Australian Journal of Crop Science
AJCS
AJCS 4(2):74-80(2010) ISSN:1835-2707

Selection efficiency in *Musa* L. under different cropping systems

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Abstract

An experiment was carried out at the High Rainfall Station of the International Institute of Tropical Agriculture (IITA) at Onne (4°43'N, 7°01'E, 10 masl), in southeastern Nigeria. The objectives of the study were (a) to assess the combining ability of *Musa* genotypes under alley and monocropping systems, (b) to estimate heritability of some quantitative traits of *Musa* species, and (c) to determine selection efficiency in each cropping system. The experimental population included about 560 progenies derived from crosses between tetraploid and diploid *Musa* hybrids. These were field established under alley and monocropping systems and evaluated for two consecutive cycles. Results indicated significant main effects of cropping system for days to flowering and plant height. The two-way interactions between cropping system x clone and crop cycle x clone was not significant. Ratio of GCA to SCA indicated the preponderance of additive gene effects in determining the inheritance of all traits under alley cropping, and days to flowering and bunch weight in the monocropping system. In a combined cropping system analysis, all the traits studied were highly heritable ($H^2 > 0.85$). Furthermore, selection based on bunch weight of 10 kg or above identified 25 individuals under alley cropping, in contrast to 8 individuals under mono cropping. Three individuals were selected in both systems, giving an efficiency of 2.2 % and 35.6 % under alley and monocropping systems, respectively. Therefore, selection under the monocropping system would likely produce genotypes suitable for cultivation under alley cropping than the reverse option.

Key words: *Musa* spp., alley and monocropping systems, environmental variability, heritability, combing ability, Selection efficiency

Introduction

Plantains and bananas (*Musa* spp.) are perennially cultivated in compound gardens or backyard soils, which are rich in organic matter and nutrients from the household refuse, either as pure stands or mixed with other crops in small fields. These gardens can be permanently cultivated for several decades with plants growing vigorously, giving an annual yield of about 30-50 tones per hectare (Nweke *et al*. 1988). Compound gardens cannot however, be readily extended, hence large-scale production will only be achieved through cultivation in field plantations under monoculture regimes. In this case, obstacles to increasing production include rapid yield decline after 1–2 years due to loss of soil organic matter and reduction in soil fertility (Ayodele 1986). This is aggravated by the fact that subsistence of agriculture in tropical Africa is characterized by production in marginal areas with great environmental variability. It is further compounded by farmers' lack of technological and economic resources to modify their environments to fit the needs of the crops. An improved system for large-scale production of plantains and bananas through alley cropping, which is dependent on managing the soil in a way that fertility is maintained, is advocated (Owoeye, 1996). Alley cropping is an agroforestry technology, which involves the cultivation of food crops between hedgerows of multipurpose trees or shrubs. It incorporates the desirable features of bush fallow into a continuously productive farming system. Crop yield is improved through enhanced nutrient recycling; organic residues from hedgerow pruning (Owoeye, 1996), and increased nitrogen availability through biological N fixation (Kang *et al*. 1984). The mulch also suppresses weeds, protects the soil during intense rainfall and conserves soil moisture during the drier periods. Perennial production of plantains can therefore be achieved in forest fields, when

Table 1. Pedigree details of five tetraploid (4x) and five diploid (2x) *Musa* lines used to develop 4x–2x families.

Breeding Number[a]	Pedigree[b]
Females (4x)	
TMPx1658-4	'Obino l'Ewai' x 'Pisang Lilin'
TMPx2796-5	'Bobby Tannap' x 'Pisang Lilin'
TMPx4698-1	'Obino l'Ewai' x 'Calcutta 4'
TMPx6930-1	'Obino l'Ewai' x 'Calcutta 4'
TMPx7002-1	'Obino l'Ewai' x 'Calcutta 4'
Males (2x)	
TMP2x1297-3	'Agbagba French reversion' x 'Calcutta 4'
TMP2x2829-62	'Bobby Tannap' x 'Calcutta 4'
TMP2x4400-8	'Bobby Tannap' x 'Calcutta 4'
TMB2x1448-1	'Obino l'Ewai' x 'Calcutta 4'
TMB2x4600-12	'Obino l'Ewai' x 'Calcutta 4'

[a] Serial cross number with prefix TMP or TMB stands for "Tropical *Musa* Plantain' (plantain-derived hybrid) or 'Tropical *Musa* Banana' (banana-derived hybrid).

[b] The accessions 'Bobby Tannap' and 'French reversion' are triploid AAB plantains that are susceptible to black Sigatoka; 'Calcutta' and 'Pisang Lilin' are diploid *Musa acuminata* (AA) accessions from south-east Asia that are resistant.

cultivation is done between rows of a multiple-species complex. Alley cropping system may be adopted as an alternative to large-scale production of plantain and banana *(Musa spp)* under monoculture regimes. The *Musa* breeder is, however, faced with the challenge of selecting varieties that will give satisfactory yield, and will not display substantial trait variations over cropping systems. Regardless of the cropping system adopted, selection of individual plants or families is made to increase genetic gain within and across generations. One of the most widely used methods of selection is truncation selection, which involves either choosing the uppermost fraction of the population or choosing individuals that exceed a given threshold value (the truncation point) as parents for the next generation (Baker, 1986). The selection process is greatly influenced by the specific growing conditions of a crop as phenotype produced by genotype is environment dependent (Baker, 1986; Hallauer and Miranda, 1988). *Musa* breeders are, therefore, faced with the challenge of selecting elite varieties which will give satisfactory yield in both alley and monocropping system. Ideally, such varieties should not display substantial trait variations over cropping systems. Another major task would be to clarify the proportion of selected hybrids under alley cropping that would also fit monocropping, and vice versa. The objectives of the study were (a) to assess the combining ability of *Musa* genotypes under alley and monocropping systems, (b) to estimate heritability of some quantitative traits of *Musa* species, and (c) to determine selection efficiency in each cropping system.

Materials and methods

Experimental site and genetic materials

This study was carried out at the High Rainfall Station of the International Institute of Tropical Agriculture at Onne (4°43'N, 7°01'E, 10 meters above sea level), in southeastern Nigeria. The soil at the Station is representtative of highly leached acid ultisol derived from coastal sediments and has been classified as a loamy and siliceous iso-hyperthermic Typic Paleudult (Hullugale *et al*., 1990). The soil according to Ortiz *et al* (1997) has good physical properties but is chemically poor, with nutrient deficiencies and soil acidity (pH 4.3 in 1:1 H_2O; upper 15 cm). Onne station is a representative of the humid rainforest ecosystem with characteristically high rainfall. The rainfall pattern is monomodal, distributed over a 10-month period from February to December, with an annual average of 2400 mm (Ortiz *et al.,* 1997).
The experimental population was made up of about 560 progenies derived from crosses between five selected tetraploid (TMPx1658-4, TMPx 2796-5, TMPx4698-1, TMPx 6930-1, TMPx 7002-1) and five diploid (TMP2x1297-3, TMP2x1448-1, TMP2x2829-62, TMP2x 4400-8 and TMP2x4600-12) *Musa* hybrids. Pedigree details of the parental accessions are given in Table 1. Zygotic embryos were extracted from seeds germinated in vitro and propagated as previously described (Vuylsteke *et al.* 1990). Seedlings were acclimatized for 6-8 weeks in the nursery prior to transfer to the field.

Field experiments

The seedlings were field established along with their parental clones under alley and monocropping system. The experimental layout was a split-plot arranged within a Randomized Complete Block Design (RCBD) with two replications. Planting was done at a spacing of 3 m between rows and 2 m within rows to achieve a population density of 1,667 plants ha^{-1}. Cultural practices were those of Swennen (1990). Data was collected on the number of days to flowering, time for fruit filling (days), plant height at flowering (cm) and bunch weight (kg) for two consecutive crop cycles.

Statistical procedure

Statistical analysis was performed using the MANOVA option of the GLM procedure in SAS (SAS, 1999) to separate effects due to (a) cropping systems (CS), (b) clone (C), (c) crop cycle (CC) and their interactions. Data were initially combined over cropping systems and crop cycles, giving the following full statistical model:

$$Y_{ijkl} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + (\alpha\gamma)_{ik} + (\beta\gamma)_{j(i)k} + \delta_l + (\gamma\delta)_{kl} + (\alpha\gamma\delta)_{ikl} + \varepsilon_{ijkl}$$

where : Y_{ijkl} is the observed performance of the k^{th} clone in the l^{th} crop cycle in the j^{th} replication at the i^{th} cropping

Table 2. F-test of significance for the main and interaction effects of the different clones, cropping systems and crop cycle on time to flowering (days), time to fruit filling (days), plant height (cm) and bunch weight (kg) of *Musa* hybrids grown at Onne for two seasons.

Source of Variation	Time to flowering (days)	Time for fruit filling (days)	Plant height (cm)	Bunch weight (kg)
Cropping system (CS)	***	ns	***	ns
Replication (R)	ns	ns	ns	ns
Clone (C)	***	***	***	***
CS*C	ns	ns	ns	ns
Crop cycle (CC)	***	ns	***	*
CS*CC	ns	ns	***	ns
CC*C	ns	ns	ns	ns
CS*CC*C	ns	ns	ns	ns

*, ** and *** indicates significant F-test at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.
ns indicates a non-significant F-test at $P < 0.05$.

system; μ is the mean of all observations of the trait; α_i is the effect of the i^{th} cropping system (i=1,2); $\beta_{j(i)}$ is the effect associated with the j^{th} replication (j=1,2) within the i^{th} cropping system; γ_k is the effect of the k^{th} clone (k=1,2,..,9); $(\alpha\gamma)_{ik}$ is the cropping system x clone interaction effect; $(\beta\gamma)_{j(i)k}$ is the clone x replication within cropping system interaction effect; δ_l is the effect of the l^{th} crop cycle (k=1,2); $(\alpha\delta)_{il}$ is the cropping system x crop cycle interaction effect; $(\gamma\delta)_{kl}$ is the clone x crop cycle interaction effect; $(\alpha\gamma\delta)_{ikl}$ is the cropping system x clone x crop cycle interaction effect, and ε_{ijkl} is the residual associated with each observation. Thereafter, reduced models which excluded cropping system effects (separate analysis for each cropping system) were used to estimate parental general combining ability (GCA) effects and the corresponding specific values of heritability for each cropping system or each cycle within cropping system. Thus, comparisons were made among estimates based on combined analysis and those using data subsets for cropping system or cycles within cropping system.

The GCA of a given parent was calculated as the mean deviation of its offspring from the overall mean of the population. Similarly, the specific combining ability (SCA) of a parental pair was estimated as the average deviation of their progeny mean from the population mean minus the sum of the GCAs of each parent (Falconer and Mackay, 1996). Standard errors were calculated for GCA and SCA effects using the procedures of Cox and Frey, (1984). The ratios of mean square components associated with GCA and SCA were calculated to estimate the relative importance of GCA in explaining progeny performance (Baker, 1978). Additive genetic effects were implied when the ratio $(GCA_f + GCA_m)/(GCA_f + GCA_m + SCA)$ were close to unity.

The broad sense heritability (H^2) was measured as the fraction of phenotypic variance attributable to genetic differences among individuals in a population (Nyquist 1991):

$$H^2 = \frac{\sigma^2 c}{\sigma^2_{c} + \sigma^2_{cs\ c\ cc}/cs\ cc + \sigma^2_{cs\ c\ /\ cs} + \sigma^2_{c\ cc\ /\ c} + \sigma^2_{e\ /\ r\ cc\ cs}}$$

where, H^2 is the broad-sense heritability; σ^2_c is the genetic variance; $\sigma^2_{cs\ c\ cc}$ is the variance associated with clone x cropping system x crop cycle interaction; $\sigma^2_{cs\ c}$ is the variance associated with clone x cropping system interaction; $\sigma^2_{c\ cc}$ is the variance associated with clone x crop cycle interaction; and σ^2_e is the experimental error. The terms cs, cc, c, and r indicate the number of cropping systems, crop cycles, clones and replications, respectively. Thus, (cs, cc, c, r) = (2, 2, 9, 2) for the full model used for the complete data set. For each data subset, the equation above was adjusted to fit the adjusted model. The standard deviation of the heritability value was calculated following Vello and Vencovsky (1974):

$$Sd\,(H^2) = \frac{2}{n_1 + 2} + \frac{2}{n2+2}\ (1 - H^2)$$

Where, n_1 and n_2 are the degrees of freedom of the genotypes and error sources of variation, respectively. Finally, truncation selection based on a specific threshold value (e.g. ≥ 10 kg) or choosing the uppermost fraction (top 10%) was used to extract the best genotypes from each system.

Results and Discussion

Significant main effects of cropping system (CS) were recorded only for days to flowering and plant height (Table 2). Main effects of clones (C) were significant for all the traits studied, while crop cycle (CC) effects was

Table 3. Cropping system-specific F-tests of significance for female, male and crop cycle effects, and their interactions on time to flowering (days), time to fruit filling (days), plant height (cm) and bunch weight (kg) of *Musa* hybrids grown at Onne.

Cropping System	Source of Variation	Plant Characteristics			
		Days to flowering	Time to fruit filling	Plant height (cm)	Bunch height (cm)
Alley Crop	Female (F)	*	*	ns	ns
	Male (M)	**	ns	**	ns
	F*M	ns	ns	ns	ns
	Crop cycle (CC)	**	ns	*	ns
	F*CC	ns	ns	ns	ns
	M*CC	ns	ns	ns	ns
	F*M*CC	ns	ns	ns	ns
Monocrop	Female (F)	ns	***	ns	ns
	Male (M)	ns	***	*	ns
	F*M	ns	ns	*	ns
	Crop cycle (CC)	**	ns	***	ns
	F*CC	ns	*	ns	ns
	M*CC	ns	ns	ns	ns
	F*M*CC	ns	ns	*	ns

*, **, and *** indicates significant F-test at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.
ns indicates a non-significant F-test at $P < 0.05$.

Table 4. F-test of significance for female and male effects on the plant crop and the first ratoon crop performance of *Musa* hybrids grown at Onne.

Cropping System	Crop Cycle	Source of Variation	Plant Characteristics			
			Days to flowering	Time to fruit filling	Plant height (cm)	Bunch height (cm)
Alley Crop	Plant crop	Female (F)	ns	***	ns	*
		Male (M)	*	*	**	ns
		F*M	ns	ns	ns	ns
	Ratoon crop	Female (F)	ns	ns	ns	ns
		Male (M)	ns	ns	ns	ns
		F*M	ns	ns	ns	ns
Monocrop	Plant crop	Female (F)	ns	ns	ns	ns
		Male (M)	ns	*	ns	ns
		F*M	ns	ns	ns	ns
	Ratoon crop	Female (F)	ns	***	ns	ns
		Male (M)	ns	***	ns	ns
		F*M	ns	ns	*	ns

*, **, and *** indicates significant F-test at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.
ns indicates a non-significant F-test at $P < 0.05$.

significant for days to flowering, plant height, and bunch weight. There was a non-significant CS x C and CC x C interaction for all the traits studied, while CS x CC interaction was significant for plant height only. The 3-way interaction between CS x CC x C was not significant. These results indicate that the expression of two traits, number of days to flowering and plant height may be system-dependent, requiring selection in both cropping systems. Cropping system effect on these traits may be related to the disparity in the nutrient status of the soil in alley and monocropping system. The biomass generated from pruning multispecies hedgerows, and nitrogen fixation by the deep roots of the woody legumes contributes to an increase in nutrient level of the soil in alley than monocropping system. Thus, greater 'N' availability in the alley cropping system may have resulted in prolonged vegetative growth and taller plants, confirming the submission of Baker (1986) that phenotype produced by genotype is environment dependent. Conversely, selection for time to fruit filling and bunch weight may be done in either system since the performance rank of the different clones is conserved across systems. The breeder would have to make a choice of either selecting hybrids for specific cropping systems or selecting for broad adaptation to both cropping systems for higher gains, following Jackson and McRae (1998). The non-significant two-way interaction between cropping system x clone and crop cycle x clone may indicate that the performance rank of the different clones were conserved across systems and crop cycles. This is important for the breeding program since it indicates that selected hybrids would perform creditably well across

Table 5. Ratio of mean square components associated with general combining ability (GCA) and specific combining ability (SCA), indicating the relative importance of GCA in explaining progeny performance in the two cropping systems.

Cropping system	Plant Characteristics	GCA(f)	GCA(m)	SCA	GCA/(GCA + SCA)
Alley crop	Time to flowering (days)	1.0	4.4	0.0	1.0
	Time to fruit filling (days)	5.1	0.0	3.3	0.6
	Plant height (cm)	0.0	17.1	0.0	1.0
	Bunch weight (kg)	9.8	0.0	0.1	1.0
Monocrop	Time to flowering (days)	0.3	0.6	0.0	1.0
	Time to fruit filling (days)	0.0	1.6	10.0	0.1
	Plant height (cm)	0.0	0.0	3.1	0.0
	Bunch weight (kg)	10.2	0.0	0.0	1.0

Table 6. Effects of cropping systems (CS) on heritability of *Musa* hybrids in Onne, Southeastern Nigeria.

Test environments	Plant Characteristics			
	Days to flowering	Time to fruit filling	Plant height (cm)	Bunch height (cm)
Combined CS analysis	0.88 ± 0.02	0.98 ± 0.004	0.98 ± 0.004	0.95 ± 0.01
CS-specific data				
Alley crop	0.67 ± 0.10	0.64 ± 0.07	0.31 ± 0.13	0.71 ± 0.05
Mono crop	-1.57 ± 0.75	0.70 ± 0.06	0.29 ± 0.13	0.49 ± 0.09
Specific crop cycle data				
Alley crop PC[*]	0.20 ± 0.27	0.36 ± 0.22	0.21 ± 0.27	0.24 ± 0.43
Alley crop RC	0.02 ± 0.36	-0.76 ± 0.64	-0.62 ± 0.59	-0.48 ± 0.54
Mono crop PC	0.06 ± 0.32	-0.18 ± 0.40	-0.45 ± 0.50	-0.23 ± 0.42
Mono crop RC	-0.72 ± 0.62	0.44± 0.20	0.66 ± 0.12	-1.01 ± 0.72

[*] PC = plant crop, RC = ratoon crop.

cropping systems and crop cycles. Individuals selected under mono-cropping perform well under alley cropping but the reverse is not necessarily true. With limited resources most farmers will not be able to match the conditions that alley-cropping provides. Therefore, breeders work under monocropping would be more likely to obtain selections that would equally reach small-holders and those farmers who can afford to invest in more nutrient-rich approaches to production. Besides, selecting under mono-cropping is less labor-intensive than under alley-cropping, the latter requiring regular pruning of the hedgerows and also propping of the plants due to their increased height. A separate analysis for each cropping system and crop cycles within system was done to determine the extent to which genetic differences were expressed. This also enabled the determination of combining ability of the parental clones. Significant main effects of the female parents were recorded for days to flowering in the alley crop, while female effects for time to fruit filling was significant in the alley and mono-cropping system. Crop cycle effects were significant for days to flowering and plant height in both systems (Table 3). There was a non-significant 2-way and 3-way interaction in the alley crop. However, female x crop cycle interaction was significant for time to fruit filling, while female x male x crop cycle interaction was significant for plant height in the mono crop. Selection for time to fruit filling and bunch weight could be carried out in plant or ratoon crop cycles in both alley and monocropping systems since there was no cycle effect. Conversely, selection for days to flowering and plant height should be carried out in the plant crop cycle of the alley crop, where there was substantial trait variation. Selection for these traits should however be done in the ratoon crop cycle of the monocropping system (Table 4). The ratio of GCA to SCA indicated that additive gene action determined the inheritance of all the traits under alley cropping, and days to flowering and bunch weight in the monocropping (Table 5). In this case, parental selection in each system would be crucial since parental value determined progeny performances for most of the traits studied. In both systems, female phenotypic performance was predictive of progeny performance for bunch weight. Two female parents, 1658-4 and 4698-1 were outstanding with significant positive GCA values for bunch weight in the two cropping systems.

Heritability and selection

The extent of genetic gain depends on the magnitude of genetic variation relative to the total variation in a population (Baker, 1986). This value is estimated by heritability. Broad sense heritability (H^2) measures the fraction of phenotypic variance attributable to genetic

Table 7. Comparative efficiency of selection for bunch weight (kg) under alley cropping or mono cropping based on truncation selection or distribution based selection.

Variables	Alley cropping	Monocropping
Population size	279.0	285.0
Mean (kg)	4.5	3.9
Standard deviation (kg)	3.5	2.7
Truncation approach (a)		
Number selected	25.0	8.0
Selection intensity (%)	0.10	0.03
Common selections	3.0	3.0
Selection intensity (%)	2.2	35.6
Distribution approach (b)		
Number selected	9.0	10.0
Selection intensity (%)	0.04	0.04
Common selections	3.0	3.0
Selection efficiency (%)	30.5	27.1

Selection efficiency (%) was based on
(a) Absolute performance, i.e., bunch weight □ 10kg
(b) Relative performance, i.e., top 2.5% (bunch weight □ mean + 2 standard deviations)

differences among individuals in a population. It is a predictor of a population's potential to change in response to selection. The results indicated that all the traits studied were highly heritable ($H^2 > 0.85$), when the data was combined over cropping systems (Table 6). Heritability estimates of all the traits were higher in the pooled data than in the CS-specific analysis. This indicated that phenotypic selection may be effective and that there may be little or no cropping system effect. Therefore, selection of individual plants or families could be done in any cropping system with the hope that such selected individuals would retain their agronomic qualities in either system. Genetic differences accounted for more than 60% of phenotypic variation for days to flowering, time to fruit filling and bunch weight under alley cropping, and time to fruit filling under monocropping. The lowest estimate of heritability was recorded for plant height ($H^2 = 0.31 \pm 0.13$), probably because of greater influence of environmental factors on the trait. Within each system, heritability values of combined crop cycle data (plant and ratoon crop cycle) were greater than single cycle data. This highlights the effectiveness of double cycle selection compared to single cycle selection, and is consistent with the findings of Ortiz (1997) and Tenkouano *et al.* (2002).

Selection within cropping systems

Within the alley cropping system, 25 individuals were identified with bunch weight of 10 kg or above, in contrast to only 8 individuals meeting this criterion under monocropping system. Only three individuals were selected under both systems, giving an efficiency of 2.2% for selection under alley cropping and 35.6% for selection under monocropping. This indicated that when selecting under monocropping, a greater proportion of selected individuals are likely to perform well when grown under alley cropping, while most selections from the alley cropping system may perform poorly under monocropping (Table 7). Selection under monocropping therefore, would likely produce genotypes that will be suitable for cultivation under alley cropping than the reverse option. When selection took into account the distribution of the data, it resulted in identical selection intensity in both systems. In this case, there was virtually no difference in selection efficiency in the two cropping systems (Table 7). However, breeders seldom use the distribution approach since it would require that one carries out selection only after data collection is completed.

Conclusion

Selection of individual plants or families that would serve as parents are made in breeding programs to increase genetic gain within and across generations. In *Musa* species studied, a greater percentage of selection efficiency is recorded under mono cropping system, indicating that selection under the system would likely produce genotypes suitable for cultivation under alley cropping system.

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