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Integrating farmers' information with geographic information systems for targeting of maize research in Kenya

R.M. HASSAN and K. NJOROGE^1

International Maize and Wheat Improvement Center (CIMMYT), P.O. Box 25171, Nairobi, Kenya. ^1 Kenya Agricultural Research Institute (KARI), Box 57811, Nairobi, Kenya.

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ABSTRACT

Information from farmers' surveys was combined with climatic information to evaluate the adequacy of the current biophysical characterisation of maize *(Zea mays)* adaptation zones (MAZs) in Kenya. The analysis showed that a better definition of MAZs was achieved by integrating farmers' information with the climatic data. Six MAZs were defined as distinct target domains for maize research as opposed to the previous four zones described by biophysical characterisation alone. The major biotic and abiotic stress factors, system constraints and socio-economic circumstances were found to vary significantly across the six zones. These attributes significantly influence farmers' decisions on maize cropping pattern and intensity, planting regimes and varietal selection, including germplasm maturity. The results indicated that the Kenya Agricultural Research Institute (KARI) needs to reallocate research resources to the transitional and mid-altitude zones and to reverse the historical bias towards the high tropics if larger gains are to be realised from maize research.

Key Words: Adaptation zones, farmers' knowledge, maize germplasm, GIS

RESUME

L'information en provenance des enquetes aupres des paysans etait combinee avec l'information climatique afin d'evaluer avec exactitude les caracteristiques biophysiques courantes des zones d'adaptation de mays (MAZs) du Kenya. L'analyse a montre que la meilleure definition de MAZs etait accomplie par l'integration de l'information des paysans et des donnees climatiques. La bonne caracterisation des systemes de production du mays ainsi que des contraintes est primodiale pour cibler la technologie du mays. Six MAZs [etaient definies comme des domaines a buts differents pour la recherche sur le mays contrairement aux 4 zones anterieures decrites seulement par la caracterisation biophysique. Les principaux facteurs de stress biotique et abiotique, le systeme des contraintes et les circonstances socio-economiques variaient significativement a travers les 6 zones. Ces facteurs influencent significativement les decisions des paysans sur l'intensite et le mode de culture du mays, les regimes de plantation et la selection varietale y compris la maturite du germoplasme. Les resultats ont indique que l'Institut de Recherche Agronomique du Kenya (KARI) a besoin de reaffecter les ressources de recherche dans les zones de transition et de moyenne altitude et d'inverser la tendance historique vers les hautes terres de tropiques si on veut realiser une plus grande production de graines de mai's a partir de la recherche.

Mots Cles: Zones d'adaptation, connaissances des agriculteurs, germoplasme du mais, GIS

INTRODUCTION

Agroecological classification is used to define spatial domains of crop production that have distinct technology needs (Hutchinson *et al.,* 1992), enabling efficient biological research, effective planning and accurate targeting of agricultural innovations. However, bio-physical suitability alone will not guarantee success and impact of planned interventions. Socio-economic, institutional and policy factors interact with the physical environment to influence the process of technology transfer. Innovations must be suited to the prevailing socio-economic environment and farmer oriented to be accepted by farmers.

Maize research in Kenya is organised to serve broadly defined adaptation zones. Since the early 1960's, the objectives of maize improvement research in Kenya were to develop the following maize germplasm to suit the four corresponding environments: late maturing varieties for the highland tropics (HT), medium maturing varieties for non-moisture-stressed mid-altitudes (MAT); early maturing varieties for moisture-stressed MAT (semi-arid); and lowland varieties for the humid low tropics (LT). These environments were defined on the basis of altitude and moisture availability (Gebrekidan *et al.,* 1992), and are consistent with the International Maize and Wheat Improvement Centers' (CIMMYT) categories of maize mega-environments, as broad zones of similar biotic and abiotic conditions for maize production (CIMMYT, 1988 unpubl. document). The present study combines information from farmer surveys with other spatial data to redefine the existing agroclimatic zonation for proper characterisation of maize production systems in Kenya.

MATERIALS AND METHODS

The Kenya Maize Data Base Project used Geographic Information Systems (GIS) techniques and climate attributes to delineate maize adaptation zones (MAZs) (Corbett, 1995). The MAZs were developed on the basis of environmental suitability and experts' definition of adaptability ranges for existing and improved maize germplasm. This zonation scheme provided the spatial frame for designing a geo-referenced survey of farmers' maize production practices (Hassan *et al.,* 1995a). Data from 1,407 farmer interviews were subsequently combined with climate and population attributes, intensity of maize cultivation, and other variables into a spatially integrated digital database which was used to assess the suitability of existing MAZs.

Climatic characterization of maize adaptation zones. Digital climatic surfaces were constructed using long-term meteorological data. Mean monthly minimum and maximum temperatures were derived using data from 81 stations. Mean monthly precipitation were derived using data from 979 stations. Cluster analysis was used to reduce the number of grid ceils to be interpreted into MAZs to a manageable number by merging similar cells using statistical criteria. Clusters with similar characteristics were then merged in a step-wise fashion (Corbett, 1995). Two zonation schemes were used to interpret the climate data into MAZs (Table 1): the current classification of MAZs adopted by KARI's maize research programme; and a new scheme with additional zone transition between the MAT and HT zones (Fig. 1). Seasonal rather than annual climate values were used and data for periods outside the maize growing season were considered irrelevant. Rainfall is bimodal and there are two cropping seasons for maize in Kenya. In most of the country, the March (long) rains support the major growing season, whereas in the eastern dry MAT the March and October (short) rains are of equal importance. Characterisation of the MAZs was based on the major season (March-August).

Farming systems data were compiled from geo-referenced farm and village level surveys. GIS techniques were employed to design a spatial frame for sampling sites and farmers from major maize producing regions in the country. Four spatial data sets were used to stratify maize regions into relatively homogenous clusters and determine sampling fractions: the agroecological zonation; population census; intensity of maize cultivation (area) maps; plus the national sampling frame of the National Sample Surveys and Evaluation Programme (NASSEP III) of the Central Bureau of Statistics (Hassan *et al.* 1995a).

A vector-based GIS software (ARC/INFO) was used to overlay the agroecological zones with intensity of maize cultivation and population coverage giving a cross-classification of the country by agroclimate, percent area under maize and population density strata. Farmers in the resulting climate-population (C-P) classes were sampled in proportion to area under maize and population density Table 1 (Hassan *et al.,* 1995a). A sample of 20 farmers per site was selected from small to medium-size farm populations in 65 sites, and 10 farmers per site from the 10 sites of large commercial farms which were surveyed as a separate stratum (Hassan *et al.,* 1995a). NASSEP Ill was utilised for the selection of sites and farmers within the C-P strata in a multi-stage stratified random sampling process.

RESULTS AND DISCUSSION

A refined definition of MAZs. Patterns of variety use deviated significantly from research recommendations, with the greatest divergence between farmers' practices and existing zonal specifications in MAT, where more farmers planted late maturity (600 series) than the medium maturity maize hybrids (500 series) developed for MAT environments. Inadequacy of the current agroecological zonation for maize germplasm adaptation, or dissatisfaction of farmers with the targeted varieties, may be the cause of farmers' failure to follow research recommendations.

MAZs were redefined to include a transitional zone (TNZ) between MAT and HT. The previous MAT zone was too vast for a single zone as it contained about 60% of the total area under maize (Table 1) and there is no distinct boundary between typical MAT and HT environments due to a continuum of climatic features. TNZ regions are naturally cooler than typical MAT but warmer than typical HT environments (Table 1). This is important for maize maturity since temperatures rather than elevation *per se* determine plant growth and development.

Figure 1. Map showing maize agroclimate zones for Kenya

The revised classification better characterised maize farmers' production practices. Land under late maturing hybrids in MAT dropped significantly after the formation of TNZ and the percent area under unimproved germplasm increased (Table 2). Most farmers in the moist parts of TNZ used late maturing hybrids but medium maturity hybrids were used more frequently in the drier parts of TNZ. While these results suggest that TNZ and MAT represent distinct environments for maize production, MAT farmers still prefer either late maturity hybrids or unimproved varieties over the 500 series targeted for their environment (Table 2). This may indicate dissatisfaction among MAT farmers with the available medium maturity varieties. Failure of MAT breeding programmes to improve on the existing medium and early maturing varieties could be due to KARI's emphasis in the past on the HT zone. Five new varieties were released for the HT over the past decade compared to none for the moist MAT and only one for thc LT and dry MAT environments (Table 2).

FARMERS' PLANTING STRATEGIES AND MAIZE MATURITY IN ADAPTATION ZONES

The early maturity zone (semi-arid). While half of the farmers in this zone used a local maize variety known as the white Machakos local (MLOC), the improved Katumani Composite (KCB) was popular especially among single maize season farmers (Table 3). KCB was released more than 25 years ago to farmers in this region, and it is probable that MLOC is a mixture of the original local variety and KCB. Also the cultivar which farmers call KCB may be a mixture as most farmers buy certified seed of KCB infrequently.

TABLE 1. Maize adaptation zones in Kenya: classification criteria, climate attributes, area under maize and sampling densities

Agroecological zone	Elevation (meters ASL) (a)	Mean seasonal rainfall (mm)	Mean daily temperature C Min.	Maxim	Area under maize (000ha (%))
Low-tropics (LT)	< 800	< 1000	20.0	29.4 (3.2)	33.0
Mid-altitude (MAT)					
Dry MAT	700-1300 (1000-1600)	< 600	16.1	27.9 (11.3)	118.0
Moist MAT	1100-1500	> 500 (11.3)	15.9	28.3	118.0
Transitional (TNZ)	1100-2000				
Dry TNZ		< 600	14.0	25.3	37.0 (3.6)
Moist TNZ		> 500	13.4	23.3	424.0 (41.0)
High-tropics (HT)	> 1600 (> 1700)	> 400	10.0	23.0	307.0 (29.6)

Table 1 contd./

Agroecological zone	Percent of sample farmers (b)	Population density (persons (c)	Average farm size (ha)
Low-tropics (LT)	7.0	121	2.4 (< 1000)
Mid-altitude (MAT)			
Dry MAT	13.0	210	3.6
Moist MAT	13.0	310	2.3 (1600-1700)
Transitional (TNZ)			
Dry TNZ	5.7	398	1.5
Moist TNZ	29.3	331	7.7

High-tropics (HT)	238	10.9	32.0

(a) Figures in brackets denote the initial altitude range that corresponds to the scheme of zonation adopted by the KARI maize research programme.
(b) Sampling densities were determined on basis of maize acreage and population density in the initial zonation, i.e., without a TNZ zone. According to the initial classification 57% of the total area sown to maize fell in the MAT zone, from which 59% of the sample was selected (Corbett, 1995; Hassan *et al.,* 1995).
(c) Average population density in surveyed sites according to the 1989 population census.

TABLE 2. Use of maize cultivar type and other farmers' practices in the major maize season

Agroecological zone	% area under late maturity hybrids (a)	% area under medium maturing hybrids (a)	% area under unimproved seed (a)
Low-tropics (LT)	0	0	84 (84)
Mid-altitude (MAT)	22 (76)	13 (2)	56 (21)
Dry	7 (7)	6 (6)	65 (66)
Moist	32 (82)	18 (2)	49 (16)
Transitional (TNZ)	82 (-)	6 (-)	16 (-)
Dry	2 (-)	10 (-)	88 (-)
Moist	87 (-)	7 (-)	6 (-)
High-tropics (HT)	86 (84)	11 (13)	5 (5)
Average	61 (61)	9 (9)	27 (27)

Table 2 contd./

Agroecological zone (b)	Varietal releases in past ten years	% farmers double cropping maize (%)	March the major season
Low-tropics (LT)	1	35	99
Mid-altitude (MAT)	1	57	-
Dry	1	50	48
Moist	0	60	96
Transitional (TNZ)	NT	45	-
Dry	NT	76	4
Moist	NT	40	98
High-tropics (HT)	5	22	89
Average	8	41	

(a) Figures in brackets represent area in the classification with no TNZ zone. The difference between 100 percent and the sum of the first three columns (% area under late and medium maturity hybrids and (b) unimproved seed) represent percent maize area sown to open pollinated varieties (composites). NT refers to environments that were not targeted by the breeding programme.

Intermediate maturity zones. The Lake Victoria region comprising the moist MAT and the higher parts of Machakos and lower Kiambu districts comprising the dry TNZ (Fig. 1) were classified as intermediate maturity maize zones. However, variety preferences differed for these two zones. Intermediate maturity maize hybrids (500 series) were used more in the dry TNZ, especially among the farmers growing two maize crops (Table 3). The lowland local (LLOC) varieties (Rachar and Nyamula) were the most common in moist MAT, and late maturity maize hybrids (600 series) were preferred to the 500 series by farmers growing one maize crop per year in this zone. The dry TNZ is higher in elevation, cooler and is expected to require longer maturity maize than the moist MAT. The H511 required less time to mature in the moist MAT than in the dry TNZ.

Farmers in the moist MAT, especially those who double-cropped maize, planted varieties that are relatively later in maturity than the 500 hybrids, apparently because the LLOCs were preferred for qualities other than short maturity. Better tolerance to low soil fertility and biotic stresses such as *Striga* may be more important to maize farmers in this zone than earliness for double-cropping. Results from field experiments have shown that selection of a tolerant genotype was more important than date of planting in reducing yield losses in maize due to infestation by *Striga* in this zone (Ransom and Osoro, 1991).

Farmers' preference for relatively early maturing varieties in the dry TNZ can be attributed to both the relative importance of the second season in that area and the general requirement for early maturity as a drought evading technology. Whereas all moist MAT farmers considered the March rains to be their major planting time, only 46% of the dry TNZ farmers indicated the same (Table 3). More than half the farmers in the dry TNZ considered the October rains more reliable. This may be the main reason why farmers' planted early maturing varieties during the March rains, allowing timely planting of their major maize crop in October. The relatively higher population density in the dry TNZ (Table 1) is another reason for the high rate of double cropping. Apparently biophysical and socioeconomic characteristics differentiate between the moist MAT, and dry TNZ as distinct production environments and target domains.

TABLE 3. Maize germplasm maturity recommendations and farmers' practices for the major season maize adaptation zone and cropping intensity (n=1407)

Agro-climate	Suitable germplasm (maturity)	Recommended varieties	Maturity range in days^b	Maize double cropping	
				Maize varieties^c	Days to^d maturity
Low-land tropics	Early Medium	HPON CCB	90-120 120-150	CLOC (84) HPON (7)	119 (19) 87 (37)
Semi-arid (Dry MAT)	Early	KCB & MCB	90-120	KCB (14) MLOC (55) H511 (11)	129 (28) 129 (29) 130 (41)
Moist MAT (Lake region)	Medium	H511, H512 & H622	120-150	LLOC (57) H511 (16)	161 (25) 135 (28)
Dry transitional	Medium	H511 & H512	120-150	MLOC (35) ULOC (32) H511 (29)	130 (32) 138 (14) 136 (32)
Moist Transitional	Medium -Late	H632, H622 H614, H625	150-180 >180	H614 (24) H625 (26) H511 (16)	177 (37) 172 (26) 137 (26)
High tropics	Late	H614, H625 & H626	> 180	H614 (37) H625 (44) H511 (13)	191 (57) 176 (34) 176 (51)

Table 3 contd./

Agro-climate	Single maize crop		Average maturity requirement^c		Variability in rainfall
	Most used variety	Days to^d maturity	Days^d	Thermal time (C days)6^	(% CV)^1
Low-land tropics	CLOC (70) KCB (13) CCB (10)	122 (36) 95 (27) 130 (34)	120 (33)	2124	3
Semi-arid (Dry MAT)	KCB (41) MLOC (48) H511 (10)	81 (36) 92 (41) 111 (42)	114 (47)	1767	52
Moist MAT (Lake region)	LLOC (35) H511 (12) H614 (26)	160 (19) 132 (43) 218 (51)	163 (40)	2461	32
Dry transition	ULOC (17) H511 (50)	146 (8) 148 (34) 144 (25)	144 (20)	1829	40
Moist transition	H614 (52) H625 (27) H626 (15)	201 (36) 189 (30) 198 (55)	181 (39)	2063	27
High tropics	H614 (53)	231 (50)	213	2066	32

H626 (16)	205 (43)	(53)
H626 (18)	213 (66)	

^a Varieties are named as follows: CCB, KCB and MCB to denote the Coast, Katumani and Makueni composites, respectively; CLOC, MLOC, LLOC, and ULOC, refer to the Coast, Machakos, Lake region and Upland locals; HPON, H511, H512, H614,etc. denote the hybrids: Pwani, H511, H512, H614.. respectively.
^b The range in days to maturity for the variety reflects the effect of intra-zone variations in altitude and hence temperature on maturity at KARI's experimental sites (KARI, 1992).
^c Figures in brackets denote percent farmers using the variety.
^d Based on time of planting and farmers' estimation of the date at which the maize crop reached maturity (ready to harvest). Figures in brackets denote percent coefficient of variation.
^e Computed as the sum of daily mean temperatures between zero and maximal rate of maize development (see Bonhomme *et al.,* 1994).
^f The percent coefficient of variation for mean total precipitation during the March-August season.

Late maturity zones. Late maturity maize germplasm is used by majority of farmers in the moist TNZ and HT zones (Tables 2 and 3). Maize double cropping is more common in the moist TNZ, possibly due to the relatively high population pressure and the bimodal rainfall pattern compared to the long single season in HT. In addition, the higher temperatures of the moist TNZ allow for earlier maturity. Maize double cropping in the moist TNZ is hindered by lack of a suitable genotype. While the 600 hybrids out-yield their 500 counterparts and fit better the March rain season of the moist TNZ, their late maturity makes it difficult for farmers to attempt a second crop. Moreover, silking of the 600 series usually coincides with the onset of the short rains ~n August causing heavy rotting losses while intermediate maturity hybrids do not fit very well in the short rains of the TNZ and are usually susceptible to blight (Njoroge *et al.,* 1992). These results suggest that, whereas numerous varieties are availed to TNZ farmers, better adapted varieties are needed.

The lowland tropics. The hot humid coastal environment is classified as a distinct maize production zone. Maize germplasm adapted to LT and the range of biotic and abiotic stress factors are different from other maize zones (Njoroge *et al.,* 1992). According to Table 3, most farmers used unimproved maize cultivars. However, average maturity ranges under farmer conditions were consistent with experimental results. The Coast Composite (CCB) matured latest followed by local coast (CLOC) varieties. KCB had the shortest maturity period. The recommended hybrid, Pwani (HPON), was used only by farmers who double crop maize. In a separate study, Hassan *et al.* (1995b) showed that the greater use of unimproved maize germplasm in LT was mainly due to lack of access to improved seed. Seed dealers were not found in many of the surveyed villages in this zone.

Duration to maturity in heat units. Average time to maturity (duration from planting to harvest) is expressed as number of calendar days as well as thermal time (in C days) in Table 3. Thermal time represents the sum of daily mean temperature between zero and maximal rate of maize development (Bonhomme *et al.,* 1994). Except for moist MAT, average days to maturity of maize genotypes planted in the defined MAZs fall within the experimental range (Table 3). The fact that moist MAT farmers used late (600 hybrids and LLOC), rather than intermediate maturity varieties, was the reason behind the relatively longer duration to maturity in this zone.

The heat units requirement of common varieties in drier environments (semi-arid and dry TNZ) were relatively low. More heat units were required for maize to reach maturity in the hot humid LT, and moist MAT than in the HT, although the rate of accumulation of the required heat units was high in those zones compared t~ the HT where the season was the longest in terms of the number of calendar days (Table 3).

CONCLUSIONS AND IMPLICATIONS FOR RESEARCH

Farmers' practices in the maize adaptation zones currently used by KARI deviate significantly from the recommended practices. New boundary conditions were, therefore, developed and zones reclassified to differentiate a new zone transition between typical MAT and HT, thereby better accounting for farmers' preferences for maize maturity times. Moreover, a historical bias towards the HT was observed in KARI's and the Kenya Seed Company's records of varietal development. A shift in KARI's maize research strategies and resources is, accordingly, needed to reverse the observed imbalance and under-investment in the important MAT and TNZ environments.

At present, maize breeding at KARI does not adequately cater for the needs of the TNZ fanners who cultivate about 45% of the total area under maize in Kenya. The HT programme at Kitale screens for late maturity and, hence, discards materials of less than 180 days to maturity. At the same time, the medium maturity programme at Embu selects germplasm of 120-150 days to maturity, rejecting later materials, and excluding materials requiring between 150-180 days to mature. However, the 150-180 days to maturity germplasm is required for the TNZ zone. It is, therefore, considered strategic and of prime importance to maize improvement research in Kenya to screen materials suitable for the TNZ zone. A maize breeder was recently (1991) posted to the Regional Research Center in Kakamega which is located in the TNZ, but Kakamega, participates only in advanced testing of maize germplasm (Njoroge *et al.,* 1992). Kakamega should be involved at much earlier stages of germplasm development i.e. top cross testing, progeny evaluation and in preliminary yield trials.

The distinction between the spectrum of diseases in MAT and cooler TNZ environments has become more evident over time and recognised by the CIMMYT maize breeding programme (CIMMYT, 1988). Although the term 'transition' has been used to indicate something less than a distinct zone, we find more and more evidence that TNZ represents a distinct biophysical environment for maize production.

Socio-economic factors such as population pressure have important influence on maize cropping patterns and intensity and, consequently, affect maturity requirements, farmers' planting strategy and varietal selection. It is therefore important to take into account population density and the quantity and quality of available land resources in designing appropriate maize technologies that are efficient and less resource degrading. For example, shorter maturity, tolerance to low soil fertility and lower dependence on external inputs must be the basis for helping resource poor maize farmers m the dry and moist portions of the M AT and TNZ zones. On the other hand, maize research needs to concentrate on developing technologies that increase the productivity of capital and labour in high potential areas where medium to large size maize farming is most dominant.

A major result of this study was the demonstration of the appropriateness of the agroecological zonation approach to research planning. More important was the significant improvement in characterising maize production systems and environments achieved by pairing survey data on farmers' practices and priorities and other socioeconomic factors with agroclimate attributes. The study has accordingly confirmed the importance of incorporating layers of information other than climatic data for proper definition of crop production environments and accurate targeting of maize research.

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