Clonally Propagated and Seed-derived Papaya Orchards: II. Yield Comparison

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Abstract. Gynodioecious papaya (*Carica papaya* L.) seedlings in commercial cropping systems in Hawaii are typically multiple-planted and thinned upon flowering to a single hermaphrodite because seedlings segregate for sex expression. Use of clonally propagated hermaphrodites would eliminate the over-planting practice and may provide other advantages. Yields of clonally propagated hermaphrodites were compared with single- and multiple-planted seedlings in three fields on two islands in Hawaii. Cloned hermaphrodites were either rooted cuttings or in vitro micropropagated plants. Clonally propagated plants bore ripe fruit 1 to 3 months earlier than thinned seedlings and had significantly higher early and cumulative yields. At each site, cumulative yields of thinned seedlings never reached the same level as those of clonally propagated plants. The yield benefit from clonally propagated plants was greatest at Keaau, the lowest sunlight and least productive test site.

Hermaphrodite papayas (*Carica papaya* L.) are important in commercial papaya production in many tropical and subtropical regions of the world. Germinating seed from self-fertilized hermaphrodites segregate two hermaphrodites to one female (Storey, 1953). The sex of vegetative seedlings is indistinguishable except by DNA analysis such as the polymerase chain reaction (PCR) testing for hermaphrodite-specific DNA bands (Deputy et al., 2002). Therefore, commercial growers typically transplant at least five seedlings per planting hole to have a good probability of having at least one hermaphrodite tree standing for orchard production. The multiple-planted seedlings compete for nutrients and sunlight until flowering 3 to 4 months after transplanting at which time females and extra hermaphrodites are removed.

Cropping systems using hermaphrodite plants would eliminate multiple-planting and the competition and thinning associated with this practice. Fields can be established with clonally propagated rooted cuttings (Allan, 1964, 1993) or micropropagated plants (Chan and Teo, 2002; Drew, 1988; Drew and Vogler, 1993; Fitch et al., 2005). Growth of micropropagated 'Rainbow' papayas (Manshardt, 1998) was compared to rooted cuttings, single

hermaphrodite seedlings, and thinned seedlings in three locations in Hawaii (Fitch et al., 2005). That study corroborated those of Allan (1964), Chan and Teo (2002), Drew (1988), and Drew and Vogler (1993) by showing that rooted cuttings and micropropagated plants flowered earlier and lower on the trunk compared to seedlings. Micropropagated papayas and rooted cuttings were also shorter in stature compared to seedlings. The question remaining to be answered is: what is the effect of the different ways of establishing the papaya crop on fruit yield? We address this question with this report on papaya fruit yield and its characteristics at the three locations in Hawaii.

Materials and Methods

Plant materials

All experiments were conducted with the papaya ringspot virus (PRSV) resistant commercial papaya hybrid 'Rainbow.' 'Rainbow' seeds were gifts of Richard Manshardt, University of Hawaii. Methods involved in the production of in vitro-grown micropropagated plants, cuttings rooted in the greenhouse, PCR-identified hermaphrodite seedlings, and multiple-planted, thinned seedlings used for the experiment were described previously (Fitch et al., 2005).

Field sites

Keaau. The first established and most extensive test was at Keaau on the island of Hawaii. The test was installed on 30 Apr. 1998 in Papai, an extremely stony soil (USDA, 1972; 1973) within a 750- to 1500-year-old lava flow (USGS,

1996) at an elevation of 60 m. The average daily temperature was 28 °C in summer and 23 °C in winter with a soil temperature range of 22 to 23 °C. Rainfall at this site averages 380 cm annually (USDA, 1973). No additional irrigation is provided. The 30-year (1932–75) solar radiation average from weather stations in Keaau ranged from 400 cal·cm⁻¹·d⁻¹ at 27 m elevation down to 380 cal·cm⁻¹·d⁻¹ at 87 m elevation (How, 1978). The test site, intermediate in elevation to the two stations, should historically receive about 390 cal·cm⁻¹·d⁻¹ solar radiation. Planting holes excavated in the lava were supplemented with about 15 L of Papai soil that had not been previously planted in papaya.

Helemano. The Helemano block was installed on 23 Oct. 1998 on the north shore of the island of Oahu. The Helemano site soil was a highly weathered Oxisol of low fertility, Lahaina silty clay (USDA, 1972). Elevation was 180 m. The average daily temperature was 27 °C in summer and 22 °C in winter (USDA, 1972). The 30-year average (1932–75) solar radiation at the nearest weather station (3.2 km) was 468 cal·cm⁻¹·d⁻¹ at 210 m elevation (How, 1978). Helemano received about 130 cm of rain per year and, except for periods of heavy rainfall, was drip-irrigated at 92 to 137 m³·ha⁻¹·week⁻¹ throughout the year.

Mokuleia. The Mokuleia block was installed on 10 Mar. 1999 on the north shore of the island of Oahu. The Mokuleia site (elevation = 9 m) had a fertile Mollisol soil, Waialua silty clay (USDA, 1972). The average daily temperature was 29 °C in summer and 26 °C in winter. The 30-year average solar radiation at the nearest weather station (6.4 km) was 435 cal·cm⁻¹·d⁻¹ at 6 m elevation (How, 1978). The site received about 130 cm of rain per year (USDA, 1972) and, except for periods of heavy rainfall, was drip-irrigated at the same rate as the Helemano site: 92 to 137 m³·ha⁻¹·week⁻¹ throughout the year.

Field test design

The experimental design was a randomized complete block with four or six replication plots containing three to five treatments as subplots consisting of a single row for each treatment. The treatments were designated as: CT, rooted cuttings; MP_{lg}, micropropagated plants 21 to 30 cm tall; MP_{sm}, micropropagated plants 12 to 20 cm tall; SD1, single seedlings; and SD5, 5 seedlings per hole. Subplots of treatments were randomized within each replication plot. The Keaau block was divided into four replication subplots containing five treatments (CT, MP_{lg}, MP_{sm}, SD1, SD5) planted as single rows of 20 plants each randomized among subplots for a total test size of 400 plants. The Helemano block was divided into six replication subplots containing three treatments (CT, MP, SD5) planted as single rows of 10 plants each randomized among subplots for a total test size of 180 plants. The Mokuleia block was divided into four replication subplots containing four treatments (CT, MP, SD1, SD5) planted as single rows of 28 plants each randomized among subplots for a total test size of 448 plants. Tree spacing was 1.50 m between trees within a row and 3 m between rows. For the single seedling treatment (SD1), a single SD was planted per

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Fig. 1. Clonally propagated and seedling 'Rainbow' trees in the Mokuleia test. Three plant types are shown, (A) rooted cuttings (CTs), (B) micropropagated plants (MPs), and (C) thinned seedlings (SD5s). All of the photographs were taken on the same harvest date. Bearing height of the plant types differed significantly.

hole. For the multiple plant treatment, the SDs were planted five per hole (SD5), about 8 cm apart and thinned to a single hermaphrodite when flower buds appeared. To eliminate edge effects, each field block was surrounded by at least two border rows of SD5 plants of the same age as the test plants.

At all three sites, growers applied fertilizer and pest control chemicals according to their standard practice that consisted of broadcasting a formulation of 11N-32K₂O fertilizer around each tree or they applied the formulation through the irrigation system at 20 kg·ha⁻¹ every fourth week during the first 3 months of growth and then increased the amount to 80 kg·ha⁻¹ every fourth week. Supplemental K₂O fertilization was added if deficiency symptoms appeared.

Micropropagation

A total of 350 micropropagated hermaphrodite plants were produced as described by Fitch et al. (2005). Briefly, 'Rainbow' papaya seeds were decontaminated with diluted commercial bleach, germinated on water agar, proliferated on modified Murashige and Skoog (1962) medium (MS0, Fitch et al., 2005) supplemented with 0.89 μ M benzylaminopurine (BA) and 1.1 μ M naphthalene acetic acid (NAA), induced to root on MS/IBA medium without BA and NAA (MS0) but containing 9.84 μ M indolebutyric acid (IBA), then rooted in vermiculite medium moistened with half-strength MS0 medium containing 30 g·L⁻¹ sucrose.

Rooted cuttings

Ex vitro cuttings from stock plants of greenhouse-grown, micropropagated 'Rainbow' hermaphrodites were dipped in 0.1 g IBA per 100 g talc and rooted under intermittent mist irrigation on heating mats at 30 °C (Fitch et al., 2005). All of the rooted cuttings in the Keaau test were derived from the same lines of hermaphrodite 'Rainbow' seedlings used in the micropropagated plant treatment. Rooted cuttings in the Mokuleia and Heleman tests were a mixture of cuttings from the greenhouse stock plants and from lateral branches of mature, field-grown hermaphrodite 'Rainbow' trees. About 10% of the rooted cuttings were produced from mature trees. A total of 350 rooted cuttings were prepared for the field tests.

Seedlings

About 5500 'Rainbow' seedlings were germinated for the three field tests including border rows. In total, 600 seedlings were PCR-tested (Deputy et al., 2002) for sex expression to obtain 252 hermaphrodite seedlings for two of the three locations, Keaau and Mokuleia. About 1700 seedlings were planted, five per hole, 5 cm apart, and thinned to 350 hermaphrodites.

Since rooted cuttings were larger and thicker in diameter than seedlings, two sizes of micropropagated plants were included in the Keaau test, large micropropagated plants (MP_{lg}) that were equivalent in height but not diameter to the rooted cuttings (21 to 30 cm tall) and small micropropagated plants (MP_{sm})

that were comparable to the seedlings (12 to 20 cm tall).

Data collection and analysis

The number and weight, to the nearest 0.5 kg, of fruit at color break to ¼ ripe were recorded for every tree in each subplot for 1 week each month. Data are presented as the 1-week mean per tree of subplots (plant type) within the site block per month. Significance of the data was calculated from analysis of variance in treatment subplots and expressed as the least significant difference (LSD) among treatments each month at $P < 0.05$ (Statistix 7 for Windows). Data were analyzed for the effect of location and time by combining the datasets for Keaau, Heleman, and Mokuleia. The yields reported are only a fraction of the true yields because in commercial practice, growers harvest their fields four or more times each month. We estimated annual yields at Mokuleia and Heleman by multiplying the 1-week cumulative yields in the eighth month (last month of harvest) by four to get a monthly estimate and then by 12 for an estimated annual yield. Unlike Keaau, the two sites on Oahu were not harvested for a full 12 months because the trees grew too tall to reach the fruit. The cumulative yield per tree in 12 months at Keaau was multiplied by four to estimate the annual yield. Annual yields per ha were estimated by multiplying mean tree yields by 1650 which is the average density of trees per ha in commercial orchards.

Results

Harvests commenced 8 to 10 months after planting. Early differences in yield between plant types were most important economically; however, differences in fruit bearing height were the most striking (Fig. 1). Yield data over 6 months of harvest at Keaau, Helemano, and Mokuleia were analyzed together to evaluate the effects of time (month of harvest), location, and plant type (Table 1). Replication differences were not significant for any yield characteristic. The fruit weight differences were highly significant ($P < 0.001$) for all sources of variation except replication. Differences in number of fruit per tree were significant ($P < 0.05$) for plant type and highly significant ($P < 0.001$) for month of harvest and location. Differences in individual fruit weight were highly significant ($P < 0.001$) for plant type and time but not location. Since replication had no effect, the differences in each of the yield characteristics were highly significant for pooled data so that each characteristic was separately analyzed for the 1-week harvest of each month.

The weight and number of fruit per tree per week for each month in Keaau varied significantly with time among plant types (Table 2). However, the individual weight per fruit did not differ between plant types.

Both types of clonally propagated plants, CTs and MPs, had significantly higher number and weight of fruit in the first 3 months of harvest compared to SD5 plants ($P < 0.05$). Yields of the MP_{sm} and SD1 plants were not significantly different. Weight of fruit per tree at the first harvest, 9 months after transplanting, was closely correlated to the percentage of trees in bud in the third month after transplanting (Fitch et al., 2005). The r^2 correlation coefficient was 0.9758 ($P < 0.002$), suggesting that a high percentage of budding in the third month of growth is a good predictor of high yields. Although hermaphrodite seedlings (SD1) were single-planted like

CTs and MPs, their harvest yields were less than those of the clonally propagated plants at the third harvest (Table 2, Fig. 2). After the third harvest, the fruit weight and number of all plant types were generally not significantly different. The early high yields of clonally propagated plants produced 8 months of significantly higher cumulative yields compared to SD5 ($P < 0.05$), Fig. 3A). Subsequent cumulative yields were not significantly different but yields of clonally propagated plants continued to be the highest for the rest of the crop cycle (Fig. 3A).

The early yield of SD5 plants in Helemano was significantly higher than that of CTs in the third harvest only, thereafter the yields were not significantly different (Table 3). MP yields were higher than SD5 plants for the fourth and fifth harvests. In general, the differences among plant types diminished with crop development over time. Individual fruit weight varied in each month but in no obvious pattern. Correlation between percentage of trees in bud in the third month of growth (Fitch et al., 2005) and yield per tree in the third harvest was high with $r^2 = 0.9673$ at $P < 0.12$. The high early yields of MPs and CTs in Helemano resulted in cumulative yields that were significantly higher than those of SD5 plants throughout the cropping cycle (Fig. 3B). The early yield advantage of the clonally propagated plants was never surpassed by SD5s for the duration of the experiment when all treatments were essentially the same.

The large differences in yield of fruit

between plant types in Keaau (Table 2, Fig. 2A) were not evident in Mokuleia (Table 4, Fig. 2C). The largest differences measured in Keaau were in the second month of harvest only. In this harvest, significantly higher yields were recorded for CTs and SD1s compared to SD5s, and the number of fruit per tree was significantly higher for CT and SD1 plants compared to SD5 plants. The yield of MPs was not significantly higher than thinned seedlings. Although there were no significant differences in earliness of flowering in the second month of growth in Mokuleia (Fitch et al., 2005) nor in yield during the second month of harvest (Table 4), there was good correlation between the percentage of plants in bud and yield, $r^2 = 0.89$, $P < 0.05$. Cumulative yields of CT and SD1 plants were significantly higher than SD5 plants for two out of eight harvests in Mokuleia (Fig. 3C). After the third harvest, the cumulative yields maintained a constant difference. Cumulative annual yields extrapolated from the eighth and final harvest to estimate annual yields for Helemano showed that MPs were the most productive at 259,875 kg·ha⁻¹, followed by CTs, 220,077 kg·ha⁻¹, and SD5s, 203,247 kg·ha⁻¹ (Table 5). All yields are considered to be extremely high for papaya. The calculated annual cumulative yields for Keaau, 84,200 to 118,223 kg·ha⁻¹, were close to the yield reported for a field test of 'Rainbow' in Puna in lava soil, 121,000 kg·ha⁻¹ (Ferreira et al., 2002). The solar radiation in Puna is 450 cal·cm⁻²·d⁻¹,

Table 1. Analysis of variance (ANOVA) for various yield characteristics of papaya as influenced by plant type (TYPE), month of harvest (MON), and location (LOC).

Source of variation	df	Wt of fruit/ tree (kg)	No. of fruit/tree	Mean wt/ fruit
Plant type (TYPE)	2	***	*	***
Replication (REP)	5	NS	NS	NS
Month of harvest (MON)	5	***	***	***
Location (LOC)	2	***	***	NS
TYPE × REP × MON × LOC	237			

NS,*,***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

Table 2. Monthly 1-week yield per tree data for cloned and seedling papaya plants at Keaau.

Plant type ^a	Month														
	Jan. 1999	Feb. 1999	Mar. 1999	Apr. 1999	May 1999	June 1999	July 1999	Aug. 1999	Sept. 1999	Oct. 1999	Nov. 1999	Dec. 1999	Jan. 2000	Mar. 2000	June 2000
	Months after transplanting														
	9 ^c	10	11	12	13	14	15	16	17	18	19	20	21	23	26 ^c
	Harvest														
	1	2	3	4	5	6	7	8	9	10	11	12	13	15	18
Weight of fruit (kg)															
CT	1.58 a ^w	2.11 a	2.49 a	1.91 a	1.08 a	1.00 a	0.82 ab	0.81 ab	0.90 a	0.83 a	0.93 a	1.63 a	1.56 a	1.65 a	0.80 a
MP _{lg}	1.41 a	1.33 a	2.02 a	1.64 a	1.41 a	0.80 a	0.66 ab	0.58 b	1.33 a	0.93 a	1.12 a	1.75 a	1.70 a	1.60 a	0.71 a
MP _{sm}	0.76 b	1.96 a	2.27 a	2.01 a	1.44 a	1.22 a	0.93 a	1.00 a	1.27 a	0.64 a	1.02 a	1.62 a	1.79 a	1.52 a	0.69 a
SD1	0.42 bc	1.46 a	1.12 b	1.17 a	1.20 a	0.82 a	0.50 b	0.77 ab	1.08 a	0.69 a	0.87 a	1.28 a	1.40 a	1.62 a	0.71 a
SD5	0.02 c	0.22 b	0.94 b	1.45 a	1.36 a	1.37 a	0.68 ab	1.15 a	1.33 a	0.70 a	0.92 a	1.59 a	1.68 a	1.77 a	0.91 a
Number of fruit per tree															
CT	2.40 a	3.35 a	4.19 a	3.04 a	1.80 a	ND ^v	1.75 a	1.39 ab	ND	ND	1.37 a	2.46 a	2.48 a	ND	1.61 a
MP _{lg}	2.42 a	2.91 ab	4.62 a	2.99 a	2.31 a	ND	1.12 b	0.91 b	ND	ND	1.61 a	2.65 a	2.70 a	ND	1.50 a
MP _{sm}	1.16 b	3.00 ab	4.63 a	3.33 a	2.40 a	ND	1.73 a	1.27 b	ND	ND	1.48 a	2.42 a	2.81 a	ND	1.35 a
SD1	0.73 bc	1.99 b	2.64 ab	2.28 a	2.21 a	ND	1.20 ab	1.48 ab	ND	ND	1.14 a	2.01 a	2.22 a	ND	1.62 a
SD5	0.04 c	0.40 c	2.16 b	2.45 a	2.37 a	ND	1.25 ab	2.07 a	ND	ND	1.61 a	2.59 a	2.71 a	ND	1.78 a
Mean weight per fruit (g)															
CT	644 a	619 a	491 a	627 a	612 a	ND	519 a	597 a	ND	ND	694 a	669 a	632 a	ND	519 a
MP _{lg}	603 a	476 a	469 a	550 a	609 a	ND	602 a	646 a	ND	ND	693 a	684 a	628 a	ND	489 a
MP _{sm}	649 a	653 a	490 a	605 a	599 a	ND	540 a	791 a	ND	ND	666 a	698 a	635 a	ND	511 a
SD1	516 a	697 a	478 a	513 a	524 a	ND	443 a	538 a	ND	ND	784 a	700 a	681 a	ND	508 a
SD5	555 a	422 a	460 a	595 a	574 a	ND	547 a	569 a	ND	ND	580 a	676 a	651 a	ND	547 a

^aFirst harvest.

^cLast harvest.

^vCT = cuttings, MP_{lg} = large micropropagated plants, MP_{sm} = small micropropagated plants, SD1 = single hermaphrodite seedlings, SD5 = thinned seedlings.

^wMean values within a column followed by different letters indicate significant differences among treatments ($P < 0.05$) according to ANOVA (LSD).

^vND = no data taken.

15 units higher than that in Mokuleia ($435 \text{ cal}\cdot\text{cm}^{-2}\cdot\text{d}^{-1}$) and about $61 \text{ cal}\cdot\text{cm}^{-2}\cdot\text{d}^{-1}$ higher than in Keaau.

Discussion

Clonally propagated papayas were reported to bear fruit earlier and lower on the trunk (Allan, 1964, 1993; Chan and Teo, 2002; Drew, 1988; Drew and Vogler, 1993; Fitch et al., 2005), and to have higher yields compared to single-planted seedlings (Drew and Vogler, 1993). The experiment presented here corroborates the Drew and Vogler (1993) study and is the only one comparing clonally propagated trees, single-planted seedlings, and multiple-planted then thinned seedlings, the latter being the typical cropping system used in many papaya growing operations worldwide. Additionally, since the experiment was carried out in three divergent locations, the environmental effects on yield of papaya, regardless of cropping system, are important considerations for growers.

Annual cumulative yields extrapolated from one harvest per week for each month for all cropping systems, CTs, MPs, SD1s, and SD5s, were higher in Mokuleia than in Keaau by 66%, 69% to 74% (MP_{lg} and MP_{sm}), 46%, and 54% (Table 5), respectively. Heleman had the highest yields for all three plant types, CTs, MPs, and SD5s (Table 5), higher than in Mokuleia by 20%, 39%, and 20%, respectively. The locations differ in average daily solar radiation, average winter and summer temperature and rainfall, and in soil type. Planting time was comparable in Keaau and Mokuleia. Fields were established about 1 year apart in mid-spring and early spring, respectively, enabling the young transplants to grow through the juvenile phase in the beginning of the warm spring and summer growing season. On the other hand, trees in the late autumn Heleman planting spent the juvenile phase in winter. Heleman had the highest solar radiation and elevation but lowest average temperatures and moderately fertile soil. The early yields at Heleman were low 11 months after planting and comparable to those in Keaau (Tables 4 and 2) and in contrast to Mokuleia (Table 3). But later in the harvest cycle, Heleman yields in the 12th to 14th months after planting were very high. The peak yield for the clonally propagated plants occurred in the 12th month after planting while the thinned seedlings peaked in the 14th month. This extraordinarily high yield could be due to a combination of planting time and high solar radiation. Drew and Vogler (1993)

Fig. 2. Yield per tree of cloned and seedlings papaya plants for 1 week per month (kg per tree) at Keaau (A), Heleman (B), and Mokuleia (C). Keaau yields of clonally propagated plants were significantly higher ($P < 0.05$, arrows) for 3 months compared to thinned seedlings. Heleman yields in three harvests differed significantly. Mokuleia second harvest yields of cuttings and single seedlings but not micropropagated plants were higher than thinned seedlings. The graphs show the monthly fluctuations due to season, weather conditions, etc. CT = cuttings, MP_{lg} = large micropropagated plants, MP_{sm} = small micropropagated plants, SD1 = single hermaphrodite seedlings, SD5 = thinned seedlings.

A

B

C

reported that in Australia, the normal planting time is just prior to winter. Over-wintering may allow plants to build up reserves of nutrients to produce many fruit early in the cropping cycle. The fact that both clonally propagated trees and thinned seedlings in Helemano showed high yields suggests that for that location and perhaps others, planting a crop in late autumn is a good cropping practice.

Cumulative yields of most of the clonally propagated plant types in all three locations were never surpassed by those of seedlings. The exceptions were micropropagated plants in Mokuleia that yielded less than thinned seedlings and single-planted seedlings that out-yielded all other plant types. Mokuleia with its high temperatures and soil fertility and low elevation may foster such rapid growth and development of seedlings that the use of clonally propagated plants may not be justified for yield. However, the shorter harvest height of clonally propagated plants (Fitch et al., 2005) could provide sufficient savings for the grower to invest in cloned plants. Helemano and Keaau showed the highest yields by clonally propagated plants compared to thinned seedlings, justifying use of cloned plants. Keaau with its low solar radiation, soil fertility, and yields, may benefit most from use of clonally propagated plants. Although SD1 plants did not have to compete for light and nutrients during early growth, some juvenile factor(s) apparently affected yield in Keaau as had been observed for growth (Fitch et al., 2005). This juvenility factor was most pronounced in Keaau seedling yield. The slightly lower yield of SD1 compared to SD5 suggests that in Keaau, multiple-planting was not detrimental to seedling yield as was juvenility.

Yield data from the lava fields planted in the springtime corroborate those of Drew and Vogler (1993) who reported that micropropagated papayas planted in the springtime had higher yields than single-planted seedlings. Yields of the fall-planted Helemano site, however, are contrary to those of Drew and Vogler (1993) who reported that micropropagated plants established in the cooler winter season did not show a yield advantage over single-planted seedlings. Micropropagated plants were the highest yielding group in Helemano. Drew and Vogler (1993) reported that planting date affected node number and maturation. The milder winters in Hawaii may not affect plant development as much as in Australia where dioecious, cold tolerant cultivars are grown. Drew and Vogler (1993) observed that plants micropropagated from adult tissues but not juveniles (inconsistent results) had higher yields than single-planted seedlings when planted in spring. We did not differentiate between micropropagated plants from seedlings or mature plants; however,

Fig. 3. Cumulative monthly 1-week data for cloned and seedling papaya plants at Keaau (A), Helemano (B), and Mokuleia (C). At Keaau, the cumulative yield of clonally propagated plants over other treatments was significantly greater ($P < 0.05$, see arrow) over eight harvests, at Helemano over six harvests, and at Mokuleia over two harvests.

Table 3. Monthly 1-week yield per tree data for cloned and seedling papaya plants at Helemano.

Plant type ^x	Month								
	Aug. 1999 ^z	Sept. 1999 a	Sept. 1999 b	Oct. 1999	Nov. 1999	Dec. 1999	Jan. 2000	Feb. 2000	May 2000 ^y
	Months after transplanting								
	10	11 a	11 b	12	13	14	15	16	19
Plant type ^x	Harvest								
	1	2	3	4	5	6	7	8	9
Weight of fruit (kg)									
CT	0.23 a ^w	1.07 a	1.22 b	5.46 ab	5.09 ab	4.52 a	2.40 a	2.22 a	0.82 a
MP	0.37 a	1.26 a	1.65 ab	7.03 a	6.09 a	5.04 a	2.43 a	2.37 a	0.84 a
SD5	0.07 a	1.06 a	1.89 a	3.55 b	3.58 b	4.77 a	2.76 a	2.87 a	0.84 a
Number of fruit per tree									
CT	0.65 a	2.27 a	2.32 b	9.70 a	8.11 a	9.17 a	5.00 a	4.41 a	1.73 a
MP	0.77 a	2.29 a	3.04 ab	12.50 a	8.68 a	9.30 a	4.90 a	4.58 a	1.78 a
SD5	0.15 a	1.90 a	3.60 a	5.87 b	5.40 b	9.35 a	5.62 a	5.28 a	2.09 a
Mean weight per fruit (g)									
CT	503 a	440 b	530 a	550 a	610 a	480 a	460 a	480 a	395 a
MP	472 a	460 b	500 a	490 b	610 a	950 a	430 a	480 a	394 a
SD5	394 a	540 a	520 a	600 a	660 a	510 a	500 a	550 a	423 a

^zFirst harvest.^yLast harvest.^xCT = cuttings, MP = micropropagated plants, SD5 = thinned seedlings.^wMean values within a column followed by different letters indicate significant differences among treatments ($P < 0.05$) according to ANOVA (LSD).

Table 4. Monthly 1-week yield per tree data for cloned and seedling papaya plants at Mokuleia.

Plant type ^z	Month							
	Nov. 1999	Dec. 1999	Jan. 2000	Feb. 2000	Mar. 2000	Apr. 2000	May 2000	June 2000 ^y
	Months after transplanting							
	8	9	10	11	12	13	14	15
Plant type ^z	Harvest							
	1	2	3	4	5	6	7	8
Weight of fruit (kg)								
CT	1.92 a ^x	3.97 a	2.57 a	2.35 a	2.50 a	2.04 a	1.83 a	0.72 a
MP	1.56 a	2.99 ab	2.35 a	2.18 a	2.62 a	1.99 a	1.87 a	0.49 a
SD1	1.94 a	3.63 a	2.83 a	2.34 a	3.32 a	2.20 a	1.90 a	0.60 a
SD5	1.10 a	2.12 b	2.29 a	2.62 a	3.30 a	2.25 a	2.21 a	0.61 a
Number of fruit per tree								
CT	3.11 a	7.72 a	5.33 a	4.65 a	4.86 a	3.65 a	3.34 a	1.63 a
MP	2.44 a	6.32 ab	4.75 a	4.50 a	4.51 a	3.53 a	3.31 a	0.92 a
SD1	3.03 a	6.93 a	5.45 a	4.51 a	6.12 a	3.98 a	3.76 a	1.43 a
SD5	1.99 a	4.37 b	4.38 a	4.13 a	6.07 a	4.42 a	4.37 a	1.41 a
Mean weight per fruit (g)								
CT	616 a	515 a	482 a	506 a	514 a	553 a	547 a	439 a
MP	639 a	473 a	497 a	484 a	580 a	564 a	564 a	528 a
SD1	642 a	524 a	519 a	518 a	543 a	558 a	504 a	417 a
SD5	550 a	484 a	523 a	634 a	543 a	508 a	505 a	436 a

^zLast harvest.^yCT = cuttings, MP = micropropagated plants, SD1 = single hermaphrodite seedlings, SD5 = thinned seedlings.^xMean values within a column followed by different letters indicate significant differences among treatments ($P < 0.05$) according to ANOVA (LSD).

Table 5. Estimates of cumulative annual yields per tree and yields per hectare for cloned and seedling papaya plants at three locations; S = small plants, L = large plants.

Treatment ^z	Yield (kg/tree/year)			Yield (kg·ha ⁻¹ ·year ⁻¹)		
	Keaau	Helemano	Mokuleia	Keaau	Helemano	Mokuleia
CT	70.62 a ^y	133.38 a	107.34 a	116,523 a	220,077 a	177,111 a
MP	71.65 a (S)	157.50 a	96.30 a	118,223 a (S)	259,875 a	158,895 a
	66.71 a (L)			110,072 a (L)		
SD1	51.03 a	ND ^x	111.95 a	84,200 a	ND	184,724 a
SD5	53.68 a	123.18 a	98.94 a	88,572 a	203,247 a	163,251 a

^zCT = cuttings, MP = micropropagated plants, SD1 = single seedlings, SD5 = thinned seedlings.^yMean values within a column followed by different letters indicate significant differences among treatments ($P < 0.05$) according to ANOVA (LSD).^xND = no data taken.

about 90% of the MPs were derived from in vitro-germinated seedlings.

Seeds are relatively inexpensive compared to in vitro-micropropagated plants and rooted cuttings. Seeds for 1 ha cost \$580 (Hawaii Papaya Industry Association, 2004) while 4 ha of micropropagated 'Rainbow' were sold to growers for \$2250/ha (M. Fitch, personal observation). Rooted cuttings especially from

field-grown stock plants are limited in their potential for mass propagation because of poor survival and rooting percentage, greenhouse space, labor, and stock maintenance. The high cost of production for micropropagation limits adoption of the technology for the Hawaiian industry. If costs can be lowered and offset by gains in yield and savings in planting, thinning, and maintenance, a clonally propagated plant

cropping system could be adopted. Micropropagated plants maintained in the greenhouse for >2 months form tall stems that are readily rooted as two to four 10-cm cuttings per plant (T. Leong, personal communication), at least tripling the number of rooted hermaphrodites in about 4 to 6 weeks. A protocol combining micropropagation and rooted cuttings could be cost effective.

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