5. Growth and production of eggplant during 10 weeks of planting season

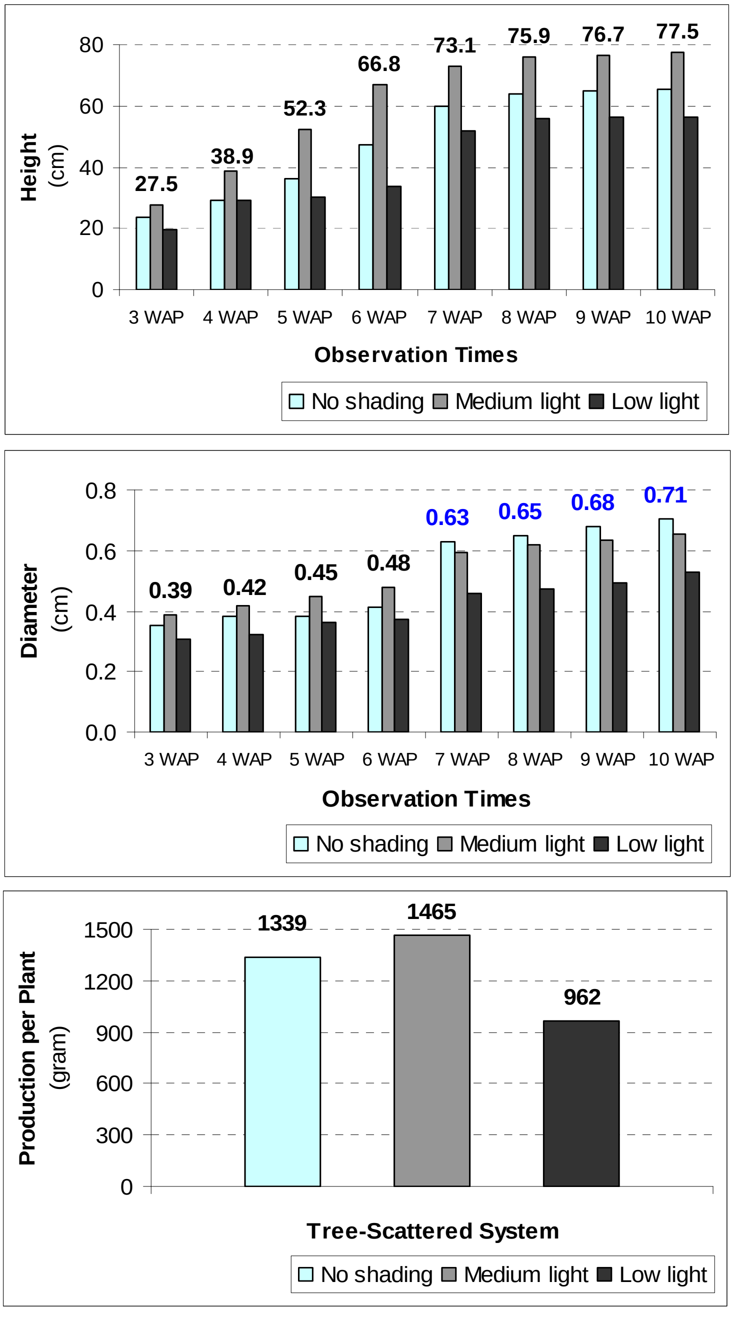

Figure 6. Growth and production of chili during 10 weeks of planting season

Relative soil humidity, light levels, plant survival rate, plant damage, alkaline concentrate (KB), and soil acidity level (H+) all had very significant effects on the height growth of chili plants at the 1% level. Relative soil humidity, light levels, plant survival rate, alkaline concentrate (KB) and soil acidity level (H+) had significant effects on diameter growth of chili plants at the 5% level. Chili production was not affected significantly by any independent variables.

Table 7. Multiple regression analysis results for the growth and production of chili.

Independent Variables	Dependent Variables		
	Height	**Diameter**	**Production**
Constant	-225.772**	-0.541	616.902
Relative soil humidity	1.172**	0.008*	11.895
Light levels	-0.078**	-0.001**	0.110
Plant survival	2.439**	0.012**	-3.561
Plant damage	0.530**	0.000	4.429
Alkaline concentrate (KB)	0.332**	-0.002*	6.843
Soil acidity level (H+)	-49.042**	-0.630**	-345.936
R square	**0.890****	**0.782****	**0.384****

Note: *Significant at the 95% level, **Significant at the 99% level

3.5 Tomato (*Lycopersicon esculentum* Miller)

In contrast to eggplant and chili, tomato plant height and stem diameter did not respond to light treatment, although initially plants in the medium light treatment were the tallest. Fruit yield did not differ between the medium light treatment and the no shade control (468 g/plant and 436 g/plant, respectively), but that of the low light level (319 g/plant) was significantly lower than that of either of the two treatments.

Almost all independent variables in Table 8 showed no significant effect on growth or production of tomato plants. Only relative soil humidity significantly affected at 1% level on diameter of plants (Table 8).

3.6 Yard-long bean (*Vigna unguiculata* L. Walp.)

Yard-long bean is a leafy vegetable species; its stem climbs a wooden stake for support. Height was measured twice, in week 3 and week 4 (Fig. 8). By week 3 plants in the medium light treatment were taller than those in the other two treatments, and by week 4 that treatment had gained another 1 m in height.

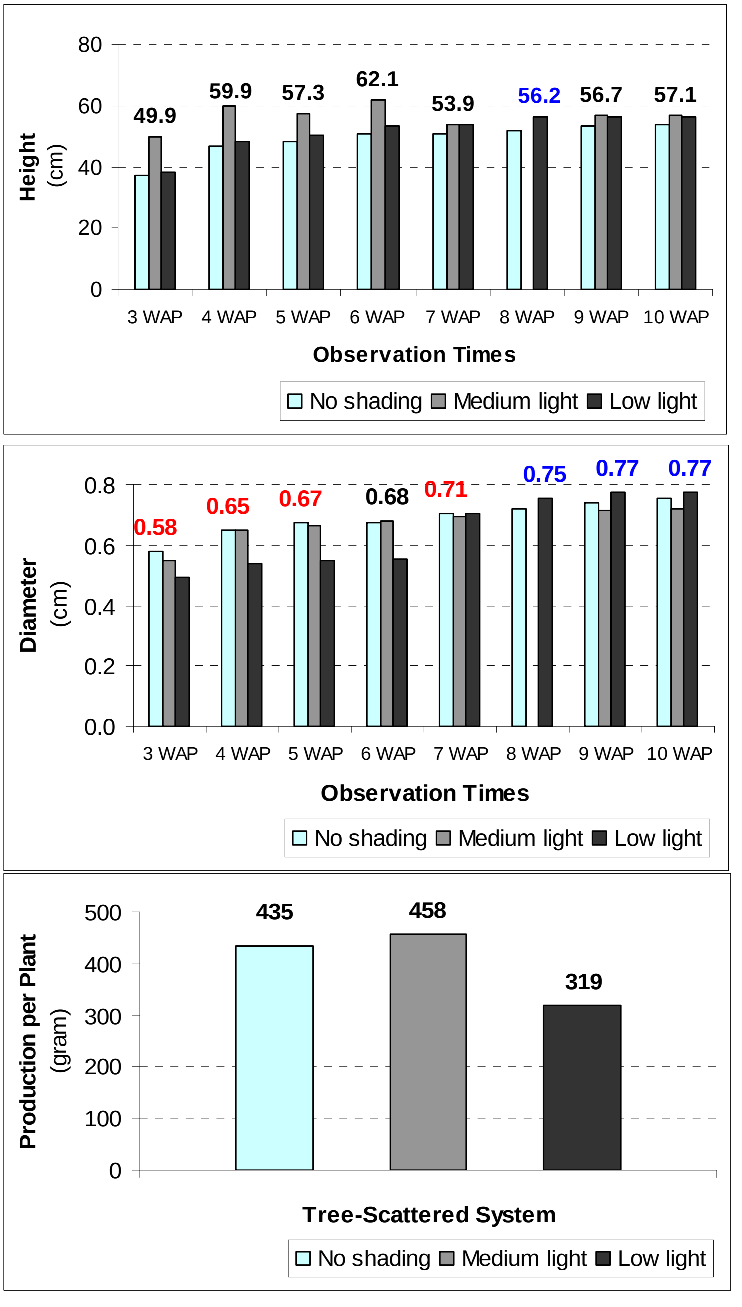

Figure 7. Growth and production of tomato during 10 weeks of planting season

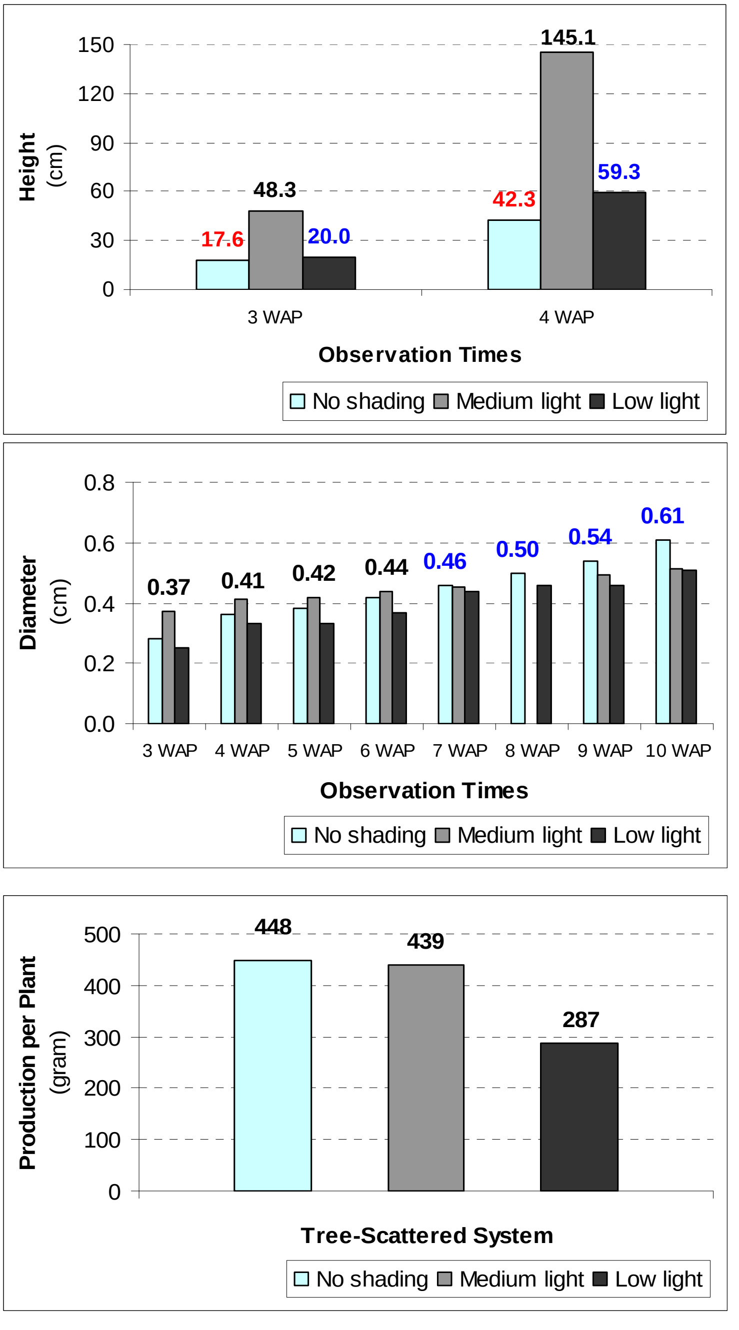

Figure 8. Growth and production of yard-long bean during 10 weeks of planting season

Table 8. Multiple regression analysis results for the growth and production of tomato

Independent Variables	Dependent Variables		
	Height	Diameter	Production
Constant	63.745**	-0.235	-228.769
Relative soil humidity	0.058	0.011**	14.784
Light levels	-0.015	0.000	-0.067
Plant survival	-0.080	-0.004	-7.779
Plant damage	-0.121	0.003	-5.338
Alkaline concentrate (KB)	0.051	0.000	5.211
Soil acidity level (H+)	-0.460	0.252	90.079
R square	**0.175**	**0.400****	**0.298****

Note: *Significant at the 95% level, **Significant at the 99% level

Plants in the low light treatment were also taller than those in the full sunlight control. Although the stem diameter of plants in the medium light treatment was greatest early in the sampling period, by the end of the sampling period the stem diameter of plants in the open was greater than those of shaded plants. Yield in the low light treatment (287 g/plant) was suppressed compared to the medium light (439 g/plant) and no shade treatments (448 g/plant). Yield under medium light and no shade treatments had no significant differences.

Plant damage and alkaline concentrate (KB) affected yard-long bean height growth significantly at the 1% level. Plant damage also significantly affected production at the 1% level (Table 9).

Table 9. Multiple regression analysis results for growth and production of yard-long bean

Independent Variables	Dependent Variables		
	Height	Diameter	Production
Constant	-275.328	-0.296	1562.896
Relative soil humidity	3.610	0.012	-15.051
Light levels	-0.055	0.000	0.524
Plant survival	-0.257	0.000	-0.764
Plant damage	8.102**	0.003	-38.693**
Alkaline concentrate (KB)	3.441**	-0.001	-1.525
Soil acidity level (H+)	-38.775	-0.207	202.500
R square	**0.889****	**0.473****	**0.432****

Note: *Significant at the 95% level, **Significant at the 99% level.

3.7 Katuk (*Sauropus androgynous* L. Merrill)

Stem diameter doubled over the sampling period (Fig. 9), with that of the medium light treatment being greatest at the end of sampling. Plant height increased slowly in all treatments for the first 6 weeks, and from then on increased considerably for the medium light treatment. Even the height of the low light treatment exceeded that of the no shade control. Yields in the medium light were two and one-half times greater than in the no shade control (48 g/plant versus 18 g/plant, respectively). Yield under low light treatment (25 g/plant) was 40% greater than in the no shade treatment.

Light levels, alkaline concentrate (KB) and soil acidity level (H+) significantly affected growth and production of katuk plants at the 1% level (Table 10).

Table 10. Multiple regression analysis results for the growth and production of katuk

Independent Variables	**Dependent Variables**		
	Height	**Diameter**	**Production**
Constant	-178.264*	0.133	-78.990*
Relative soil humidity	0.991	-0.002	0.385
Light levels	0.123**	0.001**	0.060**
Plant survival	0.182	-0.002	0.080
Alkaline concentrate (KB)	2.215**	0.007**	1.110**
Soil-acidity level (H+)	73.765**	0.320**	36.713**
R square	**0.809****	**0.439****	**0.788****

Note: *Significant at the 95% level, **Significant at the 99% level

4. Labor Input and Production

Total labor input on cultivation for each vegetable species under each light level treatment is provided in Figure 10. Labor requirement was positively correlated with the effective planting area. Vegetable cultivation in the no shading treatments required the greatest labor input, followed by medium light treatment, and low light treatment. Labor requirement also differed by species, with chili cultivation requiring the greatest, 185 person-days.

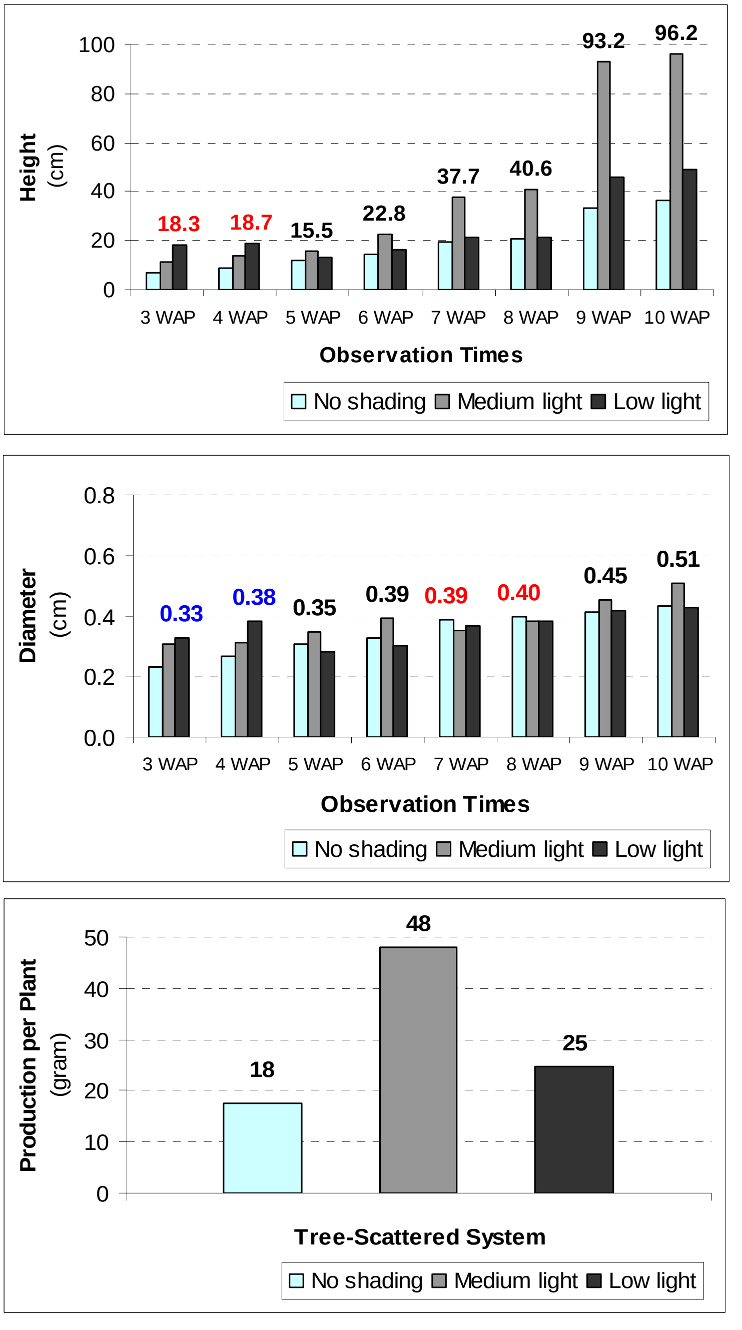

Figure 9. Growth and production of katuk during 10 weeks of planting season

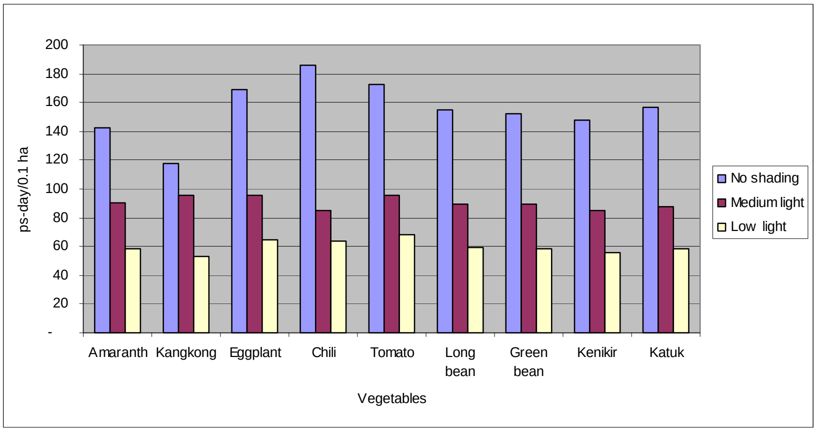

Figure 10. Total labor input (ps-day/1,000 m^2)

Prior to the study, all three sites had lain fallow for a number of years. Before the sites could be cultivated land clearing was required. Land clearing was the dominant labor input for all species and treatments, varying from 33% to 59% of the total. Land clearing averaged 70 person-day/1,000 m^2 for the no shading treatment, 44 person-day/1,000 m^2 for the medium light treatment, and 23 person-day/1,000 m^2 for the low light treatment. Land clearing is neither an annual land management practice nor normally considered part of vegetable production costs. Figure 11 provides labor inputs for vegetable cultivation (excluding land clearing labor input) for each species under each light level treatment.

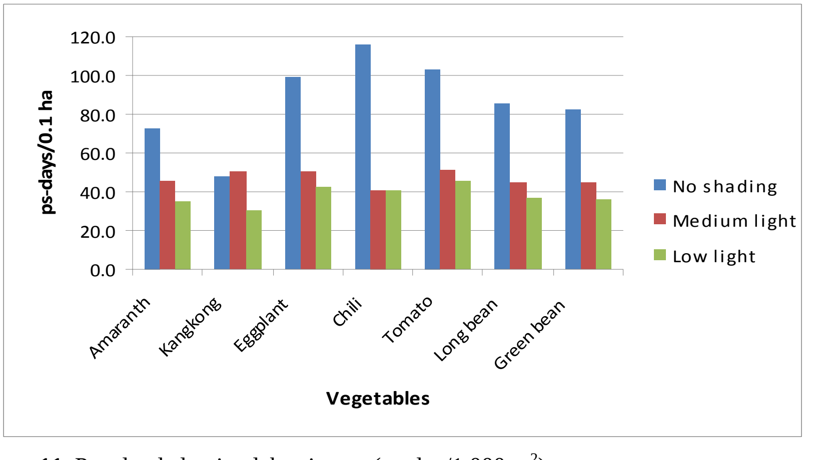

Figure 11. Post land clearing labor inputs (ps-day/1,000 m^2)

Table 11 shows the production for each vegetable species under each light treatment on a per plant basis and Table 12 shows the production on a per area basis compared to the national averages. On either basis, vegetable production was generally best under the medium light treatment. Longbean production was highest under the full sunlight treatment both per plant and per area; similarly eggplant and tomato production were better under full sunlight on a per area basis. Vegetable production under low light treatments was generally lowest on both bases. Production per area was generally lower than the national averages, with exception of amaranth and chili under the medium light treatment.

Table 11. Production of vegetable species under each light level per area with comparison to national average

Vegetable Species	Light Level Treatment (g/plant)		
	Full sunlight	**Medium light**	**Low light**
Amaranth	5.5	15.3	7.0
Kangkung	16	30	19
Eggplant	488	833	209
Chili	1,339	1,465	962
Tomato	435	458	319
Longbean	448	439	287
Katuk	18	48	25

Table 12. Production of vegetable species under each light level on a per area basis with comparison to national average

Vegetable Species	Light Level Treatment (kg/0.1ha)			National Average
	Full sunlight	**Medium light**	**Low light**	**kg/0.1 ha**
Amaranth	253	472	84	339
Kangkung	222	280	140	647
Eggplant	556	499	79	750
Chili	556	775	403	648
Tomato	204	137	91	1,270
Longbean	221	164	73	543
Katuk	39	70	28	n.a.

Note: n.a. = not available

Figure 12. Land preparation under tree system

Figure 13. Planting an indigenous vegetable (honje, *Etlingera giseke*)

5. Discussion

The vegetable species in this study showed good growth (height and diameter) and production performance in the understory of the mixed fruit-timber -bananas-annual crop systems (medium light). Their performance compared favorably with that of the full sunlight (no shading) treatment. This is noteworthy as most of the vegetables were commercial varieties bred for production under full sunlight. Production of amaranth (*Amaranthus* sp.), kangkung (*Ipomoea aquatica* Forsskal), eggplant (*Solanum melongena* L.), and katuk (*Sauropus androgynous* L. Merrill) were superior under medium light treatment compared to full sunlight treatment on both per plant and per area basis. The production of chili (*Capsicum annuum* L.), tomato (*Lycopersicon esculentum* Miller) and yard-long bean (*Vigna unguiculata* L. Walp.) were similar between the medium light and full sunlight treatments on per plant basis, but superior under full sunlight on a per area basis. Under medium light conditions, compared to full sunlight conditions, the production of those seven species ranged from 98% to 278% on a per plant basis, and 67% to 187% on a per area basis. Under low light treatments (under mixed fruit-timber systems), the growth and production performance of eggplant, chili, tomato and yard-long bean was lowest, producing only 43% to 73% of the production in the full sunlight treatment on a per plant basis and less on a per area basis. The production of amaranth, kangkung and katuk was slightly better in low light treatments compared to full sunlight on a per plant basis; but much lower on a per area basis. Per plant productivity is important for smallholder systems, where the area cultivated may be small and crop management approximates a per plant basis. On a per plant basis, height and diameter growth proved to be an accurate relative indicator of subsequent yield for amaranth, kangkung, eggplant and chili. Katuk height growth was an indicator of subsequent plant yield from 7 WAP (weeks after planting). Height and diameter growth were not accurate indicators of per plant yields for tomato or yard-long bean.

Twenty-five site parameters were assessed before the trial to determine their effect on vegetable production under the three light levels (Table 3). Regression analysis found that the following overstory parameters had no significant effect on the production of the seven vegetable species - tree density, number of tree species, basal area, tree height, canopy width, and canopy height. Light level was the only overstory parameter of direct importance. Other regression results can be summarized as unremarkable and inconsistent. Plant survival and insect damage were predictably found to affect growth and yield. Soil alkalinity and acidity affected the yield of some (kangkung, eggplant and katuk) but not all vegetables. The lack of significant and consistent results from the regression analysis emphasizes the overwhelming importance of light level to understory vegetable production.

The landowner and previous land use history varied between the sites of the three treatments. Full sunlight treatment was under the imperata grassland for 8 years prior to the experiment. Limited water supply was the main reason the owner fallowed the site which previously was a semi-irrigated paddy. Similarly the mixed fruit-timber (low light) treatment site had been fallowed for 8 years as a strategy to restore soil fertility. The mixed fruit-timber-bananas-annual crop (medium light) site had been historically intensively cultivated by the owner. When the water supply became limited during the last 10 years, the landowner converted the plot from semi-irrigated paddy field to a mixed tree-annual crop dudukuhan system under deliberate management. Unproductive trees were removed to maintain light levels that allowed understory crop production. The landowner sought to enhance soil fertility through the application of organic fertilizer and dolomite. While those measures may have altered site soil characteristics compared to other sites (Table 3), regression analysis found that differences in site soil characteristics had no significant effect on vegetable production in this study.

Previous land use significantly affected land management, specifically land clearing. Labor requirements for land management (land clearing and land preparation) of the three treatments were 78 person-day/1,000 m^2 for the no shading treatment, 53 person-day/1,000 m^2 for the medium light treatment, and 31 person-day/1,000 m^2 for the low light treatment. These figures are much higher than national averages for vegetable cultivation which report labor requirement for land preparation as 8.5 person-day/1,000 m^2 (http://ditsayur.hortikultura.go.id). Average land preparation costs in this study were 9.2 to 3.6 times greater than the national average. Labor for land clearing accounted for 90%, 86% and 78% of land management costs, respectively, for full sunlight, medium light, and low light treatments.

Production costs per kg of vegetable under each light level treatment are summarized in Table 13. The table was compiled from actual costs, local prices and national data. However it is not representative of smallholder management. While farmers were consulted regarding aims and design, the researcher-controlled trial was managed with hired labor. To isolate treatment effects, uniform and consistent management was applied to all plots, which exceeded the level of management farmers would normally apply. Hired labor was rarely engaged by smallholders and was less effective financially and in impact compared to a farmer self-management of their farms. Additionally, commercial-oriented understory cultivation of amaranth, kangkung, eggplant, tomato and katuk were new production systems in Nanggung; farmers had not yet developed management efficiencies. Based on the table, only chili at all three light levels appeared profitable. However, in a related study smallholder commercial-oriented production of katuk and kucai (*Allium odorum*) were shown to be profitable (Roshetko et al., 2012). Given the limitations of the data, Table 13 is illustrative and provided for comparative purposes.

Production costs/kg were lowest for all vegetables under medium light levels, only 31% to 84% of production costs under full sunlight. Production costs under low light levels varied greatly compared to full sunlight treatments - 75% for katuk, 84% for kangkung, approximately the same for tomato, but roughly 50% higher for amaranth and yard-long bean. Low light level production costs always exceeded those under medium light conditions, being only 25% higher for tomatoes, roughly 60% higher for kangkung and chili, but 535% higher for eggplant. Medium light levels provided the best combination of environmental conditions, labor requirement, and effective planting area for vegetable production. The production of some vegetable species may be viable under the other light levels also.

Two factors that this study does not address are the quality of the vegetable product and seasonal variation in production. A consumer study conducted in the greater Bogor area (Dahlia et al., 2012) shows that vegetable quality is a key factor determining consumers' purchase decisions. Consumers are willing to pay premium prices for quality vegetables. Similarly, consumers are willing to pay higher prices when vegetables are in short supply. Affluent consumers in towns and cities are more able and willing to pay premium prices for vegetable quality and availability.

Table 13. Illustrative vegetable production cost in the three trial plots vs. market price

Vegetables	Production Cost Rp/kg			Commodity Price, Rp/kg	
	No shading	Medium light	Low light	Nanggung	West Java 2005
Amaranth	12,267	3,783	18,479	800	
Kangkung	10,559	5,333	8,823	2,500	
Eggplant	6,893	3,992	21,354	1,500	1,300
Chili	4,235	3,292	5,284	6,000	9,400
Tomato	19,622	16,424	21,069	4,000	2,000
Yard-long bean	18,540	14,474	26,635	4,000	
Katuk	90,074	33,760	67,801	2,200	

The study identified options for expanding smallholder vegetable cultivation in the Nanggung area where land availability is restricted primarily to the understories of dudukuhan systems. Traditionally few dudukuhans are intercropped with vegetables because farmers believe understory production is not viable (Manurung et al., 2008). Results of this study indicate that understory vegetable production is very viable under medium light levels (mixed fruit-timber-bananas-annual crop dudukuhan systems) and likely viable for selected vegetables under low light levels (mixed fruit-timber dudukuhan systems). Expanding understory vegetable production provides the opportunity to raise family income and nutrition by diversifying and intensifying farm production, and correspondingly reducing their vulnerability to market risks. The cultivation practices associated with vegetable production also enhance the growth and productivity of overstory trees.

The key challenge associated with expanding understory vegetable production is the availability of labor. Agriculture accounts for only 31.2% of family incomes in Nanggung (Budidarsono et al., 2004). Farmers are reliant on off-farm employment for most of the income. Household labor is usually inadequate to meet farming needs and farmers cannot afford to hire farm labor. To successfully expand understory production, farmers and researchers will have to develop efficient and effective practices that provide adequate management. The allocation of labor to vegetable production needs to be balanced with the opportunity costs of off-farm employment. Farmers may be well served by focusing production on higher quality vegetable crops and markets that offer price premiums.

Figure 14. Eggplant under tree system

Figure 15. Yard-long bean plant under tree system

Figure 16. Kangkung under tree system

6. Conclusions

Understory vegetable production is a viable option for smallholder agroforestry systems. The medium light levels (95-245*1000 lux) of mixed fruit-timber-banana-annual crop systems are most conducive to vegetable productivity and profitability, comparing favorably with production under full sunlight (127-603*1000 lux) and the low light levels (75-135*1000 lux) of mixed fruit-timber systems. Full sunlight treatments had greater *effective planting areas* requiring more labor input, but did not always produce the greatest yields. Medium and low light treatments required less labor input, but had smaller effective planting areas. Labor input, effective planting area, and light intensity interact to determine production potential.

Production/plants was greatest in medium light levels; production/area was generally best under medium light levels, but better for a few species under full sunlight. High production/plant was significant in smallholder agroforestry systems where plant management may approximate a per plant basis because of the systems' limited size. Significantly, vegetable production costs/kg were lowest under medium light levels. The production costs/kg under low light levels for some vegetables (tomato, kangkung and chili) were only slightly higher than production costs under medium light levels. These results demonstrate that opportunity exists for smallholders to expand vegetable production where the only available land is under existing tree garden systems.

Plant height and diameter growth were an accurate relative indicator of subsequent yield for amaranth, kangkung, eggplant and chili. Height growth was an indicator of subsequent yield for katuk. However, height and diameter growth were not indicators of subsequent yield for tomato or yard-long bean. Understory light level was the only parameter of the 25 site and overstory characteristics assessed to have a significant and consistent effect on understory production of all species. The appropriateness of understory sites for vegetable production can be assessed by evaluating light levels.

This study yielded valuable information, demonstrating the viability of understory vegetable production in smallholder agroforestry systems. Further research is required to address the question of vegetable quality and seasonal variation, cropping rotation, tree-vegetable-site matching, labor input requirements, and overall profitability under varied light levels. Results of the study also demonstrate the need for commercial vegetable varieties that are bred for production under partial shade conditions. The knowledge gained from such research would provide key input to the development of efficient and effective practices for understory vegetable production in smallholder agroforestry systems. Findings from this and related studies indicate that farmers may be well served by focusing understory vegetable production on higher quality vegetable crops and markets that offer price premiums.

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