Measurement and management of genotype-environment interaction (GxE) for the improvement of rainfed lowland rice yield in Cambodia.

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Abstract

The magnitude and nature of genotype-by-environment interactions (G?E) for grain yield (GY) and days to flower (DTF) in Cambodia were examined using a random population of 34 genotypes taken from the Cambodian rice improvement program. These genotypes were evaluated in multi-environment trials (MET) conducted across three years (2000 to 2002) and eight locations in the rainfed lowlands. The G?E interaction was partitioned into components attributed to genotype-by-location (G?L), genotype-by-year (G?Y) and genotype-by-location-by-year (G?L?Y) interactions. The G?L?Y interaction was the largest component of variance for GY. The G?L interaction was also significant and comparable in size to the genotypic component (G). The G?Y interaction was small and non significant. A major factor contributing to the large G?L?Y interactions for GY was the genotypic variation for DTF in combination with environmental variation for the timing and intensity of drought. Some of the interactions for GY associated with timing of plant development and exposure to drought were repeatable across the environments enabling the identification of three-target populations of environments (TPE) for consideration in the breeding program. Four genotypes were selected for wide adaptation in the rainfed lowlands in Cambodia.

Media summary

The scientists in Cambodia and The University of Queensland developed a method to release new rice varieties for farmers.

Keywords

Yield, Phenology, G?E interactions, Drought, Adaptation

Introduction

Investigations of genotypic variation and genotype-by-environment (G?E) interactions for GY of rainfed lowland rice have been conducted in and across a number of Asian countries (Cooper and Somrith, 1997; Wade et al., 1999). A major objective of these studies was to investigate environmental and genetic constraints to the improvement of broad and specific adaptation of rainfed lowland rice for a range of target populations of environments (TPE) (Cooper et al., 1999). An understanding of these constraints is a basis for defining breeding strategies that would contribute to higher and more stable GYs for the variable rainfed lowland environments, thereby reducing farmers risk and uncertainly while increasing productivity. In addition to the variation in the rainfed environments, the method of rice establishment is changing with more direct seeding of rice as labour becomes less available. Previous studies of rainfed lowland rice consistently identified large G?E interactions for yield. Crossover G?E interactions can be a significant barrier to selection strategies that aim to improve broad adaptation. Alternatively, where some aspects of the G?E interactions are repeatable, it may be possible to select for components of specific adaptation to the relevant TPE. Some of the repeatable GxE is associated with the timing of drought relative to the phenology of a variety. Fukai and Cooper, (1995) have recommended that plant breeding programs aimed at improving rice for the variable rainfed environments should incorporate a selection and testing strategy that aims to ensure broad adaptation and capture the specific adaptation to repeatable drought events.

The objectives of this study were to: (1) document the magnitude of genotypic, G?E interaction, and error variation for GY, based on a random population of rice genetic materials used in the breeding program in Cambodia; (2) examine the influence of timing of drought and genotypic variation for flowering time on G?E interactions for GY; and (3) identify TPEs based on the environmental characterisation of the occurrence of drought at flowering to better target the deployment of varieties in the heterogenous rainfed lowlands of Cambodia.

Materials and methods

A random population of 34 genotypes, including local land races, improved cultivars from CARDI selection program and introductions from Thai-ACIAR population (Cooper, 1999) were used for the MET. The trial was conducted at eight locations, which were representative of the five main soil types (White et al., 1997) for the rainfed lowlands in Cambodia, across three years, 2000 to 2002 as shown in Table 1.

Table 1. Locations for the multi environment trial (MET) in Cambodia, the abbreviated names used for these locations and the soil types and the rice plant establishment method used at each site in the wet seasons, 2000 to 2002.

Location	Abbreviations	Soil type	Method of establishment		
Name			2000	2001	2002
Phnom Penh	CA	Prat. Lang	TP, DS	TP DS, DR	TP DS, DR
Prey Veng	PV	Prat. Lang	TP	TP, DR	TP, DR
.Battambang	BB	Samrong	TP	TP, DS	TP, DS
.Kampog Thom	KT	Krakor	TP	TP	TP, DS
.Kampot	KP	Bakan	TP	TP	TP
.Kirivong	KV	Bakan	-	TP	TP
Slakou	SL	P. Khmer	TP	TP	TP
Siem Reap	SR	P. Khmer	-	TP	TP

TP = Transplanting, DS = Direct seeding, DR = Simulated drought by draining water at flowering stage.

The MET's were conducted as randomised complete block designs with three replicates. Most of the trials were established by transplanting and some were direct seeded. The experimental plots were five rows by 5m with 25cm between hills and 1-3 seedlings were planted per hill. Direct seeding was done at the time of seedbed establishment for transplanting experiments at three sites. Drought conditions were imposed at two locations by draining water from the field at 50% flowering stage. Fertiliser was applied as a basal application of 18 kg N ha^{-1}, 37 kg P_2O_5 ha^{-1} and 37 kg K_2O ha^{-1} and as a top dressing of 18 kg N ha^{-1} prior to flowering at all sites. Data for GY at 14 % moisture content and DTF measured as the time from seeding to when approximately 50-75% of the plants in a plot had flowered were recorded. . Plants from three middle rows (leaving 25cm border from both side) were harvested to estimate GY for the trials established by TP, while in the DS trials plants were harvested from a 3375cm^2 area from the middle of the plot.

Analyses of variance

The phenotypic observation y_{ijkl} on line *i*, in replicate *l* of location *j* and year *k* was modelled using the following linear mixed model

$$y_{ijkl} = \mu + l_j + y_k + (ly)_{jk} + (r/ly)_{ljk} + g_i + (gl)_{ij} + (gy)_{ik} + (gly)_{ijk} + \varepsilon_{ijkl},$$

where μ = grand mean; l_j, y_k, $(ly)_{jk}$ are fixed effects of location, year and interactions, $(r/ly)_{ljk}$ = random effect of replicates, g_i, $(gy)_{ik}$, $(gl)_{ij}$, $(gly)_{ijk}$, ε_{ijkl} are random effects of genotype and genotype-by-year, genotype-by-location, genotype-by-year-by-location and residuals. Analyses were conducted for 2 years (19 environments), 3 years (32 environments) and only transplanted environments in 3 years (26) using the REML software. The variance components and best liner unbiased predictors (BLUPS) were estimated.

(a) Cluster analysis

GY BLUPS obtained from the analysis using the linear mixed model defined above were used to conduct cluster analysis using the GEBEI software. The cluster analysis was conducted for both genotypes and environments, using squared Euclidean distance as the proximity measure and incremental sum of squares as the grouping strategy.

Results

There was a range of water environments with varying water availability during vegetative, reproductive and grain filling stages. The pattern of clustering water environments is discussed later in this paper.

Analyses of variance

The significant components of variance for GY for the 2 and 3-year analysis and for the TP only are shown in Table 2. The G?L?Y interaction component was 3.5 times larger than the G component when separate analysis were made for the 2 and 3-years data, and 4.5 times larger when only transplanting environments were analysed together for 3 years. The Genotype-by-Year (G?Y) interaction component was small in the 2 and 3-year analysis and non-significant in the TP trials. The Genotype-by-Location (G?L) interaction component was significant and was slightly smaller than the G component in all analysis. The components of variance for DTF are not shown. The G component for DTF was large and 4.6 times that of the G?L?Y, which was also significant. The estimate of heritability for GY was greater than 0.6 and similar for the 2 and 3-year analysis and for the TP system. The pattern of the relationship between GY and DTF across environments suggested that the late flowering genotypes in the late season drought environments had more yield losses than the genotypes in the intermittent drought environments.

Table 2. The components of variance for grain yield measured from multi environment trials (32 MET) 34 rainfed lowland rice cultivars over 8 locations and for 2 and 3 years and with different planting systems. The proportion (%) of the G to their G?L?Y variance and heritability estimates are also shown.

Source of variation	Two years (19)	Three years (32)	Three years (only TP), (26)
Genotype (G)	6.36	5.32	5.80
G x L	6.08	5.12	5.56
G x Y	1.26	1.04	0.00
G x L x Y	22.08	18.91	26.43
Residual	4.60	4.70	4.70
Heritability (h^2)	0.67	0.614	0.681
G : G x L x Y	1: 3.50	1:3.55	1:4.5

Cluster analysis

The grouping of the environments and genotypes for grain yield was done by cluster analysis. Truncation at the three-group level of environments accounted for 76% of the total variance. The different environmental groups appeared to be due to difference in drought intensity and timing and there was a tendency for environments with no drought, or little evidence of water stress, to group together (e.g.CA and BB). Among these groups, only at 2 locations there was a tendency for the different years of testing to group together (CA and BB in 3 year). There was no pattern associated with soil type or planting system. Truncation at the 5 group level of genotypes captured 94% of the variance. Three genotypes introduced from the Thai-ACIAR breeding program and an improved cultivar, Santepheap from Cambodia, grouped together. The mean yield of this group was 2.9t ha^{-1} with good performance in most environments. Another group consisting of 5 genotypes performed well in the low water environments but poorly under more favourable conditions. Six genotypes having aromatic characters grouped together, suggesting that genetic similarity among those lines for performance across environments. They had an overall mean yield of 2.2 tha^{-1} and did poorly in high yielding environments.

There was some association between the hierarchical grouping (based on GY) and the pattern of maturity among these groups. For example there was a tendency for the late flowering group to produce high yield in favourable environments but low yields in stressed environments. The association between GY and DTF varied among environment groups 23 (2.15 t h^{-1}), 28 (2.78 t ha^{-1}) and 29 (2.18 t ha^{-1}). Flowering occurred earlier in Group 28 by about 10 days (115 day after sowing) (Figure 2). This indicates that the variation in phenology of mid and late maturing genotypes was influenced by the water availability at flowering (Figure 2).

Discussion and conclusions

The analysis of the sources of variation based on the results of the MET identified significant components of genotypic G?E interaction and error variation for GY. Partitioning the G?E interaction component indicated that the three-factor G?L?Y interaction was consistently the largest source of G?E interaction for GY. The G?L?Y interaction was 4.5 times (only TP) the size of the G component of variance for GY.

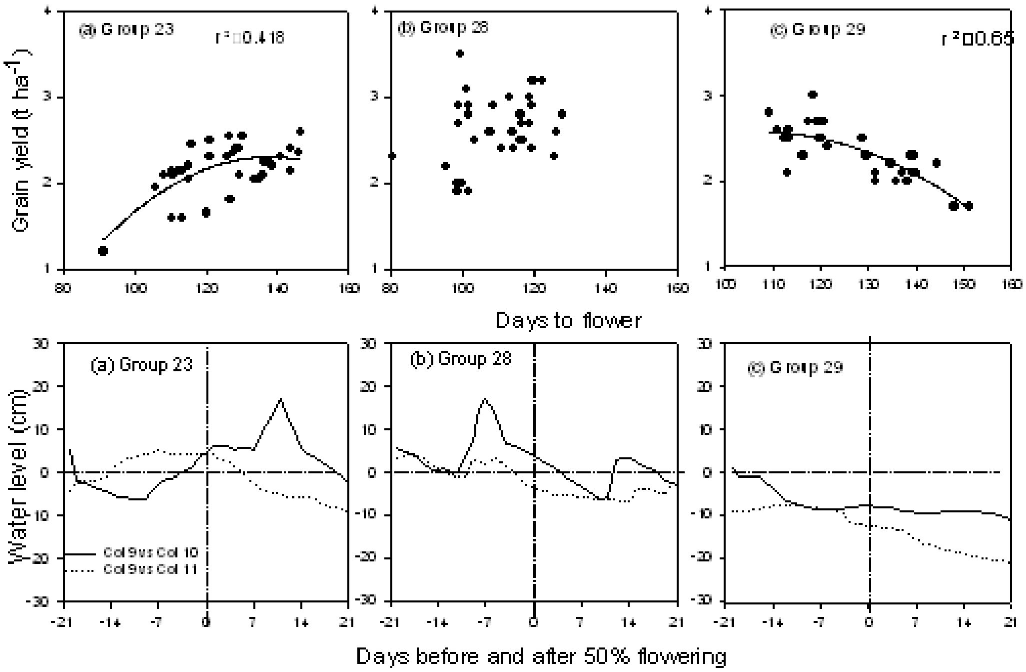

Figure 2 Relationship between days to flower and grain yield of 34 lines under three groups of environments (a=23, b=28 and c=29) (above) and the water levels at 3 weeks before and after flowering in mid and late maturing genotypes grown under three groups of environments (below).

The strong contribution of G?E interactions to the GY variation among genotypes is consistent with the results of other studies in SE Asia that were based on diverse sets of genotypes (Cooper et al, 1999). However, unlike Thailand, the G?Y was small suggesting that two years yield testing would be adequate. The large genotypic component of variation in days-to-flower together with the association with GY in the three TPEs' indicates that DTF can be effectively manipulated within the existing materials available in the breeding program. This is consistent with the results reported by Cooper et al. (1999) that flowering days shows relatively simple genetic control for rainfed lowland rice. It is evident that broadly adapted genotypes can be released based on the results of MET in Cambodia. Three types of TPE were identified based on water availability at flowering. However, to make a good assessment of genotype performance across TPE, multi-environment trials should be conducted in at least two years.

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