Indian J. Genet., 57 (1): 1–10 (1997)

CHARACTERIZATION AND DELINEATION OF AGRO-ECOLOGICAL ZONES AND EVALUATION OF CROP GENOTYPES

D. SHARMA

56, ICRISAT Colony, Tarbund, Secunderabad 500009

(Received: July 15, 1991; accepted: December 27, 1991)

ABSTRACT

Success of a crop breeding programme depends on the efficiency of evaluation of the available genotypes and identifying high yielding types adapted to a given environment and management conditions. Crop growing environments in tropics and subtropics are highly diverse and complex due to the effect of abiotic and biotic factors and the varying crop management systems. For such environmental complexities it is almost impossible to define the environment under which varieties should be selected. A reasonable compromise is to test the materials over a sample of a wide range of the conditions in the target growing environment. Identification of broad agroecological regions (zones) and common and uncommon features between the test sites within a region allows the determination of an optimum regional and national testing programme. The paper discusses the importance of G x E interactions caused by weather, edaphic and biological factors in an apparently homogeneous geoclimatic subdivision analysis of abiotic and biotic factors, but also the cultivar response to environment for improving the efficiency of a testing network. Recent developments in the analytical techniques for delineating environments and their relevance to the national testing network in the developing countries are indicated.

Key words: G x E interaction, ecosystem, agro-ecological regions, microenvironment, environmental index.

Activities of a crop breeding programme can be broadly grouped into 1) assembling of desirable genetic variability and 2) evaluation and identification of new genotypes as improved cultivars. In recent years, establishment of international crop research institutes and germplasm banks, and increasing communication between the international and national programmes under different networks have facilitated the availability of genetic variability a great deal. This is particularly helpful to the developing countries with inadequate financial resources and skilled manpower for a reasonable scale of a basic breeding programme. However, the ultimate success of any crop breeding programme, big or small, depends on the efficiency of evaluating the available genotypes and identifying high yielding types adapted to a given environment and management conditions.

The easiest and practical approach is to thoroughly evaluate the promising genotypes in the environment in which they are finally intended to be grown. Small area-specific localized breeding programmes can do that effectively and in the past, selection either by the farmers or local breeding stations (early plant breeding efforts) has resulted in area-specific balanced ecosystem adaptation of local cultivars or land races, with emphasis on risk avoidence. However, in the green revolution era of sixtees, the success of breeding high yielding crop cultivars responsive to improved management techniques has opened up new dimensions of international ecogeographical, national and regional efforts and involvement in breeding improved cultivars. In the beginning large international programmes laid emphasis on high yielding management responsive (high plant population, irrigation, high doses of fertilizer and intensive plant protection) crop cultivars. However, now it is widely recognized that stress free crop production area and resources for high inputs are limited to start with, and their overuse is a serious threat to sustainability of ecosystem. Therefore, cultivar development needs to be directed towards optimum production in a given environment rather than to maximum production with high input management. This can be best achieved, if the genetic component of environmental adaptation (ecosystem adaptation) of genotypes in terms of specific and general adaptation is fully exploited.

Crop growing environments in tropics and subtropics are highly diverse and complex, and crop management varies a lot from one farm, often less than a hectare, to another. Abiotic (soil moisture conditions ranging from arid to very wet, warm low lands to cool lands, saline, alkaline and leached acid soils with low cation exchange capacity and aluminium toxicity, low nitrogen, low phosphorus and micronutrient deficiencies and toxicities), biotic (large number of diseases and pests perpetuating at all stages of crop growth, cropping systems and crop culture; and management practices) and socioeconomic factors interact to create highly unpredictable complexities of crop growing environments.

With such environmental complexities, it is almost impossible to closely define the environment under which a crop variety should be selected. Theoretically, maximum progress is possible when all genotypes are grown in as many environments as possible. But field trials are expensive in terms of skilled person-hours, supplies, land area, supervision and coordination logistics. Therefore, a logical compromise is to test over a sample of a wide range of these conditions to get the best prediction of a genotype to be selected for next season or finally for general cultivation. The sample sites should represent the common features of the target growing environment and also uniqueness of the situations (for example periodic drought or flooding or occurrence of particular disease epidemic) often encountered.

Approach and methodology to classify and characterize a region (zone) and a site or sites within a zone depend on the objective and available resources of a research network. For example regional and site characterization for farming systems research lays major emphasis on resource characterization, that is on analysis of physical (soil, water, temperature, humidity, etc.), biological (crop species grown and used, cropping systems, tree plantations, pests, diseases, livestock, fisheries etc.) and socioeconomic (land unit, capital available, farm energy and farm labour) environments of an agro-ecological unit in a farming systems perspective. While site characterization in the context of crop improvement research (crop variety and production technology development) and application is the analysis of physical and biological factors obtaining at an experimental site or sites in a given target area or ecological zone and their relevance as a sample to the target area as a research intervention unit. Of course farming systems perspective is an additional consideration, but main emphasis is laid on interrelationship of the sample sites and their efficiency in predicting and extrapolating the cultivar performance in a zone, and optimizing the number of experimental sites.

IMPORTANCE OF ZONES

Identification of broad agro-ecological regions (zones) and common and uncommon features between the test sites within a region allows the determination of an optimum regional and national testing programme. A meaningful characterization and classification of regional and test sites environment is likely to provide predictive information required for determining the varietal characteristics and performance; and finally allow extrapolation of test results to actual farm conditions. Also, such a characterization is highly beneficial for directing specific objective oriented exchanges of germplasm and information at the national and the international levels.

GENOTYPE X ENVIRONMENT INTERACTION AND IMPLICATIONS

Cultivar yield trials have been a routine activity of the plant breeding programmes. However, it is a common experience that a set of genotypes tested over a number of locations or years do not have the same ranking in any two trials (Fig. 1). These changes in varietal rankings result partly from experimental error and the remainder from the genotype environment (G x E) interactions caused by differential phenotypic response of the genotypes to the change in the environment (Fig. 2). A significant G x E interaction reduces the utility of genotype means over locations and years as a criteria for selection and causes difficulty in identifying superior cultivars [1, 2]. Therefore, in recent years considerable attention has been given in the developed countries to improve the efficiency of testing programmes through optimizing the number of replications, number of sites, and characterization and choice of sites on one hand, and refining the statistical analyses, particularly related to consistency of performance and stability of genotypes across environments and years, on the other.

Environmental variables can be classified as predictable and the unpredictable. Predictable factors comprise of topography, soil type, daylength, and agronomic practices, which can be controlled such as sowing date, method of seeding and fertilizer rate. Unpredictable factors are those which fluctuate inconsistently, such as, rainfall, temperature, relative humidity; and various micro-environmental factors and biotic stresses, such as, diseases and pests.

Genotypes differ in their specific and general adaptation to environmental conditions. For example, specific adaptation to short season due to limited moisture supply or occurrence of frost, high salt tolerance, rice varieties for deep water condition, and general adaptation of photoperiod insensitive rice and wheat cultivars to large areas with different photoperiods and temperature regimes.

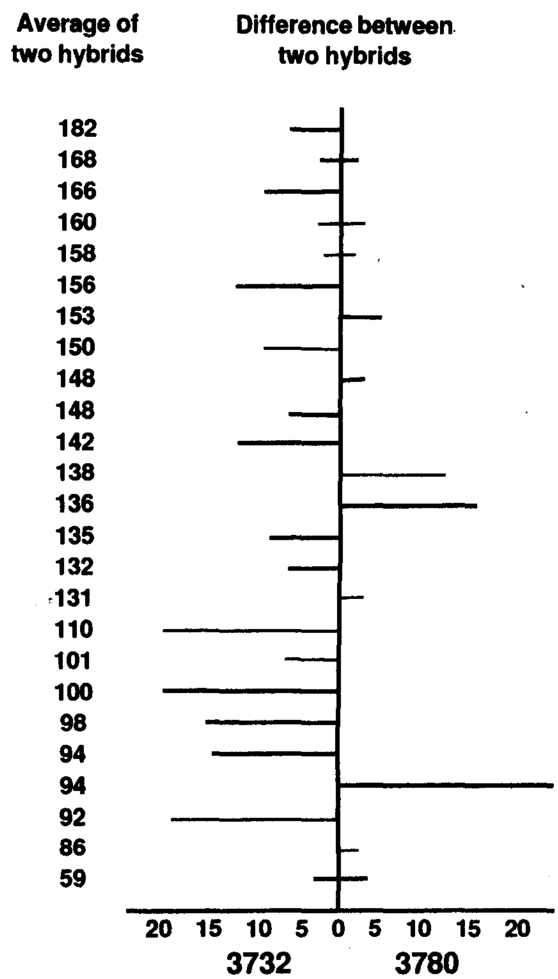

Fig. 1. Average yield (in bushels per acre) and difference in yield of two hybrids, 3732 and 3780, at 25 locations in 1977 [3].

Development of crop cultivars with low G X E interaction is possible by either of the following two approaches: (1) subdividing a heterogeneous area for which the cultivars are being bred into smaller regions, so that each of them has a more homogeneous geoclimatic environment and its own characteristic cultivars, and (2) development of cultivars which show a high degree of stability in performance over a wide range of environments.

DELINEATION OF ZONES

For both of the above stated approaches to be effective, detailed characterization of environment and a good understanding of the extent and nature of G X E interaction is

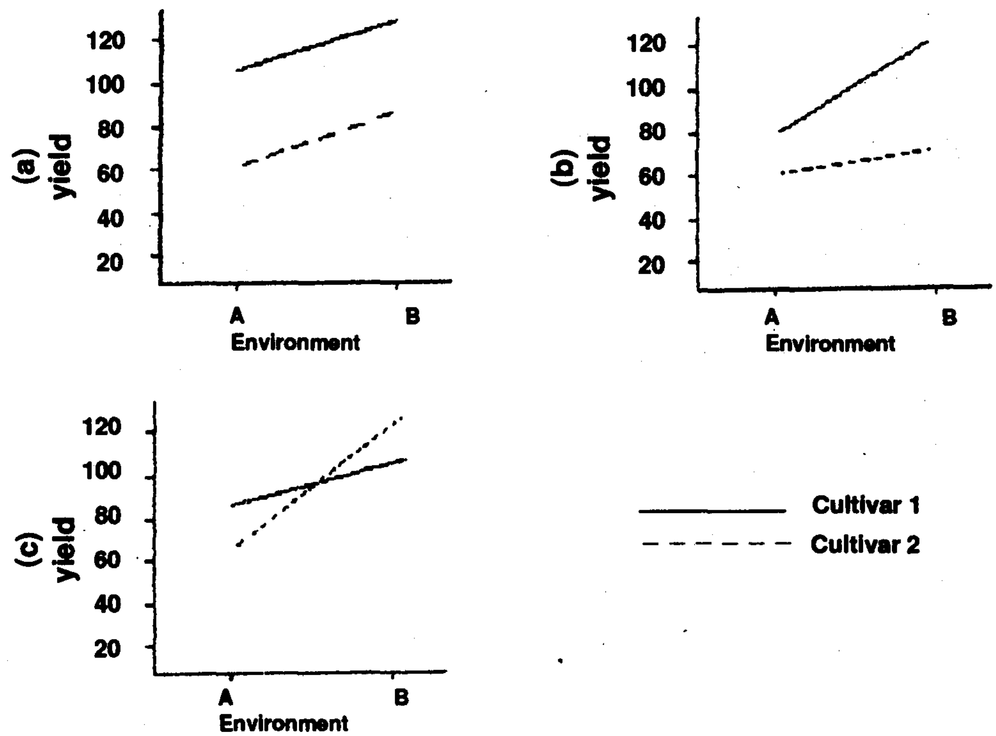

Fig. 2. The relative performance of two cultivars in two environments.
(a) No genotype x environment interaction is present.
(b) Genotype x environment interaction is present but does not alter genotypic ranking.
(c) Genotype x environment interaction is present and alters genotypic ranking [4].

essential. Generally, zoning for the regional cultivar tests is based on the following considerations.

1. Traditional well recognized production areas of the crop.
2. Location of the breeding centres and their mandate area (administrative and logistic).
3. Broad geoclimatic regions of a country : latitude, longitude and altitude.
4. Agro-ecosystem-based:
    a. Agroclimatic.
    b. Cropping systems and farming systems : rice-based, wheat-based, intercropping, mixed farming and agroforestry etc.

c. Ecological: lowland, swamps, uplands, perennial forest or plantation crop ecosystem etc.

d. Pathosystem: prevalence of particular disease or pest and their population structure.

e. Abiotic stresses: drought, waterlogging, problem soils (alkaline, saline, acidic etc.).

Emphasis and importance of a basis for zoning homogeneous test areas depends on the objectives and the stage/scale of a crop breeding programme. Large international and national programmes give major consideration to crop production areas, institutional structure and their mandate areas, and broad geoclimatic factors. While the area-specific regional programs need to emphasize the importance of specific agroecosystem, pathosystem and abiotic and biotic stresses prevalent in the region. Essentially the approach is to move from generality to specificity. A balanced integrated consideration of all the above stated aspects in determining the crop cultivar testing zones is likely to result in a meaningful hierarchial network of testing and exchange of germplasm, involving international, national and regional programmes. One need not wait for all this information to be available, to start a testing programme, but with due appreciation building of appropriate data base and analysis is continued to improve the efficiency and accuracy of the programme as we proceed.

A broad description of a crop growing zone includes environmental factors, such as, rainfall, temperature, humidity, evapotranspiration, soil type and daylength. Specific adaptation at a macrolevel for these factors is easily discernible and gross genotypic variations for adaptation to specific major changes in these factors is easily identified and established. However, almost in all developing countries the main problem is either absence or inadequacy of pertinent climatological observations as well as lack of proper analysis of relationship of such factors with crop performance (crop growth analysis in relation to environment).

Information within a large geo-climatic zone, particularly on unpredictable environmental factors is all the more limiting, which is the major cause of high G X E interaction in case of advance cultivar tests in a region (zone).

In USA, Saeed and Francis [5] found that in case of sorghum rainfall and temperature were the most important weather factors contributing to G X E interaction. However, Gorman et al. [6] reported that differential fertility and/or cultural practices contributed the greatest of G X E interaction in addition to rainfall. They concluded that there are other unpredictable environmental factors besides the environmental index and weather variables responsible for G X E interaction. These factors are not easy to identify. However, a better understanding and identification of weather, edaphic and biological (crop-ecosystem, pathosystem) factors in a homogeneous geoclimatic subdivision of a zone (test sites), coupled with proper analysis of cultivar response to environment may allow a reasonable prediction of adaptation and performance of the genotypes in a testing zone.

MAJOR APPROACHES FOR CHARACTERIZATION OF ENVIRONMENTS AND TEST SITES

1. Climatic classification based on soil and weather analysis, and modelling allowing probability prediction of a set of weather variables, such as rainfall, maximum and minimum temperatures, humidity and soil moisture availability.

2. Analysis of cultivar response (performance) across locations and relationship among test sites. Also characterization of specific adaptation to abiotic and biotic stresses.

In principle the two approaches are complementary to each other in substantiating the conclusions drawn about the similarities or the differences between environments influencing the phenotypic expression of the genotypes. In the last two decades, considerable progress has been made in analytical techniques using soil and weather data and cultivar response for delineating environments and describing relationships among test sites. Soil and climatic factors and related techniques are dealt by the agro-climatologists. The analytical techniques based on cultivar performance are mentioned in general terms as under.

Evaluation of genotype x environment (G X E) variance component. Horner and Frey [7] made the first attempt to classify the environment to minimize G X E interaction by subdividing the state of Iowa into oat growing sub-areas, which minimized cultivar x location interaction within the sub-area. Subsequently Miller et al. [8], Liang et al. [9] and Schutz and Bernard [10] studied genotype x environment interaction in cotton, small grains and soyabean respectively, and discussed the implications on cultivar testing programme.

Correlations. Guitard [11] used diallel correlations of cultivar yield among test sites and Hamblin et al. [12] used correlations of cultivar yields to average performance across the locations.

Cluster and pattern analysis. Grouping of the test sites by pattern analysis of the genotype x location effects or by two way pattern analysis of a large data set for determining varietal adaptation [13 – 15]. Johnson et al. [16] used cluster analysis to define six production areas of potato in USA on soil permeability, pH, and water holding capacity. Such defined areas provided a basis for recommendations concerning the allocation of funding for cooperative multi-state research.

Principal component analysis. It is a multivariate technique for reducing a large number of correlated variables to a small number of hypothetical main factors [17]. Correlations of cultivar yield among test sites can be used as a measure of similarities of environmental stresses and determination of principal environments (factors) would help in describing relationships among a large number of locations. Peterson and Pfeiffer [18] used 17 years of yield data from the International Wheat Performance Nursery to group international test locations into regional and subregional divisions, based on cultivar yield responses.

Mapping of equipotential zones for cultivar yield pattern evaluation: Gusmao et al. [19] attempted a method of mapping the zones within which one relative yield pattern of cultivars can be assessed with sufficient accuracy and precision, which is useful in making the decision for release of cultivars.

CONCLUSION

Edaphic and climatological analysis provides the basis for delineating the broad agroclimatic zones and specific requirements for genotype adaptation.

Analysis of the weather data coupled with the analysis of abiotic and biotic stresses prevailing on the test sites within the region will result in identification of locations responsible for specific G X E interaction caused by a particular stress, which can be used for screening the genotypes for resistance or tolerance to that stress.

In India broad ecogeographical regions (zones) for different crops have been delineated by the All-India Coordinated Crop Improvement Programme on various crops, but little attempt has been made to characterize in depth abiotic and biotic crop response features of different zones and the efficiency of testing sites within a zone. Varieties have been released on their mean performance in a zone or across zones. This apparently has worked well in case of wheat and rice varieties under irrigated conditions, but has limitations under highly variable rainfed environment in different agro-ecological areas. Training of scientist in site characterization involving various aspects of agroclimatic analysis and techniques of crop response analysis for defining areas of abiotic and biotic homogeneity; and characterization of test locations and their interrelationships will go a long way in making a beginning for realizing an effective national cultivar testing network and systematic variety development for specific agro-ecological niches particularly in rainfed farming areas.

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