Yield Performance of Cowpea Plant Introductions Grown in Calcareous Soils

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SUMMARY. Cowpea or southernpea (*Vigna unguiculata*) is an important legume crop used as a feed for livestock, as a green vegetable and for consumption of its dry beans, which provide 22% to 25% protein. The crop is very sensitive to alkaline soil conditions. When grown at a soil pH of 7.5 or higher, cowpea develops severe leaf chlorosis caused by deficiencies of iron, zinc, and manganese resulting in stunted plant growth and yield reduction. We evaluated in replicated field experiments at St. Croix, U.S. Virgin Islands, and Miami, FL, four PIs and one commercial cultivar, some of which have shown some tolerance to alkaline soils in unreplicated, seed regeneration plots of the U.S. cowpea collection. At both locations, PI 582702 had significantly higher seed protein concentration than the other PIs, averaging 28%. Alkaline soil conditions at St. Croix were severe resulting in average yield of PIs at this location being significantly lower and 69% less than that in Florida. Nevertheless, some PIs performed well at both locations. For example, PI 582605 had significantly higher yield in Florida, whereas in St. Croix, PIs 582605, 582674, and 582702 were the highest yielders. These PIs may serve as an alternative to growers or home gardeners wishing to establish a legume crop in areas where agricultural production is severely restricted by high soil alkalinity.

Cowpea is an important grain legume crop used as a feed for livestock and as a green vegetable, and its dry beans provide 22% to 25% protein (Goenaga et al., 2008; Murillo-Amador et al., 2006). Because of its versatility, high nutrition, and self-pollinating nature, cowpea has been advocated as a candidate crop for space agriculture (Nelson et al., 2008). World production of cowpea was 5.63 million tons in 2010 with 95% of total production originating in African nations (Food and Agriculture Organization of the United Nations, 2012).

Calcareous soils, where cowpea is often grown, cover more than 30% of the earth's soil surface (George et al., 2012). When grown at pH >7.5, cowpea develops severe leaf chlorosis

caused by deficiencies of iron (Fe), zinc (Zn), and often manganese (Mn). To our knowledge, there are no commercial cowpea cultivars possessing alkaline soil tolerance, but evidence of genotypic differences has been observed (R. Goenaga, unpublished data). For over 10 years, seeds of photoperiod-sensitive accessions in the U.S. Department of Agriculture (USDA) cowpea collection has been regenerated at the USDA-Agricultural Research Service (ARS) facilities in St. Croix, U.S. Virgin Islands (Gillaspie et al., 1999), in part because incidence of pests and diseases of cowpea at this site are minimal because of the absence of large plantings of this or related crops. Genetic diversity for tolerance to alkaline soil conditions, such as those encountered at St. Croix, has been observed

by the authors during these regeneration cycles in field plots with pH >8.0. Tolerance is defined in this study as the ability of a PI to produce a good crop (seed yield over 1000 kg·ha⁻¹) when field grown at a pH >7.5.

The present study was conducted with the objective of determining yield potential of selected cowpea PIs that have shown alkaline soil tolerance in unreplicated seed regeneration plots as an effort to identify PIs that could be used in areas where agricultural production may be limited by high soil alkalinity of calcareous soils.

Materials and methods

This study was conducted at the USDA-ARS, Germplasm Introduction and Research Unit in St. Croix, U.S. Virgin Islands (coarse-loamy, carbonatic, isohyperthermic Typic Calciustolls) and at the USDA-ARS, Subtropical Horticulture Research Station, Miami, FL (Loamy-skeletal, carbonatic, hyperthermic Lithic Udorthents). Soil and climatic characteristics at each site are described in Tables 1 and 2.

Field experiments in St. Croix were established on 11 Sept. 2008 and 2 July 2009 and in Miami on 9 Sept. 2008 and 2 July 2009. The phenotypic descriptors and origin of the PIs in the experiment are described in Table 3. These PIs had shown some tolerance to alkaline soils in unreplicated, seed regeneration plots of the U.S. cowpea germplasm collection. The tropically adapted commercial cultivar Coronet was used as a commercial control. The experiments were planted in a randomized complete block design with five replications. Because of the prostrate growth habit of some PIs, experimental plots consisted of four, 20-ft rows spaced 3.0 ft apart. Seedlings were thinned to an

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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
1	cbar	kPa	1
29.5735	fl oz	mL	0.0338
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
1000	mmho/cm	μS·cm ⁻¹	0.0010
28.3495	oz	g	0.0353
1	ppm	mg·kg ⁻¹	1
0.9072	ton(s)	ton(s)	1.1023
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Table 1. Average preplant soil characteristics at Miami, FL, and St. Croix, U.S. Virgin Islands, measured to a depth of 20 cm (7.9 inches) at the experimental sites.

Soil characteristic ^z	St. Croix		Florida
	2008	2009	2008–09 ^y
pH in water	8.2	8.1	8.3
pH in calcium chloride	7.6	7.6	7.6
Electrical conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$)	124.2	141.0	110.6
Ammonium nitrogen ($\text{mg}\cdot\text{kg}^{-1}$)	140	104	147
Nitrate nitrogen ($\text{mg}\cdot\text{kg}^{-1}$)	60	143	64
Organic carbon (%)	1.35	1.40	0.95
Phosphorus ($\text{mg}\cdot\text{kg}^{-1}$)	39	59	79
Potassium ($\text{mg}\cdot\text{kg}^{-1}$)	318	743	634
Calcium ($\text{mg}\cdot\text{kg}^{-1}$)	4256	3407	1432
Magnesium ($\text{mg}\cdot\text{kg}^{-1}$)	206	215	20
Bicarbonate (mM)	4.2	2.9	4.0
Iron ($\text{mg}\cdot\text{kg}^{-1}$)	ND ^x	ND	ND
Manganese ($\text{mg}\cdot\text{kg}^{-1}$)	0.7	2.4	1.3
Zinc ($\text{mg}\cdot\text{kg}^{-1}$)	ND	ND	0.6

^z1 $\text{mg}\cdot\text{kg}^{-1}$ = 1 ppm, 1 $\mu\text{S}\cdot\text{cm}^{-1}$ = 0.0010 mmho/cm.^yThe same plot was used in Florida in 2008 and 2009.^xND = not determined.**Table 2.** Total rainfall and average daily maximum and minimum temperatures in Miami, FL, and in St. Croix, U.S. Virgin Islands, during the growth experimental period.

Site characteristic ^z	Location			
	Florida		St. Croix	
	2008	2009	2008	2009
Rainfall (mm)	39.7	59.7	46.6	20.9
Maximum temperature ($^{\circ}\text{C}$)	28.4	32.8	29.9	32.1
Minimum temperature ($^{\circ}\text{C}$)	21.1	25.6	23.4	25.8

inrow spacing of 15 cm. Fertilization was provided one month after planting, using a 12N–5.2P–10K fertilizer at a rate of 422 $\text{kg}\cdot\text{ha}^{-1}$. Plants were drip irrigated at both locations when the soil water tension at a depth of 30 cm exceeded ≈ 15 kPa. Midbloom and maturity were determined as the number of days after planting at which 50% of plants flowered and the first dry pod appeared, respectively. Pods were harvested by hand as they matured, dried at 38 $^{\circ}\text{C}$, 25% relative humidity, and shelled. Seed yield was then determined by extrapolating total plot seed weight to a per area basis. Plant height was measured with a ruler at midrow. Pod length was determined by averaging the length of 10 mature pods from each of five plants selected randomly from each plot. Random 100-seed samples from each replication were weighed to determine seed weight for each PI. Seed nitrogen (N) was determined using the micro-Kjeldahl

procedure and multiplied by the factor 6.25 to obtain percent seed protein (Association of Official Analytical Chemists, 2000).

Soil from each block was sampled ≈ 3 weeks before planting by taking four borings at a depth of 0 to 20 cm from each of the projected cultivar rows. Samples were air-dried and passed through a 20-mesh screen. Soil pH in water and 0.01 M calcium chloride (1 soil:2 water) were measured with a glass electrode. Exchangeable cations [potassium (K), magnesium (Mg), calcium (Ca), manganese (Mn)] were extracted with neutral 1 N ammonium acetate and determined by atomic absorption spectroscopy (Sumner and Miller, 2007). Phosphorus (P) was extracted with pH 8.5 sodium bicarbonate and determined using the ascorbic acid method (Nelson and Sommers, 2007). Organic carbon (C) was determined by the Walkley–Black method

(Nelson and Sommers, 2007). Soil electrical conductivity was determined with a conductivity meter (Orion 3-Star; Thermo Scientific, Fort Collins, CO) using 20 g of soil in 40-mL distilled water. Soil ammonium and nitrate were determined by steam distillation (Mulaney, 2007). Bicarbonate was determined in a saturated soil paste by titrating with 0.05 N sulfuric acid standardized with 0.01% methyl orange indicator (USDA, 1996).

Analysis of variance was carried out using the GLM procedure of SAS (release 9.1 for Windows; SAS Institute, Cary, NC). After significant F tests at $P \leq 0.05$, means separation was performed using the Tukey's Studentized range test.

Results and discussion

Location and PIs showed significant effects ($P \leq 0.05$) on most crop parameters were measured in the study. The PI $\times$ location interaction was significant for yield, 100-seed weight, seed protein, days to mid-bloom and maturity, plant height, and pod length (Table 4).

Average yield of PIs at St. Croix was significantly lower than at Florida (Table 4). A combination of soil factors may explain the cause of this average yield reduction at St. Croix. These include P fertilization of plants concomitant with nondetectable levels of soil Zn and Fe at the experimental site. Legumes are reported to have a high P requirement for root and plant growth and to initiate nodule formation (Ojo et al., 2007; Oseni, 2009); however, studies have shown that when both P and Zn are limiting in soil, P fertilizer application as done in this experiment can promote plant growth and cause dilution in tissue Zn, which may further complicate Zn deficiency (Goh et al., 1995; Oseni, 2009). Iron deficiency or lime-induced chlorosis brought about by high levels of calcium and magnesium carbonates in the soil most probably was also a factor in causing lower cowpea yield at St. Croix than at Florida (Fig. 1; Tables 1 and 4). Carbonates are regarded as a major causal factor for Fe and Zn deficiency in many crop species grown in calcareous soils (Cartmill et al., 2007; De la Guardia and Alcántara, 2002; Mengel et al., 1984; Nikolic and Römhild, 1999; Valdez-Aguilar and Reed, 2010; Yang et al., 1994). Indeed, very severe leaf chlorosis was

Table 3. Plant and grain descriptors and origins of four cowpea PIs (PI) and one cultivar grown at two locations: Miami, FL, and St. Croix, U.S. Virgin Islands.

PI or cultivar	Flower color	Leaf shape	Plant habit	Dry pod color	Pod placement	Pod position	Plant and grain descriptors ^a					Seed texture	Seed size	Seed shape	Seed pattern	Seed color	Seed coat color	Post per peduncle (no.)	Origin
							Seed	coat	color	color	color								
PI 582471	W	SH	P	S	AF	P		W	B	E	N	L						1	Botswana
PI 582605	L	H	P	S	FL	P		R	R	S	C	M						2	Kenya
PI 582674	L	SH	E	S	FL	P		T	B	E	N	L						2	Botswana
PI 582702	L	SH	E	S	AF	P		R	R	S	N	M						1	Botswana
'Coronet'	W	SH	E	P	FL	P		W	P	E	N	L						2	United States

^aFlower color (L = lavender, W = white); leaf shape (H = hastate, SH = subhastate); plant habit (E = erect, P = prostrate); dry pod color (S = straw, P = purple); pod placement (AF = above foliage, FL foliage level); pod position (P = pendant); seedcoat color (R = red, T = tan, W = white/cream); seed pattern color (B = brown, P = purple, R = red); seed pattern (E = eye, S = solid); seed shape [C = crowder (seed flat on both ends), N = noncrowder (seed rounded on both ends)]; seed size (L = large, M = medium); seed texture (R = rough, S = smooth).

observed in plants grown at St. Croix particularly on cultivar Coronet and PI 582471 (Fig. 1). Seeds of these PIs germinated but plants grew poorly afterward and eventually died or became stunted without producing pods. Leaf chlorosis was also evident in Florida but symptoms were not as severe as in St. Croix.

PI 582605 had significantly higher yield than all other PIs in Florida (1420 kg·ha⁻¹) but it did not differ significantly with the yield obtained by PIs 582674 and 582702 in St. Croix averaging 366 kg·ha⁻¹. Although these yields are not high (<1500 kg·ha⁻¹), they are acceptable considering the high soil pH, along with other adverse soil characteristics (Table 1) in which these PIs were grown. These yields are also higher than those obtained by commercial cultivar Coronet and by those obtained by 26 PIs grown at St. Croix in a previous study (Goenaga et al., 2010). Cultivar Coronet and PI 582471 showed very low adaptability to alkaline soil conditions at both locations yielding significantly lower than other PIs (Table 4). In a multisite experiment seeking to identify suitable seed regeneration sites for cowpea germplasm, it was found that mean seed production at St. Croix was 40 times less than at Isabela, PR. This difference was attributed to a very high soil pH, which limited plant growth at St. Croix (Gillaspie et al., 1999).

As an important staple in many developing areas of the world, particularly the semiarid tropics where alkaline soils are common, it is important to identify not only high-yielding cowpea PIs but also those having high seed protein content. There was a significant year effect for seed protein concentration with higher average seed protein obtained in year 2 (25.3%) than in year 1 (23.3%) (data not shown). Being cowpea a heat adapted legume, it is possible that the higher temperatures and longer daylength encountered in year 2 (Table 2) because of earlier planting may have resulted in higher photosynthetic efficiency than in year 1, thus resulting in higher protein concentration. However, a similar response was not observed for yield. At both locations, PI 582702 had significantly higher seed protein concentration, averaging 28% (Table 4).

This value is higher than that obtained for 32 cowpea PIs studied by the authors since 2008 and which had an average seed protein concentration of 24% (Goenaga et al., 2008, 2010, 2011). Thus, this PI may serve as a source of dietary protein particularly in the vegetarian diets of developing countries (Burstin et al., 2011).

Seed weight is an important characteristic because along with seed color it determines grain quality for commercialization (Da Conceição-Lopes et al., 2003). The existing variation for seed weight in cowpea ranges from less than 10 g per 100 seeds to almost 30 g (Ehlers and Hall, 1997). Seed weight varied significantly among PIs and locations (Table 4). At Florida, cultivar Coronet had the highest 100-seed weight, whereas at St. Croix, this cultivar had the lowest 100-seed weight because of poor growth at this location resulting from adverse soil characteristics. PIs 582674 and 582605 had significantly higher 100-seed weight at St. Croix, averaging 13.2 g.

Midbloom mean for all PIs was 48.6 d at St. Croix and 45.2 d at Florida (Table 4). At St. Croix, cultivar Coronet and accessions PI 582605 and 582471 took significantly longer to attain midbloom. In Florida, accession PI 582471 took significantly longer to reach midbloom and maturity. PI 582702 attained midbloom and maturity sooner than the other PIs at both locations (Table 4). At St. Croix, the accessions PI 582605, 582674, and 582702 were significantly taller than the other PIs averaging 36.3 cm in height, whereas in Florida, the accession PI 582605 was significantly taller (19.3 cm) than the rest. Plants were smaller and took longer to reach maturity at Miami probably as a response to photoperiod and cooler temperatures. Average pod length of PIs was significantly higher at Miami than at St. Croix.

In conclusion, PIs 582605 and 582674 performed relatively well despite the harsh soil environment encountered at both locations. These PIs could be used by growers or home gardeners wishing to establish a legume crop such as cowpea in areas where agricultural production may be severely restricted by high soil alkalinity of calcareous soils.

Table 4. Average yield, weight of 100 seeds, seed protein, midbloom, maturity, plant height, and pod length of 26 cowpea PIs and one cultivar in field experiments conducted at Miami, FL (FL), and at St. Croix, U.S. Virgin Islands, (SC) in 2008 and 2009.

	Yield (kg·ha ⁻¹) ^z		100-seed wt (g) ^z		Seed protein (%)		Midbloom (d)		Maturity (d)		Plant ht (cm) ^z		Pod length (cm)	
	FL	SC	FL	SC	FL	SC	FL	SC	FL	SC	FL	SC	FL	SC
PI 582471	388.8	132.3	13.8	7.2	24.9	23.2	59.3	49	97.9	92	11.9	15.6	16.4	7.8
PI 582605	1420.4	429.1	11	12.4	24.3	24	49	51.4	89.2	106.7	19.3	37.6	18.2	16.8
PI 582674	1012.7	435.1	12.3	14.1	21	20.8	39.2	46.8	74.9	104.6	15	35.8	17.3	14.5
PI 582702	746.8	234.7	8.8	9.6	28.1	27.9	34.4	44.4	73.5	104.6	13.2	35.5	20.1	18.4
‘Coronet’	319.7	26.3	15.4	1.7	23.3	22.8	44	51.5	84.1	92.5	14.5	5.2	16.8	1.5
Average	806.4	251.5	12.3	2.3	24.5	23.7	45.2	48.6	83.9	100.1	14.8	25.9	17.8	11.8
HSD (0.05) ^y	297.3	206.9	0.6	3.3	1.4	3.3	1.5	4.3	2.1	2.3	2.3	6.4	1.4	2.8
Yr ^x	NS	NS	NS	**	*	*	***	NS	**	***	NS	NS	NS	*
PI	***	***	***	***	***	***	***	***	***	***	***	***	***	***
PI × Y	***	NS	NS	***	**	NS	***	NS	***	**	***	***	NS	***
Location (L)	***		***		NS		**		***		***		***	
L × PI	***		***		***		***		***		***		***	

^z1 kg·ha⁻¹ = 0.8922 lb/acre, 1 g = 0.0353 oz, 1 cm = 0.3937 inch.

^yTukey’s Studentized range test at $P = 0.05$.

^xNS, ***, **, * Nonsignificant or significant at $P \leq 0.001$, 0.01, or 0.05, respectively.

Fig. 1. Field growth of cowpea PIs planted in two alkaline soils in St. Croix, U.S. Virgin Islands, and in Miami, FL.

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