academicJournals

Vol. 9(32), pp. 2520-2527, 7 August, 2014
DOI: 10.5897/AJAR2013.8727
Article Number: 868FD9346498
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Phenology, biomass and yield of cowpea in terms of climate and trellis type

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Received 30 March, 2014; Accepted 26 June, 2014

Cowpea (*Vigna unguiculata* (L.) Walp) is a considerable protein, carbohydrates, vitamins, minerals and fiber source. Indeterminate habit cultivars require trellis to achieve higher development. This practice increases production cost. Alternatively, crops like maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.) can be used to reduce expenses and provide physical support. Growth and yield of cowpea was evaluated using conventional and live trellis, under summer rain conditions in 2012. Experiments were setup in warm (Cocula, Guerrero, México) and temperate climate (Montecillo, Edo. Méx.). One indeterminate growth variety of cowpea was used to measure yield and total biomass. Additionally, harvest index, water use efficiency and profitability for each trellis setup (conventional (CC), maize (CM) and sunflower (CS)). Maximum and minimum temperatures, rain quantity and evaporation were recorded. Warm climate grown cowpea had higher water use efficiency, which translated into higher grain yield (68 g m^{-2}) and total biomass (253 g m^{-2}). Cowpea grown with maize trellis had higher yield by 13% compared to the one grown with sunflower. Net income was higher with maize trellis, followed by sunflower and conventional trellises. Live trellis is an alternative for cowpea production.

Key words: *Vigna unguiculata*, conventional trellis, economic analysis, live trellis.

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) has high social and economic values, as well cultural, nutritional and medicinal importance. Moreover, it is an important source of protein, carbohydrates, vitamins and minerals. Its high fiber content permits its use in obesity control treatments; obesity is a major problem of the Mexican population (Valencia and Román, 2004).

Vigna grain world production for 2008 is estimated around 4.5 million tons (FAOSTAT, 2012). Producing states in Mexico are Tamaulipas, Baja California Sur, Northern Sinaloa and Southern Sonora. Most of the production comes from traditional cropping systems, and it is destined for self-consumption (Murillo et al., 2000). The State of Mexico does not report cowpea sowing. It is sowed in the Tierra Caliente and Northern regions of the state of Guerrero. Cowpea cropping surface has decreased

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due to the high investment for trellis, and trellises are required for physical support of the plant.

Cowpea sowing with conventional trellis, wooden sticks, increases production costs by up to 30%. This practice causes ecological damage due to woody species deforestation (Angulo and Obando, 1994). Farmers, thus resort to using an associated species to act as live trellis.

In Mexico, 30% of common bean production (*Phaseolus vulgaris* L.) is associated, mainly to maize, in small plots. Under this system, maize becomes a live trellis, and labor provided by the owner's family is important to keep up with the crop requirements (Francis, 1986). Yield under association decreases, yet total associated production increases when compared to one crop. Interspecific competition occurs between the crop and the trellis (Kruk and Satorre, 2003). In binary crop systems resource availability plays an important role in crop behavior. Resources not used by one species could be used by the other; this complementation explains the advantages derived of this cropping system (Morales et al., 2006).

Maize and sunflower, because of their particular morphology (tall and erect), can serve as cowpea support while providing potential benefits like erosion control and soil organic matter structure and content improvement. The Mexican population bases its diet on maize, particularly among popular classes. Per capita consumption is 127 kg year^{-1}, and it provides 70% daily caloric and 50% daily protein intakes (Guerra and Osorio, 2002). Sunflower is economically important in the world. Its main product is seed (botanically, it is the fruit) oil for human consumption, chemical industry and chicken feed.

Muleba and Mwanke (1991) mention that cowpea adapts easily to diverse agricultural and climatic conditions; however, most studies in Mexico and other parts of the world have been carried out under warm weather conditions; temperate climate studies are scarce. Thus, this study determines the influence of trellis type and climate conditions over phenology, biomass, yield and cowpea components; and evaluates the profitability of this agricultural system in warm and temperate climates.

MATERIALS AND METHODS

The experiment was set up in the Summer of 2012 under seasonal rain conditions in Cocula, Guerrero, México (18° 19´ N, 99° 39´ O and 640 m), under a warm climate (Aw_0) with Summer rains in a clay-like texture soil, with pH 7.1, electric conductivity of 0.23 dS m^{-1} and organic matter of 1.7%; and at Colegio de Postgraduados in Montecillo, Edo. De Méx., Mexico (19° 29´ N; 98° 54´ O and 2250 m), under temperate climate (Cw_1), with Summer rains (García, 2005) in a clay-like texture soil, with pH 8.0, electric conductive of 0.7 dS m^{-1} and organic matter of 0.9%.

In each location, indeterminate growth habit cowpea was sowed with three trellis systems, conventional (wooden posts and plastic mesh, CC), H-516 maize (warm climate) and H-34 maize (temperate climate) (CM); and sunflower cv. "Victoria" (CS). Sowing happened on June 8th in the warm climate and on June 15th in the temperate climate. Sowing density was 6.2 plants m^{-2} (40 × 80 cm). For each climate, experiments were designed into completely random blocks with four repetitions. The experimental unit was 5.0 by 2.4 m.

The crop was fertilized with 100-100-100 kg ha^{-1} of nitrogen (N), phosphorus (P) and potassium (K), by applying all the P, K and half of N 15 days after sowing (DAS) and the remaining N 45 DAS.

During the experiment, maximum temperature (Tmax, °C), minimum temperature (Tmin, °C), evaporation (Ev., mm) and daily precipitation (PP, mm) were recorded. Phenological stages were also recorded for cowpea: days to emergence (E), days to anthesis (R6) and days to physiological maturity (R9) (Escalante and Kohashi, 1993). For each phenological stage, heat unit accumulation for the crop (HU, °C) was registered by the residual method. The following equation describes this method:

$$HU = \frac{Tmax + Tmin}{2} - TB$$

Where, Tmax = maximum daily temperature (°C), Tmin = minimum daily temperature (°C) and TB = base temperature of 10°C for cowpea (Barrios and López, 2009). Crop evapotranspiration (ETc, mm) was calculated from evaporation from tank type "A", using 0.75 (Ke) as evapometer coefficient, and Kc values based on crop development percentage, using the following equation (Allen et al., 2006).

$$ETc = Ev \times Ke \times Kc$$

At harvest, based on the criteria proposed by Escalante and Kohashi (1993), total aerial biomass (dry matter TB, g m^{-2}), harvest index (HI = GY / TB, %), grain yield (GY, grain weight at 10% humidity, g m^{-2}), normal grain number per m^2 (GN), hundred grains weight (100GW), normal pod number per m^2 (PN), grains per pod (GP). Water use efficiency (WUE) for total biomass and grain yield (g m^{-2} mm^{-1}) were calculated using the equation:

WUE = TB or GY / ETc (Escalante, 1995).

The recorded variables were analyzed using combined ANOVA with model climate * trellis (C*E). Treatment differences were tested using Tukey at 5% probability. Additionally, a discrete economic analysis was applied to grain yield variables in cowpea, maize and sunflower to calculate greater net income, using the equation:

NI = YPy - (∑XiPi + FC)

Where NI = net income, Y = yield (kg ha^{-1}), Py = price per grain kg, ∑XiPi = sum of variable costs, FC = fixed cost (Volke, 1982).

RESULTS AND DISCUSSION

Climate elements

In warm climate, average Tmax and Tmin during crop development was 35 and 20°C respectively. Highest temperature was recorded twenty days after emergence, and it decreased as crop physiological maturity (PM) arrived. Accumulated rainfall (PP) from sowing to PM was 810 mm. Highest PP occurred between flowering and grain filling (57%). In temperate climate for the whole crop cycle, average Tmax and Tmin were 25 and 11°C respectively, and it decreased as the crop achieved PM. Total accumulated PP was 611 and 199 mm less than in

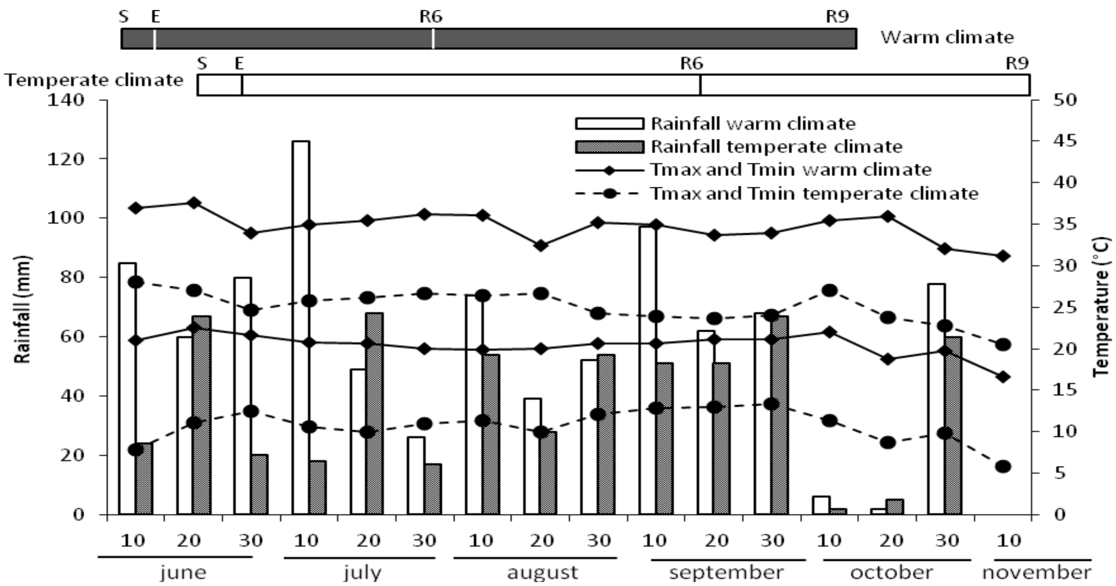

Figure 1. Rainfall distribution (ten days sum), maximum and minimum temperature (ten days average) during crop growth in warm and temperate climate. Summer, 2012. S = sowing, E = emergence, R6 = start of flowering, R9 = physiological maturity.

warm climate. Figure 1 shows that cowpea in temperate climate was exposed to water deficit for longer periods during the reproductive stage, which could have limited greater growth. These differences in climate elements were determined in growth and crop grain production.

Phenology

Growth cycle for cowpea was shorter in warm climate than in the temperate climate (125 and 150 days respectively). In warm climate, the period from sowing to emergence (E, 5 days), flowering initiation (R6, 50 days) and PM (R9, 125 days) decreased 2, 45 and 25 days respectively, with respect to temperate climate (7, 95 and 150 days at E, R6 and R9 respectively). The greater length of the crop cycle in temperate climate compared to warm climate can be attributed to lower seasonal temperatures, which were, in average, 10 and 9°C lower for Tmax and Tmin respectively (Figure 1). Ávila et al. (2006) mention that in cowpea cv. "Sesenteño" under semi-arid climate, flowering (R6) happened at 75 days and PM at 105 days. This short crop period is attributed to high temperatures during the crop growth season. González et al. (2008) evaluated common bean sowing in two seasons and found crop cycle decreased by 11 days per increases by 4°C in mean ambient temperature.

Heat units

Heat units (HU) accumulation in cowpea was similar among trellis types. However, they differed in terms of climate. In warm climate, HU for vegetative (VS), reproductive (RS) and the complete crop cycle (CC) stages was 905, 1303 and 2208°C respectively (Figure 2). In temperate climate, the cropping cycle was longer with lower accumulated HU's; VS was 788, RS was 360 and CC was 1148°C, respectively. Guanyao et al. (2006) mentioned that in Mediterranean climate, cowpea of different growth habit had HU of 1500°C for all the cropping cycle (using a 10°C base temperature). The highest accumulated HU in warm climate (with shorter cropping cycle compared to temperate climate) was determined by the highest Tmax and Tmin in the region (35 and 20°C in warm climate; 25 and 11°C in temperate climate). This suggests that as temperature increase, the cropping cycle shortens when thermal requirements are met. HU can be estimated using the equations HU = 17.47 DAS, R^2 = 0.99** and HU = 8.03 DAS, R^2 = 0.99** for warm and temperate climates respectively (Figure 2).

Crop evapotranspiration

Cowpea evapotranspiration (ETc) was similar among trellis types, but it was different in terms of climate. In warm climate, total ETc was 441 mm, and it distributed into 183 mm for VS and 258 mm for RS (Figure 2). In temperate climate, ETc was lower in the RS and CC stages (130 and 377 mm respectively), but it was higher in VS (247 mm), possibly due to VS extension. In warm climate, accumulated ETc at VS was lower by 64 mm compared to temperate climate. Meanwhile, for RS and

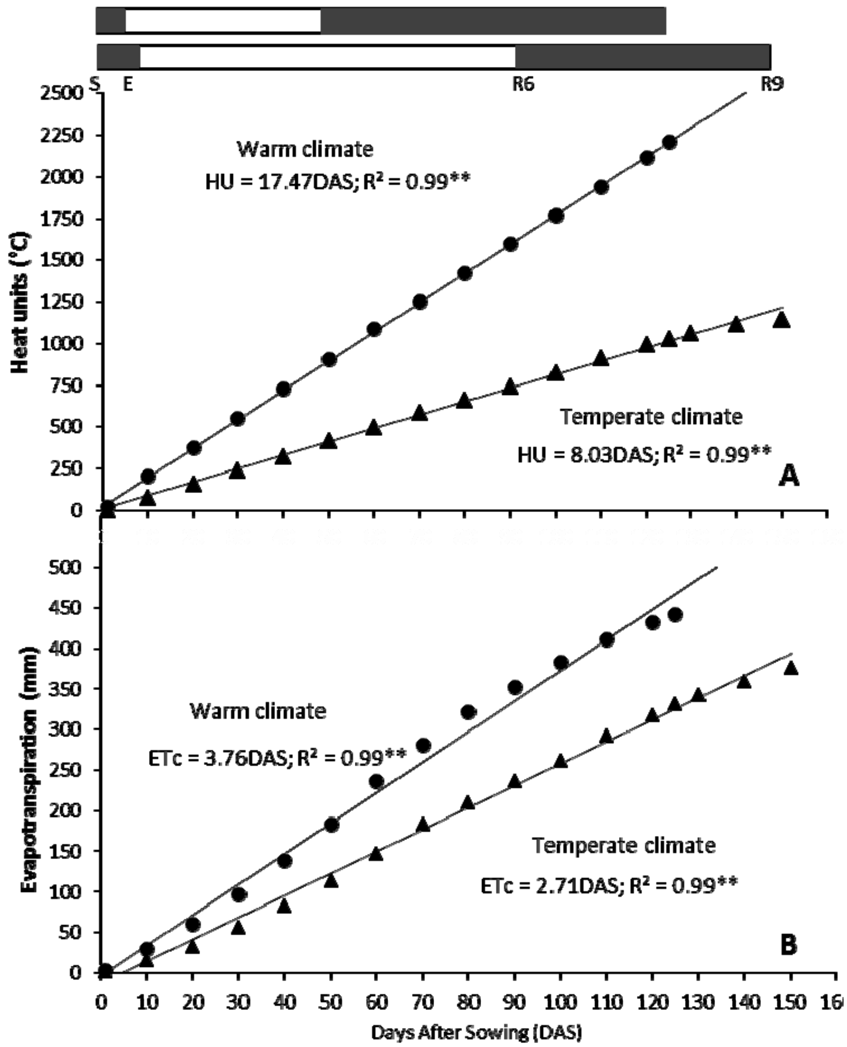

Figure 2. Heat units (A) and accumulated evapotranspiration (B) during cowpea growth in warm and temperate climates (Summer, 2012). S = sowing, E = emergence, R6 = start of flowering, R9 = physiological maturity.

CC, it was superior by 129 and 65 mm respectively. The higher ETc in warm climate during these stages could be associated to higher than usual rainfall and temperature in this region. Labarca et al. (1999) found similar ETc values (436 mm) for this species. Cowpea ETc can be estimated by the equations ETc = 3.76 DAS, R^2 = 0.99** and ETc = 2.71 DAS, R^2 = 0.99**, for warm and temperate climate, respectively. This indicates that wind evaporation demand is higher in warm climate (Figure 2).

Grain and component yields

Grain yield (GY), grain number per m^2 (GN), weight of hundred grains (100GW), pod number per m^2 (PN) and grains per pod (GP) showed significant changes due to climate effect (C). Differences were only observed in GY, GN and PN when trellis type is considered. For the interaction climate * trellis type (C * E) only GY and GN showed significant statistical differences (Table 1). In warm climate, GY, GN, 100GW, PN and GP, were superior by 98, 92, 57, 75 and 53% compared to the temperate climate results respectively. Low GY in temperate climate could be attributed to delayed flowering and short reproductive cycle, as consequences of lower temperature and lower rainfall (Galindo and Clavijo, 2009).

In terms of trellis type, higher GY, GN and PN was found at CC; it improved at CM by 51, 53 and 64% and at CS by 57, 61 and 64% respectively. Similar tendencies were found by Olowe et al. (2006) with soybean (*Glycine max* (L.) Merr) and sunflower-associated cowpea in southern Nigeria. Cowpea yields for the single crop were 93 and 39 g m^{-2} when associated to sunflower.

Table 1. Grain yield, yield components, total biomass, harvest index, water use efficiency for the grain and biomass for cowpea under warm and temperate climates and different trellis types (Summer, 2012).

Climate	Trellis type	GY (g m^{-2})	GN	100GW g	PN	GP	TB g m^{-2}	HI %	WUEG g m^{-2} mm^{-1}	WUEB g m^{-2} mm^{-1}
Warm	CC	$68^{a¶}$	329^{a}	20^{a}	19^{a}	17^{a}	253^{a}	27^{c}	0.154^{a}	0.57^{a}
	CM	34^{b}	172^{b}	21^{a}	10^{b}	17^{a}	109^{c}	31^{a}	0.085^{b}	0.27^{c}
	CS	29^{c}	139^{b}	21^{a}	8^{bc}	17^{a}	104^{d}	28^{b}	0.074^{c}	0.27^{c}
Temperate	CC	3^{d}	43^{bc}	9^{b}	8^{bc}	9^{b}	154^{b}	2^{d}	0.007^{d}	0.41^{b}
	CM	0.3^{e}	4^{d}	9^{b}	0.4^{c}	8^{b}	70f	0.5^{e}	0.001^{e}	0.20^{e}
	CS	1^{e}	5^{cd}	10^{b}	1^{c}	9^{b}	78^{e}	0.7^{e}	0.002^{e}	0.23^{d}
Climate	Warm	44^{a}	214^{a}	21^{a}	12^{a}	17^{a}	156^{a}	29^{a}	0.104^{a}	0.4^{a}
	Temperate	1^{b}	17^{b}	9^{b}	3^{b}	8^{b}	101^{b}	1^{b}	0.003^{b}	0.3^{b}
Trellis type	CC	35^{a}	186^{a}	15^{a}	14^{a}	13^{a}	204^{a}	14^{b}	0.081^{a}	0.49^{a}
	CM	17^{b}	88^{b}	15^{a}	5^{b}	12^{a}	90^{b}	16^{a}	0.043^{b}	0.24^{c}
	CS	15^{c}	72^{b}	15^{a}	5^{b}	13^{a}	91^{b}	14^{b}	0.038^{c}	0.25^{b}
Overall mean		22	115	15	8	13	128	15	0.05	0.32
Prob F (MSD)	Climate	** (1)	**(99)	** (2)	** (5)	** (2)	** (2.7)	** (0.4)	** (0.003)	** (0.006)
	Trellis	** (1)	* (71)	NS (2)	** (5)	NS (1)	** (2.3)	** (0.2)	** (0.002)	** (0.006)
	Climate*Trellis	** (2)	* (135)	NS (3)	NS (9)	NS (3)	** (4.1)	** (0.5)	** (0.004)	** (0.01)

[¶]Means with the same letter within each column are statistically equal, Tukey (α = 0.05) *'** = P ≤ 0.01 and 0.05, respectively. NS = not significant. MSD = minimum significant difference at 5% error probability. GY = grain yield (g m^{-2}), GN = grain number per m^2, 100GW = hundred grains weight (g), PN = pod number per m^2, GP = grains per pod, TB = total biomass (g m^{-2}), HI = harvest index (%), WUEG = water use efficiency for grain (g m^{-2} mm^{-1}) and WUEB = water use efficiency for biomass (g m^{-2} mm^{-1}). CC = cowpea in conventional trellis, CM = cowpea in maize trellis and CS = cowpea in sunflower trellis.

Jana et al. (2000) studied the efficiency of maize - bean association and found lower GY (25 g m^{-2}) when associated, than when sowed individually (76 g m^{-2}). This indicates there are differences in competition degrees among species used as live trellis, and those differences are related to foliage size (Apáez et al., 2011).

Analysis of the interaction climate * trellis type shows that CC in warm climate has greater GY, GN, 100GW, PN and GP, improving over the temperate climate by 96, 87, 55, 58 and 47% respectively. The CM-material sowed in warm climate followed with increments, compared to the temperate climate, of 98, 98, 57, 96 and 53% respectively. The lowest treatment was CS, which improved the values of the temperate climate by 97, 96, 52, 88 and 47% respectively (Table 1). Even though low cowpea yield in temperate climate was obtained, getting any yield under an environment not appropriate for its growth suggests varieties adapted to these environmental conditions can be generated.

Total biomass

Total biomass (TB) showed significant differences due to climate (C), trellis type and the climate* trellis (C * E) (Table 1). Highest TB was found under warm climate and the lowest under temperate climate. CC produced the highest TB, followed by CS and CM; the latter two are significantly equal.

In terms of the interaction climate* trellis, the highest TB was obtained under warm climate with CC, followed by warm climate CC. Under warm climate, CM was higher than CS. The lowest TB was found under temperate climate with CS and CM. Lower TB of cowpea with live trellis is the result of competition from the trellis for space, water, light and nutrients (Sarandón and Chamorro, 2003). Morales and Escalante (2004) point out that competition of sunflower on “Canario 107” bean caused lower dry matter production. Higher TB under warm climate suggests this is the most favorable climate for this species growth, as the greater than 25°C requirement indicates (Benacchio, 1982). Cowpea biomass estimation is important, since it is highly appreciated as fresh forage in herding and as preserved bails (Castillo et al., 2009).

Harvest index

Harvest index (HI) showed significant changes due to climate (C), trellis type (E), and the interaction climate * trellis type (C * E) (Table 1). Under warm climate, HI was greater than temperate climate. CM had the highest HI, superior by 2% to CC and CS. In the climate * trellis interaction, the highest HI was found under warm climate with CM, followed by CS and CC. Under warm climate, CC surpassed CM and CS with 1.5 and 1.3% increments respectively. HI differences between warm and temperate climates are related to differences in GY. According to Andriani et al. (1991), the highest cowpea HI found in live trellis and warm climate indicates a greater distribution of dry matter to the grain. However, Morales et al. (2006) found that bean cv. “Michoacán” HI in single cropping system and in association with sunflower was similar (22%); Vélez et al. (2007) point out an HI reduction of bean associated with maize compared to a single cropping system, which could be caused by lower photosynthate demand due to lower number of pods (Escalante and Rodríguez, 2010).

Water use efficiency

Cowpea water use efficiency for total biomass (WUEB) and grain yield (WUEG) showed significant changes for climate (C), trellis type (E) and C * E interaction (Table 1). Under warm climate, it was found that WUEG and WUEB were higher; while under temperate climate both were only 0.003 and 0.3 g m^{-2} mm^{-1} respectively. In average in both climates, CC showed the highest WUEG and WUEB, improving by 0.038 and 0.25 g m^{-2} mm^{-1} to CM and CS. De Lacerda et al. (2006) indicate that in conventional trellis with cowpea WUEG was 0.3 g m^{-2} mm^{-1} and WUEB was 0.8 g m^{-2} mm^{-1}; these values are slightly higher than those found in this study. In the C * E interaction, the highest WUEG and WUEB was found under warm climate with CC, followed by CM. For WUEB, the highest value was for the system under temperate climate with CC. The lowest efficiency was found under temperate climate with CM (Table 1). The higher value of WUE of cowpea under warm climate is due to higher water availability and more appropriate temperature conditions for its growth. Temperature for cowpea growth should be higher to 25°C (Benacchio, 1982).

Economic analysis based on trellis type

Under warm climate, CM generated higher net income (NI) ($4592) followed by CS ($3721) and CC (-$19910) (Table 2). In warm climate, production income was lower to investment. Even though corn and sunflower yield in temperate climate was higher than in warm climate, cowpea yield was much lower, causing lower net income (Table 2). Conventional trellis usage contributes to uncontrolled logging of slow-regeneration woody species to be used as guides, causing a big environmental problem. Additionally, it is not profitable due to the high cost of trellis management; using live trellis carries lower costs, aside from production from the associated species.

General considerations

Cowpea under warm climate and conventional trellis had the highest GY (68 g m^{-2}) and TB (253 g m^{-2}) compared to temperate climate (3 and 154 g m^{-2} for GY and TB respectively). The temperature and water availability conditions, due to higher rainfall, are more appropriate for cowpea development (Benacchio, 1982). Higher growth and yield in conventional trellis was due to null nutrients and solar radiation competition for growth, compared to combined cowpea-maize and cowpea-sunflower systems. However, with live trellis, two products are obtained on the same surface, reducing production costs compared to live trellis; therefore, greater profitability is obtained.

Conclusions

Cowpea yield was determined by trellis type and climate. Under warm climate, cowpea shows a shorter growth cycle and higher evapotranspiration, heat accumulation, biomass, yield and water use efficiency. Higher grain yield, biomass and water use efficiency can be achieved using CC. When using live trellis, the system cowpea-maize exceeds the cowpea-sunflower system. Greater

Table 2. Yield, total income, fixed, variable and total costs, and net income for three agricultural systems under warm and temperate climates (Summer, 2012).

Climate		Grain yield (kg ha^{-1})	Total income	Fixed cost	variable cost	Total cost	Net income
			$MXN				
Warm	CC	682[z]	13,633	3,158	30,385	33,543	-19,910
	CM	339[z]	6,771	1,579	600	2,179	4,592
	CS	289[z]	5,780	1,579	480	2,059	3,721
Temperate	CC	26[z]	520	3,158	30,385	33,543	-33,023
	CM	3.4[z]	68	1,579	120	1,699	-1,631
	CS	5.8[z]	116	1,579	120	1,699	-1,583
Warm	CM	3,435[y]	22,563	3,158	1,560	4,718	17,845
	CS	1,398[y]	11,801	3,158	1,200	4,358	7,443
Temperate	CM	3,438[y]	17,587	3,158	1,560	4,718	12,869
	CS	2,071[y]	11,328	3,158	1,440	4,598	6,730

[z] = grain yield only cowpea, [y] = grain yield cowpea + trellis type. Total income = grain yield * cowpea grain prices ($ 20.00 per kilogram), maize grain ($ 5.10 per kilogram) and sunflower grain ($ 5.43 per kilogram). Fixed cost = includes cost of land preparation, weeding, pest and disease control and fertilization. Variable costs = include the cost of the mesh, poles, accommodation guide, cowpea harvest, maize and sunflower. Total cost = fixed cost + variable cost. Net income = total income - total cost. CC = cowpea in conventional trellis, CM = cowpea in maize trellis and CS = cowpea in sunflower trellis.

profitability can be achieved with CM, followed by CS. Lower net income is obtained with CC.

Conflict of Interest

The author(s) have not declared any conflict of interest.

ACKNOWLEDGMENTS

The authors are grateful to Consejo Nacional de Ciencia y Tecnología (CONACyT) because of the granted support for the realization of this research, Registre No. 222753 (2008).

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