Yields of Organically Grown Sweet Pepper Cultivars and Lines during the Hot-wet and Cool-dry Season in the Tropics

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SUMMARY. Organic production is considered by many researchers to be a viable alternative to conventional farming systems. Equivalent yields already have been demonstrated in several studies. The major objective of our study was to collect data on total and marketable fruit yields of sweet pepper (*Capsicum annuum*) under organic farming conditions in the tropics. Experiments were conducted during the hot-wet season from 7 Mar. 2007 to 30 July 2007 and during the cool-dry season from 27 Nov. 2007 to 7 Apr. 2008. The six experimental entries included four commercial F₁ hybrids and two genotypes bred at AVRDC-The World Vegetable Center (Shanhua, Taiwan). During the hot-wet season, high total (44.6–55.7 t·ha⁻¹) and marketable yields (36.9–45.6 t·ha⁻¹) were achieved under organic farming conditions in the open field similar to yields of conventionally produced sweet pepper in previous field experiments at AVRDC. The total yield of the commercial cultivars Queen Star and Hercules exceeded 50 t·ha⁻¹; however, this was not significantly different compared with the other trial entries. During the cool-dry season, the total (25.4–45.7 t·ha⁻¹) and marketable yields (21.1–37.8 t·ha⁻¹) of all trial entries were reduced, probably because the relatively late planting date in November and relatively low air temperature resulted in reduced fruit set. The commercial cultivars Andalus and Green Bell Improved realized in both seasons a total fruit yield of more than 40.0 t·ha⁻¹, suggesting that these can be grown successfully in hot-wet and cool-dry seasons. The relatively high yields of sweet pepper achieved on-station under tropical climatic conditions may encourage farmers and agricultural stakeholders to consider organic farming approaches as a viable alternative to conventional farming systems.

Sweet pepper is an economically important crop for organic and conventional farmers. It is grown in most countries of the world (Bosland and Votava, 2000). Sweet pepper fruit are good sources of many essential nutrients, including vitamins A, C, and E, carotenoids, minerals (e.g., calcium and iron), and other secondary plant compounds (Marin et al., 2004). Pesticide residues in fruit and vegetables are of concern to consumers; consequently, interest in organically grown organic fruit and vegetables has increased (United Nations, 2003).

Very little information is available on yields of sweet pepper and other vegetables grown organically in tropical countries (Juroszek et al., 2008). Scholberg et al. (2000) mentioned that detailed growth studies and yield analysis are common for most arable crops, but so far, their application to horticultural crops is limited. The lack of information on the yield potential of organically grown vegetables is one reason organic production is not considered to be a viable alternative to conventional vegetable production systems (Chellemi and Roskopf, 2004).

Studies by Chellemi and Roskopf (2004) and Delate et al. (2003, 2008) conducted in the United States, and by Cesar et al. (2007) undertaken in

Brazil, concluded that the yields of sweet pepper were similar in organic and conventional production systems. Chellemi and Roskopf (2004) realized up to 30 t·ha⁻¹ of marketable sweet pepper fruit yield in humid subtropical Florida, and concluded that organic production systems for fresh market sweet pepper can produce yields similar to those obtained in conventional farming systems. In a recent greenhouse study, Del Amor (2007) has found that marketable yield of sweet pepper (7.3 kg·m⁻²) fertilized with organic fertilizer equaled yields of sweet peppers that received organic and mineral fertilizer. The author concluded that with a proper manure dosage, chemical fertilizer input could be reduced in sweet pepper cultivation, reducing production costs and groundwater pollution, without decreasing fruit yield.

It is beyond the scope of this study to discuss topics such as availability of high-quality seed, seed cost, and marketing opportunities of organically grown vegetables in the tropics, including sweet pepper. Interested readers are referred to publications cited in this article, such as Juroszek et al. (2008) and United Nations (2003). In contrast, this study sought to document the yields of organically grown sweet pepper under a tropical environment. Information on potential yields of organically grown sweet pepper under tropical climatic conditions can assist researchers in evaluating the yield performance of organically cultivated sweet pepper under tropical climatic conditions elsewhere. Decision makers in agriculture also benefit from knowing about the conditions under which organic production can be a viable alternative to conventional production systems.

Materials and methods

EXPERIMENTAL AREA AND CLIMATIC CONDITIONS. Research experiments of the Organic Vegetable

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha ⁻¹	0.8922
4.8824	lb/ft ²	kg·m ⁻²	0.2048
28.3495	oz	g	0.0353
2.2417	ton/acre	t·ha ⁻¹	0.4461
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Program of AVRDC were performed at the Center's headquarters in the tropical southwest of Taiwan, about 50 km south of the Tropic of Cancer and at about 40 m above sea level. The experimental site has been in organic production for about 3 years, adhering to the *Production Standards for Organic Agricultural Products: Crops of Taiwan* (Council of Agriculture, Taiwan, 2005). Monthly mean temperature during the hot-wet season from May to September ranges from 27.0 to 29.0 °C; during the cool-dry season from October to April the temperature ranges from 17.4 to 25.9 °C. Mean annual precipitation is about 1670 mm, distributed bimodally. The mean precipitation during the hot-wet season from May to September is about 1450 mm; during the cool-dry season from October to April, it is about 220 mm (Central Weather Bureau, Taiwan, 2008). The soil type is Sandstone-Shale Alluvium with lime concretions. The soil pH is about 7.5. The surface soil texture is silty loam. The experimental site was, in general, suitable for vegetable production, including sweet pepper.

WEATHER CONDITIONS DURING THE EXPERIMENTS. The on-farm field study was conducted during the hot-wet season from 7 Mar. 2007 to 30 July 2007 [143 d after transplanting (DAT)] and during the cool-dry season from 27 Nov. 2007 to 7 Apr. 2008 (132 DAT). Table 1 shows information on the prevailing air temperature, precipitation, and evaporation. In the first week of Oct. 2007, a typhoon contributed to the unusually high

precipitation of 237 mm; October is usually the beginning of the dry season with a monthly mean precipitation of about 30 mm (Central Weather Bureau, Taiwan, 2008). In Feb. 2008, the mean monthly minimum temperature was relatively low, at 12.9 °C compared with the long-term monthly mean of 14.5 °C (Central Weather Bureau, Taiwan, 2008).

CULTIVAR SELECTION. Cultivar choice did not specifically consider traits that may be desired particularly in organic farming (De Melo, 2003; Lammerts van Bueren, 2002). In general, the commercial cultivars selected were known to be high yielding under conventional farming conditions in Taiwan. In addition, one test hybrid and one advanced line bred at AVRDC were evaluated. Cultivars tested included Green Bell Improved (Evergrow Seed Co., Tainan City, Taiwan), Queen Star (Known-You Seed Co., Kaohsiung, Taiwan), Hercules (Known-You Seed Co.) Andalus (Syngenta Seeds, Enkhuizen, The Netherlands), COA677 (AVRDC test F₁ hybrid), and PP9852-131 (AVRDC breeding line). All trial entries were F₁ hybrids except PP9852-131, which is open-pollinated (OP). The cultivars differed in maturity, fruit characteristics, growth habit, virus disease resistance, and tolerance to extreme temperatures (Table 2). During the cool-dry season, COA672 was used instead of COA677 because COA677 seed were not available. However, both are hybrids and their genetic background is very similar (Table 2).

EXPERIMENTAL DESIGN. Sweet pepper seed were sown on 1 Feb. and were transplanted on 7 Mar. 2007 for the hot-wet season trial, and were sown on 22 Oct. and transplanted on 27 Nov. 2007 for the cool-dry season trial, respectively. The previous crop in both seasons was fallow. The trials were arranged as randomized complete-block designs with four replications. Plots were established as raised beds, covered with plastic film mulch. The plot size was 1.0 m wide × 4.5 m long. Furrow space between raised beds was 0.5 m. Twenty plants were grown in double rows per plot. Spacing was 50 cm between rows and 45 cm between plants. The plants were staked.

NITROGEN FERTILIZER APPLICATION. In both seasons, according to the expected total yield of about 50 t·ha⁻¹, we applied about 300 kg·ha⁻¹ nitrogen (N) in sweet pepper at a rate and application method similar to those recommended for conventional sweet pepper production in the open field in Taiwan (AVRDC—The World Vegetable Center, 2004; C.H. Ma, personal communication). According to this recommendation, commercial organic fertilizers were applied, including locally produced compost basal [about 1.8N-4.5P-2.1K (Ten-Lo #1; Ten-Lo Co., Tian-Chong, Taiwan)] at about 200 kg·ha⁻¹ N, soybean meal [about 7.5N-1.6P-2.7K (Fwu-Sow Industrial Co., Lu-gang, Taiwan)] enriched with grass ash [about 0.1N-2.9P-33.8K (Fwu-Sow Industrial Co.)] in total four sidedressings each of about 25 kg·ha⁻¹ N, and a one-time

Table 1. Monthly weather records from Mar. 2007 to Mar. 2008 at AVRDC—The World Vegetable Center weather station, Shanhua, Taiwan.

Month	Mean monthly minimum/mean/maximum air temp (°C) ^z	Minimum daily air temp (°C)	Maximum daily air temp (°C)	Precipitation (mm) ^z	Evaporation (mm)
March 2007	18.3/22.6/26.9	13.1	32.1	23	114
April 2007	19.6/23.9/28.2	12.8	33.0	48	133
May 2007	23.5/27.4/31.3	20.3	34.6	268	154
June 2007	25.5/29.2/32.9	23.1	36.9	416	145
July 2007	26.8/30.8/34.9	24.6	35.9	163	168
August 2007	25.7/29.2/32.7	24.0	35.9	1,208	81
September 2007	25.4/29.1/32.9	24.0	35.6	205	96
October 2007	22.9/26.6/30.4	19.3	33.3	237	106
November 2007	19.0/23.1/27.2	14.0	30.1	19	109
December 2007	16.7/21.3/26.1	11.9	30.4	0	90
January 2008	15.2/19.6/24.0	9.5	31.0	40	89
February 2008	12.9/16.6/20.3	9.4	26.6	13	78
March 2008	17.2/22.0/26.8	12.0	31.6	19	136

^z(1.8 × °C) + 32 = °F, 1 mm = 0.0394 inch.

Table 2. Characteristics of sweet pepper cultivars and lines according to the product label of commercial hybrids or expert knowledge.

Cultivar/line	Harvest ^a	Fruit color ^b and shape	Fruit size ^c L × W (cm) ^x	Fruit wt ^c (g) ^w	Traits ^v
'Green Bell Improved'	Early to medium	Dark green, upright bell	17 × 8	300	Strong flower set, heat tolerant, TMV resistant
'Queen Star'	Early (45 DAT) ^u	Bluish green, upright conical bell	14 × 7	220	Vigorous, early, uniform size and high yielding, TMV tolerant
'Hercules'	Late (83 DAT)	Red, bell	9 × 7.5	150–180	Vigorous, thick crispy flesh, PVY tolerant
'Andalus'	Early (60 DAT)	Green, long bell	10.9 × 8.5	180	Tolerant to cool temperatures, TMV resistant and PVY tolerant
COA677	Early (<60 DAT)	Yellowish green, short bell	6.2 × 8.8	190	PB (race1) and BS (race1) resistant
COA672	Early (<60 DAT)	Yellowish green, short bell	9 × 9	210	PB (race1) and BS (race1) resistant
PP9852–131	Early (<60 DAT)	Yellowish green, conical bell	9.1 × 3.6	36	CMV and PVY resistant

^aFruit harvest date, fruit size, and fruit weight can be different depending on cultivation methods used and growing conditions in different years and seasons.

^bFruit color of the immature fruit (color of mature fruit is red for each cultivar/line).

^cLength of the fruit × width of the fruit, 1 cm = 0.3937 inch.

^w1 g = 0.0353 oz.

^vTMV = tobacco mosaic virus, PVY = potato virus Y, PB = phytophthora blight (*Phytophthora capsici*), BS = bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*), CMV = cucumber mosaic virus.

^uDAT = days after transplanting.

homemade organic starter solution technology (OSST). The principle of OSST is to raise the N concentration in the soil by applying a concentrated N solution (derived through fermentation of sugar cane molasses and fish residues) immediately after transplanting to enhance early growth and overall yields of vegetable crops (AVRDC—The World Vegetable Center, 2008). When necessary, the crops were furrow-irrigated about every 2 to 3 weeks, usually immediately after applying fertilizer side-dressings to promote plant nutrient availability and uptake.

PEST INCIDENCE AND PLANT PROTECTION. Few problems were encountered with plant diseases and pests during the hot-wet season in 2007, but during the cool-dry season, sweet pepper plants were challenged by moderate to high numbers of pests, including aphids (Aphidae), thrips (Thripidae), owl moth larvae (Noctuidae), white flies (Aleyrodidae), and mites (Acaridae); later during the cool-dry season, problems started with the fungal disease, anthracnose (*Colletotrichum* spp.). A *Bacillus thuringiensis* (*Bt*) product [*B. thuringiensis* ssp. *aizawai* strain ABTS1857 (XenTari[®]; Valent BioSciences, Libertyville, IL)] and a neem product [*Azadirachta indica* (BioFree.I[®]; Global Ecosys, Taichung City, Taiwan)] were used to manage owl moth larvae/small-sized insect pests and mites, respectively. During the hot-wet season trial,

the *Bt* and neem products were applied weekly as a preventative measure. The biopesticides were applied less frequently during the cool-dry season trial—about every second week, for a total seven times. In addition to the above-mentioned *Bt* product, a second product that included *B. thuringiensis* ssp. *kurstaki* (Delfin[®]; Novartis Crop Protection, Greensboro, NC) was used to reduce the risk of resistance build-up in insect pest populations against one of the *Bt* subspecies. Applications were suspended when it was observed that the neem product was not sufficiently effective, and *Bt* was not needed. Pest management also included physical controls (sticky paper and pheromone traps) and cultural methods (moderate irrigation, field sanitation, cleaning tools, and crop rotation). Plastic film mulch cover on raised beds was used for weed management and improved water use efficiency.

DATA COLLECTION AND STATISTICAL ANALYSIS. In both seasons, harvest was performed when the immature fruit reached a shining green color. Sweet pepper harvest during the hot-wet season was from 60 to 142 DAT (nine harvests); during the cool-dry season it was from 92 to 132 DAT (three harvests). Sixteen plants per plot were harvested regularly by hand; plants on the edges of the plots were omitted. Fruit from each plot were graded and weighed immediately after each harvest. The

data were statistically evaluated using analysis of variance (procedure GLM of SAS, version 8.2; SAS Institute, Cary, NC). Comparisons of means were carried out using Tukey's test at $P < 0.05$.

Results and discussion

FRUIT WEIGHT. In the hot-wet and cool-dry seasons, mean fruit weight of the small-fruited line PP9852–131 was 52 and 63 g, respectively, and was significantly lower compared with the other trial entries in both seasons. The mean fruit weights of the other trial entries ranged from 115 to 183 g across seasons, and were not significantly different from one another in either season (data not shown). Fruit weight varied with harvest date, but was not necessarily determined by harvest date.

SWEET PEPPER YIELDS DURING THE HOT-WET SEASON. During the hot-wet season 2007, the commercial cultivars and sweet pepper lines both produced relatively high total yields (up to 55.7 t·ha⁻¹) and marketable yields (up to 45.6 t·ha⁻¹) that were not significantly different from each other (Table 3).

Yields were similar to those in previous field experiments at AVRDC under conventional farming conditions during the hot-wet season. For example, when conventionally managed sweet pepper was transplanted in Mar. 2003, a mean total fruit yield of 36.7 t·ha⁻¹ (range of 20.8–55.0

Table 3. Mean total and marketable fruit yield during the hot-wet season 2007 and cool-dry season 2007–08 and percent yield reduction in the cool-dry versus hot-wet season of six sweet pepper cultivars and lines, AVRDC–The World Vegetable Center organic fields in Shanhua, Taiwan.

Cultivar/line	Total yield ^z			Marketable yield		
	Hot-wet 2007 ^y (t·ha ⁻¹)	Cool-dry 2007–08 ^x (t·ha ⁻¹)	Reduction ^w (%)	Hot-wet 2007 (t·ha ⁻¹)	Cool-dry 2007–08 (t·ha ⁻¹)	Reduction (%)
‘Green Bell Improved’	45.0 a	40.2 ab ^v	–10.7	40.3 a	34.0 a	–15.6
‘Queen Star’	55.7 a	37.8 ab	–32.1	45.6 a	31.9 ab	–30.0
‘Hercules’	53.1 a	33.3 bc	–37.3	41.9 a	28.8 ab	–31.3
‘Andalus’	49.8 a	45.7 a	–8.2	42.1 a	37.8 a	–10.2
COA677/COA672 ^u	47.5 a	25.4 c	–46.5	36.9 a	21.1 b	–42.3
PP9852–131	44.6 a	29.9 bc	–33.0	39.9 a	26.2 ab	–34.3

^zMarketable and unmarketable fruit (e.g., adversely affected by blossom end rot, insect pests, mites, and diseases or malformed).

^yHot-wet season 2007: transplanted on 7 Mar. 2007, harvest duration from 60 to 142 d after transplanting (DAT), nine harvests; 1 t·ha⁻¹ = 0.4461 ton/acre.

^xCool-dry season 2007–08: transplanted on 27 Nov. 2007, harvest duration from 92 to 132 DAT, three harvests.

^wPercent yield reduction in the cool-dry versus hot-wet season.

^uMeans within columns followed by different letters are significantly different at $P < 0.05$ according to Tukey’s test.

^uDuring the cool-dry season COA672 was used instead of COA677; however, both entries are hybrids and their genetic background is very similar including fruit weight (see Table 2).

t·ha⁻¹) and a mean marketable fruit yield of 26.5 t·ha⁻¹ (range of 14.5–41.1 t·ha⁻¹) was achieved across 12 advanced entries; among them was ‘Andalus’ with a total and marketable yield of 55.0 t·ha⁻¹ and 41.1 t·ha⁻¹, respectively (AVRDC—The World Vegetable Center, 2004). It should be noted that the aim of this study was to collect preliminary data on yields of organically grown sweet pepper cultivars in the tropics rather than to compare different production systems. Therefore, organic sweet pepper yields were not compared side-by-side with conventionally grown sweet peppers using the same cultivars, although this method to compare yield data of different production systems is more meaningful than comparisons of yields across years.

SWEET PEPPER YIELDS DURING THE COOL-DRY SEASON. During the cool-dry season 2007–08, the total and marketable yields of all entries were reduced by as much as 46.5% and 42.3%, respectively, compared with the hot-wet season (Table 3); probably mainly due to unusually low temperatures during the growing season. The commercial hybrid ‘Andalus’ showed the least decline in total and marketable yields, while the AVRDC test F₁ hybrid showed the greatest (see “Discussion”). Particularly in Feb. 2008 during the harvest period, the mean monthly minimum air temperature was relatively low, at 12.9 °C (see Table 1) compared with the long-term monthly mean of 14.5 °C, and may have impacted sweet pepper growth, flowering, fruit set, and fruit development. When air

temperatures fall below 18 °C for extended periods, growth and yield of sweet pepper are usually decreased (Berke et al., 2003). For example, harvest started later during the cool-dry (92 DAT) compared with the hot-wet (60 DAT) season. In addition, fruit were harvested three times during this cool-dry season, while nine harvests were completed during the hot-wet season (see footnote of Table 2). However, we cannot exclude that other factors contributed to the lower yield achieved during the cool-dry season such as the lower number of harvest dates that might have directly reduced yield but also indirectly through reduced fruit set. Large fruit acts as a sink for nutrients, and inhibits the development of additional fruit on the plant (Robinson and Decker-Walters, 1997). Insect pest infestation levels were in general greater during the cool-dry compared with hot-wet season and may have resulted in more plant damage and reduced plant growth and yields. It is unknown why during the hot-wet season the impact of pests (insects and mites) was minor, even though the sweet pepper field trial was a mere 50 m away from a cucumber (*Cucumis sativus*) field trial that suffered severe pest infestations. Lower temperatures in the cool-dry season (see Table 1) may have reduced organic nitrogen mineralization processes and resulted in lowered N availability to the crop. To summarize, earlier crop establishment may have produced higher yields because transplanting in September compared with November is better for attaining extremely high

sweet pepper yields in Taiwan (S.C. Shieh, personal communication) as long as temporary flooding and strong winds caused by typhoons do not harm early crop development.

YIELD REDUCTION AMONG TRIAL ENTRIES DURING THE COOL-DRY SEASON. ‘Andalus’ is tolerant to low temperatures according to the product label. Tolerance to low temperatures is the most plausible explanation for its relative high total and marketable yields during the cool-dry season, although its total yield was not significantly different from those of ‘Green Bell Improved’ and ‘Queen Star’ (Table 3). However, ‘Green Bell Improved’, which is noted for heat tolerance, showed like ‘Andalus’ a relative small reduction of around 10% in total yield during the cool-dry compared with hot-wet season (Table 3). ‘Andalus’ and ‘Green Bell Improved’ may be tolerant to high and low temperatures, thus they may produce reliable yields across a relative broad range of locations and seasons.

The influence of temperature on flower development and fruit set of sweet pepper is intensively discussed by Hodges et al. (1995). These authors also found differences in yield among four sweet pepper cultivars that were evaluated for marketable yield across locations, years, and planting dates. Among other factors, these yield differences were related to adaptation to extreme temperatures. For example, in their study, ‘Hybelle’ appeared to be better adapted to conditions where low temperatures occur during the growing season.

SWEET PEPPER YIELDS IN ORGANIC AND CONVENTIONAL PRODUCTION SYSTEMS WORLDWIDE. With the long-term field studies of Delate (2002) and Delate et al. (2003, 2008), it was also found that sweet pepper yields are similar in organic and conventional production systems. For example, Delate et al. (2008) have recently reported that from 2001 to 2003, mean marketable yields of sweet pepper were similar in organic (26.9, 15.6, and 18.8 t·ha⁻¹) and conventional (25.6, 15.7, and 11.0 t·ha⁻¹) production systems that received compost or mineral fertilizer at 112 kg·ha⁻¹ N, respectively, in 2 of 3 years. In the third year of their study, the organically managed sweet pepper plants produced a significantly higher fruit yield. These sweet pepper yields were gained under lower input levels compared with the study presented here (300 kg·ha⁻¹ N according to the expected total yield of 50 t·ha⁻¹ applied) and may explain, to a certain extent, the lower yields compared with this study.

Chellemi and Roskopf (2004) realized up to 30 t·ha⁻¹ of marketable sweet pepper fruit yield in humid subtropical Florida and concluded that organic production systems for fresh market sweet pepper can produce yields similar to those obtained in conventional farming systems. In their study, the maximum marketable yield of conventionally produced sweet pepper was about 37 t·ha⁻¹—similar to the statewide average in Florida of 35.8 t·ha⁻¹ for conventional sweet peppers from 1996 to 2001. The marketable fruit yields reported here are well above 30 t·ha⁻¹ during the hot-wet season and also during the cool-dry season in three commercial cultivars; comparable to those of Cesar et al. (2007) who have realized in a 1-year study in organically grown sweet pepper an average marketable yield of 37 t·ha⁻¹ across two cultivars and two treatments with a maximum value of 43 t·ha⁻¹.

Conclusions

The on-station field experiments using organic farming methods reported here found total and marketable fruit yields of sweet pepper similar to those of previous AVRDC cultivar evaluation experiments based on conventional farming techniques. This is

in agreement with studies performed in the United States.

Yield data of sweet pepper gained under tropical conditions in Taiwan can assist in evaluating the yield performance of organically produced vegetables under tropical climatic conditions elsewhere. The relatively high yields achieved on-station in tropical Taiwan, which are comparable to those achieved in a 1-year study in Brazil, may encourage farmers and agricultural stakeholders to consider organic farming as a viable alternative to conventional farming systems in tropical and subtropical countries worldwide.

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