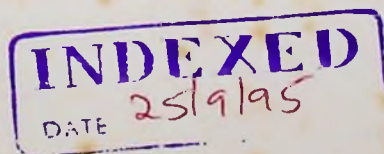


INHERITANCE OF TOLERANCE TO SOIL ACIDITY AND EFFECTS ON AGRONOMIC  
CHARACTERISTICS AND LEAF MINERAL ELEMENT CONCENTRATIONS  
IN SORGHUM [Sorghum bicolor (L.) Moench].

By

Vincent Makumbi Zake

A Dissertation  
Submitted to the Faculty  
of Mississippi State University  
in Partial Fulfillment of the Requirements  
for the Degree of Doctor of Philosophy  
in the Department of Agronomy



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Candidate for Degree of Doctor of Philosophy

Acid infertile tropical soils are a major constraint on production in much of the tropics. The objectives of this study were to identify attributes of acid soil tolerance and study their inheritance. Thirty four genotypes consisting of 10 parents and 24 F<sub>1</sub> hybrids from a North Carolina Mating Design II were evaluated in Mississippi and at four acid soil locations in Kenya in 1990 and 1991.

There were significant differences among genotypes for days to flower, plant height, head length, peduncle length, number of grains per head, grain yield, and 1000 seed weight at most of locations in both years; however, differences among parents and expressions of heterosis were generally confined to the better environments, Mississippi State University and Obambo. Agronomic traits which appeared to be good indicators of tolerance to acid soil conditions included earlier maturity, taller plants, longer heads, and higher yields. General combining ability was the primary source of genetic variation for these traits and,

consequently, should respond rapidly to selection and could be utilized in either a cultivar or an  $F_1$  hybrid.

Soil acidity had an adverse effect on most agronomic characteristics; however, several superior hybrids were identified in acid soil environments. Tolerant males, IS7254C and IA28, consistently imparted good agronomic characteristics to their hybrids under low pH conditions, while TX623 and Wheatland were the best female general combiners.

There were significant differences among genotypes for most leaf mineral element concentrations. Elements which showed the most promise as indicators of tolerance to acid soil were calcium and magnesium; however, measurements of leaf mineral element concentrations are expensive, time consuming, and require highly skilled labor. Consequently, agronomic traits would be more efficient evaluators of acid soil tolerance, particularly in developing countries, where much of the world's acid soils are found.

Broad-sense and narrow-sense heritabilities for most traits tended to be higher in the better environments. Heritabilities for days to flower, plant height, and peduncle length were generally high, but other agronomic characteristics were typically in the low to intermediate range and showed considerable variation across locations. Heritabilities for mineral element concentrations tended to be low to intermediate.

## DEDICATION

Dedicated  
in  
memory of  
Francis Kisitu, my brother-in-law.

#### ACKNOWLEDGEMENTS

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V. M. Z.

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## CHAPTER I

### INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] ranks fifth in importance among the world's cereals, after wheat (*Triticum aestivum*), rice (*Oryza sativa*), maize (*Zea mays*) and barley (*Hordeum vulgare*). Sorghum is of major importance as a daily food for half a billion people (Rooney et al., 1986), primarily in Asia, Africa and Latin America. In the United States of America and developed countries of the temperate regions, sorghum is important for animal feed (Doggett, 1970). In China, India and the United States, the total sorghum plant is used in various forms for green chop, hay, silage, and pasture. In some areas, the stalks are used as building materials and the remaining plant materials are used for fuel after harvest (Doggett, 1970). In industry, products such as starch, syrup, sugar, and industrial fuel; and by-products such as glucose, dextrans, and sorghum oil have been successfully manufactured from sorghum, at one time or the other (Doggett, 1970). Broomcorn [*Sorghum bicolor* (L.) Moench] is important in the broom-making industry. In China, sorghum is used in production of wines. In third world countries, use of about 35% sorghum adjunct in the brewing industry, has yielded beers which are comparable to commercial barley malted lager in alcoholic content, taste, and acceptability.

Sorghum has achieved importance as a well-adapted crop of the arid and semi-arid tropics due to its tolerance to drought and many other

stress conditions and its relatively lower fertilizer requirements. Sorghum can be grown successfully on a wide range of soils. It will grow on heavy deep-cracking vertisols, as well as light soils; however, it occupies heavier sands in the tropics (Doggett, 1988). Grain sorghum roots will penetrate to a depth of approximately 182 cm or until a chemically or physically impenetrable barrier is encountered (Doggett, 1988). The lower pH limit for sorghum growth has been reported to be 4.0 to 5.0 (Shuman *et al.*, 1990; Sutton and Dick, 1989). Sorghum tolerates a pH range of 5.5 to 8.5 and some degree of salinity, alkalinity, and poor drainage (Doggett, 1988).

In Eastern Africa, where 75% of the land area is semi-arid with an average annual rainfall of 400 to 1000 mm, sorghum is considered to be the most important crop in the region (Guiragossian, 1986). The countries of Eastern Africa collectively produce about 4,000,000 tons of sorghum grain on about 6,000,000 hectares of land. The region consists of Burundi, Ethiopia, Kenya, Rwanda, Uganda, Somalia, Sudan, and Tanzania. These countries have much in common: history of origin, large land masses consisting of poor soils, unreliable weather, and economic, political, and scientific problems. Due to elevation and physiographic diversity, agricultural systems and cropping patterns in the region are divergently adapted to the various agro-climatic zones. As a result, soil, animal, and crop husbandry, diseases and pests, social and economic management, and demographic density vary according to these systems and patterns (Guiragossian, 1986).

Soil management currently is based on traditional cultural practices with no systematic, uniform, or organized trends of

operation. Land utilization in most areas is not based on its potential productivity and capability. Consequently, land is not being managed according to its requirements. Soil degradation and erosion are widespread. With the degradation of more fertile soils, and faced with increased land requirements to intensify the use of new arable land due to increasing population pressure, large areas known to be marginally productive, have been brought under cultivation (Lopes *et al.*, 1987).

The practice of liming acid soils has long been recognized as necessary for optimum crop production in such soils. The adoption of liming is limited by its cost in agricultural systems which are basically subsistence farming and which use relatively few inputs. Moreover, liming the soil surface does little to correct the chemical impediments to root penetration found in the subsoil (Gourley, 1987b).

Using plants tolerant to acidity is an important complementary approach to soil management. In subsistence agriculture, stable performance is more important than high yields in favorable environments. Laboratory and greenhouse procedures for evaluating sorghum tolerance to acid soils with low fertility status in the tropics have been developed. Gourley *et al.* (1990) reported inconsistencies between acid soil and solution culture techniques and demonstrated that different genetic responses to the treatments were being measured. The objectives of this study were to:

- (1) identify attributes of acid soil tolerance and transfer these to high yielding agronomically acceptable cultivars;
- (2) determine the influence of soil acidity limitations on the

performance of sorghum in low fertile acid soils in major sorghum producing low altitude areas of Kenya;

- (3) evaluate combining ability for tolerance to soil acidity; and
- (4) study genotype-environmental interactions, heritability, and heterosis in relation to soil acidity and identify plants that better tolerate mineral deficiency and toxicity stresses associated with these soils.

## CHAPTER II

### LITERATURE REVIEW

#### Soil acidity

Soil acidification is a natural process which starts when rock surfaces are first colonized by algae and lichens. Acids, largely derived from carbon (C) and nitrogen (N) cycles, are involved in the dissolution of soil and rock minerals during the process of soil development. In natural ecosystems, soils gradually become more acidic with time. The older and more weathered soils are generally more acidic than young soils. In general, superimposing agricultural production on an ecosystem results in faster rates of soil acidification (Helyar and Porter, 1989). In agricultural and natural ecosystems, the N cycle plays an important role in causing soil acidification (Helyar and Porter, 1989). In agricultural ecosystems, acids in the sulfur (S) cycle are sometimes important (acid sulfate soils, acid rain, elemental S, or finely divided sulfides in fertilizers). Over periods involved in soil formation, iron ( $\text{Fe}^{3+}$  to  $\text{Fe}^{2+}$ ) and manganese ( $\text{Mn}^{4+}$  to  $\text{Mn}^{2+}$ ) transformations have been implicated in acidification (Mann, 1983).

Water in soil contains carbonic acid ( $\text{HCO}_3$ ) in equilibrium with carbon dioxide ( $\text{CO}_2$ ) in the soil air. As water percolates through the soil, acidification occurs when bicarbonates are leached. In acid

soils, inputs, outputs, and the accumulation of  $\text{HCO}_3$  can be significant causes of pH change. Acid rain reduces soil pH to levels at which aluminum (Al) and other acid soil problems [hydrogen ( $\text{H}^+$ ) and Mn toxicity, and calcium ( $\text{Ca}^{2+}$ ) deficiency] are highly likely (Helyar and Porter, 1989). Low molecular weight organic acids such as glutamic, aspartic, malic, citric, and tartaric acid are usually present in acid soils (Huang, 1988).

Aluminum is released from soil minerals by chemical and biochemical weathering reactions. The hydrolysis and polymerization of Al releases protons, leading to acidification of the environment (Huang, 1988). Released protons attack Al-bearing minerals, resulting in the dissolution of Al. The dissolved Al undergoes hydrolytic reactions and releases protons to soil solutions and natural waters and thereby generation of protons is perpetuated. The proton generation process can be accelerated by the presence of silica relics. Consequently, the weathering of Al-bearing minerals, which can be enhanced by leaching, natural vegetation, farming, and other anthropogenic activities, would lead to acidification of soils and the associated environment (Huang, 1988).

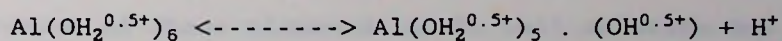
Soil acidity has also been defined in terms of potassium chloride (KCl) extractable and pH-dependent acidity (Sharma *et al.*, 1990). Extractable acidity was ascribed to isomorphous substitution while pH-dependent acidity was ascribed to polymers of Fe and Al and soil organic matter. Exchangeable  $\text{H}^+$ ,  $\text{Al}^{3+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Mn}^{2+}$ , and certain other hydrolyzable ions on the soil exchange complex also contribute to acidity on hydrolysis (Sharma *et al.*, 1990). They concluded that in

soils in which there was a high base saturation percentage and low pH, the major portion of the acidity must have originated from the hydrolysis of Al, Fe, and Mn thereby forming hydronium ion ( $\text{H}_3\text{O}^+$ ) which lowers the pH of the soils.

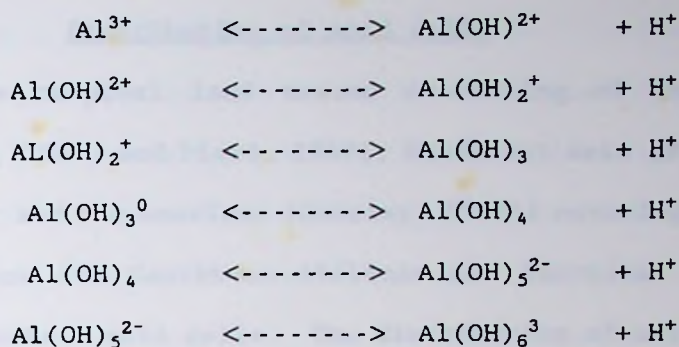
#### Distribution of aluminum in soils

Aluminum is the most abundant metallic element in soils and the associated environment (Huang, 1988). Besides affecting soil acidity, microbial events, enzyme activities, transformation of organic matter, soil structure, and status of nutrients for plant and animal production, transformation of Al can also affect the bioavailability of environmental pollutants and biocides and the subsequent food chain contamination in terrestrial systems. Distribution of Al in soils is either octahedrally or tetrahedrally coordinated with oxygen ( $\text{O}_2$ ) in crystalline and short-range ordered Al-bearing minerals. It also exists as exchangeable Al and hydroxy Al interlayers and as coatings on the edges and external planar surfaces (Huang, 1988).

In very acid soils ( $\text{pH} < 4.0$ ), Al ions are present as aluminohexahydronium ions  $[(\text{Al}.6\text{H}_2\text{O})^{3+}]$ , but are usually designated  $\text{Al}^{3+}$ . The aluminohydronium ions sequentially dissociate  $\text{H}^+$  as pH increases, leaving  $\text{OH}^-$  in place of  $\text{OH}_2$  groups, i.e.



The usual sequence of  $\text{H}^+$  dissociations is as follows:



At pH values greater than 6.5, Al becomes increasingly soluble as negatively charged aluminates form. The positively charged monomeric  $\text{Al(OH)}^{2+}$  and  $\text{Al(OH)}_2^+$  species can polymerize to form both large and small positively charged polynuclear complexes (Haynes, 1984). Soluble Al species may be divided into two groups: monomers and polymers (Huang, 1989; and Ritchie, 1989). The proportion of soluble Al in each category may be estimated theoretically using thermodynamic principles or, alternatively, by assuming that Al species which react quickly (< 2 min) with a colored complex are monomeric (labile) and Al species that react more slowly (> 30 min) are polymeric or non-labile (Ritchie, 1989). As soil pH increases, Fe also precipitates as hydroxy-Fe species and Mn precipitates as Mn oxides. The presence of oxides containing Al and Fe in amorphous and crystalline phases has been observed in soils and it has been shown that positively charged Al- and Fe- hydroxy copolymers could form by bridging of  $\text{Al}^{3+}$  and  $\text{Fe}^{3+}$  through hydroxyl groups. Acidity increases the solubility of Fe, Al, and Mn and the concentration of these elements in the soil solution may reach toxic levels in very acid soils (Grundon *et al.*, 1987).

### Distribution of acid soils

Considerable tropical land masses consisting of the African continent (Larson, 1986; and Pieri, 1987); Southeast Asia (Pushparajah and Bachik, 1987); and the Americas (Gourley, 1987b) covering South and Central America and the Caribbean (Salinas and Castilla, 1987; and Gourley, 1987b) contain acid soils. The distribution of acid soils in the tropics generally occurs between 23°N and 23°S latitude (Gourley, 1987b). Acid soils are generally formed by Oxisols, Ultisols, and Inceptisols which occupy 23, 20, and 14% of the land area of the tropics, respectively (Gourley, 1987b). Continent-wise, these major soil orders in the Americas, Africa, and Asia cover 1463, 1143, and 810 million hectares, respectively.

About 50% of the tropical land mass in Africa has acid soil. Pieri (1987) has categorized acid soils of Africa into:

- 1) acid soils in the humid tropics and savannas; and
- 2) acidified cultivated soils common in Western Africa that cover humid, subhumid, and semi-arid zones.

The acid soils in humid tropical zones of Africa cover several hundred million hectares: the zone of the Benin Gulf, the Adamaoua Plateau, Cameroon, the Congo Basin, the high Plateau of Madagascar, and the highlands dividing the Zaire and Nile basins (Pieri, 1987). A large majority of soils in sub-Saharan western Africa belong to the Alfisol tropical subgroups. In East Africa, the suborders, Tropudults with Orthox, are predominant in Uganda; Ustalfs with Usterts in Kenya; and Ustalfs with Usterts and Ustox with Ustalfs in Tanzania. Most of the area has an acidic to Ustic soil moisture regime and a thermic or

isohyperthermic soil temperature regime. The area Northwest of Lake Victoria extending into northern Kenya and beyond is acidic isohyperthermic. Many contain fragments or consolidated materials and are extremely acidic within 50 cm of the surface (Larson, 1986).

Fluctuations in surface soil acidity occur in response to several factors:

- 1) most significant in tropical areas, is decreased acidity from ash after either the burning of fallow or from additions of lime, when applied;
- 2) acidification occurs in response to addition of acid-forming fertilizers, or more commonly from organic acids released during reactions involved in organic matter decomposition, which is especially active after initiation of cultivation;
- 3) duration and intensity of the surface soil pH and exchangeable Al flux after any of the above cultural events depend upon a multitude of parameters; and
- 4) sandy textured soils generally respond more dramatically because of their cation exchange capacity (CEC) and low organic matter contents than do finer textured soils (Huang, 1988).

#### Characteristics of acid soils

Acid infertile tropical soils are considered marginal for agricultural production (Pieri, 1987; Lopes *et al.*, 1987; and Gourley, 1987a). The major constraints to crop production on the land are mineral stress, low soil organic matter content, acidity, shallow soil

depth which affects rooting depth, and drought (Larson, 1986). Kaolinitic soils are characterized by a surface horizon that is usually coarse textured, poorly buffered, and low in organic matter (Pieri, 1987) accompanied by a low capacity for retaining water for growth (Pieri, 1987; Lopes *et al.*, 1987). Ultisols have very few primary minerals left to supply bases in the root zones of most crops (Pushparajah and Backik, 1987); are high in Fe and Al; have low fertility, and are often shallow in depth with large areas prone to drought (Clark and Gourley, 1987). Surface reactivity of Fe and Al oxides is a key factor controlling the phosphorus (P) sorption capacity of soils (Juo, 1987). Oxisols have also low capacity for retaining water for growth (Pieri, 1987; and Lopes *et al.*, 1987). The clay fraction of oxisols is dominated by minerals that have a low surface area and CEC. Consequently, an oxisol may have high clay content, be very infertile, and have a low capacity for retaining water for growth. An effective CEC value of 14meq/100g clay has been proposed as the criterion to differentiate soils with low activity clays from those with high activity clays (Juo, 1987). In humid climates, weathering leaching processes lead, sooner or later, to natural acidification of permeable soils. The fundamental factors that limit the fertility of such soils are

- 1) impoverished nutrient status [e.g. deficiencies of P, molybdenum (Mo), S, potassium (K), Ca, copper (Cu), magnesium (Mg), or zinc (Zn)]; and
- 2) the presence of phytotoxic substances (e.g. soluble Al, Fe, and Mn).

In particular, phosphate presents special difficulties because it is subject to strong fixation by soil components (Clark and Gourley, 1987; Haynes, 1984).

Despite the enormous area covered by acid tropical soils and the differences between humid and savanna acid soils, these soils, as a group, have common constraints. These constraints are usually chemical rather than physical (Gourley, 1987a). The magnitude and significance of the constraints, however, varies with the ecosystem and the use and management of these soils (Lopes *et al.*, 1987). Deficiencies of N, and P are by far the most limiting soil chemical constraints in terms of percentage of total area affected. Deficiencies of K, S, Ca, Mg, Zn, and Cu; Al toxicity; P fixation; and low CEC complete the list of major constraints (Lopes *et al.*, 1987). Aluminum toxicity is more widespread than Mn toxicity (Nelson, 1983).

#### Influence of soil pH

The greatest influence of soil pH on plant growth is its effect on the availability of nutrients. At low soil pH, Mo forms insoluble compounds with Fe and is unavailable. The factors adversely affecting crop growth on strongly acid soils are complex, but at low pH, the most characteristic problems are the result of toxic levels of Al, Fe, and Mn and deficiencies of Ca, P, Mg, and Mo (Clark and Gourley, 1987). The greatest risks of allowing soil pH in farming and pastoral areas to decline are, besides the obvious effects of low yield, restricted choice of species, reduction in the fertility of subsoil, and high erosion risk following the failure of plants to provide adequate ground

cover and soil stabilization (Crogan *et al.*, 1989).

#### Detrimental effects of Al on plant growth

Aluminum, as a major soil constituent, is an important growth limiting factor for plants in many acid soils below soil pH 5.0 (Taylor, 1989), but can limit growth at pH levels as high as 5.5 (Aniol *et al.*, 1980). The major characteristics of Al toxicity to most crop species are inhibition of root growth, resulting in swollen, stubby roots and the complete absence of lateral and branch root development; and top growth (Rhue *et al.*, 1978; Haynes, 1984). Lateral roots appear to be more sensitive to damage than primary roots, but all root growth is reduced as Al levels increase. Consequently, the root system is inefficient in absorbing nutrients and water. There is inhibition of the uptake and translocation of P by plants (Haynes, 1984). Phytotoxic metals inhibit root growth more severely than leaf growth (Taylor, 1989). Strong subsoil acidity with Al at toxic levels reduces root penetration and the plant's ability to withstand drought (Boye-Goni and Marcarian, 1985; Goldman *et al.*, 1989); reduces nutrient uptake; and causes a reduction in yield and P and Ca contents of plants. Low shoot dry matter yields in sorghum have been reported in ferric and aluminum phosphate soils (Furlani *et al.*, 1986). Ohki (1986) reported that in sorghum, Al toxicity decreased photosynthesis and chlorophyll concentration and there was enhanced red pigmentation induced in leaves by K, Ca, Mg, and Mn deficiencies and mineral element toxicities. High Al concentration in sand culture has been reported to delay nodulation and depress plant growth in *Stylosanthes* species.

Inorganic monomeric species of Al have been reported to be toxic to root growth, whereas Al present in soluble organically complexed forms is of low toxicity (Kerven *et al.*, 1989). In rye (*Secale cereale* L.), Al ions have been reported to accumulate in the cell nucleus, disturbing the mechanism of deoxyribonucleic acid (DNA) replication (Aniol *et al.*, 1980). Aluminum has been reported to accumulate in the cytoplasm of plant cells in a form bound to ribonucleic acid (RNA) and to the membrane, thereby interfering with protein synthesis and energy production (Haynes, 1984). Soil Al availability was observed to reduce vesicular-arbuscular mycorrhizae (VAM) colonization of sorghum roots and VAM activity in the soil (Raju *et al.*, 1988).

#### Tolerance to soil acidity

Species vary in their reaction to soil acidity. The existence of such differences has raised the possibility of breeding agriculturally important plants for improved tolerance to soil acidity. Acid tolerant varieties have eliminated the need for liming on large areas that previously could not be cropped without heavy lime application (Atlin and Frey, 1989). Moreover, liming may be ineffective in preventing subsoil acidification. Liming gives only small yield improvement because the zone of ameliorated soil does not extend far enough down the profile. Root growth is frequently confined to the amended top soil because the toxicities of the soil below, particularly excess Al, strongly restrict root extension and root growth in this zone (Crogan *et al.*, 1989). Besides being costly in land-locked countries and subsistence farming systems, the negative effects of liming can include

reduced P availability, suppressed availability of Mg and K, and induced deficiencies of micro nutrients such as boron (B) (Robson and Abbott, 1989).

Most Al-tolerant cultivars have come from areas known to have acid Al-toxic soils (Doggett, 1970) and the least tolerant cultivars have generally originated from areas with calcareous soils (Boye-Goni and Marcarian, 1985). Gourley (1987b) reported that higher percentages of sorghum lines in the tolerant and moderately tolerant category were selected from acid soil areas in Kenya and Uganda than from the other African countries. Gourley, (1987c) reported a higher percentage of moderate to highly Al-tolerant entries from the guinea race of *Sorghum bicolor* than from the other four sorghum races. Hayne (1984) reported large differences in relative Al tolerances of triticale (*X Triticosecale* Wittmack) and wheat. Tolerance differences of these cultivars were related to differences in Al tolerance of the parent species used.

Physiological mechanisms of Al tolerance differ in different plant species and cultivars and may be controlled by different genes through different biochemical pathways. Scott and Fisher (1989) suggested plant tolerance to Al may operate in several ways:

- 1) the pH in the root zone may be increased thus decreasing solubility and toxicity of Al;
- 2) lower CEC of the roots;
- 3) resistance of plasmalemma to Al damage;
- 4) morphological change under Al stress (e.g. production of mucigel to protect the root from Al damage);

- 5) in plant tissue, cytoplasmic Al is inactivated or detoxified as Al is complexed by organic molecules, so that it does not disrupt cell metabolism;
- 6) differential distribution of tissue Al in tops and roots; and
- 7) tolerance to low internal concentrations of Mg, Ca, P, and Fe.

Aluminum accumulation within plants in relation to Al tolerance has no general pattern. Some plant species which are tolerant to high levels of solution Al, accumulate and detoxify Al within their tissues. Tea (*Camellia sinensis* L. Ktze) detoxifies Al by complexing it with organic acids and polyphenols and accumulating it in older leaves. In contrast, the tops of some Al-tolerant plants contain lower concentrations of Al than do those of sensitive plants, which is often due to accumulation of Al in the roots of tolerant plants (Foy and Fleming, 1978). A third group of Al-tolerant plants contain lower concentrations of Al in the roots than do sensitive plants, but have similar concentrations in their tops.

Evidence suggests that the pH induced by roots of plants grown in solution culture or soils, often increases with increasing resistance of plant species or cultivars to Al toxicity (Haynes, 1984). Differential pH-changing abilities among Al-tolerant and Al-sensitive wheat cultivars have been postulated to be due to differences in nitrate absorption. Aluminum tolerance in wheat cultivars has been characterized by the ability to use nitrate N efficiently in the presence of ammonium N, thus raising the pH of the growth medium (Foy and Fleming, 1978).

Aluminum tolerance has been associated with Al accumulation in roots expressed as magnitude of the net negative charge of the root (root CEC). Some Al-tolerant cultivars of ryegrass (*Lolium perenne* L.), wheat, and barley have lower root CECs and accumulate less Al in their roots than do Al-sensitive ones. Such a mechanism assumes that most of the Al in roots is held by exchange-adsorption to cell walls of the free space (presumably as Al), whereas evidence suggests that it is precipitated in nonexchangeable forms (Haynes, 1984).

The ability of plants to utilize phosphate and Ca in the presence of Al was suggested as a possible mechanism of tolerance of plants to acid soil condition. In some cultivars of wheat, barley, soybean (*Glycine max* L.), and snapbean (*Phaseolus vulgaris* L.), Al tolerance has been associated with the ability to resist Al-induced Ca deficiency (Foy and Fleming, 1978). In some Al-tolerant wheat, maize, and tomato (*Lycopersicon esculentum* Mill.) cultivars, Al tolerance has been associated with the ability to tolerate low phosphate levels in the presence or absence of Al (Foy and Flemming, 1978). Ambient Al in nutrient culture solution has been reported to increase P concentration in the tops of Al-tolerant legumes, but decrease in those of Al-sensitive species (Andrew and Vandenberg, 1973). Andrew *et al.* (1973) studied the effects of Al treatment on Al, N, P, Ca, K, Mg, and Na content in plant tops of tropical and temperate pasture legume species. In tropical species, Al concentrations in plant tops increased. In all species, Ca concentration in plant tops was reduced. In species sensitive to Al, the content of P and K decreased. In the majority of

tolerant species, K concentration increased. There was no consistent effect of Al on N concentration in plant tops; however, there was little effect on Mg levels and no significant effects on Na. They concluded that the reduction in Ca concentration in plant tops of tolerant species was balanced by reciprocal increases in K and Mg.

Since Al and Mn toxicities are related to soil acidity, plants growing in acid soils might be expected to be tolerant of both Al and Mn. Macfie and Taylor (1989) reported that Mn tolerance was positively correlated with Al tolerance in wheat; however, other workers have reported that Mn tolerance was not related to Al tolerance in studies with *Amaranthus tricolor*. Tolerance to excess Al was not necessarily correlated with tolerance to excess Mn in rice (Nelson, 1983). In *Phalaris aquatica* (L.), Al has been reported to counter the effects of Mn toxicity (Culvenor, 1985). In rice, reduction in Mn uptake caused by Al is in contrast to the situation in *Brassica* where Al increased Mn concentrations and consequently toxicity symptoms (Culvenor, 1985). In potato (*Solanum tuberosum*) and maize, Mg uptake was greater in cultivars tolerant of Al toxicity than in sensitive cultivars (Scott and Fisher, 1989). Other studies suggest that K, Ca, Mg, and ammonium ( $\text{NH}_4$ ) have significant effects in alleviating Al toxicity in various crops (Alva et al., 1986).

In sorghum, tolerance to acid tropical soil conditions has been associated with differences in plant part distribution of mineral element concentrations in plant tissue (Clark and Gourley, 1987). Seminal root lengths have been used to assess Al tolerance of sorghum (Furlani and Clark, 1981). The effect of Al toxicity on root

elongation and death of the growing point is the current basis of the many rapid tests for Al tolerance in plants. The ability of plants to tolerate low internal concentrations of Ca, P, and Fe has been suggested as the basis for Al tolerance. Duncan (1987) reported that the most Al-tolerant genotypes accumulated higher levels of Cu, Mn, Ca, and Mg, as well as lower levels of K than other genotypes. Differential distribution of Al between sorghum plant tops and roots has been reported as a possible tolerance mechanism (Gourley, 1987a). Duncan (1987) reported that Al concentrations in sorghum leaves collected from different soil pH treatments were identical. Gourley (1987a) reported that most Al-susceptible genotypes grown on Al toxic, low base status soils in the tropics died within 2 to 4 weeks while other genotypes differed in their responses to Al-toxicity stress at different stages of plant growth. Under 60% Al saturation, about 10% of the genotypes exhibited a high degree of tolerance to Al toxicity. Duncan and Shuman (1990) reported, however, that an Al saturation of 50% with soil organic matter contents of < 5% was the maximum field stress level which the sorghum genus was able to withstand.

Characteristics commonly used to evaluate field grown plants for tolerance to soil acidity are survival, rating of visual toxicity symptoms (plant vigor), weight of aerial plant parts, grain yields, and leaf mineral contents (Flores *et al.*, 1988). Flores *et al.* (1988) reported that genotypes tolerant to acid soil grown at 63% saturation (pH 4.1) had higher harvest indices, were taller, and showed more favorable growth and yield traits, than susceptible genotypes. Head length was not affected by stress due to high Al saturation. Days to

flowering was delayed 3 days for tolerant genotypes as compared to 8 days for susceptible genotypes (Flores *et al.*, 1988).

Clark and Gourley (1987) reported that element contents disrupted the most when plants were grown on acid soils were P, Ca, K, and Mg. They suggested that silicon (Si) may be associated with overcoming Mn and Fe toxicity in some plants. Concentrations of P, K, Ca, Mg, Cu, and Si were lower; Mn, Fe, and Al were higher; and chlorine (Cl), S, and Zn remained unchanged in leaves of plants grown on an acid soil compared to leaves of plants grown on a neutral soil. They further reported that in two acid soils treated with 2 and 6 tons lime ha<sup>-1</sup>, respectively, concentrations of Ca and Si increased and Mn, Fe, and Al decreased in leaves of plants. Galvez *et al.* (1987) reported Si effects were not sufficient to completely overcome Mn and Al toxicity effects on sorghum.

### Heterosis

The discovery of genetic male-sterile gene, *ms*<sub>2</sub>, and cytoplasmic male sterile gene, *msc*<sub>1</sub>, in sorghum made the use of commercial sorghum hybrids by farmers possible and made the hybrid seed production industry a commercial success. Heterosis, defined as the superiority of an F<sub>1</sub> hybrid over the midparent, and heterobeltiosis, defined as the superiority of an F<sub>1</sub> hybrid over the better of its two parents, have been characterized in sorghum. Heterosis for yield is usually measured as the yield increase of the F<sub>1</sub> compared to the mean of the combined parental yields, although for practical purposes it is often better to take the yield of the better parent as the baseline (Doggett, 1988).

Measurement of heterosis over different environments provides information useful in selection of lines for hybridization. The yield increase of the hybrid relative to a conventional cultivar is rather constant over a wide range of growing conditions and management levels. Percentage heterosis is a statistic which is applicable only to the trial in which it was measured (Doggett, 1988).

Heterosis in sorghum is mainly due to faster plant growth (Quinby, 1974). Finkner *et al.* (1981) and Wilson *et al.* (1978) reported that grain yield was determined by dominant or overdominant gene action. Rubaihayo and Makumbi (1976) found yield to be under the control of significant dominant and epistatic effects. They reported that most yield components of sorghum showed significant heterotic effects, but the degree of heterosis depended on the type of hybrid. Finkner *et al.* (1981) reported that 43% of test crosses yielded significantly better than their midparent mean and 35% of the crosses yielded significantly more than the highest yielding parent. Wilson *et al.* (1978) observed highly significant differences among parents and  $F_2$  hybrids for grain yield in sorghum. Also, Laosuwan and Atkins (1977) and Liang *et al.* (1972) observed greater heterosis for grain yield than for any of the yield components they studied. Nandanwankar (1990) reported that the manifestation of heterosis for grain yield in sorghum was due to increased number of seeds per earhead, earhead length, and grain size. He further reported that some hybrids exhibited significant positive heterosis for earhead length, involving long x long panicle parents. Doggett (1988) considered heterosis to be the result of additive gene action and yield increase in hybrids was

ascribed to the use of superior parents. Quinby (1974) reported that grain yield advantage in sorghum hybrids consistently results from a larger number of grains per panicle than in either parental line. Liang *et al.* (1972) obtained low heterobeltiosis for plant height and negative heterobeltiosis for days-to-first-bloom and kernel weight. Quinby (1972) found that mature kernels of male parents were heavier than those of hybrids.

#### Combining ability

The concept of general and specific combining ability has become increasingly important in plant breeding because of the widespread use of hybrid cultivars in many crops (Wilson *et al.*, 1978). Although additive genetic variance may result from the action of genes that also display dominance, knowledge of the relative amount of additive variance for important quantitative traits is useful in predicting the amount of improvement when selection is to be practiced (Bittinger *et al.*, 1981). Wilson *et al.* (1978) reported that general combining ability (GCA) and specific combining ability (SCA) effects for sorghum grain yield were significant and that the relative magnitude of GCA and SCA effects indicated that SCA was much more important than GCA, emphasizing the importance of dominant gene action. Laosuwan and Atkins (1977) reported that in single and three-way hybrids, GCA effects of the R-lines accounted for the largest portion of the of the variation expressed for grain yield, heads/plant, 100-seed weight, and seeds/head. Significant GCA effects for females were expressed for all characters in single crosses, but this effect was significant only for

seeds/head in the three way hybrids. Specific combining ability made the smallest contribution to the inheritance of all traits in both types of hybrids. Ross *et al.* (1983) studied a number of traits in forage sorghum and reported that GCA effects exceeded SCA effects for all traits except plant height in females and grain and leaf yields in males. Modi and Dabholkar (1989) obtained significant GCA and SCA for days to 50% flowering, harvest index, dry weight of leaves and stem, primary branches/panicle, and grains/primary branch. They identified some varieties as desirable combiners for harvest index on the basis of their GCA and also identified some hybrids that were superior combinations for harvest index on the basis of their SCA effects.

Gorz *et al.* (1987) analyzed sorghum plant tissue and observed that GCA effects exceeded SCA effects for N, Mg, S, Si, K, Ca, Mn, Cu, and Zn; however, these GCA effects did not exceed SCA effects for P, Cl and Fe in females and S and Cl in males. The GCA and SCA of females were low for both Fe and Cu. Boye-Goni and Marcarian (1985) obtained highly significant GCA and SCA effects for Al-tolerance. General combining ability effects were much more important than SCA effects. Aluminum-tolerance showed predominantly additive genetic effects with some degree of dominance.

#### Gene action

In order to develop high yielding acid soil tolerant cultivars and hybrids, it is essential to identify the sources of tolerance and study the inheritance of tolerance. The relative contribution of different genes depends on the magnitude of gene effects (Wilson *et*

*al.*, 1978). Tolerance to Al toxicity is generally considered to be dominant. In maize, Rhue *et al.* (1978) found Al tolerance of all  $F_1$  hybrids to be as great as that of the more tolerant parent and reported that Al tolerance was controlled at a single locus by a multiple allelic series. In sorghum, tolerance to Al toxicity was inherited as a dominant character (Gourley *et al.*, 1990); however, Boye-Goni and Marcarian (1985) reported that the Al-tolerance in sorghum showed predominantly additive genetic effects with some degree of dominance. Borgonovi *et al.* (1987) suggested the existence of genes with complementary effects for tolerance to Al toxicity. They suggested that there are a few major genes in sorghum with a dominant trend and several minor genes with at least some additive effect involved in the genetic control of tolerance to Al. Culvenor *et al.* (1986) proposed a two-gene hypothesis in which inheritance of Al tolerance in *Phalaris aquatica* requires at least one dominant allele at each locus. Modifiers of these genes may also be involved. Gorz *et al.* (1987) cited other workers who indicated that mineral concentration was at least partially under genetic control and suggested that considerable progress was possible by selection for either high or low mineral accumulation.

#### Partitioning of genetic variance

Wilson *et al.* (1978) reported both additive and nonadditive components of genetic variation among different sorghum genotypes. Finkner *et al.* (1981) reported that additive gene action was more (82%) important than nonadditive (18%) gene action for grain yield in

sorghum. Genetic variances due to males were greater than those due to females. Bittinger *et al.* (1981) reported additive genetic variance to be greater than dominance variance for flowering, plant height, lodging, panicle weight, seed weight, and panicle length, but not for grain yield. Laosuwan and Atkins (1977) were of the view that nonadditive gene effects also contributed to the variation expressed for grain yield among single crosses and for seeds/head among three-way hybrids.

Modi and Dabholkar (1989) found additive and nonadditive genetic variance for days to 50% flowering, harvest index, dry weight of leaves and stems, primary branches/panicle, and grains/primary branch. They considered efficient partitioning of dry matter into components an important attribute of high yielding cultivars. Sorghum genotypes manifest variability for dry matter accumulation. Local cultivars which are late in maturity produce more dry matter per plant; however, only 29% of the dry matter is in the form of grain as against 50% in the high yielding hybrids (Modi and Dabholkar, 1989).

### Heritability

Heritability estimates provide information on the transmission of characteristics from parent to progeny and can be used to predict genetic advance under selection (Liang *et al.*, 1972). Genetic ratios, resembling heritability, were used by Gorz *et al.* (1987) who reported higher GCA relative to SCA variances for mineral element content with the exception of Cl and Fe in females and S and Cl in males. Ross *et al.* (1983) also reported higher ratios of GCA to SCA variances for

agronomic forage traits in sorghum, except for plant height in females and tillering in males.

Liang *et al.* (1972) obtained relatively high narrow-sense heritability estimates for days-to-first-bloom, plant height, and kernel weight. Low narrow-sense heritability estimates for grain yield were indicative of the important role of environmental and non-additive genetic effects which constituted a major proportion of the total phenotypic variation for many  $F_2$  populations. Ekebil *et al.* (1977) obtained high broad-sense heritability estimates for bloom date, plant height, yield, and kernel weight; however, estimates for heads per plant were low. For grain yield in sorghum, Finkner *et al.* (1981) reported a narrow-sense heritability of 44%. Bittinger *et al.* (1981) reported that flowering and panicle length showed relatively high heritabilities (73%); yield showed the lowest heritability (37%); and plant height, lodging, panicle weight, and seed weight were intermediate (56% to 64%).

Boye-Goni and Marcarian (1985) reported heritability of Al-tolerance in sorghum to be high. Narrow-sense and broad-sense heritabilities were 78 and 99%, respectively. Culvenor *et al.* (1986) reported heritability estimates for relative root extension in Al solution of 48 to 75% for *Phalaris aquatica* L. grown in a field high in aluminum. Heritability estimates for shoot growth were low and insignificant.

### Stability of yield

Stability of yield, defined as the ability of a genotype to avoid substantial fluctuation in yield over a range of environments is a breeding objective which is difficult to achieve (Heinrich *et al.*, 1983). In practical terms, plant breeders are concerned with performance in sub-optimal environments such as tolerance to problem soils and drought stress. For quantitative traits such as yield, the relative performance of cultivars often changes from one environment to another (Saeed and Francis, 1983).

Eberhart and Russell (1966) developed a method of measuring crop yield stability based on a regression technique. They calculated an environmental index for each of the environments used in a series of trials as the mean yield of all cultivars at one environment minus the grand mean of all cultivars in all environments of the trials. They then showed that both the regression coefficient and the deviation from regression of a given cultivar's yield on the environmental indices could be considered as a measure of the yield stability of the cultivar.

Faris *et al.* (1981) recommended the use of stability parameters in selection among high yielding cultivars in any particular area of adaptation before cultivars are recommended for release on the basis of yield performance from different trails.

Mechanisms of yield stability can be categorized into:

- 1) genetic heterogeneity,
- 2) yield component compensation,
- 3) stress tolerance, and

- 4) capacity to recover rapidly from stress (Heinrich *et al.*, 1983).

A genotype with high tolerance to stress would normally have a low regression coefficient stability and genetic variances in stress environments would generally be lower than in non-stress environments (Rosielle and Hamblin, 1981). Comparison of regression coefficients of yield on environmental index show that hybrids (Jowett, 1972) and hybrid blends (Reich and Atkins, 1970) are more stable than cultivars in terms of yield components. Hybrids have been reported to maintain high numbers of heads/m<sup>2</sup>, seeds/head, and seed weight in poor environments (Heinrich *et al.*, 1983). Majisu and Doggett (1972) indicated that highly heterotic and stable hybrids would show a large yield advantage over equally stable cultivars.

Linear regression has been regarded as a measure of average response of particular genotypes, whereas the deviation about the regression line has been considered as the most suitable measure of stability. Genotypes with the lowest standard error or deviation about the regression line would be the most stable (Nayeem and Bapat, 1989).

In sorghum, heads/m<sup>2</sup> and seeds/head have been reported to increase with improved environments (Heinrich *et al.*, 1983). Early and medium maturing sorghum genotypes, have appeared to be more stable than the late maturing genotypes (Saeed and Francis, 1983). Genotypes that possess special characteristics such as acid soil tolerance are considered the largest contributors to Genotype X Environment (G X E) interaction. Plant breeders are interested in selecting superior

genotypes in the presence of G x E interaction (Francis and Kannenberg, 1978).

### Correlations

There is concern that plants tolerant of acid soils may be low yielding and poorly adapted to non-acid soils. The notion that cultivars tolerant of acid soils are low yielding occurred because traditional cultivars grown in acid soil areas were both acid soil tolerant and low yielding when compared with modern high yield potential "green revolution" cultivars. These newer cultivars had not been selected for acid soil tolerance (Scott and Fisher, 1989). In sorghum, there is very limited information on correlation between acid soil tolerance and agronomic characters. Phenotypic correlations represent the associations actually observed (Gorz *et al.*, 1987).

Bittinger *et al.* (1981) reported that yield showed highly significant positive phenotypic and genotypic correlations with flowering and panicle weight. Other significant positive correlations included plant height with flowering and panicle weight with lodging. Grain yield per unit area has been reported to be highly correlated with number of grains per head, plant height, and threshing percentage (Eckebil *et al.*, 1977). Rubaihayo and Makumbi (1976) obtained significant phenotypic, genotypic, and environmental correlations among yield components in sorghum, but the results were not consistent across sorghum groups studied. Gorz *et al.* (1987) reported 30 phenotypic correlations among 12 mineral elements in sorghum to be statistically significant. Some of the highest values were from the relationships of

N with P, S, Cu, and Zn; Mg with Si and Cu; Si with Ca; P with Ca and Zn; S with K; and Cu with Zn. Further, some of the highest phenotypic correlations calculated among the mineral elements and 12 agronomic and quality traits were the positive association of protein with P; the negative relationship of plant height with N and P; brix of stem juice with K; and neutral detergent fiber (NDF) with P. Johnson and Ohki (1984) reported that low soil pH significantly reduced dry weight, flag leaf area, and grain yield in wheat. Grain yield was related to soil pH, but not to flag leaf area.

The 10 parental genotypes were as follows:

| Entry | Genotype   | Description   | Sex    |
|-------|------------|---------------|--------|
| 1     | Challenger | AI 1000000000 | Female |
| 2     | Challenger | AI 1000000000 | Female |
| 3     | Challenger | AI 1000000000 | Female |
| 4     | Challenger | AI 1000000000 | Female |
| 5     | Challenger | AI 1000000000 | Female |
| 6     | Challenger | AI 1000000000 | Female |
| 7     | Challenger | AI 1000000000 | Female |
| 8     | Challenger | AI 1000000000 | Female |
| 9     | Challenger | AI 1000000000 | Female |
| 10    | Challenger | AI 1000000000 | Female |
| 11    | Challenger | AI 1000000000 | Female |
| 12    | Challenger | AI 1000000000 | Female |
| 13    | Challenger | AI 1000000000 | Female |
| 14    | Challenger | AI 1000000000 | Female |
| 15    | Challenger | AI 1000000000 | Female |
| 16    | Challenger | AI 1000000000 | Female |
| 17    | Challenger | AI 1000000000 | Female |
| 18    | Challenger | AI 1000000000 | Female |
| 19    | Challenger | AI 1000000000 | Female |
| 20    | Challenger | AI 1000000000 | Female |
| 21    | Challenger | AI 1000000000 | Female |
| 22    | Challenger | AI 1000000000 | Female |
| 23    | Challenger | AI 1000000000 | Female |
| 24    | Challenger | AI 1000000000 | Female |
| 25    | Challenger | AI 1000000000 | Female |
| 26    | Challenger | AI 1000000000 | Female |
| 27    | Challenger | AI 1000000000 | Female |
| 28    | Challenger | AI 1000000000 | Female |
| 29    | Challenger | AI 1000000000 | Female |
| 30    | Challenger | AI 1000000000 | Female |
| 31    | Challenger | AI 1000000000 | Female |
| 32    | Challenger | AI 1000000000 | Female |
| 33    | Challenger | AI 1000000000 | Female |
| 34    | Challenger | AI 1000000000 | Female |
| 35    | Challenger | AI 1000000000 | Female |
| 36    | Challenger | AI 1000000000 | Female |
| 37    | Challenger | AI 1000000000 | Female |
| 38    | Challenger | AI 1000000000 | Female |
| 39    | Challenger | AI 1000000000 | Female |
| 40    | Challenger | AI 1000000000 | Female |
| 41    | Challenger | AI 1000000000 | Female |
| 42    | Challenger | AI 1000000000 | Female |
| 43    | Challenger | AI 1000000000 | Female |
| 44    | Challenger | AI 1000000000 | Female |
| 45    | Challenger | AI 1000000000 | Female |
| 46    | Challenger | AI 1000000000 | Female |
| 47    | Challenger | AI 1000000000 | Female |
| 48    | Challenger | AI 1000000000 | Female |
| 49    | Challenger | AI 1000000000 | Female |
| 50    | Challenger | AI 1000000000 | Female |
| 51    | Challenger | AI 1000000000 | Female |
| 52    | Challenger | AI 1000000000 | Female |
| 53    | Challenger | AI 1000000000 | Female |
| 54    | Challenger | AI 1000000000 | Female |
| 55    | Challenger | AI 1000000000 | Female |
| 56    | Challenger | AI 1000000000 | Female |
| 57    | Challenger | AI 1000000000 | Female |
| 58    | Challenger | AI 1000000000 | Female |
| 59    | Challenger | AI 1000000000 | Female |
| 60    | Challenger | AI 1000000000 | Female |
| 61    | Challenger | AI 1000000000 | Female |
| 62    | Challenger | AI 1000000000 | Female |
| 63    | Challenger | AI 1000000000 | Female |
| 64    | Challenger | AI 1000000000 | Female |
| 65    | Challenger | AI 1000000000 | Female |
| 66    | Challenger | AI 1000000000 | Female |
| 67    | Challenger | AI 1000000000 | Female |
| 68    | Challenger | AI 1000000000 | Female |
| 69    | Challenger | AI 1000000000 | Female |
| 70    | Challenger | AI 1000000000 | Female |
| 71    | Challenger | AI 1000000000 | Female |
| 72    | Challenger | AI 1000000000 | Female |
| 73    | Challenger | AI 1000000000 | Female |
| 74    | Challenger | AI 1000000000 | Female |
| 75    | Challenger | AI 1000000000 | Female |
| 76    | Challenger | AI 1000000000 | Female |
| 77    | Challenger | AI 1000000000 | Female |
| 78    | Challenger | AI 1000000000 | Female |
| 79    | Challenger | AI 1000000000 | Female |
| 80    | Challenger | AI 1000000000 | Female |
| 81    | Challenger | AI 1000000000 | Female |
| 82    | Challenger | AI 1000000000 | Female |
| 83    | Challenger | AI 1000000000 | Female |
| 84    | Challenger | AI 1000000000 | Female |
| 85    | Challenger | AI 1000000000 | Female |
| 86    | Challenger | AI 1000000000 | Female |
| 87    | Challenger | AI 1000000000 | Female |
| 88    | Challenger | AI 1000000000 | Female |
| 89    | Challenger | AI 1000000000 | Female |
| 90    | Challenger | AI 1000000000 | Female |
| 91    | Challenger | AI 1000000000 | Female |
| 92    | Challenger | AI 1000000000 | Female |
| 93    | Challenger | AI 1000000000 | Female |
| 94    | Challenger | AI 1000000000 | Female |
| 95    | Challenger | AI 1000000000 | Female |
| 96    | Challenger | AI 1000000000 | Female |
| 97    | Challenger | AI 1000000000 | Female |
| 98    | Challenger | AI 1000000000 | Female |
| 99    | Challenger | AI 1000000000 | Female |
| 100   | Challenger | AI 1000000000 | Female |

## CHAPTER III

### MATERIALS AND METHODS

#### Genotypes

Thirty-four genotypes consisting of six cytoplasmic genetic male sterile A-lines, represented by their respective maintainer B-lines, as female parents, four restorer R-lines, as male parents, and their 24 F<sub>1</sub> hybrids from a North Carolina Mating Design II were utilized in this study. The parental genotypes originated from the USA and were selected based on previous performance under acid conditions. In Kenya, Seredo, popular improved cultivar from Uganda, was included as a local check for purposes of agronomic performance, bearing in mind that the materials for the study had not been tested in the area before.

The 10 parental genotypes were as follows:

| Entry | Genotype          | Description    |        |
|-------|-------------------|----------------|--------|
| 1     | TX623             | Al Susceptible | Female |
| 2     | WHEATLAND         | Al Susceptible | Female |
| 3     | B-YEL PI          | Al Susceptible | Female |
| 4     | (AT-1)-52-2-1-2-1 | Al Tolerant    | Female |
| 5     | (AT-2)-10-6-1-2-1 | Al Tolerant    | Female |
| 6     | (AT-1)-36-4-2-2-1 | Al Tolerant    | Female |
| 7     | IS7254C           | Al Tolerant    | Male   |
| 8     | IA28              | Al Tolerant    | Male   |
| 9     | TX430             | Al Susceptible | Male   |
| 10    | TX432             | Al Susceptible | Male   |
| 35    | SEREDO            | Local cultivar | Check  |

### Locations

Four locations were selected in Western Province, Kenya on the basis of soil pH (Table 1). One additional location was established at the Plant Science Research Center (PSRC) Mississippi State, MS. The locations used in Kenya were in Temperature Zone (TZ) 3 MAT 20-22°C with bimodal rainy seasons. The first (long) rainy season commenced in March and the second (short) in September. These locations were situated in low altitude, low fertile acid soil, where sorghum is an important crop in the subsistence farming systems. Three locations, Buburi, Mumias, and Ukwala, were chosen for low soil pH (<5.2) while the Obambo trial location was selected to test performance at a soil pH above 5.2. With the exception of the Buburi trial location, trials were conducted on sites located on farmers' fields under the Fertilizer Use Recommendation Project (FURP). All trial sites used had no history of farmyard manure or fertilizer application by the FURP project or by farmers.

### Soil sampling

At each trial site in Kenya, soil samples were taken for physical and chemical analysis to determine the nutrient status of the soil. Soil samples of depth levels of 0 to 20 cm, referred to as topsoil, and 20 to 40 cm, referred to as subsoil, were collected from four holes randomly dug and composited separately for each soil depth within each replicate. Soil samples were kept in polythene bags and sent to National Agricultural Research Laboratories (NARL), Nairobi, Kenya for

Table 1. Detailed description of trial sites in Western Province, Kenya, 1990 and 1991.

| Name of Site | District | Center coordinates | Alt.  | Agricultural Ecological Zone(AEZ)                           | Agro-Climatic Zone(ACZ) | Geology                                                                                                                                                                                                              | Origin (Veg)                                                    | Soil classification <sup>a</sup>       |
|--------------|----------|--------------------|-------|-------------------------------------------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------|
| Ukwala       | Siaya    | E33.8 and N21.0    | 1200M | Marginal Sugarcane Zone (IM2) <sup>b</sup> 65-80% (PE) (EO) | III 3                   | Soils are shallow to moderately deep strong brown to brown in color and consists of firm clay. Within 60 cm there is a transition to petroplinthite (murram). Soil reaction (pH): strongly acidic, Acidity (Hp):low. | Cultivated Abizia-Bridelia vernonia with scattered chlorophora. | Ferralsol orthic Acrisol Petro-ferric. |
| Obambo       | Siaya    | E36.2 and N05.6    | 1200M | Cotton Zone (IM3) 50-65% (PE) (EO)                          | II 3                    | Soils are deep, dark red to reddish brown in color and consist of friable to firm clay. PISO-ferric material occurs in the deeper subsoil. Soil reaction (pH): slightly acid. Acidity (Hp):low.                      | Derived clearings, communities and bush-land:undifferentiated.  | Chromic Luvisol.                       |

Table 1. (continued)

| Name of Site        | District | Center coordinates | Alt.  | Agricultural Ecological Zone(AEZ)  | Agro-Climatic Zone(ACZ) | Geology                                                                                                                                                                                                                                                           | Origin (Veg)                    | Soil classification <sup>a</sup> |
|---------------------|----------|--------------------|-------|------------------------------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|----------------------------------|
| Mumias              | Kakamega | E58.1 and N35.6    | 1200M | Sugarcane Zone (IM1) 80% (PE) (EO) | I 3                     | Soils very deep brown grayish brown in color and consists of mottled friable sandy clay loam with soft plinthite. They have a structure which is weak to moderate blocky and a moderate to high bioporosity. Soil reaction (pH):strongly acid. Acidity (Hp):high. | Cultivated Ficus Al-bizia, etc. | Plinthic Acrisol.                |
| Buburi <sup>c</sup> | Busia    | E21.0 and N24.2    | 1118M | Cotton Zone (IM3) 50-65% (PE) (EO) | III 3                   | Soils are deep,dark red in color and consist of friable clay. They have a moderate, subangular blocky substructure and a very high bioporosity is prevalent. Soil reaction (pH):strongly acid. Acidity (Hp):low.                                                  | Albizia coriaria Turraea type.  | Ferralsol chromic Acrisol.       |

<sup>a</sup>Soil classification (FAO/UNESCO,1974).<sup>b</sup>PE = Potential evaporation.<sup>c</sup>Not FURP trial site.

Source: MAG, NAL, FURP Final Report. 1987. Annex III Description of the first priority sites in the various districts. Vols. 4, 5, and 7. Nairobi, Kenya.

soil test analyses. Soil samples were taken prior to land preparation and after harvesting the trials in 1990 and 1991.

#### Physical and chemical analyses of soil samples

The soil samples were air dried and crushed to pass through a 2-mm screen. The following characteristics were determined: sand, clay, and silt percentages; classification of topsoil and subsoil to determine soil texture; soil pH (1:1.25 KCl); organic carbon; total N; P, K, Mg, Na, Ca, Mn, Zn, Cu, and Fe contents, based on milliequivalent per 100 g of soil. Carbon to nitrogen (C:N) ratio and exchangeable acidity (Hp) were also determined.

#### Trials

Trials were grown in 1990 and 1991 during the long rains season in Kenya and during the summers of 1990 and 1991 in Mississippi. The experimental design for each location was a randomized complete block with four replicates. In Kenya, plots consisted of a single row 5 m in length with 75 cm between rows. Seed for each genotype was sown sparingly by hand. After emergence, seedlings were thinned to 20 cm between plants within rows. Rows around the field were planted to Seredo to serve as guard rows to reduce border effects.

Periodic sprays of recommended insecticides were used to control major insect pests. Birds were scared away at all sites in Kenya from the grain filling period through harvest period. In Kenya, pre-emergence herbicides and fertilizers were not used. This was done to simulate typical sorghum management practices of Western Kenya. All

trials were maintained weed-free throughout the growing period.

#### Agronomic characteristics

The following agronomic characters were evaluated:

- (1) days to flower as judged by the number of days from date of planting to date when 50% of the plants were flowering;
- (2) plant height (cm) was measured as the distance from the first basal node to the top of the panicle after flowering;
- (3) peduncle length (cm) was measured as the distance from the base of the flag leaf node to the base of the panicle;
- (4) head length (cm) was measured as the distance from the base of head to the tip of the head;
- (5) leaf length (cm) of the fourth leaf from the top of the plant;
- (6) leaf width (cm) of the fourth leaf from the top of the plant;
- (7) fourth leaf area (FLA) ( $\text{cm}^2$ ) was calculated as the product of leaf length, excluding the sheath, and leaf width of the fourth leaf from the top the plant  $\times 0.75$  (Stickler *et al.*, 1961);
- (8) number of heads per plot;
- (9) grain yield per plot (kg) was measured as total weight of threshed grain per plot;
- (10) thousand seed weight (g) was measured as an average of two samples from each plot containing 250 grains each and

converted to 1000 grains;

(11) number of grains per heads;

(12) total dry weight (kg) per plot;

(13) harvest index (%) was recorded as the ratio of grain yield per plot to total dry matter yield (Flores *et al.*, 1988).

Due to differences in maturity among materials under study, harvesting was done at different times. All heads in each plot were harvested from plants and collectively put in bags. Heads were sun-dried before threshing and weighing. Before harvesting, five representative plants were randomly chosen in each plot and cut at ground level; sun-dried; weighed to determine total plant dry matter; and converted to a per plot basis.

#### Leaf mineral analysis

Before harvesting, three representative plants per plot were randomly selected and one leaf from each plant was harvested from the second node from the top. Three leaves per plot were placed in a paper bag and sun-dried. The dried leaf samples from the four locations in Kenya were sent to Dr. R. B. Clark, University of Nebraska, Lincoln for mineral analyses. Samples were cleaned free of soil and other impurities before analysis. Samples were ground to pass through a 0.5 mm (40-mesh) screen and later made into pellets (Clark and Gourley, 1987). Mineral compositions were determined using energy dispersive x-ray fluorescence (EDXFR) (Clark and Gourley, 1987). The minerals evaluated included: Mg, K, Al, Ca, Si, P, S, Cl, Mn, Fe, Cu, and Zn.

### Statistical data analyses

Statistical computations were made on a plot basis. Data for each characteristic were analyzed in accordance with North Carolina Mating Design II with a random model (Comstock and Robinson, 1948). Expected mean square components (EMS) were as follows:

| Source      | df          | MS  | EMS                                          |
|-------------|-------------|-----|----------------------------------------------|
| Reps        | r-1         | MS1 |                                              |
| Males (M)   | m-1         | MS2 | $\sigma_e^2 + r\sigma_{mf}^2 + rf\sigma_m^2$ |
| Females (F) | f-1         | MS3 | $\sigma_e^2 + r\sigma_{mf}^2 + rm\sigma_f^2$ |
| M x F       | (m-1)(f-1)  | MS4 | $\sigma_e^2 + r\sigma_{mf}^2$                |
| Error       | (r-1)(mf-1) | MS5 | $\sigma_e^2$                                 |

where:

r = number of replications

m = number of males

f = number of females

$\sigma_m^2$  = male variance

$\sigma_f^2$  = female variance

$\sigma_{mf}^2$  = male x female variance

$\sigma_e^2$  = environmental variance.

With inbred parents the genetic expectations of the variance components would be

$$\sigma_m^2 = \sigma_f^2 = 1/2 \sigma_A^2$$

$$\sigma_{mf}^2 = \sigma_D^2$$

where:

$\sigma_A^2$  - additive genetic variance

$\sigma_D^2$  - dominant genetic variance.

Broad-sense heritability (Hb) was estimated as:

$$Hb = \frac{\sigma_A^2 + \sigma_D^2}{\sigma_A^2 + \sigma_D^2 + \sigma_e^2}$$

Narrow-sense heritability (Hn) was estimated as:

$$Hn = \frac{\sigma_A^2}{\sigma_A^2 + \sigma_D^2 + \sigma_e^2}$$

Means of treatments were separated using Fisher's Protected Least Significant Difference (LSD) at the 0.05 level of significance following analysis of variance. Analyses of variance were conducted using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS Institute, 1985).

## CHAPTER IV

### RESULTS AND DISCUSSION

#### Soil characteristics of locations

Significant differences among locations in Kenya were observed for all characteristics in both years except Zn which differed only in 1991 (Tables 2-5). Thus, the locations selected for the study varied in acidity, levels of fertility stresses, and physical properties: however, significant interactions were observed for many soil characteristics. There was a significant Location X Time X Depth interaction for Mn, K, Na, and Ca in 1990. Significant Location X Time interactions existed for P, Mg, Na, Ca, and Mn in 1990; and for P, Ca, Mn, and Zn in 1991. Significant Location X Depth interactions were obtained in 1990 for K, Na, Ca, sand, clay, Zn, Cu, and exchangeable acidity (Hp). There were fewer significant interactions in 1991 than in 1990. There were significant differences between soils taken at planting and harvesting times for soil pH, Mg, Na, Ca, Mn, and P in 1990; and for pH, P, and Ca in 1991. Significant differences between soil depths existed for percent clay, K, Hp, Na, Ca, and Mn in 1990 and percent clay and silt, in 1991.

Means for physical and chemical characteristics of soils sampled at the four locations in Kenya are presented in Tables 6-9. There were significant differences among locations for sand, silt, and clay contents; however, differences between soil depths within locations were generally not significant.

Table 2. Analyses of variance for soil characteristics measured in four locations used for sorghum trials in Kenya, 1990.

| Source             | df | Mean Squares |    | Mean Squares |          |          |          |          |         |  |
|--------------------|----|--------------|----|--------------|----------|----------|----------|----------|---------|--|
|                    |    | pH           | df | P            | K        | Mg       | Na       | Ca       | Mn      |  |
| Locations (L)      | 3  | 5.07 **      | 3  | 99.31 **     | 0.270 ** | 16.38 ** | 0.056 ** | 53.51 ** | 2.63 ** |  |
| Rep/Loc            | 12 | 0.07         | 12 | 11.45        | 0.011    | 0.29     | 0.002    | 0.28     | 0.04    |  |
| Depth              | 1  | 0.00         | 1  | 0.77         | 0.098 ** | 0.01     | 0.012 *  | 0.83 *   | 0.06 *  |  |
| Loc X Depth        | 3  | 0.08         | 3  | 7.27         | 0.035 *  | 0.31     | 0.008 *  | 0.67 *   | 0.02    |  |
| Rep X Depth/Loc    | 12 | 0.03         | 12 | 4.56         | 0.007    | 0.19     | 0.001    | 0.17     | 0.01    |  |
| Time               | 1  | 1.74 **      | 1  | 40.64 *      | 0.001    | 11.65 ** | 0.016 ** | 8.48 **  | 0.90 ** |  |
| Loc X Time         | 2  | 0.00         | 3  | 129.89 **    | 0.002    | 10.64 ** | 0.006 ** | 3.92 **  | 0.33 ** |  |
| Time X Depth       | 1  | 0.003        | 1  | 0.39         | 0.050 ** | 0.04     | 0.002    | 0.93 *   | 0.06    |  |
| Loc X Time X Depth | 2  | 0.05         | 3  | 9.39         | 0.039 ** | 0.12     | 0.005 ** | 0.81 **  | 0.05 *  |  |
| Error              | 18 | 0.02         | 24 | 9.28         | 0.005    | 0.18     | 0.001    | 0.13     | 0.02    |  |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 3. Analyses of variance for physical and chemical characteristics measured in four locations in Kenya, 1990.

| Source       | df | Mean Squares (MS) |           |            |        |          |           |    | MS      |  |
|--------------|----|-------------------|-----------|------------|--------|----------|-----------|----|---------|--|
|              |    | Sand              | Silt      | Clay       | Zn     | Cu       | Fe        | df | Hp      |  |
| Location (L) | 3  | 4106.17 **        | 283.33 ** | 2687.50 ** | 0.45   | 25.58 ** | 631.51 ** | 3  | 2.41 ** |  |
| Rep/Loc      | 12 | 75.33             | 10.42     | 56.08      | 0.99   | 3.23     | 87.60     | 11 | 0.23    |  |
| Depth        | 1  | 36.13             | 24.50     | 264.50 **  | 0.32   | 0.36     | 6.13      | 1  | 0.62 ** |  |
| Loc X Depth  | 3  | 125.79 **         | 13.83     | 85.50 *    | 2.72 * | 1.65 *   | 34.81     | 3  | 0.15 *  |  |
| Error        | 12 | 19.29             | 16.42     | 20.58      | 0.68   | 0.46     | 68.75     | 11 | 0.03    |  |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 4. Analyses of variance for percent nitrogen (N) and carbon dioxide (C) measured at four locations in Kenya, 1990.

| Source    | df | Mean Squares |           |
|-----------|----|--------------|-----------|
|           |    | N            | C         |
| Locations | 3  | 0.0014**     | 0.4253 ** |
| Error     | 12 | 0.0001       | 0.0691    |

\*,\*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 5. Analyses of variance for physical and chemical soil characteristics measured in four locations used for sorghum trials in Kenya, 1991.

| Source             | Mean Squares |         |    | Mean Squares (MS) |           |            | MS |           |    |          |    |
|--------------------|--------------|---------|----|-------------------|-----------|------------|----|-----------|----|----------|----|
|                    | df           | pH      | df | Sand              | Silt      | Clay       | df | P         | df | K        | MS |
| Locations (L)      | 2            | 4.10 ** | 3  | 7825.58 **        | 311.06 ** | 5147.06 ** | 3  | 246.52 ** | 3  | 0.294 ** |    |
| Rep/Loc            | 9            | 0.05    | 12 | 72.08             | 48.65     | 29.40      | 12 | 22.24     | 12 | 0.012    |    |
| Depth              | 1            | 0.02    | 1  | 3.06              | 115.56 *  | 196.00 **  | 1  | 2.40      | 1  | 0.074    |    |
| Loc X Depth        | 2            | 0.02    | 3  | 20.40             | 8.73      | 17.17      | 3  | 8.24      | 3  | 0.034    |    |
| Rep X Depth/Loc    | 9            | 0.02    | 12 | 98.23             | 81.90     | 25.83      | 12 | 4.32      | 12 | 0.016    |    |
| Time               | 1            | 0.83 ** | 1  | 4.00              | 3.06      | 7.56       | 1  | 375.00 ** | 1  | 0.012    |    |
| Loc X Time         | 2            | 0.00    | 3  | 62.00             | 35.90     | 9.73       | 3  | 255.26 ** | 3  | 0.002    |    |
| Time X Depth       | 1            | 0.09    | 1  | 22.56             | 22.56     | 2.25       | 1  | 6.67      | 1  | 0.001    |    |
| Loc X Time X Depth | 2            | 0.02    | 3  | 55.23             | 51.73     | 68.42      | 3  | 1.83      | 3  | < 0.001  |    |
| Error              | 12           | 0.02    | 24 | 61.70             | 51.10     | 29.70      | 20 | 0.00      | 24 | 0.006    |    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 5. (Continued).

| Source             | df | Mean Squares |          |          |         |          |          |            |
|--------------------|----|--------------|----------|----------|---------|----------|----------|------------|
|                    |    | Mg           | Na       | Ca       | Mn      | Zn       | Cu       | Fe         |
| Locations (L)      | 3  | 50.20 **     | 0.030 ** | 35.47 ** | 3.42 ** | 15.11 ** | 32.45 ** | 2623.18 ** |
| Rep/Loc            | 12 | 0.13         | 0.003    | 0.21     | 0.04    | 2.09     | 2.15     | 332.62     |
| Depth              | 1  | 0.26         | 0.013    | 0.26     | 0.06    | 0.64     | 8.48     | 1.13       |
| Loc X Depth        | 3  | 0.13         | 0.002    | 0.44     | 0.03    | 1.05     | 1.27     | 30.17      |
| Rep X Depth/Loc    | 12 | 0.10         | 0.003    | 0.57     | 0.02    | 1.47     | 1.92     | 109.11     |
| Time               | 1  | 0.35         | 0.003    | 1.72 **  | 0.01    | 0.56     | 8.34     | 274.32     |
| Loc X Time         | 3  | 0.08         | 0.005    | 0.96 **  | 0.27 ** | 6.95 *   | 4.28     | 88.34      |
| Time X Depth       | 1  | 0.17         | 0.006    | 0.01     | 0.07    | 3.33     | 1.66     | 108.94     |
| Loc X Time X Depth | 3  | 0.07         | 0.002    | 0.32     | 0.03    | 1.58     | 3.57     | 134.11     |
| Error              | 24 | 0.24         | 0.003    | 0.13     | 0.03    | 1.56     | 2.18     | 163.22     |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 6. Means of physical and chemical characteristics of soils measured at two soil depth levels at four locations in Kenya, 1990.

| Characteristic |       |               |       |       |                 |       |       |       |       |      |       |
|----------------|-------|---------------|-------|-------|-----------------|-------|-------|-------|-------|------|-------|
| Site           | Depth | Sand          | Silt  | Clay  | pH              | P     | K     | Mg    | Na    | Ca   | Mn    |
| - cm -         |       | ----- % ----- |       |       | ----- meq ----- |       |       |       |       |      |       |
| Obambo         | 0-20  | 20.3a         | 17.0a | 59.0b | 5.6a            | 9.5a  | 0.43a | 3.1a  | 0.28a | 5.0a | 0.89a |
|                | 20-40 | 16.8b         | 17.5a | 69.5a | 5.7a            | 10.3a | 0.38a | 2.8a  | 0.31a | 5.0a | 0.88a |
| Buburi         | 0-20  | 20.0a         | 24.5a | 55.5a | 5.1a            | 11.1a | 0.42a | 1.6a  | 0.28a | 2.1a | 1.3a  |
|                | 20-40 | 21.5a         | 21.0a | 57.5a | 4.9a            | 9.9a  | 0.21b | 1.3a  | 0.21b | 1.3b | 1.1b  |
| Ukwala         | 0-20  | 43.0a         | 21.5a | 35.5a | 4.6a            | 5.1a  | 0.15a | 0.60a | 0.16a | 1.2a | 0.38a |
|                | 20-40 | 49.0a         | 17.0a | 34.0a | 4.7a            | 6.3a  | 0.13a | 0.71a | 0.17a | 1.2a | 0.39a |
| Mumias         | 0-20  | 72.5a         | 8.5a  | 19.0a | 4.3a            | 12.0a | 0.17a | 0.98a | 0.17a | 1.2a | 0.43a |
|                | 20-40 | 60.0a         | 9.0a  | 31.0a | 4.3a            | 10.5a | 0.13b | 0.79a | 0.17a | 1.2a | 0.33b |

Means within a characteristic for each location not followed by the same letter differ significantly ( $P < 0.05$ ) according to the F-test.

Table 6. (Continued).

| Site   | Depth  | Characteristic |      |       |      |
|--------|--------|----------------|------|-------|------|
|        |        | Zn             | Cu   | Fe    | Hp   |
|        | - cm - |                | meq  |       |      |
| Obambo | 0-20   | 3.6a           | 5.3a | 35.4a | 0.3a |
|        | 20-40  | 4.7a           | 5.6a | 40.0a | 0.3a |
| Buburi | 0-20   | 4.6a           | 7.1a | 23.3a | 0.6b |
|        | 20-40  | 2.9b           | 5.5b | 21.6a | 1.1a |
| Ukwala | 0-20   | 3.6a           | 3.6a | 25.0a | 1.1a |
|        | 20-40  | 3.6a           | 4.0a | 24.0a | 1.2a |
| Mumias | 0-20   | 4.1a           | 2.3a | 42.5a | 1.5a |
|        | 20-40  | 4.1a           | 2.3a | 37.0a | 1.9a |

Means within a characteristic for each location not followed by the same letter differ significantly ( $P < 0.05$ ) according to the F-test.

Table 7. Means of physical and chemical characteristics of soils measured at planting and harvest at four locations in Kenya, 1990.

| Site   | Date     | Characteristic          |      |      |       |       |       |       |      |       |
|--------|----------|-------------------------|------|------|-------|-------|-------|-------|------|-------|
|        |          | C                       | N    | pH   | P     | K     | Mg    | Na    | Ca   | Mn    |
|        |          | ----- % ----- meq ----- |      |      |       |       |       |       |      |       |
| Obambo | Planting | 0.79                    | 0.07 | 5.4b | 11.6a | 0.42a | 1.3b  | 0.32a | 6.1a | 0.63b |
|        | Harvest  |                         |      | 5.9a | 8.1a  | 0.38a | 4.5a  | 0.26b | 4.0b | 1.10a |
| Buburi | Planting | 1.3                     | 0.07 | 4.9b | 12.3a | 0.33a | 1.1b  | 0.27a | 1.8a | 0.98b |
|        | Harvest  |                         |      | 5.1a | 8.8a  | 0.30a | 1.8a  | 0.21b | 1.6a | 1.40a |
| Ukwala | Planting | 0.50                    | 0.05 | 4.6  | 8.8a  | 0.13a | 0.79a | 0.18a | 1.4a | 0.42a |
|        | Harvest  |                         |      | —    | 2.6b  | 0.15a | 0.53b | 0.15a | 1.0b | 0.35a |
| Mumias | Planting | 0.64                    | 0.05 | 4.2b | 7.9b  | 0.15a | 0.99a | 0.16a | 1.3a | 0.35b |
|        | Harvest  |                         |      | 4.4a | 14.6a | 0.15a | 0.78a | 0.18a | 1.1a | 0.40a |

Means within a characteristic for each location not followed by the same letter differ significantly ( $P < 0.05$ ) according to the F-test.

Table 8. Means of physical and chemical characteristics of soils measured at two soil depth levels at four locations in Kenya, 1991.

| Site   | Depth  | Characteristic |       |       |      |       |       |       |       |      |       |
|--------|--------|----------------|-------|-------|------|-------|-------|-------|-------|------|-------|
|        |        | Sand           | Silt  | Clay  | pH   | P     | K     | Mg    | Na    | Ca   | Mn    |
|        |        |                |       |       |      |       |       |       |       |      |       |
|        | - cm - | %              |       |       |      |       |       |       |       |      |       |
| Obambo | 0-20   | 19.1a          | 22.3a | 58.6a | 5.6a | 10.4a | 0.47a | 4.2a  | 0.28a | 4.1a | 1.40a |
|        | 20-40  | 18.4a          | 18.0a | 63.6a | 5.7a | 10.9a | 0.38a | 4.3a  | 0.25a | 4.2a | 1.20a |
| Buburi | 0-20   | 18.3a          | 24.8a | 57.0a | 4.7a | 11.3a | 0.38a | 2.2a  | 0.24a | 2.0a | 0.95a |
|        | 20-40  | 19.3a          | 21.5a | 59.3a | 4.7a | 11.6a | 0.19b | 1.8b  | 0.19a | 1.3a | 0.96a |
| Ukwala | 0-20   | 56.0a          | 16.8a | 27.3a | —    | 3.3a  | 0.14a | 0.55a | 0.19a | 1.2a | 0.42a |
|        | 20-40  | 52.5a          | 16.0a | 32.8a | —    | 3.4a  | 0.16a | 0.51a | 0.17a | 1.3a | 0.42a |
| Mumias | 0-20   | 58.8a          | 11.8a | 26.8a | 4.9a | 2.4a  | 0.14a | 0.58a | 0.17a | 0.9a | 0.39a |
|        | 20-40  | 60.3a          | 13.0a | 28.0a | 4.9a | 1.8a  | 0.13a | 0.39a | 0.17a | 0.8a | 0.23b |

Means within a characteristic for each location not followed by the same letter differ significantly ( $P < 0.05$ ) according to the F-test.

Table 8. (Continued).

| Site   | Depth  | Characteristic |      |       |  |
|--------|--------|----------------|------|-------|--|
|        |        | Zn             | Cu   | Fe    |  |
|        | - cm - |                | meq  |       |  |
| Obambo | 0-20   | 3.3a           | 6.7a | 24.8a |  |
|        | 20-40  | 4.2a           | 6.8a | 27.4a |  |
| Buburi | 0-20   | 4.9a           | 6.3a | 27.9a |  |
|        | 20-40  | 4.8a           | 6.8a | 28.3a |  |
| Ukwala | 0-20   | 3.3a           | 3.4a | 34.1a |  |
|        | 20-40  | 3.5a           | 4.4a | 35.9a |  |
| Mumias | 0-20   | 5.6a           | 3.9a | 56.0a |  |
|        | 20-40  | 5.4a           | 5.2a | 52.4a |  |

Means within a characteristic for each location not followed by the same letter differ significantly ( $P < 0.05$ ) according to the F-test.

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Table 9. Means of physical and chemical characteristics of soils measured at planting and harvest at four locations in Kenya, 1991.

| Site            | Time     | Sand  | silt  | Clay  | pH   | Characteristic |       |       |       |      |       |
|-----------------|----------|-------|-------|-------|------|----------------|-------|-------|-------|------|-------|
|                 |          |       |       |       |      | P              | K     | Mg    | Na    | Ca   | Mn    |
|                 |          |       |       |       |      |                |       |       |       |      |       |
| ----- % -----   |          |       |       |       |      |                |       |       |       |      |       |
| ----- meq ----- |          |       |       |       |      |                |       |       |       |      |       |
| Obambo          | Planting | 20.8a | 18.0a | 61.3a | 5.8a | 12.0a          | 0.45a | 4.20a | 0.28a | 4.2a | 1.20a |
|                 | Harvest  | 16.8b | 22.3a | 61.0a | 5.5a | 9.3b           | 0.40a | 4.30a | 0.24a | 4.1a | 1.40a |
| Buburi          | Planting | 18.3a | 23.3a | 58.5a | 4.9a | 8.5b           | 0.30a | 1.80b | 0.19a | 1.2b | 1.20a |
|                 | Harvest  | 19.3a | 23.0a | 57.8a | 4.5b | 15.3a          | 0.26a | 2.10a | 0.24a | 2.1a | 0.80b |
| Ukwala          | Planting | 54.5a | 16.0a | 29.5a | —    | 2.6b           | 0.16a | 0.54a | 0.16a | 1.0b | 0.35a |
|                 | Harvest  | 54.0a | 16.8a | 30.5a | —    | 4.0a           | 0.14a | 0.53a | 0.19a | 1.5a | 0.49a |
| Mumias          | Planting | 56.8a | 14.5a | 28.8a | 4.9a | 2.2a           | 0.13a | 0.35b | 0.17a | 0.8a | 0.30a |
|                 | Harvest  | 62.3a | 11.5a | 26.0a | 4.9a | 1.8a           | 0.14a | 0.61a | 0.18a | 0.9a | 0.32a |

Means within a characteristic for each location not followed by the same letter differ significantly ( $P < 0.05$ ) according to the F-test.

Table 9. (Continued).

| Site   | Time     | Characteristic |      |       |
|--------|----------|----------------|------|-------|
|        |          | Zn             | Cu   | Fe    |
| Obambo | Planting | 3.8a           | 6.5a | 26.9a |
|        | Harvest  | 3.7a           | 7.0a | 25.3a |
| Buburi | Planting | 3.8b           | 6.8a | 23.4b |
|        | Harvest  | 5.9a           | 6.2a | 33.0a |
| Ukwala | Planting | 3.7a           | 3.0a | 32.4b |
|        | Harvest  | 3.1a           | 4.8a | 37.6a |
| Mumias | Planting | 5.8a           | 4.0a | 52.6a |
|        | Harvest  | 5.2a           | 5.1a | 55.8a |

Means within a characteristic for each location not followed by the same letter differ significantly ( $P < 0.05$ ) according to the F-test.

### Soil pH

Obambo had a mean pH of 5.6 in both years and was considered the most favorable site for sorghum production. Obambo had relatively higher concentrations of K, Mg, Ca, Na, and Mn than the other locations in Kenya. Soil pH at Buburi, Ukwala, and Mumias ranged from 4.3 to 5.0 in 1990 and from 4.7 to 4.9 in 1991. Mumias and Ukwala were characterized by low soil pH, high Fe content, high Hp, and deficient levels of Mg and Ca. The Hp levels at these two locations were in the toxic range. Similar observations were made by Clark and Gourley (1987).

In 1990, subsoils (20-40 cm) had significantly lower levels of K, Na, Ca, Mn, Zn, and Cu and higher (toxic) levels of Hp than top soils at Buburi. Similar results were obtained for K, and Mn at Mumias in 1990; for K and Mg at Buburi in 1991; and for Mn at Mumias in 1991. These results are agreement with Crogan *et al.* (1989) who found that one of the consequences of declining soil pH, was a reduction in fertility of the subsoil. The significantly higher levels of Hp and Mn in the subsoils at Buburi and Mumias, respectively, represented additional toxicity risks to the developing roots of crops in the subsoil.

Tables 7 and 9 present means of physical and chemical characteristics of soils measured at planting and harvest at the four locations in Kenya during 1990 and 1991. A significantly lower pH was observed at planting than at harvest at all locations except Ukwala. This soil pH fluctuation was attributed to the differences in relative amount of rainfall at the two periods. At planting time, significantly lower levels of P were observed at Mumias; Mg at Obambo and Buburi; and Mn at Obambo, Buburi and Mumias, than at harvest, in 1990. Significantly lower levels were

observed for P and Mg at Ukwala; for Na at Obambo and Buburi; and for Ca at Obambo at harvest than at planting time in 1990. In 1991, significant lower values were obtained for P at Buburi and Ukwala; for Mg at Buburi and Mumias; and for Ca at Buburi and Ukwala at planting than at harvest time. Significantly lower means were obtained for P at Obambo; and for Mn at Buburi and Mumias at harvest time in 1991. The significant changes in the mineral content over time was attributed to the pH changes in the soil profile which affected pH sensitive minerals such as Mg at Obambo and Buburi, P at Mumias, and Mn at Obambo, Buburi and Mumias in 1990. Although no significant pH differences between the two time periods were observed, there were significant changes in the concentrations of P, Mg, Ca, Mn, Zn, and Fe levels. Reduction in mineral content at harvest time may have been partially due to crop utilization. Carbon concentration and C:N ratio were significantly higher at Buburi than at the other three locations in Kenya in 1990 indicating a higher organic matter content.

#### Agronomic characteristics

The combined analyses of variance for agronomic characteristics of 35 sorghum genotypes measured at five locations in 1990 and 1991 are presented in Tables 10 and 11. In both years, all characters exhibited significant genotype x location interactions except for number of grains per head and total dry weight. Consequently, each location was analyzed separately.

Analyses of variance of agronomic characteristics for agronomic characteristics are presented in Tables 12-21. At Buburi and Mumias, data for the both years was based on two replicates due to effects of soil

Table 10. Analyses of variance for agronomic characteristics of 35 sorghum genotypes measured in five locations, 1990.

| Source        | Mean Squares (MS) |                | MS  |              | MS  |             | MS  |                 |             |
|---------------|-------------------|----------------|-----|--------------|-----|-------------|-----|-----------------|-------------|
|               | df                | Days to Flower | df  | Plant Height | df  | Head Length | df  | Peduncle Length | Leaf Length |
| Location (L)  | 4                 | 19495.41 **    | 4   | 69093.85 **  | 4   | 1914.36 **  | 4   | 6862.31 **      | 15927.20 ** |
| Rep/L         | 11                | 88.14          | 11  | 1067.18      | 15  | 41.45       | 11  | 592.07          | 198.00      |
| Genotypes (G) | 34                | 119.81 **      | 34  | 4669.58 **   | 34  | 61.88 **    | 34  | 320.83 **       | 173.19 **   |
| G x L         | 130               | 37.46 **       | 130 | 420.32 **    | 129 | 17.20 **    | 129 | 72.42 **        | 94.43 **    |
| Error         | 339               | 11.39          | 325 | 138.76       | 312 | 4.97        | 325 | 34.63           | 26.27       |

\*\* significant at the 0.01 level of probability.

Table 10. (Continued).

| Source        | MS  |             | MS  |               | MS  |            |             |
|---------------|-----|-------------|-----|---------------|-----|------------|-------------|
|               | df  | Leaf Length | df  | Leaf Area     | df  | Head/Plot  | Grain Yield |
| Location (L)  | 4   | 393.09 **   | 4   | 2078196.20 ** | 4   | 3783.49 ** | 14.49 **    |
| Rep/L         | 11  | 5.62        | 11  | 27360.18      | 11  | 250.60     | 0.04        |
| Genotypes (G) | 34  | 2.49 **     | 34  | 12292.18 **   | 34  | 394.63 **  | 0.31 **     |
| G x L         | 129 | 1.11 **     | 129 | 7364.98 **    | 132 | 111.63 **  | 0.11 **     |
| Error         | 324 | 0.69        | 326 | 3207.56       | 358 | 50.59      | 0.03        |

\*\* significant at the 0.01 level of probability.

Table 10. (Continued).

| Source        | df  | MS            |             | df  | MS            |               | df | MS |  |
|---------------|-----|---------------|-------------|-----|---------------|---------------|----|----|--|
|               |     | 1000 Seed Wt. | Grains/Head |     | Total Dry Wt. | Harvest Index |    |    |  |
| Location (L)  | 4   | 1233.78 **    | 19.25 **    | 2   | 218.24 **     | 2.35 **       |    |    |  |
| Rep/L         | 11  | 129.32        | 0.74        | 7   | 1.57          | 0.002         |    |    |  |
| Genotypes (G) | 34  | 160.97 **     | 0.79 **     | 33  | 10.44 **      | 0.016 **      |    |    |  |
| G x L         | 132 | 50.54 **      | 0.35 **     | 66  | 6.37 **       | 0.011 **      |    |    |  |
| Error         | 357 | 20.68         | 0.17        | 226 | 2.62          | 0.006         |    |    |  |

\*\* significant at the 0.01 level of probability.

Table 11. Analyses of variance for agronomic characteristics of 35 sorghum genotypes measured in five locations, 1991.

| Source        | Mean Squares (MS) |                |              |             |     |            |
|---------------|-------------------|----------------|--------------|-------------|-----|------------|
|               | df                | Days to Flower | Plant Height | Head Length | df  | MS         |
| Location (L)  | 4                 | 22778.70 **    | 22917.15 **  | 1695.81 **  | 4   | 4820.78 ** |
| Rep/L         | 11                | 86.11          | 605.28       | 25.48       | 11  | 80.09      |
| Genotypes (G) | 34                | 190.64 **      | 4389.85 **   | 79.57 **    | 34  | 342.70 **  |
| G x L         | 135               | 74.46 **       | 678.97 **    | 20.41 **    | 118 | 95.67 **   |
| Error         | 364               | 36.63          | 194.58       | 6.80        | 339 | 27.26      |
|               |                   |                |              |             | 262 | 42.23      |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 11. (Continued).

| Source        | df  | MS         |               |  | df  | MS         |  | df  | Grain Yield |
|---------------|-----|------------|---------------|--|-----|------------|--|-----|-------------|
|               |     | Leaf Width | Leaf Area     |  |     | Head/Plot  |  |     |             |
| Location (L)  | 3   | 224.69 **  | 1023704.83 ** |  | 3   | 7948.91 ** |  | 4   | 7.08 **     |
| Rep/L         | 8   | 2.56       | 18221.85      |  | 8   | 874.80     |  | 11  | 0.11        |
| Genotypes (G) | 34  | 2.62 **    | 12801.45 **   |  | 34  | 470.94 **  |  | 34  | 0.17 **     |
| G x L         | 102 | 1.23 *     | 5476.69 *     |  | 102 | 157.13 **  |  | 135 | 0.09 **     |
| Error         | 262 | 0.86       | 3979.52       |  | 267 | 93.38      |  | 361 | 0.02        |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 11. (Continued).

| Source        | MS  |               | MS  |             | MS  |               | MS  |               |
|---------------|-----|---------------|-----|-------------|-----|---------------|-----|---------------|
|               | df  | 1000 Seed Wt. | df  | Grains/Head | df  | Total Dry Wt. | df  | Harvest Index |
| Location (L)  | 4   | 6299.72 **    | 3   | 5.76 **     | 4   | 21.00         | 3   | 2.69 **       |
| Rep/L         | 11  | 128.09        | 8   | 1.22        | 8   | 8.76          | 8   | 0.02          |
| Genotypes (G) | 34  | 84.50 **      | 34  | 0.46        | 34  | 4.82          | 34  | 0.03 **       |
| G x L         | 134 | 70.44 **      | 94  | 0.73        | 102 | 5.72          | 102 | 0.02 **       |
| Error         | 361 | 22.43         | 226 | 0.70        | 262 | 8.70          | 262 | 0.01          |

\*,\*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 12. Analyses of variance for agronomic characteristics of 34 sorghum genotypes measured at Obambo, 1990.

| Source          | df | Mean Squares (MS) |                 |                |                    |                |         | Leaf<br>Width | Leaf<br>Area |
|-----------------|----|-------------------|-----------------|----------------|--------------------|----------------|---------|---------------|--------------|
|                 |    | Days to<br>Flower | Plant<br>Height | Head<br>Length | Peduncle<br>Length | Leaf<br>Length |         |               |              |
| Rep(R)          | 3  | 28.28 *           | 715.94 **       | 58.76 **       | 16.59              | 248.44 **      | 8.60 ** | 56642.31 **   |              |
| Genotypes (G)   | 33 | 108.06 **         | 1007.26 **      | 25.66 **       | 128.47 **          | 107.12 **      | 1.00 ** | 7751.52 **    |              |
| Parents (P)     | 9  | 150.30 **         | 613.63 **       | 29.14 **       | 125.68 **          | 166.98 **      | 1.72 ** | 15305.29 **   |              |
| Fl's vs Parents | 1  | 546.12 **         | 311.12 **       | 51.17 **       | 57.76 *            | 72.51 *        | 0.31    | 266.55        |              |
| Fl's            | 23 | 51.81 **          | 624.04 **       | 8.19           | 90.64 **           | 82.87 **       | 0.66    | 4367.32 *     |              |
| Male (M)        | 3  | 89.20 **          | 2853.69 **      | 15.41 *        | 225.94 **          | 362.90 **      | 1.89 ** | 14638.88 **   |              |
| Female (F)      | 5  | 119.69 **         | 672.34 **       | 9.52           | 195.17 **          | 88.58 **       | 0.55    | 1958.63       |              |
| M x F           | 15 | 21.71 **          | 162.01 **       | 6.31           | 28.73 **           | 24.97 **       | 0.44    | 3115.90       |              |
| Error           | 99 | 8.41              | 48.01           | 4.28           | 8.76               | 11.01          | 0.51    | 2435.43       |              |
| Error (P)       | 27 | 11.45             | 39.64           | 3.04           | 8.55               | 12.86          | 0.47    | 2255.40       |              |
| Error (Fl's)    | 69 | 7.43              | 53.32           | 4.88           | 8.39               | 10.58          | 0.53    | 2557.87       |              |
| Residual        | 3  | 3.59              | 1.21            | 1.64           | 19.16              | 4.25           | 0.41    | 1239.58       |              |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 12. (Continued).

| Source          | df | MS             |                  |  | Heads/<br>Plot | df | MS              |  | Total<br>Dry wt. | df | MS |  | Harvest<br>Index |
|-----------------|----|----------------|------------------|--|----------------|----|-----------------|--|------------------|----|----|--|------------------|
|                 |    | Grain<br>Yield | 1000<br>Seed Wt. |  |                |    | Grains/<br>Head |  |                  |    |    |  |                  |
| Rep(R)          | 3  | 0.05           | 46.58            |  | 199.24 *       | 3  | 1.81 **         |  | 0.41             | 3  |    |  | 0.001            |
| Genotypes(G)    | 33 | 0.52 **        | 92.28 **         |  | 138.29 **      | 33 | 1.28 **         |  | 1.73 **          | 33 |    |  | 0.037 **         |
| Parents (P)     | 9  | 0.16 **        | 30.29            |  | 141.62 **      | 9  | 0.58 **         |  | 0.92 *           | 9  |    |  | 0.030 **         |
| Fl's vs Parents | 1  | 0.38 **        | 177.41 **        |  | 0.03           | 1  | 1.74 *          |  | 0.05             | 1  |    |  | 0.067 **         |
| Fl's            | 23 | 0.49 **        | 98.49 **         |  | 132.48 **      | 23 | 1.30 **         |  | 1.39 **          | 23 |    |  | 0.033 **         |
| Male (M)        | 3  | 1.15 **        | 236.82 **        |  | 86.78          | 3  | 6.89 **         |  | 2.05 **          | 3  |    |  | 0.067 **         |
| Female (F)      | 5  | 0.96 **        | 219.26 **        |  | 335.98 **      | 5  | 0.56            |  | 3.01 **          | 5  |    |  | 0.036 **         |
| M x F           | 15 | 0.20 **        | 30.57            |  | 72.28          | 15 | 0.40            |  | 0.74 *           | 15 |    |  | 0.025 *          |
| Error           | 98 | 0.04           | 25.33            |  | 52.20          | 97 | 0.32            |  | 0.41             | 94 |    |  | 0.009            |
| Error (P)       | 26 | 0.03           | 25.84            |  | 41.21          | 26 | 0.14            |  | 0.33             | 23 |    |  | 0.007            |
| Error (Fl's)    | 69 | 0.05           | 25.59            |  | 53.90          | 68 | 0.39            |  | 0.41             | 68 |    |  | 0.010            |
| Residual        | 3  | 0.03           | 14.93            |  | 108.35         | 3  | 0.29            |  | 1.05             | 3  |    |  | 0.002            |

\*,\*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 13. Analyses of variance for agronomic characteristics of 35 sorghum genotypes measured at Obamto, 1991.

| Source          | df  | Mean Squares (MS) |              |             |                 |             |            |             |
|-----------------|-----|-------------------|--------------|-------------|-----------------|-------------|------------|-------------|
|                 |     | Days to Flower    | Plant Height | Head Length | Peduncle Length | Leaf Length | Leaf Width | Leaf Area   |
| Rep (R)         | 3   | 128.65 **         | 864.79 **    | 35.63 *     | 63.93 *         | 203.33 **   | 3.00 **    | 23334.31 ** |
| Genotypes (G)   | 34  | 71.47 **          | 1495.55 **   | 32.00 **    | 156.74 **       | 124.49 **   | 0.77 **    | 6759.90 **  |
| Parents (P)     | 9   | 134.65 **         | 528.66 **    | 21.52 **    | 126.87 **       | 169.12 **   | 0.56 *     | 6276.27 **  |
| F1's vs Parents | 1   | 434.08 **         | 24.15        | 5.49        | 0.59            | 223.64 **   | 0.75       | 723.51      |
| F1's            | 23  | 35.46 **          | 1000.95 **   | 13.50 **    | 100.69 **       | 86.65 **    | 0.64       | 4753.36 *   |
| Male (M)        | 3   | 20.47 **          | 5272.27 **   | 34.77 **    | 346.51 **       | 410.70 **   | 1.58 **    | 17169.04 ** |
| Female (F)      | 5   | 119.98 **         | 864.20 **    | 33.47 **    | 163.88 **       | 120.59 **   | 0.73       | 6713.56 *   |
| M x F           | 15  | 10.28             | 192.26 **    | 2.59        | 30.46 **        | 10.53       | 0.41       | 1616.83     |
| Error           | 100 | 7.66              | 69.30        | 2.92        | 7.59            | 10.88       | 0.37       | 1887.21     |
| Error (P)       | 25  | 7.97              | 54.69        | 2.45        | 4.80            | 11.39       | 0.22       | 1067.53     |
| Error (F1's)    | 69  | 7.05              | 75.92        | 3.15        | 8.17            | 10.48       | 0.43       | 2196.90     |
| Residual        | 6   | 13.38             | 54.05        | 2.23        | 12.55           | 13.35       | 0.31       | 1741.11     |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 13. (Continued).

| Source          | df  | MS             |    | df  | Grain<br>Yield | 1000<br>Seed Wt. | Grains/<br>Head | Total<br>Dry Wt. | Harvest<br>Index |
|-----------------|-----|----------------|----|-----|----------------|------------------|-----------------|------------------|------------------|
|                 |     | Heads/<br>Plot | MS |     |                |                  |                 |                  |                  |
| Rep(R)          | 3   | 175.87 *       |    | 3   | 0.35 **        | 5.74             | 0.062           | 2.86 **          | 0.048 *          |
| Genotypes(G)    | 34  | 205.02 **      |    | 34  | 0.37 **        | 81.29 *          | 0.382 **        | 1.05 **          | 0.053 **         |
| Parents (P)     | 9   | 406.08 **      |    | 9   | 0.24 **        | 43.02 **         | 0.264 **        | 0.70 **          | 0.057 **         |
| F1's vs Parents | 1   | 52.38          |    | 1   | 0.04           | 146.81 *         | 0.012           | 1.11 **          | 0.0002           |
| F1's            | 23  | 92.90 **       |    | 23  | 0.33 **        | 62.48 **         | 0.409 **        | 0.73 **          | 0.055 **         |
| Male (M)        | 3   | 77.59          |    | 3   | 1.36 **        | 148.42 **        | 1.631 **        | 0.69             | 0.267 **         |
| Female (F)      | 5   | 70.31          |    | 5   | 0.24 **        | 172.44 **        | 0.408 **        | 1.80 **          | 0.005            |
| M x F           | 15  | 103.49 *       |    | 15  | 0.16 **        | 8.64 **          | 0.165 **        | 0.38             | 0.029 *          |
| Error           | 101 | 44.61          |    | 100 | 0.04           | 2.74             | 0.049           | 0.25             | 0.014            |
| Error (P)       | 26  | 36.06          |    | 25  | 0.01           | 3.02             | 0.061           | 0.10             | 0.012            |
| Error (F1's)    | 69  | 38.25          |    | 69  | 0.03           | 2.66             | 0.041           | 0.26             | 0.015            |
| Residual        | 6   | 154.80         |    | 6   | 0.28           | 2.49             | 0.091           | 0.76             | 0.011            |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 14. Analyses of variance for agronomic characteristics of 35 sorghum genotypes measured at Buburi, 1990.

|                 |    | Mean Squares (MS) |              |             |                 |             |            |            |
|-----------------|----|-------------------|--------------|-------------|-----------------|-------------|------------|------------|
| Source          | df | Days to Flower    | Plant Height | Head Length | Peduncle Length | Leaf Length | Leaf Width | Leaf Area  |
| Rep(R)          | 1  | 554.41 **         | 3514.51 **   | 68.01 *     | 5526.91 **      | 0.39        | 8.23 *     | 4717.47    |
| Genotypes(G)    | 34 | 29.39 *           | 565.42       | 10.58       | 186.82          | 87.70       | 1.10       | 4357.04    |
| Parents (P)     | 9  | 25.91 **          | 155.83       | 7.34        | 62.27           | 52.12       | 0.36       | 1432.21    |
| F1's vs Parents | 1  | 114.00 *          | 480.39       | 3.59        | 39.41           | 1.00        | 0.12       | 166.52     |
| F1's            | 23 | 20.75             | 597.78       | 9.83        | 143.93          | 79.36       | 1.16       | 4523.68    |
| Male (M)        | 3  | 7.24              | 2259.58 **   | 25.61       | 324.08          | 94.97       | 1.06       | 4428.42    |
| Female (F)      | 5  | 64.69             | 518.53       | 2.25        | 328.79          | 169.75 *    | 2.38 *     | 10075.56 * |
| M x F           | 15 | 8.81              | 291.83       | 9.19        | 46.28           | 46.11       | 0.77       | 2692.11    |
| Error           | 34 | 15.71             | 442.57       | 13.37       | 171.91          | 75.12       | 1.29       | 4577.57    |
| Error (P)       | 9  | 3.20              | 148.49       | 9.12        | 68.27           | 37.13       | 0.94       | 1991.30    |
| Error (F1's)    | 23 | 15.01             | 469.08       | 14.08       | 131.97          | 53.20       | 0.86       | 3516.46    |
| Residual        | 2  | 80.06             | 1461.07      | 24.33       | 1097.60         | 498.16      | 7.81       | 28418.55   |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 14. (Continued).

| Source          | df | MS         |  | df | MS          |  | df | MS             |  |
|-----------------|----|------------|--|----|-------------|--|----|----------------|--|
|                 |    | Heads/Plot |  |    | Grain Yield |  |    | 1000 Grain Wt. |  |
| Rep(R)          | 1  | 534.26 **  |  | 1  | 0.006       |  | 1  | 24.53          |  |
| Genotypes(G)    | 34 | 157.10 *   |  | 34 | 0.030 **    |  | 34 | 22.72          |  |
| Parents (P)     | 9  | 218.20 *   |  | 9  | 0.015       |  | 9  | 18.85          |  |
| F1's vs Parents | 1  | 163.55     |  | 1  | 0.036 **    |  | 1  | 15.90          |  |
| F1's            | 23 | 117.87     |  | 23 | 0.025 **    |  | 23 | 25.07          |  |
| Male (M)        | 3  | 15.67      |  | 3  | 0.022 **    |  | 3  | 32.19          |  |
| Female (F)      | 5  | 322.94 **  |  | 5  | 0.042 **    |  | 5  | 11.61          |  |
| M x F           | 15 | 69.42      |  | 15 | 0.019 **    |  | 15 | 28.44          |  |
| Error           | 30 | 67.69      |  | 31 | 0.005       |  | 30 | 36.03          |  |
| Error (P)       | 7  | 48.57      |  | 7  | 0.009       |  | 7  | 16.06          |  |
| Error (F1's)    | 23 | 75.74      |  | 23 | 0.003       |  | 22 | 44.36          |  |
| Residual        | 0  | —          |  | 1  | 0.023       |  | 1  | 0.66           |  |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 15. Analyses of variance for agronomic characteristics of 35 sorghum genotypes measured at Buburi, 1991.

| Source          | df | Mean Squares (MS) |              |             | df | MS              |             |
|-----------------|----|-------------------|--------------|-------------|----|-----------------|-------------|
|                 |    | Days to Flower    | Plant Height | Head Length |    | Peduncle Length | Leaf Length |
| Rep(R)          | 1  | 1.16 **           | 2043.36 **   | 7.89        | 1  | 16.56           | 557.23 *    |
| Genotypes (G)   | 34 | 95.92             | 1359.00 **   | 23.65 *     | 17 | 89.24           | 93.51       |
| Parents (P)     | 9  | 84.61             | 762.36 **    | 26.55 *     | 2  | 19.70           | 137.65      |
| F1's vs Parents | 1  | 440.76 *          | 8.96         | 1.17        | 1  | < 0.01          | 27.02       |
| F1's            | 23 | 106.42            | 1236.21 **   | 13.88       | 14 | 100.73          | 83.42       |
| Male (M)        | 3  | 43.83             | 5903.21 **   | 11.31       | 3  | 69.51           | 33.91       |
| Female (F)      | 5  | 256.38 *          | 1157.77 **   | 20.73       | 4  | 122.44          | 142.64      |
| M x F           | 15 | 68.95             | 328.96       | 12.12       | 7  | 61.53           | 73.58       |
| Error           | 34 | 86.63             | 198.74       | 11.92       | 9  | 76.79           | 99.85       |
| Error (P)       | 9  | 82.38             | 90.96        | 8.20        | 1  | 26.52           | 75.84       |
| Error (F1's)    | 23 | 78.74             | 246.71       | 10.84       | 14 | 92.53           | 97.61       |
| Residual        | 2  | 196.49            | 132.10       | 41.08       | —  | —               | 233.66      |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 15. (Continued).

| MS              |    |            |           |            |             |               |
|-----------------|----|------------|-----------|------------|-------------|---------------|
| Source          | df | Leaf Width | Leaf Area | Heads/Plot | Grain Yield | 1000 Seed Wt. |
| Rep (R)         | 1  | 3.80       | 37060.48  | 864.51 **  | 0.0243      | 1355.20 **    |
| Genotypes (G)   | 34 | 2.72       | 14226.91  | 98.91      | 0.0550 *    | 154.65        |
| Parents (P)     | 9  | 1.70       | 12056.16  | 128.89 **  | 0.0515 **   | 145.67        |
| F1's vs Parents | 1  | 0.51       | 478.90    | 472.87 **  | 0.0012      | 191.53 **     |
| F1's            | 23 | 3.24       | 15984.51  | 73.91      | 0.0594      | 162.45        |
| Male (M)        | 3  | 2.72       | 10059.87  | 26.19      | 0.1300 *    | 104.69        |
| Female (F)      | 5  | 7.33       | 32381.18  | 191.52     | 0.1100      | 296.50 *      |
| M x F           | 15 | 1.98       | 11703.88  | 44.25      | 0.0290      | 129.31        |
| Error           | 34 | 2.81       | 16125.44  | 61.37      | 0.0301      | 99.82         |
| Error (P)       | 9  | 2.43       | 12467.31  | 6.20       | 0.0021      | 108.42        |
| Error (F1's)    | 23 | 2.96       | 17189.58  | 78.82      | 0.0420      | 100.94        |
| Residual        | 2  | 2.80       | 20349.42  | 108.96     | 0.0190      | 48.24         |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 15. (Continued).

| Source          | df | MS          |               | df | MS            |  |
|-----------------|----|-------------|---------------|----|---------------|--|
|                 |    | Grains/Head | Total Dry Wt. |    | Harvest Index |  |
| Rep(R)          | 1  | 1.59        | 0.87          | 1  | 0.014         |  |
| Genotypes (G)   | 30 | 0.78        | 0.83          | 34 | 0.031 *       |  |
| Parents (P)     | 8  | 0.58 **     | 0.65 **       | 9  | 0.052 **      |  |
| F1's vs Parents | 1  | < 0.01      | 0.40          | 1  | 0.058 *       |  |
| F1's            | 20 | 0.99        | 0.84          | 23 | 0.026 *       |  |
| Male (M)        | 3  | 1.29        | 0.52          | 3  | 0.050 *       |  |
| Female (F)      | 5  | 1.71        | 1.80          | 5  | 0.049 **      |  |
| M x F           | 12 | 0.47        | 0.58          | 15 | 0.013         |  |
| Error           | 15 | 0.38        | 0.73          | 34 | 0.009         |  |
| Error (P)       | 3  | 0.02        | 0.08          | 9  | 0.005         |  |
| Error (F1's)    | 10 | 0.54        | 1.01          | 23 | 0.012         |  |
| Residual        | 2  | 0.12        | 0.44          | 2  | 0.005         |  |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 16. Analyses of variance for agronomic characteristics of 34 sorghum genotypes measured at Mumias, 1990.

| Source          | df | Days to Flower | Plant Height | Head Length | Peduncle Length | Leaf Length |
|-----------------|----|----------------|--------------|-------------|-----------------|-------------|
|                 |    |                |              |             |                 |             |
| Rep(R)          | 1  | 14.13          | 58.92        | 89.24 **    | 1.09            | 0.01        |
| Genotypes (G)   | 33 | 82.57 *        | 1217.71 **   | 37.77 **    | 113.85 **       | 88.97       |
| Parents (P)     | 9  | 72.27          | 571.55 *     | 32.78       | 97.26           | 133.85      |
| F1's vs Parents | 1  | 23.55          | 2902.58 **   | 295.44 **   | 163.88 *        | 128.12      |
| F1's            | 23 | 48.91          | 933.41 **    | 31.85 **    | 85.41 **        | 75.05       |
| Male (M)        | 3  | 87.50          | 5079.79 **   | 84.59 **    | 248.99 **       | 32.65       |
| Female (F)      | 5  | 78.75          | 853.13 **    | 74.49 **    | 135.96 **       | 113.30      |
| M x F           | 15 | 31.25          | 130.89       | 7.09        | 35.84           | 70.78       |
| Error           | 33 | 38.56          | 143.13       | 10.15       | 25.40           | 50.41       |
| Error (P)       | 9  | 42.94          | 152.22       | 12.60       | 33.16           | 68.19       |
| Error (F1's)    | 23 | 38.32          | 145.15       | 9.34        | 22.65           | 45.35       |
| Residual        | 1  | 4.66           | 14.86        | 6.73        | 18.81           | 6.77        |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 16. (Continued).

|                 |    | MS         |           |            |             |
|-----------------|----|------------|-----------|------------|-------------|
| Source          | df | Leaf Width | Leaf Area | Heads/Plot | Grain Yield |
| Rep (R)         | 1  | 3.58       | 4136.54   | 106.25     | 0.006       |
| Genotypes (G)   | 33 | 1.14       | 4632.53   | 86.58      | 0.005 **    |
| Parents (P)     | 9  | 1.33       | 6000.55   | 87.47      | 0.003 **    |
| F1's vs Parents | 1  | 3.36       | 10920.01  | 0.02       | 0.004       |
| F1's            | 23 | 1.11       | 4284.70   | 82.12      | 0.006 *     |
| Male (M)        | 3  | 0.74       | 2552.05   | 74.72      | 0.011 *     |
| Female (F)      | 5  | 2.16       | 7620.28   | 205.98 *   | 0.007 *     |
| M x F           | 15 | 0.83       | 3519.39   | 42.31      | 0.005       |
| Error           | 33 | 1.11       | 3392.99   | 65.64      | 0.002       |
| Error (P)       | 9  | 1.26       | 4055.70   | 46.72      | < 0.001     |
| Error (F1's)    | 23 | 1.08       | 3237.56   | 72.34      | 0.002       |
| Residual        | 1  | 0.45       | 1003.49   | 81.82      | 0.016       |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 16. (Continued).

| Source          | df | MS            |             | df | MS          |               | Total Dry Wt. | Harvest Index |
|-----------------|----|---------------|-------------|----|-------------|---------------|---------------|---------------|
|                 |    | 1000 Seed Wt. | Grains/Head |    | Grains/Head | Total Dry Wt. |               |               |
| Rep (R)         | 1  | 108.76        |             | 1  |             | 0.01          | 0.0020 *      |               |
| Genotypes (G)   | 33 | 96.96         |             | 33 |             | 1.57 **       | 0.0008 *      |               |
| Parents (P)     | 9  | 123.46        |             | 7  | 0.004       | 1.28 **       | 0.0006 *      |               |
| F1's vs Parents | 1  | 0.63          |             | 1  | < 0.001     | 4.66 **       | 0.0002        |               |
| F1's            | 23 | 52.91         |             | 23 | 0.021       | 1.50 **       | 0.0008        |               |
| Male (M)        | 3  | 114.85        |             | 3  | 0.037       | 3.56 **       | 0.0020 *      |               |
| Female (F)      | 5  | 94.59         |             | 5  | 0.013       | 3.37 **       | 0.0008        |               |
| M x F           | 15 | 24.64         |             | 15 | 0.019       | 0.46          | 0.0005        |               |
| Error           | 33 | 59.70         |             | 33 |             | 0.28          | 0.0004        |               |
| Error (P)       | 9  | 92.83         |             | 5  | 0.001       | 0.11          | 0.0002        |               |
| Error (F1's)    | 23 | 47.27         |             | 19 | 0.026       | 0.35          | 0.0004        |               |
| Residual        | 1  | 47.42         |             | 1  |             | 0.20          | 0.0022        |               |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 17. Analyses of variance for agronomic characteristics of 35 sorghum genotypes measured at Mumias, 1991.

| Source          | df | Mean Squares   |              |             |                 | df | MS       |
|-----------------|----|----------------|--------------|-------------|-----------------|----|----------|
|                 |    | Days to Flower | Plant Height | Head Length | Peduncle Length |    |          |
| Rep (R)         | 1  | 490.91         | 977.52       | 34.91       | 465.84 *        | 1  | 252.02   |
| Genotypes (G)   | 34 | 165.40         | 992.10       | 37.23       | 214.62 *        | 34 | 96.51    |
| Parents (P)     | 9  | 104.87         | 1783.01      | 51.34       | 208.67          | 9  | 128.52 * |
| F1's vs Parents | 1  | 22.37          | 835.97       | 14.09       | 51.50           | 1  | 50.67    |
| F1's            | 23 | 198.30         | 703.80       | 31.12       | 175.75          | 23 | 79.63    |
| Male (M)        | 3  | 722.60         | 789.68       | 15.33       | 171.06          | 3  | 6.78     |
| Female (F)      | 5  | 64.64          | 874.90       | 31.63       | 128.40          | 5  | 39.81    |
| M x F           | 15 | 135.52         | 664.49       | 33.22       | 187.59          | 15 | 105.31   |
| Error           | 32 | 266.78         | 1287.52      | 27.03       | 126.54          | 30 | 95.48    |
| Error (P)       | 9  | 146.53         | 1173.72      | 20.49       | 74.76           | 8  | 35.43    |
| Error (F1's)    | 21 | 266.41         | 1135.88      | 20.03       | 123.63          | 20 | 94.68    |
| Residual        | 2  | 811.79         | 3391.84      | 129.96      | 390.11          | 2  | 343.68   |

\*,\*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 17. (Continued).

| Source          | df | MS         |           | df | MS         |             | df | MS |  |
|-----------------|----|------------|-----------|----|------------|-------------|----|----|--|
|                 |    | Leaf Width | Leaf Area |    | Heads/Plot | Grain Yield |    |    |  |
| Rep (R)         | 1  | 2.32       | 7729.19   | 1  | 3249.00 *  | 0.0118      | 1  |    |  |
| Genotypes (G)   | 34 | 1.32       | 2802.55   | 34 | 364.46     | 0.0041      | 34 |    |  |
| Parents (P)     | 9  | 1.25       | 3288.08   | 9  | 249.86     | 0.0060      | 9  |    |  |
| F1's vs Parents | 1  | 0.30       | 675.01    | 1  | 167.90     | 0.0071      | 1  |    |  |
| F1's            | 23 | 1.24       | 2471.41   | 23 | 420.99     | 0.0033      | 23 |    |  |
| Male (M)        | 3  | 0.32       | 368.62    | 3  | 1264.63    | 0.0052      | 3  |    |  |
| Female (F)      | 5  | 0.53       | 908.46    | 5  | 296.62     | 0.0064      | 5  |    |  |
| M x F           | 15 | 1.66       | 3373.67   | 15 | 287.59     | 0.0018      | 15 |    |  |
| Error           | 30 | 0.99       | 2318.58   | 31 | 476.71     | 0.0059      | 30 |    |  |
| Error (P)       | 8  | 0.56       | 1203.48   | 8  | 512.22     | 0.0070      | 8  |    |  |
| Error (F1's)    | 20 | 1.07       | 2405.98   | 22 | 473.34     | 0.0034      | 22 |    |  |
| Residual        | 2  | 1.91       | 5904.98   | 1  | 266.77     | —           | 0  |    |  |

\*,\*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 17. (Continued).

| Source          | df | MS     |          | df | MS          |               | df | MS            |       |
|-----------------|----|--------|----------|----|-------------|---------------|----|---------------|-------|
|                 |    | 1000   | Seed Wt. |    | Grains/Head | Total Dry Wt. |    | Harvest Index |       |
| Rep (R)         | 1  | 23.54  |          | 1  | < 0.001     |               | 1  | 0.538 *       | 0.005 |
| Genotypes (G)   | 33 | 72.63  |          | 30 | 0.005       |               | 34 | 0.078         | 0.006 |
| Parents (P)     | 9  | 85.06  |          | 8  | 0.005       |               | 9  | 0.082         | 0.006 |
| F1's vs Parents | 1  | 21.51  |          | 1  | < 0.001     |               | 1  | 0.067         | 0.018 |
| F1's            | 23 | 71.30  |          | 21 | 0.005       |               | 23 | 0.090         | 0.008 |
| Male (M)        | 3  | 112.35 |          | 3  | 0.006       |               | 3  | 0.117         | 0.009 |
| Female (F)      | 5  | 51.37  |          | 5  | 0.012 *     |               | 5  | 0.114         | 0.014 |
| M x F           | 15 | 71.58  |          | 13 | 0.003       |               | 15 | 0.087         | 0.005 |
| Error           | 30 | 130.33 |          | 13 | 0.007       |               | 30 | 0.108         | 0.007 |
| Error (P)       | 8  | 94.94  |          | 4  | 0.011       |               | 8  | 0.133         | 0.006 |
| Error (F1's)    | 21 | 127.10 |          | 8  | 0.003       |               | 21 | 0.087         | 0.006 |
| Residual        | 1  | 481.28 |          | 1  | 0.023       |               | 1  | 0.349         | 0.036 |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 18. Analyses of variance for agronomic characteristics of 32 sorghum genotypes measured at Ukwala, 1990.

| Source          | df | MS             |              | df | MS          |                 | df | MS          |  | df | MS |  |
|-----------------|----|----------------|--------------|----|-------------|-----------------|----|-------------|--|----|----|--|
|                 |    | Days to Flower | Plant Height |    | Head Length | Peduncle Length |    | Leaf Length |  |    |    |  |
| Rep (R)         | 3  | 30.23 **       | 461.45       | 3  | 6.96        | 107.58          | 3  | 69.84 **    |  |    |    |  |
| Genotypes (G)   | 31 | 10.52 **       | 1554.45 **   | 30 | 30.29 **    | 96.32 **        | 30 | 89.49 **    |  |    |    |  |
| Parents (P)     | 8  | 4.54           | 519.52       | 7  | 8.85        | 30.89           | 7  | 50.73 *     |  |    |    |  |
| Fl's vs parents | 1  | < 0.01         | < 0.01       | 1  | < 0.01      | < 0.01          | 1  | < 0.01      |  |    |    |  |
| Fl's            | 22 | 12.62 **       | 1688.60 **   | 22 | 26.31 **    | 85.18 *         | 22 | 60.06 **    |  |    |    |  |
| Male (M)        | 3  | 25.48 **       | 6831.54 **   | 3  | 37.23 **    | 141.61 *        | 3  | 141.29 **   |  |    |    |  |
| Female (F)      | 5  | 30.95 **       | 758.91 *     | 5  | 67.06 **    | 192.17 **       | 5  | 97.42 **    |  |    |    |  |
| M x F           | 15 | 4.49           | 504.72 *     | 14 | 5.15        | 26.02           | 14 | 20.26       |  |    |    |  |
| Error           | 74 | 4.52           | 262.85       | 62 | 4.15        | 43.61           | 61 | 12.97       |  |    |    |  |
| Error (P)       | 12 | 4.94           | 290.51       | 8  | 5.09        | 68.01           | 7  | 8.65        |  |    |    |  |
| Error (Fl's)    | 59 | 4.53           | 268.66       | 51 | 3.80        | 39.83           | 51 | 13.03       |  |    |    |  |
| Residual        | 3  | 2.64           | 90.32        | 3  | 7.59        | 42.80           | 3  | 22.03       |  |    |    |  |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 18. (Continued).

| Source          | df | MS         |             | df | MS        |            | df | MS         |             | df | MS         |             |
|-----------------|----|------------|-------------|----|-----------|------------|----|------------|-------------|----|------------|-------------|
|                 |    | Leaf Width | Leaf Area   |    | Leaf Area | Heads/Plot |    | Heads/Plot | Grain Yield |    | Heads/Plot | Grain Yield |
| Rep (R)         | 3  | 2.58 **    | 13924.06 ** | 3  | 78.66     |            | 3  | 0.012      |             |    |            |             |
| Genotypes (G)   | 30 | 1.74 **    | 10514.03 ** | 30 | 143.06 ** |            | 33 | 0.077 **   |             |    |            |             |
| Parents (P)     | 7  | 0.85       | 3590.23     | 7  | 38.95     |            | 9  | 0.023 **   |             |    |            |             |
| F1's vs Parents | 1  | < 0.01     | < 0.01      | 1  | 396.93 ** |            | 1  | 0.018      |             |    |            |             |
| F1's            | 22 | 1.66 **    | 8976.54 **  | 22 | 189.73 ** |            | 23 | 0.056 **   |             |    |            |             |
| Male (M)        | 3  | 5.43 **    | 23266.86 ** | 3  | 204.72 ** |            | 3  | 0.005      |             |    |            |             |
| Female (F)      | 5  | 1.92 **    | 13009.73 ** | 5  | 489.44 ** |            | 5  | 0.070 **   |             |    |            |             |
| M x F           | 15 | 0.50       | 2649.04     | 15 | 86.83 **  |            | 15 | 0.063 **   |             |    |            |             |
| Error           | 61 | 0.48       | 2154.97     | 61 | 46.13     |            | 99 | 0.014      |             |    |            |             |
| Error (P)       | 7  | 0.23       | 1150.23     | 7  | 70.90     |            | 27 | 0.004      |             |    |            |             |
| Error (F1's)    | 51 | 0.52       | 2315.02     | 51 | 33.82     |            | 69 | 0.017      |             |    |            |             |
| Residual        | 3  | 0.38       | 1778.51     | 3  | 114.59    |            | 3  | 0.032      |             |    |            |             |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 18. (Continued).

| Source          | df | MS            |    | df | MS         |    |
|-----------------|----|---------------|----|----|------------|----|
|                 |    | 1000 Seed Wt. |    |    | Grain/Head |    |
| Rep (R)         | 3  | 105.57        | ** | 3  | 0.203      |    |
| Genotypes (G)   | 33 | 108.63        | ** | 33 | 0.463      | ** |
| Parents (P)     | 9  | 100.41        | ** | 9  | 0.062      |    |
| F1's vs Parents | 1  | 8.03          |    | 1  | 1.40       | ** |
| F1's            | 23 | 98.16         | ** | 23 | 0.513      | ** |
| Male (M)        | 3  | 464.11        | ** | 3  | 0.914      | ** |
| Female (F)      | 5  | 121.95        | ** | 5  | 1.037      |    |
| M x F           | 15 | 17.04         | *  | 15 | 0.259      | *  |
| Error           | 99 | 8.39          |    | 98 | 0.111      |    |
| Error (P)       | 27 | 9.88          |    | 26 | 0.096      |    |
| Error (F1's)    | 69 | 7.04          |    | 69 | 0.115      |    |
| Residual        | 3  | 26.03         |    | 3  | 0.149      |    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 19. Analyses of variance for agronomic characteristics of 35 sorghum genotypes measured at Ukwala, 1991.

| Source          | df | Mean Squares (MS) |              |             |                 |    | MS          |  |
|-----------------|----|-------------------|--------------|-------------|-----------------|----|-------------|--|
|                 |    | Days to Flower    | Plant Height | Head Length | Peduncle Length | df | Leaf Length |  |
| Rep (R)         | 3  | 17.17             | 230.60       | 25.65       | 51.51           | 3  | 96.69       |  |
| Genotypes (G)   | 34 | 89.27 **          | 1877.62 **   | 40.75 **    | 193.40 **       | 34 | 87.94 **    |  |
| Parents (P)     | 9  | 118.27 **         | 705.65 **    | 16.18 *     | 177.90 **       | 9  | 73.01 **    |  |
| F1's vs Parents | 1  | 11.66             | 1290.32 **   | 221.44 **   | 191.64 **       | 1  | 29.00       |  |
| F1's            | 23 | 50.90 **          | 1450.84 **   | 35.76 **    | 102.99 **       | 23 | 85.14 *     |  |
| Male (M)        | 3  | 64.22 **          | 8302.45 **   | 73.44 **    | 14.09           | 3  | 244.67 *    |  |
| Female (F)      | 5  | 147.98 **         | 1206.09 **   | 99.54 **    | 331.21 **       | 5  | 101.67      |  |
| M x F           | 15 | 14.32 *           | 154.40       | 6.65 *      | 43.31 *         | 15 | 43.78       |  |
| Error           | 99 | 9.35              | 108.55       | 4.39        | 20.05           | 98 | 37.94       |  |
| Error (P)       | 25 | 17.85             | 121.43       | 6.78        | 24.79           | 24 | 13.34       |  |
| Error (F1's)    | 68 | 6.63              | 111.56       | 3.38        | 19.77           | 68 | 47.86       |  |
| Residual        | 6  | 4.76              | 41.54        | 5.88        | 3.47            | 6  | 23.91       |  |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 19. (Continued).

| source          | df | MS         |  | df | MS          |  | df  | MS         |  | df | MS          |  |
|-----------------|----|------------|--|----|-------------|--|-----|------------|--|----|-------------|--|
|                 |    | Leaf Width |  |    | Leaf Area   |  |     | Heads/Plot |  |    | Grain Yield |  |
| Rep (R)         | 3  | 1.78 *     |  | 3  | 10327.39 ** |  | 3   | 785.77 **  |  | 3  | 0.017       |  |
| Genotypes (G)   | 34 | 1.35 **    |  | 34 | 6382.05 **  |  | 34  | 308.59 **  |  | 34 | 0.051 **    |  |
| Parents (P)     | 9  | 0.36       |  | 9  | 2634.86     |  | 9   | 301.34 **  |  | 9  | 0.032 **    |  |
| F1's vs Parents | 1  | 7.83 **    |  | 1  | 15287.14 *  |  | 1   | 77.02      |  | 1  | 0.081 **    |  |
| F1's            | 23 | 1.76 **    |  | 23 | 7247.60 **  |  | 23  | 196.82 **  |  | 23 | 0.899 **    |  |
| Male (M)        | 3  | 4.29 **    |  | 3  | 20457.77 ** |  | 3   | 422.98 **  |  | 3  | 0.079 **    |  |
| Female (F)      | 5  | 3.51 **    |  | 5  | 11054.81 ** |  | 5   | 183.93 **  |  | 5  | 0.068 **    |  |
| M x F           | 15 | 0.70       |  | 15 | 3134.20     |  | 15  | 155.98 **  |  | 15 | 0.021 **    |  |
| Error           | 98 | 0.64       |  | 98 | 2409.11     |  | 102 | 35.28      |  | 98 | 0.005       |  |
| Error (P)       | 24 | 0.31       |  | 24 | 1213.38     |  | 27  | 27.69      |  | 24 | 0.002       |  |
| Error (F1's)    | 68 | 0.75       |  | 68 | 2754.00     |  | 68  | 35.37      |  | 68 | 0.006       |  |
| Residual        | 6  | 0.71       |  | 6  | 3283.28     |  | 7   | 63.68      |  | 6  | 0.006       |  |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 19. (Continued).

| Source          | df | MS            |               |               |               |
|-----------------|----|---------------|---------------|---------------|---------------|
|                 |    | 1000 Seed Wt. | Grains / Head | Total Dry Wt. | Harvest Index |
| Rep (R)         | 3  | 3.65          | 2.67          | 20.03         | 0.003         |
| Genotypes (G)   | 34 | 24.86 **      | 1.61          | 23.99         | 0.011 **      |
| Parents (P)     | 9  | 32.50 **      | 0.17          | 0.26 **       | 0.021 **      |
| F1's vs Parents | 1  | 8.58          | 0.07          | 34.27         | 0.026 *       |
| F1's            | 23 | 20.77 **      | 2.22          | 33.87         | 0.008         |
| Male (M)        | 3  | 30.67 **      | 4.65          | 37.62         | 0.002         |
| Female (F)      | 5  | 33.09 **      | 1.57          | 30.53         | 0.021 **      |
| M x F           | 15 | 15.25 **      | 1.89          | 32.79         | 0.004         |
| Error           | 98 | 3.78          | 1.50          | 22.73         | 0.004         |
| Error (P)       | 24 | 4.46          | 0.15          | 0.04          | 0.003         |
| Error (F1's)    | 68 | 3.06          | 2.05          | 32.32         | 0.005         |
| Residual        | 6  | 9.22          | 0.67          | 4.80          | 0.002         |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 20. Analyses of variance for agronomic characteristics of 34 sorghum genotypes measured at PSRC, Mississippi State, 1990.

| Mean Squares (MS) |    |                |              |             |                 |             |
|-------------------|----|----------------|--------------|-------------|-----------------|-------------|
| Source            | df | Days to Flower | Plant Height | Head Length | Peduncle Length | Leaf Length |
| Rep (R)           | 3  | 32.32 **       | 66.09        | 6.75 **     | 36.46 **        | 62.23 *     |
| Genotypes (G)     | 33 | 58.53 **       | 3561.49 **   | 42.23 **    | 133.54 **       | 181.33 **   |
| Parents (P)       | 9  | 73.89 **       | 1393.18 **   | 46.72 **    | 105.56 **       | 288.25 **   |
| F1's vs Parents   | 1  | 70.23 **       | 103.43       | 78.41 **    | 18.01           | 812.77 **   |
| F1's              | 23 | 50.50 **       | 3039.20 **   | 10.72 **    | 76.61 **        | 123.36 **   |
| Male (M)          | 3  | 260.82 **      | 17805.43 **  | 27.36 **    | 159.17 **       | 570.00 **   |
| Female (F)        | 5  | 12.79 **       | 2684.15 **   | 16.54 **    | 181.34 **       | 131.46 **   |
| M x F             | 15 | 21.00 **       | 204.31 **    | 5.45 **     | 25.18 **        | 29.93       |
| Error             | 99 | 7.48           | 32.47        | 2.05        | 9.00            | 20.67       |
| Error (P)         | 27 | 5.83           | 24.00        | 1.25        | 11.96           | 17.18       |
| Error (F1's)      | 69 | 8.28           | 36.78        | 2.14        | 8.15            | 21.24       |
| Residual          | 3  | 3.93           | 9.57         | 7.18        | 1.91            | 38.97       |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 20. (Continued).

|                 |    | MS         |             |            |             |
|-----------------|----|------------|-------------|------------|-------------|
| Source          | df | Leaf Width | Leaf Area   | Heads/Plot | Grain Yield |
| Rep (R)         | 3  | 0.97       | 11142.57    | 78.01      | 0.09        |
| Genotypes (G)   | 33 | 2.09 **    | 19295.12 ** | 281.99 **  | 0.30 **     |
| Parents (P)     | 9  | 1.07       | 20526.81 ** | 377.17 **  | 0.04        |
| Fl's vs Parents | 1  | 0.22       | 47314.56 ** | 117.22     | 0.66 **     |
| Fl's            | 23 | 1.15       | 10587.73 ** | 169.39 **  | 0.22 **     |
| Male (M)        | 3  | 2.68 *     | 46369.09 ** | 131.65     | 0.63 **     |
| Female (F)      | 5  | 2.08 *     | 11813.13 *  | 614.31 **  | 0.17 *      |
| M x F           | 15 | 0.53       | 3023.01     | 28.63      | 0.16 **     |
| Error           | 99 | 0.67       | 4226.20     | 47.88      | 0.04        |
| Error (P)       | 27 | 0.55       | 3422.65     | 42.83      | 0.02        |
| Error (Fl's)    | 69 | 0.69       | 4360.61     | 49.38      | 0.05        |
| Residual        | 3  | 1.29       | 8366.72     | 58.83      | 0.02        |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 20. (Continued).

| MS              |    |               |             |               |               |
|-----------------|----|---------------|-------------|---------------|---------------|
| Source          | df | 1000 Seed Wt. | Grains/Head | Total Dry Wt. | Harvest Index |
| Rep (R)         | 3  | 8.34          | 0.16        | 3.22          | 0.003         |
| Genotypes (G)   | 33 | 35.59 **      | 0.57 **     | 4.27 **       | 0.007 **      |
| Parents (P)     | 9  | 47.22 **      | 0.15 **     | 0.80          | 0.004         |
| F1's vs Parents | 1  | 5.98          | 0.07        | 5.02          | 0.003         |
| F1's            | 23 | 28.87 **      | 0.37 **     | 4.33 **       | 0.007 *       |
| Male (M)        | 3  | 132.41 **     | 0.91 **     | 8.03 **       | 0.029 **      |
| Female (F)      | 5  | 11.36         | 0.61 **     | 6.46 **       | 0.007         |
| M x F           | 15 | 7.86          | 0.19        | 2.87 *        | 0.003         |
| Error           | 99 | 4.88          | 0.09        | 1.44          | 0.004         |
| Error (P)       | 27 | 2.84          | 0.03        | 1.73          | 0.004         |
| Error (F1's)    | 69 | 5.71          | 0.11        | 1.35          | 0.004         |
| Residual        | 3  | 4.15          | 0.17        | 0.90          | 0.004         |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 21. Analyses of variance for agronomic characteristics of 34 sorghum genotypes measured at PSRC, Mississippi State, 1991.

| Source          | df | Mean Squares   |              |             |                 |             |               |
|-----------------|----|----------------|--------------|-------------|-----------------|-------------|---------------|
|                 |    | Days to Flower | Plant Height | Head Length | Peduncle Length | Grain Yield | 1000 Seed Wt. |
| Rep (R)         | 3  | 5.89 *         | 117.03       | 17.89 *     | 49.78 *         | 0.010       | 0.71          |
| Genotypes (G)   | 33 | 50.75          | 2696.58 **   | 43.57 **    | 182.72 **       | 0.123 **    | 14.20 **      |
| Parents (P)     | 9  | 66.50 **       | 1386.68 **   | 40.90 **    | 161.76 **       | 0.038 **    | 26.04 **      |
| F1's vs Parents | 1  | 11.63 **       | 39.54        | 21.02 *     | 0.15            | 0.071 **    | 0.70          |
| F1's            | 23 | 27.86 **       | 1852.30 **   | 24.28 **    | 93.71           | 0.124 **    | 6.75 **       |
| Male (M)        | 3  | 127.23 **      | 11196.09 **  | 70.95 **    | 130.10 **       | 0.656 **    | 5.69 **       |
| Female (F)      | 5  | 31.34 *        | 1589.34 **   | 50.07 **    | 237.86 **       | 0.079 **    | 14.71 **      |
| M x F           | 15 | 6.82 *         | 71.20        | 6.34        | 38.38 *         | 0.033 **    | 4.30 **       |
| Error           | 99 | 1.61           | 52.48        | 4.82        | 16.65           | 0.009       | 1.52          |
| Error (P)       | 27 | 1.46           | 25.07        | 3.90        | 13.14           | 0.008       | 2.29          |
| Error (F1's)    | 69 | 1.70           | 61.45        | 5.13        | 17.84           | 0.010       | 1.25          |
| Residual        | 3  | 0.89           | 92.86        | 5.97        | 20.87           | 0.005       | 0.80          |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

erosion and water drainage problems that were experienced in the early part of crop growth period at each location, respectively. Many of the materials were not well adapted to the environmental stresses encountered in Kenya, which resulted in additional missing plots at some locations. The major stresses included central shootfly (*Antherigona soccata*), witch weed (*Striga hermonthica*), sorghum midge (*Contarinia sorghicola*), aphids (*Rhopalsiplus maidis* Fitch), and bird damage which hurt crop performance at various stages of growth in various locations.

#### Days to Flower

There were significant differences among genotypes for days to flower at all locations in 1990, but only at Obambo and MSU in 1991 (Tables 12-21). The ten parental genotypes differed significantly at all locations in both years except at Ukwala in 1990, Buburi in 1991, and Mumias in both years. Significant average heterosis for days to flower was observed at Obambo, Buburi, and MSU in both years as indicated by the significant contrast of  $F_1$ s vs. Parents.  $F_1$ s tended to be earlier maturing than the inbred parents at these locations; however, this average heterosis was not exhibited at Mumias and Ukwala, the locations with lowest soil pH values. Differences among the  $F_1$ s were found at Obambo, Ukwala, and MSU in both years. Significant male effects (GCA) were expressed for days to flower at MSU, Obambo, and Ukwala in both years. Significant female effects (GCA) were expressed for this trait at MSU and Ukwala in both years, at Obambo in 1990, and at Buburi in 1991. This indicated the importance of additive genetic variance for this trait. A significant male x female interaction was observed for days to flower at

MSU and Obambo in 1990, and at MSU and Ukwala in 1991. Male x female interaction is a measure of specific combining ability (SCA) and is indicated the presence of non-additive gene action for days to flower.

Generally, all genotypes flowered earlier at Obambo and MSU than at other locations in both years indicating that the locations with low soil pH reduced the rate of plant growth and, consequently, flowering was delayed (Table 22). These results are in agreement with Flores *et al.* (1988) who reported that days to flower was delayed by 3 days for tolerant genotypes as compared to 8 days for susceptible genotypes due to soil acidity. The earliest parent at most locations in both years was generally Wheatland, except at Mumias. IS7254C was the earliest parent at Mumias in 1990; however, IS7254C and Wheatland exhibited comparable numbers of days to flower in both years at Obambo and Ukwala. In 1990, F<sub>1</sub>s flowered earlier than parents except at Ukwala. Similarly in 1991, hybrids flowered earlier than parents except at Buburi and Mumias. These results are in agreement with Quinby (1974) who found that heterosis in sorghum is mainly due to faster plant growth. Liang *et al.* (1972) reported negative heterobeltiosis for days-to-first-bloom. Generally, hybrid combinations involving females, Wheatland and B-Yel-PI, and male, TX432, flowered earlier than other hybrids in both years across locations. These hybrid combinations were also earlier than their respective parents. In the better environments, hybrid combinations involving tolerant male parent, IA28, flowered later than other hybrids in both years, but the trend changed in locations with low soil pH.

Male GCA effects were significant for early flowering for TX432 at MSU in both years, and at Ukwala in 1990; for IS7254C at MSU and Ukwala in

Table 22. Mean number days to flower of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No.     | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|---------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|               |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- d ----- |          |      |      |        |      |        |      |        |      |        |      |
| 1             | 1x7      | 67   | 52   | 47     | 61   | 90     | 69   | 64     | 73   | 77     | 97   |
| 2             | 1x8      | 72   | 61   | 46     | 60   | 84     | 71   | 68     | 79   | 77     | 83   |
| 3             | 1x9      | 68   | 54   | 54     | 63   | 82     | 70   | 65     | 78   | 92     | 117  |
| 4             | 1x10     | 71   | 55   | 55     | 63   | 83     | 71   | 63     | 82   | 85     | 94   |
| 5             | 2x7      | 66   | 51   | 46     | 58   | 86     | 67   | 63     | 66   | 77     | 107  |
| 6             | 2x8      | 74   | 53   | 46     | 57   | 86     | 69   | 61     | 69   | 77     | 83   |
| 7             | 2x9      | 67   | 52   | 53     | 59   | 84     | 67   | 63     | 71   | 77     | 125  |
| 8             | 2x10     | 68   | 52   | 47     | 58   | 81     | 71   | 60     | 67   | 77     | 92   |
| 9             | 3x7      | 69   | 52   | 46     | 63   | 83     | 69   | 66     | 74   | 77     | 102  |
| 10            | 3x8      | 77   | 55   | 44     | 64   | 84     | 67   | 65     | 74   | 85     | 96   |
| 11            | 3x9      | 66   | 51   | 53     | 64   | 84     | 75   | 64     | 75   | 85     | 103  |
| 12            | 3x10     | 63   | 50   | 50     | 58   | 85     | 67   | 64     | 73   | 85     | 83   |
| 13            | 4x7      | 67   | 52   | 50     | 62   | 90     | 69   | 65     | 72   | 77     | 84   |
| 14            | 4x8      | 75   | 57   | 55     | 65   | 88     | 69   | 65     | 76   | 77     | 101  |
| 15            | 4x9      | 67   | 51   | 55     | 64   | 87     | 70   | 65     | 75   | 77     | 100  |
| 16            | 4x10     | 67   | 51   | 49     | 65   | 85     | 64   | 63     | 71   | 77     | 92   |
| 17            | 5x7      | 70   | 53   | 54     | 64   | 87     | 65   | 66     | 72   | 77     | 94   |
| 18            | 5x8      | 72   | 57   | 51     | 63   | 90     | 82   | 67     | 74   | 85     | 104  |
| 19            | 5x9      | 71   | 55   | 53     | 67   | 90     | 83   | 66     | 74   | 85     | 103  |
| 20            | 5x10     | 70   | 54   | 49     | 62   | 90     | 94   | 64     | 74   | 77     | 104  |

1991; and for IA28 at Obambo in 1991. Significant male GCA effects for late flowering existed for TX430 at Obambo in 1990; and for IA28 at MSU in both years. Wheatland and (AT-1)-36-4-2-2-1 exhibited the most significant female GCA effects for days to flower. Both B-Yel-PI and (AT-2)-10-6-1-2-1 were location specific female combiners. Female GCA effects for days to flower were negative for Wheatland. The expression of GCA effects for days to flower indicated significant additive genetic variance. Modi and Dabholkar (1989) also obtained significant GCA effects for days to flower.

Significant SCA effects were obtained in hybrid combinations involving IA28 with all females except (AT-1)-36-4-2-2-1 at MSU and Obambo. Positive SCA effects were more frequent than negative SCA in IA28 crosses suggesting dominance for late flowering. Specific combining ability appeared to be of less importance than GCA for days to flower at most locations. Modi and Dabholkar (1989) also reported significant SCA effects for days to flower.

#### Plant Height

Analyses of variance for plant height are presented in Tables 12-21. Significant differences among genotypes were observed at all locations except Buburi in 1990 and Mumias in 1991. Significant differences among parents were observed at all locations except Buburi and Ukwala in 1990 and Mumias in 1991. The contrast of  $F_1$ s vs Parents was significant only at Obambo and Mumias in 1990 and Ukwala in 1991.  $F_1$ s showed significant variation at all locations in both years except for Buburi in 1990 and Mumias in 1991. Significant male GCA effects for plant height were

obtained at all locations except for Mumias in 1991. Significant female GCA effects were also obtained in all locations except Buburi in 1990 and Mumias in 1991. This indicated that additive gene action was important for plant height. Male x female interactions (SCA) were significant at MSU in 1991 indicating that non-additive gene action was also important in controlling this character at this location.

Means of plant height for all entries, by location and year, are presented in Table 23. Generally, all entries were taller at MSU in both years than at any other location. Lowest over all plant height means were obtained at Buburi in 1990 which was attributed to central shootfly damage and a short dry spell that occurred shortly after thinning the crop. In both years, over all means for Obambo and Ukwala were comparable. Plant height was suppressed at Mumias in both years. Wheatland was the shortest parent across locations in both years except at Mumias in 1991. IS7254C was the tallest parent at all locations except for Mumias in 1991. Generally, hybrids were taller than parents at most locations indicating heterosis for plant height. Hybrids involving male parent IS7254C were tallest, regardless of female parent, at most locations in both years. Hybrids of Wheatland with TX430 or TX432 were invariably shorter than other hybrids across locations in both years. Although Rubaihayo and Makumbi (1976) reported considerable heterosis for this character, the results of this study are more in agreement with Liang et al. (1972) who obtained low heterobeltiosis for plant height. Doggett (1988) stated that heterosis is a statistic which is applicable only to the trial in which it is measured, and emphasized the need for its measurement over different environments in order to be able to select lines that express heterosis

Table 23. Mean plant heights of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

|    |      |     |     |     |     |     |     |     |     |     |     |
|----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | 1x7  | 217 | 188 | 154 | 160 | 118 | 206 | 173 | 155 | 126 | 112 |
| 2  | 1x8  | 163 | 154 | 130 | 126 | 52  | 124 | 80  | 124 | 101 | 131 |
| 3  | 1x9  | 138 | 141 | 113 | 114 | 64  | 109 | 107 | 106 | 71  | 81  |
| 4  | 1x10 | 147 | 152 | 119 | 126 | 54  | 139 | 139 | 115 | 102 | 80  |
| 5  | 2x7  | 156 | 166 | 126 | 130 | 78  | 132 | 129 | 129 | 118 | 111 |
| 6  | 2x8  | 134 | 123 | 108 | 109 | 61  | 103 | 104 | 104 | 91  | 114 |
| 7  | 2x9  | 120 | 119 | 101 | 100 | 63  | 95  | 90  | 92  | 66  | 97  |
| 8  | 2x10 | 119 | 120 | 109 | 101 | 53  | 115 | 99  | 98  | 67  | 118 |
| 9  | 3x7  | 177 | 183 | 131 | 140 | 85  | 162 | 145 | 140 | 138 | 73  |
| 10 | 3x8  | 132 | 136 | 108 | 101 | 73  | 119 | 101 | 111 | 100 | 98  |
| 11 | 3x9  | 114 | 128 | 105 | 106 | 60  | 113 | 110 | 105 | 84  | 108 |
| 12 | 3x10 | 132 | 145 | 122 | 129 | 90  | 129 | 114 | 127 | 92  | 93  |
| 13 | 4x7  | 192 | 183 | 142 | 143 | 103 | 170 | 148 | 154 | 131 | 127 |
| 14 | 4x8  | 150 | 140 | 122 | 116 | 75  | 119 | 119 | 110 | 111 | 110 |
| 15 | 4x9  | 123 | 135 | 109 | 105 | 78  | 111 | 98  | 109 | 95  | 95  |
| 16 | 4x10 | 141 | 143 | 130 | 123 | 90  | 150 | 123 | 132 | 110 | 108 |
| 17 | 5x7  | 196 | 188 | 129 | 127 | 103 | 154 | 147 | 160 | 136 | 121 |
| 18 | 5x8  | 150 | 146 | 113 | 111 | 68  | 130 | 144 | 112 | 100 | 98  |
| 19 | 5x9  | 138 | 140 | 114 | 107 | 58  | 112 | 99  | 114 | 94  | 101 |
| 20 | 5x10 | 140 | 149 | 123 | 122 | 63  | 122 | 108 | 126 | 120 | 106 |

cm

Table 23. (Continued).

| Entry No.  | Genotype | MSU   |       | Obambo |       | Buburi |       | Ukwala |       | Mumias |      |
|------------|----------|-------|-------|--------|-------|--------|-------|--------|-------|--------|------|
|            |          | 1990  | 1991  | 1990   | 1991  | 1990   | 1991  | 1990   | 1991  | 1990   | 1991 |
|            |          | cm    |       |        |       |        |       |        |       |        |      |
| 21         | 6x7      | 203   | 185   | 126    | 144   | 75     | 136   | 158    | 157   | 146    | 52   |
| 22         | 6x8      | 154   | 147   | 111    | 108   | 71     | 108   | 114    | 126   | 106    | 126  |
| 23         | 6x9      | 138   | 138   | 113    | 108   | 61     | 117   | 104    | 111   | 92     | 77   |
| 24         | 6x10     | 145   | 162   | 129    | 131   | 60     | 115   | 131    | 128   | 99     | 80   |
| 25         | 1        | 131   | 142   | 113    | 102   | 45     | 118   | 127    | 106   | 54     | 89   |
| 26         | 2        | 94    | 89    | 90     | 88    | 55     | 87    | 84     | 80    | 52     | 119  |
| 27         | 3        | 93    | 104   | 91     | 87    | 50     | 91    | 118    | 95    | 82     | 43   |
| 28         | 4        | 116   | 122   | 108    | 99    | 60     | 101   | 75     | 99    | 87     | 114  |
| 29         | 5        | 119   | 124   | 95     | 92    | 55     | 109   | —      | 98    | 77     | 108  |
| 30         | 6        | 127   | 122   | 97     | 102   | 63     | 100   | —      | 92    | 75     | 72   |
| 31         | 7        | 154   | 145   | 124    | 121   | 75     | 143   | 114    | 120   | 101    | 87   |
| 32         | 8        | 103   | 94    | 85     | 80    | 63     | 72    | 94     | 75    | 64     | 140  |
| 33         | 9        | 112   | 106   | 93     | 82    | 53     | 88    | 101    | 76    | 53     | 126  |
| 34         | 10       | 107   | 110   | 89     | 94    | 68     | 105   | 97     | 95    | 85     | 129  |
| 35         | Seredo   | —     | —     | —      | 153   | 93     | 133   | —      | 139   | —      | 71   |
| Mean       |          | 140.4 | 140.1 | 114.0  | 114.3 | 69.4   | 121.0 | 116.6  | 115.4 | 95.0   | 99.5 |
| LSD (0.05) |          | 8.0   | 10.2  | 9.7    | 11.9  | ns     | 28.6  | 30.6   | 14.9  | 24.3   | ns   |

over a wide range of environments. Male GCA effects were significant at all locations in both years except for Mumias in 1991. At all locations in both years, tolerant male IS7254C had high GCA means and the highest frequency of positive male GCA effects of any male, except at Mumias in 1991. It was also observed that other male combiners invariably had negative male GCA effects. Male GCA effects were significant for all the four males. Over locations and years, IS7254C and TX430 were the best male combiners and TX432 was the poorest male combiner. In all cases where significant GCA male effects were obtained, GCA effects were positive for IS7254C and negative for IA28 and TX430. Hybrids involving IA28 and TX430 tended to be shorter than the other hybrids. These two male parents would appear to be good combiners for making short hybrids which are desirable for situations where lodging is a problem. Female GCA effects were significant for all female combiners except (AT-1)-52-2-1-2-1. Wheatland was the best female combiner across locations and years, followed by TX623. Tolerant female combiners were invariably poor combiners for plant height as none demonstrated significant GCA effects in acid soil stressed locations except for (AT-1)-36-4-2-2-1 at Ukwala in 1991. The significant female GCA effects obtained were invariably negative for Wheatland and positive for TX623. Significant SCA effects for plant height were observed for IS7254C crossed with TX623, Wheatland, B-Yel PI, and (AT-1)-52-2-1-2-1 in one year. TX623 X IS7254C and TX623 X IA28 had significant SCA effects at Obambo and Ukwala in the same year. Both GCA and SCA effects were present for plant height; however, additive genetic variance was more important than non-additive genetic variance in controlling plant height.

### Head Length

Analyses of variance for head length at individual locations in both years are presented in Tables 12-21. Significant genotypic differences were observed at all locations in both years except for Buburi in 1990 and Mumias in 1991. Significant differences among parents were observed at MSU and Obambo in both years; and at Buburi and Ukwala in 1991. The contrast of  $F_1$ s vs Parents was significant at Obambo, Mumias, and MSU in 1990; and at MSU and Ukwala in 1991 indicating the existence of heterosis for head length. There were significant differences among  $F_1$ s at all locations except Obambo in 1990, Mumias in 1991, and Buburi in both years. There were significant differences among males at all locations except Buburi in both years and Mumias in 1991. Females were significant in both years at MSU and Ukwala, in 1991 at Obambo and in 1990 at Mumias. This indicated significant additive genetic variance for head length. Male x female interactions were only significant at MSU in 1990 and at Ukwala in 1991. This indicated that GCA effects were more important than SCA effects in controlling head length at most locations.

Means of head lengths of all entries are presented in Table 24. Generally, location means were comparable between years, except at Buburi. Male parent TX430 and female parent TX623 had expressed particularly long head lengths across locations in both years except at Ukwala and Mumias. (AT-2)-10-6-1-2-1 and IA28 showed the least fluctuation in head length among locations. Hybrid combinations involving male parents, IS7254C and IA28, generally had longer heads than other hybrids combinations and the expression was more pronounced at stressed locations. There was pronounced heterotic expression for head length at MSU, Obambo, Ukwala,

Table 24. Mean head lengths of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

|    |      |    |    |    |    |    |    |    |    |    |    |
|----|------|----|----|----|----|----|----|----|----|----|----|
| 1  | 1x7  | 31 | 33 | 31 | 31 | 21 | 32 | 28 | 23 | 21 | 23 |
| 2  | 1x8  | 32 | 35 | 33 | 29 | 17 | 26 | -- | 24 | 17 | 19 |
| 3  | 1x9  | 32 | 35 | 32 | 29 | 20 | 27 | 27 | 22 | 14 | 18 |
| 4  | 1x10 | 31 | 30 | 28 | 27 | 25 | 30 | 29 | 20 | 15 | 15 |
| 5  | 2x7  | 28 | 29 | 28 | 27 | 22 | 26 | 25 | 22 | 20 | 23 |
| 6  | 2x8  | 31 | 30 | 30 | 28 | 20 | 27 | 25 | 23 | 19 | 18 |
| 7  | 2x9  | 30 | 29 | 29 | 27 | 19 | 25 | 25 | 22 | 15 | 18 |
| 8  | 2x10 | 30 | 28 | 31 | 24 | 18 | 25 | 21 | 20 | 11 | 19 |
| 9  | 3x7  | 29 | 30 | 30 | 29 | 24 | 29 | 26 | 23 | 24 | 13 |
| 10 | 3x8  | 28 | 31 | 30 | 27 | 19 | 30 | 28 | 26 | 19 | 20 |
| 11 | 3x9  | 31 | 31 | 30 | 28 | 22 | 29 | 29 | 24 | 21 | 22 |
| 12 | 3x10 | 28 | 27 | 30 | 26 | 20 | 27 | 24 | 22 | 14 | 16 |
| 13 | 4x7  | 30 | 30 | 30 | 27 | 22 | 28 | 28 | 25 | 21 | 23 |
| 14 | 4x8  | 29 | 31 | 29 | 27 | 19 | 31 | 27 | 24 | 21 | 19 |
| 15 | 4x9  | 31 | 31 | 30 | 26 | 21 | 32 | 28 | 26 | 21 | 17 |
| 16 | 4x10 | 29 | 29 | 29 | 24 | 21 | 28 | 23 | 23 | 19 | 20 |
| 17 | 5x7  | 30 | 32 | 30 | 29 | 26 | 29 | 32 | 31 | 26 | 25 |
| 18 | 5x8  | 30 | 32 | 32 | 30 | 20 | 28 | 30 | 28 | 25 | 19 |
| 19 | 5x9  | 32 | 36 | 32 | 30 | 19 | 25 | 30 | 28 | 25 | 24 |
| 20 | 5x10 | 31 | 31 | 31 | 29 | 19 | 24 | 27 | 24 | 22 | 18 |

Table 24. (Continued).

| Entry No.  | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|            |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| Cm         |          |      |      |        |      |        |      |        |      |        |      |
| 21         | 6x7      | 29   | 30   | 28     | 30   | 22     | 27   | 34     | 31   | 25     | 10   |
| 22         | 6x8      | 30   | 33   | 31     | 28   | 21     | 29   | 30     | 28   | 21     | 24   |
| 23         | 6x9      | 35   | 37   | 32     | 29   | 21     | 35   | 28     | 28   | 21     | 14   |
| 24         | 6x10     | 32   | 31   | 28     | 26   | 18     | 25   | 28     | 23   | 17     | 14   |
| 25         | 1        | 31   | 31   | 31     | 24   | 19     | 28   | 22     | 18   | 10     | 17   |
| 26         | 2        | 24   | 26   | 26     | 24   | 16     | 25   | 23     | 20   | 10     | 19   |
| 27         | 3        | 23   | 27   | 26     | 22   | 15     | 22   | 28     | 22   | 15     | 8    |
| 28         | 4        | 24   | 24   | 26     | 20   | 18     | 17   | 22     | 19   | 19     | 20   |
| 29         | 5        | 27   | 30   | 26     | 23   | 18     | 29   | --     | 24   | 20     | 20   |
| 30         | 6        | 26   | 29   | 25     | 22   | 20     | 23   | --     | 20   | 19     | 15   |
| 31         | 7        | 19   | 20   | 25     | 24   | 20     | 22   | 23     | 20   | 20     | 18   |
| 32         | 8        | 25   | 28   | 29     | 27   | 21     | 24   | 27     | 24   | 17     | 25   |
| 33         | 9        | 29   | 29   | 29     | 27   | 20     | 28   | 22     | 22   | 11     | 24   |
| 34         | 10       | 24   | 26   | 22     | 21   | 19     | 26   | 22     | 20   | 15     | 25   |
| 35         | Seredo   | --   | --   | --     | 24   | 21     | 23   | --     | 21   | --     | 12   |
| Mean       |          |      |      |        |      |        |      |        |      |        |      |
| ISD (0.05) |          | 28.9 | 30.0 | 29.1   | 26.4 | 19.9   | 26.8 | 26.3   | 23.4 | 18.6   | 18.5 |
|            |          | 2.0  | 3.1  | 2.9    | 2.4  | ns     | 7.0  | 3.8    | 3.0  | 6.5    | ns   |

and Mumias in some years. Similar results were also reported by Rubaihayo and Makumbi (1976) and Nandanwankar (1990) who reported significant positive heterosis for head length. Significant male GCA effects for head length existed for all males except IA28. The best male combiners were IS7254C and TX432; however, it was observed that IS7254C had longer heads and TX432 had shorter heads than the location means at Ukwala and Mumias. Male GCA effects for TX430 were significant at MSU in both years and TX430 had significantly longer heads than other males at MSU. Significant female GCA effects were found for all females. The best female combiners were TX623, Wheatland, and (AT-2)-10-6-1-2-1, while B-Yel-PI and (AT-1)-52-2-1-2-1 were the poorest combiners. It was observed that GCA means obtained at Ukwala and Mumias were higher for tolerant than for susceptible females. While significant male x female interactions existed at MSU and Ukwala, only hybrid (AT-2)-10-6-1-2-1 x TX430 showed a significant SCA effect. Bittinger *et al.* (1981) reported that additive genetic variance was greater than dominance variance for head length. It appeared that additive gene action was more important than non-additive gene action for this trait.

#### Peduncle Length

Analyses of variance for peduncle length are presented in Tables 12-21. Significant differences among genotypes existed at all locations except Buburi. Mean squares for parents were only significant at Ukwala in 1991 and at MSU and Obambo in both years. Mean squares for  $F_1$ s vs Parents were significant at Obambo and Mumias in 1990 and at Ukwala in 1991. Differences among  $F_1$ s were significant at all locations except

Buburi in both years and MSU and Mumias in 1991. Mean squares for males were significant at all locations except Buburi, indicated additive genetic variance for peduncle length. Females were significant at all locations except Buburi indicating significant GCA effects for females. Male x female interactions were significant at Ukwala in 1991 and at MSU and Obambo in both years. While both additive and non-additive genetic variance existed for peduncle length, additive genetic variance was the predominant source of variation for this trait.

Means of peduncle length for all entries are presented in Table 25. Significant differences among parents existed in the better environments. (AT-2)-10-6-1-2-1 had a consistently longer peduncle than IA28 across locations and years. Generally, for reasons not clear, peduncle length tended to increase in the poor environments, except at Buburi where it was suppressed for all entries in both years. Hybrids of male parent TX432 had longer peduncles compared to other hybrids, even in some of the stressed environments. TX623 x IS7254C and (AT-1)-52-2-1-2-1 x TX432 showed the least variability across locations in both years. Significant male GCA effects were found for all male combiners. TX432 was the best general combiner for long peduncle length across locations while IA28 was the poorest general combiner. Male GCA effects for TX430 were negative for all locations and years. All females showed significant GCA effects. (AT-2)-10-6-1-2-1 was the best female general combiner and in most locations and years demonstrated the highest GCA means which were significantly higher than the overall location means, even in stressed environments. (AT-1)-52-2-1-2-1, B-Yel-PI, Wheatland, and TX623 were poor female combiners. (AT-1)-36-4-2-2-1 showed negative female GCA effects.

Table 25. Mean peduncle lengths of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
|           |          | cm   |      |        |      |        |      |        |      |        |      |
| 1         | 1x7      | 46   | 50   | 50     | 46   | 35     | 34   | 43     | 49   | 49     | 50   |
| 2         | 1x8      | 49   | 48   | 54     | 47   | 34     | 16   | --     | 52   | 49     | 46   |
| 3         | 1x9      | 45   | 52   | 49     | 47   | 34     | 11   | 41     | 48   | 44     | 55   |
| 4         | 1x10     | 47   | 57   | 54     | 52   | 39     | 18   | 50     | 46   | 54     | 38   |
| 5         | 2x7      | 48   | 51   | 52     | 51   | 27     | 27   | 50     | 55   | 53     | 54   |
| 6         | 2x8      | 41   | 57   | 54     | 55   | 21     | 14   | 55     | 63   | 54     | 56   |
| 7         | 2x9      | 42   | 54   | 47     | 51   | 21     | 12   | 47     | 54   | 37     | 56   |
| 8         | 2x10     | 45   | 49   | 53     | 53   | 15     | 16   | 53     | 52   | 44     | 51   |
| 9         | 3x7      | 52   | 54   | 56     | 52   | 43     | 27   | 39     | 55   | 55     | 34   |
| 10        | 3x8      | 44   | 53   | 49     | 49   | 30     | --   | 40     | 53   | 56     | 53   |
| 11        | 3x9      | 42   | 51   | 50     | 51   | 17     | --   | 45     | 55   | 43     | 68   |
| 12        | 3x10     | 49   | 59   | 59     | 61   | 26     | --   | 52     | 61   | 59     | 47   |
| 13        | 4x7      | 52   | 48   | 52     | 47   | 47     | --   | 41     | 55   | 52     | 55   |
| 14        | 4x8      | 45   | 50   | 50     | 49   | 33     | --   | 43     | 52   | 55     | 46   |
| 15        | 4x9      | 45   | 49   | 49     | 48   | 37     | --   | 38     | 52   | 49     | 48   |
| 16        | 4x10     | 49   | 54   | 55     | 55   | 36     | 30   | 47     | 58   | 50     | 64   |
| 17        | 5x7      | 56   | 58   | 54     | 50   | 37     | 33   | 40     | 60   | 57     | 56   |
| 18        | 5x8      | 55   | 63   | 57     | 57   | 24     | 28   | 44     | 61   | 55     | 62   |
| 19        | 5x9      | 50   | 59   | 57     | 53   | 17     | 27   | 42     | 66   | 54     | 48   |
| 20        | 5x10     | 53   | 64   | 64     | 64   | 19     | 21   | 47     | 64   | 67     | 53   |

Table 25. (Continued).

| Entry No.  | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|            |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| cm         |          |      |      |        |      |        |      |        |      |        |      |
| 21         | 6x7      | 47   | 50   | 44     | 47   | 34     | --   | 40     | 57   | 55     | 28   |
| 22         | 6x8      | 39   | 48   | 45     | 45   | 30     | --   | 39     | 52   | 49     | 63   |
| 23         | 6x9      | 45   | 47   | 45     | 44   | 28     | 30   | 39     | 52   | 49     | 46   |
| 24         | 6x10     | 48   | 59   | 55     | 57   | 28     | 31   | 42     | 56   | 41     | 42   |
| 25         | 1        | 42   | 49   | 53     | 40   | 16     | --   | 36     | 43   | 35     | 52   |
| 26         | 2        | 38   | 38   | 50     | 48   | 21     | --   | 38     | 47   | 46     | 51   |
| 27         | 3        | 38   | 44   | 45     | 45   | 17     | --   | 37     | 52   | 45     | 27   |
| 28         | 4        | 38   | 46   | 44     | 45   | 18     | 24   | 29     | 41   | 37     | 56   |
| 29         | 5        | 50   | 56   | 56     | 54   | 17     | --   | --     | 60   | 49     | 61   |
| 30         | 6        | 38   | 46   | 41     | 38   | 19     | 27   | --     | 40   | 40     | 43   |
| 31         | 7        | 44   | 47   | 48     | 40   | 34     | --   | 42     | 48   | 47     | 51   |
| 32         | 8        | 30   | 32   | 37     | 34   | 20     | --   | 34     | 37   | 32     | 57   |
| 33         | 9        | 38   | 41   | 44     | 39   | 14     | --   | 34     | 41   | 55     | 61   |
| 34         | 10       | 37   | 42   | 46     | 46   | 19     | --   | 40     | 47   | 44     | 59   |
| 35         | Seredo   | --   | --   | --     | 43   | 50     | --   | --     | 45   | --     | 34   |
| Mean       |          |      |      |        |      |        |      |        |      |        |      |
| LSD (0.05) |          | 44.9 | 50.8 | 50.6   | 48.8 | 27.2   | 22.6 | 43.2   | 52.3 | 49.0   | 50.4 |
|            |          | 4.2  | 5.7  | 4.2    | 3.9  | ns     | ns   | 12.2   | 6.4  | 10.3   | ns   |

Significant male x female interaction (SCA) effects were observed only for Wheatland x TX432 which expressed SCA for shorter peduncle length at MSU and Obambo. Additive genetic variance was more prevalent than non-additive genetic action for peduncle length.

#### Leaf Length

Significant differences among genotypes for leaf length of the fourth leaf from the head were noted at Obambo and Ukwala in both years and at MSU in 1990 (Tables 12-21). There were significant differences among the 10 parents at Obambo and Ukwala in both years, at Mumias in 1991, and at MSU in 1990. A significant  $F_1$ s vs Parents contrast was seen only at MSU and Obambo, indicating the lack of heterotic expression for leaf length in stressed areas.  $F_1$  genotypes differed significantly in both years at Obambo and Ukwala, and in 1990 at MSU. Significant male GCA effects were found in both years at Obambo and Ukwala and at MSU for 1990. Significant female effects existed for both years at Obambo, and in 1990 at MSU, Buburi, and Ukwala. A significant male x female interaction was observed only at Obambo in 1990. This indicates that GCA effects were more predominant than SCA effects in the inheritance of leaf length.

Means of leaf length are presented in Table 26. In general, male parent IS7254C had lower mean leaf length than other parents, and parents, TX623 and TX430, had the longest leaves at most locations. Some hybrids of TX430 had higher leaf length means than other hybrids. At some locations, some hybrids involving male parent IS7254C had shorter leaves than hybrids involving male parents, TX430 and TX432. Male GCA effects for leaf length were significant for all males with IA28 being the best

Table 26. Means of fourth leaf length from the top of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
|           |          | cm   |      |        |      |        |      |        |      |        |      |
| 1         | 1x7      | 69   | --   | 68     | 68   | 46     | 71   | 64     | 60   | 40     | 46   |
| 2         | 1x8      | 70   | --   | 75     | 77   | 61     | 59   | --     | 66   | 40     | 37   |
| 3         | 1x9      | 77   | --   | 76     | 75   | 50     | 62   | 64     | 61   | 35     | 36   |
| 4         | 1x10     | 75   | --   | 75     | 77   | 50     | 69   | 76     | 58   | 45     | 35   |
| 5         | 2x7      | 68   | --   | 66     | 62   | 48     | 57   | 60     | 46   | 45     | 42   |
| 6         | 2x8      | 76   | --   | 67     | 69   | 45     | 59   | 65     | 62   | 55     | 35   |
| 7         | 2x9      | 82   | --   | 72     | 71   | 41     | 62   | 67     | 58   | 41     | 44   |
| 8         | 2x10     | 79   | --   | 64     | 64   | 41     | 61   | 57     | 56   | 36     | 43   |
| 9         | 3x7      | 66   | --   | 65     | 64   | 56     | 64   | 60     | 55   | 45     | 24   |
| 10        | 3x8      | 66   | --   | 70     | 72   | 56     | 72   | 67     | 66   | 41     | 34   |
| 11        | 3x9      | 75   | --   | 75     | 72   | 50     | 65   | 66     | 56   | 55     | 43   |
| 12        | 3x10     | 72   | --   | 69     | 68   | 48     | 70   | 61     | 58   | 41     | 34   |
| 13        | 4x7      | 65   | --   | 63     | 64   | 53     | 62   | 64     | 58   | 40     | 44   |
| 14        | 4x8      | 66   | --   | 73     | 72   | 50     | 70   | 69     | 62   | 40     | 30   |
| 15        | 4x9      | 75   | --   | 71     | 70   | 50     | 68   | 66     | 62   | 56     | 33   |
| 16        | 4x10     | 74   | --   | 69     | 66   | 54     | 73   | 60     | 61   | 55     | 48   |
| 17        | 5x7      | 71   | --   | 69     | 64   | 47     | 60   | 67     | 65   | 51     | 47   |
| 18        | 5x8      | 72   | --   | 76     | 74   | 50     | 69   | 76     | 66   | 51     | 36   |
| 19        | 5x9      | 72   | --   | 78     | 76   | 39     | 51   | 70     | 65   | 41     | 36   |
| 20        | 5x10     | 81   | --   | 66     | 71   | 34     | 52   | 64     | 56   | 41     | 38   |

Table 26. (Continued).

| Entry No.       | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|                 |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- Ctn ----- |          |      |      |        |      |        |      |        |      |        |      |
| 21              | 6x7      | 62   | --   | 60     | 63   | 37     | 56   | 64     | 59   | 50     | 27   |
| 22              | 6x8      | 63   | --   | 70     | 73   | 49     | 66   | 68     | 64   | 46     | 49   |
| 23              | 6x9      | 77   | --   | 74     | 73   | 51     | 70   | 72     | 63   | 55     | 34   |
| 24              | 6x10     | 74   | --   | 69     | 67   | 43     | 55   | 63     | 58   | 46     | 33   |
| 25              | 1        | 73   | --   | 77     | 72   | 39     | 77   | 54     | 57   | 55     | 28   |
| 26              | 2        | 75   | --   | 66     | 64   | 31     | 59   | 60     | 58   | 50     | 41   |
| 27              | 3        | 67   | --   | 65     | 60   | 37     | 55   | 55     | 54   | 31     | 32   |
| 28              | 4        | 66   | --   | 68     | 63   | 43     | 67   | 64     | 57   | 56     | 43   |
| 29              | 5        | 66   | --   | 71     | 70   | 47     | 71   | --     | 61   | 50     | 37   |
| 30              | 6        | 65   | --   | 64     | 63   | 39     | 57   | --     | 54   | 45     | 31   |
| 31              | 7        | 50   | --   | 54     | 50   | 37     | 54   | 50     | 46   | 50     | 35   |
| 32              | 8        | 60   | --   | 67     | 68   | 44     | 55   | 64     | 59   | 40     | 49   |
| 33              | 9        | 80   | --   | 76     | 71   | 45     | 71   | 58     | 61   | 36     | 45   |
| 34              | 10       | 74   | --   | 70     | 70   | 47     | 69   | 58     | 59   | 55     | 50   |
| 35              | Seredo   | --   | --   | --     | 71   | 49     | 60   | --     | 62   | --     | 26   |
| -----           |          |      |      |        |      |        |      |        |      |        |      |
| Mean            |          | 70.7 | --   | 69.3   | 68.3 | 45.7   | 63.3 | 63.5   | 59.1 | 45.4   | 38.0 |
| LSD (0.05)      |          | 6.4  | --   | 4.7    | 4.7  | ns     | ns   | 6.8    | 9.0  | ns     | ns   |

general combiner and TX432 the poorest general combiner. Female GCA effects for leaf length were only significant for TX623, Wheatland, and (AT-2)-10-6-1-2-1; however, only TX623 showed positive female GCA effects for leaf length. Significant SCA effects were observed for (AT-2)-10-6-1-2-1 x TX432 at Obambo in 1990. It appeared that additive genetic variance was more important than non-additive gene variance for controlling leaf length.

#### Leaf Width

There were significant differences among genotypes for maximum leaf width at MSU, Obambo and Ukwala (Tables 12-21). Significant differences among parental genotypes occurred only at Obambo. A significant  $F_1$ s vs Parents contrast was found only at Ukwala in 1991, indicating that there was little heterotic response for leaf width. Environmental influences on this character were large. Ukwala was the only location that produced significant differences among  $F_1$ s in both years. Significant male GCA effects were expressed at MSU, Obambo, and Ukwala. Significant female GCA effects existed at MSU, Buburi, and Ukwala. No significant male x female interactions were noted, indicating the lack of non-additive genetic variance and the importance of additive gene variance for leaf width.

Means of the maximum leaf width are presented in Table 27. There few differences among parents and  $F_1$ s. Male IS7254C had the widest leaf width at MSU. At MSU, Obambo, and Ukwala parents had narrower leaves than  $F_1$ s, in general. Generally, the GCA means of the tolerant males were higher than the location means and the GCA means of the susceptible males, except for IA28 at MSU and Obambo in 1990. At Obambo and Ukwala, GCA

Table 27. Means of maximum leaf length of the fourth leaf from the top of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

|    |      |    |    |   |   |   |    |    |   |   |   |
|----|------|----|----|---|---|---|----|----|---|---|---|
| 1  | 1x7  | 10 | -- | 8 | 7 | 5 | 9  | 7  | 6 | 4 | 4 |
| 2  | 1x8  | 9  | -- | 7 | 7 | 6 | 6  | -- | 6 | 4 | 3 |
| 3  | 1x9  | 9  | -- | 7 | 6 | 6 | 6  | 6  | 5 | 5 | 3 |
| 4  | 1x10 | 9  | -- | 7 | 7 | 6 | 6  | 7  | 5 | 5 | 3 |
| 5  | 2x7  | 11 | -- | 8 | 6 | 5 | 7  | 7  | 4 | 4 | 4 |
| 6  | 2x8  | 9  | -- | 7 | 7 | 5 | 6  | 7  | 5 | 4 | 3 |
| 7  | 2x9  | 10 | -- | 8 | 7 | 4 | 6  | 7  | 5 | 5 | 4 |
| 8  | 2x10 | 10 | -- | 7 | 6 | 4 | 6  | 5  | 4 | 4 | 4 |
| 9  | 3x7  | 10 | -- | 8 | 7 | 6 | 8  | 7  | 6 | 5 | 2 |
| 10 | 3x8  | 10 | -- | 7 | 7 | 6 | 8  | 7  | 7 | 5 | 4 |
| 11 | 3x9  | 10 | -- | 8 | 7 | 5 | 7  | 7  | 5 | 6 | 4 |
| 12 | 3x10 | 10 | -- | 7 | 7 | 5 | 8  | 6  | 5 | 5 | 3 |
| 13 | 4x7  | 10 | -- | 8 | 7 | 6 | 8  | 8  | 6 | 5 | 4 |
| 14 | 4x8  | 9  | -- | 8 | 7 | 5 | 10 | 8  | 6 | 5 | 3 |
| 15 | 4x9  | 10 | -- | 8 | 7 | 5 | 10 | 8  | 6 | 6 | 2 |
| 16 | 4x10 | 10 | -- | 7 | 6 | 6 | 8  | 6  | 6 | 6 | 4 |
| 17 | 5x7  | 9  | -- | 8 | 7 | 5 | 7  | 8  | 7 | 6 | 4 |
| 18 | 5x8  | 9  | -- | 7 | 7 | 6 | 8  | 8  | 6 | 5 | 3 |
| 19 | 5x9  | 9  | -- | 8 | 7 | 5 | 5  | 7  | 6 | 4 | 3 |
| 20 | 5x10 | 10 | -- | 7 | 7 | 4 | 5  | 7  | 5 | 4 | 4 |

cm

Table 27. (Continued).

| Entry No.  | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|            |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| cm         |          |      |      |        |      |        |      |        |      |        |      |
| 21         | 6x7      | 11   | --   | 8      | 7    | 4      | 6    | 8      | 6    | 6      | 1    |
| 22         | 6x8      | 9    | --   | 8      | 7    | 5      | 8    | 7      | 6    | 6      | 5    |
| 23         | 6x9      | 10   | --   | 8      | 8    | 5      | 8    | 8      | 6    | 6      | 3    |
| 24         | 6x10     | 11   | --   | 8      | 7    | 4      | 6    | 7      | 5    | 5      | 3    |
| 25         | 1        | 9    | --   | 8      | 6    | 4      | 8    | 5      | 5    | 6      | 2    |
| 26         | 2        | 8    | --   | 7      | 6    | 4      | 6    | 7      | 5    | 5      | 4    |
| 27         | 3        | 8    | --   | 6      | 6    | 4      | 5    | 5      | 5    | 3      | 2    |
| 28         | 4        | 9    | --   | 8      | 6    | 5      | 7    | 6      | 5    | 5      | 4    |
| 29         | 5        | 9    | --   | 8      | 7    | 5      | 7    | -      | 5    | 5      | 4    |
| 30         | 6        | 8    | --   | 7      | 7    | 4      | 7    | -      | 5    | 5      | 3    |
| 31         | 7        | 9    | --   | 7      | 6    | 4      | 7    | 6      | 5    | 6      | 3    |
| 32         | 8        | 8    | --   | 7      | 6    | 5      | 6    | 7      | 6    | 4      | 4    |
| 33         | 9        | 9    | --   | 8      | 7    | 5      | 7    | 6      | 6    | 4      | 4    |
| 34         | 10       | 10   | --   | 7      | 6    | 5      | 8    | 6      | 6    | 5      | 4    |
| 35         | Seredo   | --   | --   | -      | 6    | 6      | 7    | -      | 6    | -      | 2    |
| Mean       |          | 9.4  | --   | 7.5    | 6.6  | 4.7    | 7.0  | 6.9    | 5.6  | 4.8    | 3.1  |
| ISD (0.05) |          | 1.15 | --   | 1.0    | 0.87 | ns     | ns   | 1.3    | 1.2  | ns     | ns   |

means for tolerant females were higher than for susceptible females and were above location means except for (AT-2)-10-6-1-2-1 in 1990 at Obambo and (AT-1)-52-2-1-2-1 in 1991 at Obambo. Susceptible females had higher GCA means than tolerant female combiners at Buburi in 1990, except for Wheatland. No significant female GCA effects existed except for Wheatland at Ukwala in 1991 where the GCA effect was negative. While additive genetic variance may be important for leaf width, environment may have played a major part in the expression of leaf width.

#### Leaf Area

There were significant differences among genotypes for leaf area at MSU, Obambo, and Ukwala (Tables 12-21). Significant differences among parents existed only at MSU and Obambo. Significant average heterosis for leaf area was at MSU and Ukwala only as denoted by a significant  $F_1$ s vs Parents contrast. Significant differences among  $F_1$ s were seen at MSU, Obambo, and Ukwala. Significant male effects were expressed at MSU, Obambo, and Ukwala while significant female GCA effects existed at MSU, Obambo, Buburi, and Ukwala. The existence of significant GCA effects indicated an important role for additive genetic effects in controlling leaf area. Male x female interactions were not significant at any location, indicating that non-additive genetic variance was not important in the inheritance of leaf area. At Mumias and Buburi, no significant differences of any kind were observed for leaf area in either year.

Means for leaf area of the 35 genotypes are presented in Table 28. Location means were highest at MSU and Obambo and then decreased drastically as the degree of environmental stress increased. As expected,

Table 28. Means of leaf area of the fourth leaf from the top of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU             |      | Obambo |       | Buburi |       | Ukwala |       | Mumias |       |
|-----------|----------|-----------------|------|--------|-------|--------|-------|--------|-------|--------|-------|
|           |          | 1990            | 1991 | 1990   | 1991  | 1990   | 1991  | 1990   | 1991  | 1990   | 1991  |
|           |          | cm <sup>2</sup> |      |        |       |        |       |        |       |        |       |
| 1         | 1x7      | 503.8           | --   | 406.2  | 365.6 | 178.5  | 455.1 | 354.7  | 261.8 | 111.7  | 144.0 |
| 2         | 1x8      | 483.4           | --   | 405.3  | 391.3 | 250.1  | 295.9 | --     | 306.8 | 112.8  | 83.3  |
| 3         | 1x9      | 541.8           | --   | 416.6  | 364.6 | 207.0  | 296.2 | 311.0  | 243.7 | 121.2  | 64.1  |
| 4         | 1x10     | 510.5           | --   | 409.2  | 387.3 | 234.8  | 332.2 | 402.6  | 217.2 | 164.1  | 67.5  |
| 5         | 2x7      | 552.3           | --   | 413.3  | 288.0 | 178.1  | 302.8 | 313.7  | 190.8 | 138.8  | 109.1 |
| 6         | 2x8      | 527.5           | --   | 363.6  | 352.4 | 148.9  | 281.2 | 340.0  | 246.1 | 147.0  | 78.8  |
| 7         | 2x9      | 634.5           | --   | 423.8  | 361.0 | 106.5  | 283.6 | 334.2  | 231.6 | 160.8  | 130.5 |
| 8         | 2x10     | 598.6           | --   | 331.1  | 297.4 | 127.5  | 282.5 | 231.6  | 185.4 | 111.6  | 114.4 |
| 9         | 3x7      | 472.3           | --   | 380.8  | 315.1 | 256.9  | 372.3 | 323.6  | 233.2 | 164.0  | 27.0  |
| 10        | 3x8      | 476.6           | --   | 379.5  | 366.2 | 252.0  | 439.2 | 373.7  | 337.3 | 144.7  | 88.1  |
| 11        | 3x9      | 557.2           | --   | 456.3  | 376.7 | 185.6  | 381.2 | 359.8  | 225.4 | 229.7  | 114.0 |
| 12        | 3x10     | 545.3           | --   | 370.1  | 346.1 | 178.1  | 424.3 | 292.5  | 231.7 | 160.4  | 93.0  |
| 13        | 4x7      | 485.1           | --   | 368.6  | 321.9 | 218.6  | 364.9 | 358.6  | 278.6 | 160.7  | 135.4 |
| 14        | 4x8      | 437.1           | --   | 437.0  | 389.4 | 166.5  | 496.0 | 397.5  | 279.8 | 136.1  | 74.3  |
| 15        | 4x9      | 545.2           | --   | 402.3  | 348.6 | 187.5  | 492.0 | 386.0  | 291.4 | 243.8  | 58.5  |
| 16        | 4x10     | 548.2           | --   | 384.2  | 303.5 | 225.0  | 440.6 | 259.0  | 262.4 | 253.4  | 142.5 |
| 17        | 5x7      | 499.0           | --   | 415.0  | 357.2 | 173.3  | 353.0 | 390.3  | 337.8 | 208.5  | 141.4 |
| 18        | 5x8      | 507.8           | --   | 413.0  | 403.0 | 222.8  | 422.2 | 481.6  | 304.8 | 204.9  | 70.5  |
| 19        | 5x9      | 576.0           | --   | 446.2  | 387.9 | 137.3  | 191.6 | 370.4  | 300.2 | 123.6  | 86.3  |
| 20        | 5x10     | 610.4           | --   | 371.6  | 356.1 | 90.8   | 203.2 | 331.6  | 210.6 | 122.4  | 99.4  |



leaf area means for locations fluctuated between years. TX623 and (AT-2)-10-6-1-2-1 generally had high mean leaf areas across locations in both years, except at Mumias in 1991. IS7254C had the lowest mean leaf area across sites as compared to the other parental genotypes. In 1991, regardless of genotype, leaf area of genotypes at Mumias, was drastically decreased. Superior hybrids for leaf area included TX623 x IS7254C, (AT-2)-10-6-1-2-1 x IS7254C, Wheatland x TX430, B-Yel-PI x TX430, (AT-1)-52-2-1-2-1 x TX430, and (AT-1)-36-4-2-2-1 x IA28. The general lack of heterotic response was attributed to effect of the stress environments, as seen in not being able to detect significant differences among parents and hybrids in these environments. These results disagree with those reported by Rubaihayo and Makumbi (1976) who obtained highly significant heterosis for leaf area; however, they measured the area of the flag leaf and the experiment was done under optimum crop growth conditions. In 1990, tolerant males at Obambo, Buburi, and Ukwala had higher GCA means than susceptible males, for except IS7254C at Obambo. In 1991, at Obambo, Buburi, and Ukwala a similar trend was observed for the tolerant male combiners. The male GCA means for IA28 were generally the highest in most locations, except in the less acid locations. In both years, the best combiners were IA28 and TX432; however, TX432 combiners had invariably negative male GCA effects in low fertile acid areas including Obambo.

Tolerant females generally had higher GCA means than susceptible females; however, tolerant females varied considerably with locations and years. Despite high GCA means in both tolerant and susceptible females, the only significant female GCA effects expressed were in Wheatland and (AT-2)-10-6-1-2-1. (AT-2)-10-6-1-2-1 was a better general combiner for

leaf area than Wheatland as the female GCA effects were invariably negative for Wheatland, except at MSU where the best of the environments for growth existed. It appeared, therefore, that additive genetic variance was important for leaf area and male GCA effects were more important than female GCA effects. No significant SCA effects were found at any location indicating a lack of non-additive genetic variance for leaf area.

#### Number of Heads per Plot

Significant genotypic differences for number of heads per plot were found at all locations except Mumias (Tables 12-21). Differences among parents were significant at all locations except at Mumias. The contrast of  $F_1$ s vs parents was significant only at Ukwala and Buburi in 1990 and 1991, respectively, indicating a limited heterotic response for heads per plot. Differences among  $F_1$ s were significant at MSU, Obambo and Ukwala. Male GCA effects were significant only at Ukwala in both years. Mean squares for female GCA effects were significant at all locations in 1990, but were significant only at Ukwala in 1991. There was a significant male x female interaction at Obambo in 1991 and at Ukwala in both years indicating that both GCA and SCA were important in the inheritance of number of heads per plot.

Means of number of heads per plot are presented in Table 29. All location produced fewer heads per plot in 1990 than in 1991, except for Buburi. More heads were produced at MSU in 1990 than at any other of the Kenyan locations. On the average, parents had a higher number of heads than hybrids. In 1991, Buburi had, by far, the lowest number of heads of

Table 29. Mean number of heads per plot of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| 1         | 1x7      | 37   | --   | 24     | 34   | 15     | 14   | 25     | 29   | 24     | 40   |
| 2         | 1x8      | 40   | --   | 22     | 32   | 20     | 7    | 22     | 23   | 30     | 39   |
| 3         | 1x9      | 40   | --   | 16     | 31   | 23     | 19   | 18     | 23   | 25     | 13   |
| 4         | 1x10     | 35   | --   | 19     | 34   | 29     | 10   | 24     | 21   | 32     | 33   |
| 5         | 2x7      | 29   | --   | 29     | 32   | 27     | 20   | 28     | 24   | 10     | 18   |
| 6         | 2x8      | 35   | --   | 22     | 34   | 25     | 17   | 27     | 34   | 17     | 25   |
| 7         | 2x9      | 32   | --   | 24     | 31   | 38     | 14   | 32     | 32   | 18     | 9    |
| 8         | 2x10     | 27   | --   | 29     | 37   | 32     | 17   | 26     | 40   | 25     | 63   |
| 9         | 3x7      | 20   | --   | 14     | 33   | 20     | 5    | 13     | 24   | 23     | 10   |
| 10        | 3x8      | 26   | --   | 18     | 30   | 12     | 11   | 14     | 31   | 16     | 57   |
| 11        | 3x9      | 21   | --   | 17     | 27   | 6      | 9    | 11     | 29   | 12     | 38   |
| 12        | 3x10     | 20   | --   | 18     | 37   | 15     | 14   | 20     | 32   | 17     | 47   |
| 13        | 4x7      | 27   | --   | 30     | 35   | 17     | 3    | 16     | 29   | 27     | 28   |
| 14        | 4x8      | 29   | --   | 29     | 33   | 35     | 9    | 25     | 23   | 22     | 45   |
| 15        | 4x9      | 34   | --   | 26     | 27   | 23     | 11   | 19     | 20   | 23     | 28   |
| 16        | 4x10     | 29   | --   | 29     | 27   | 22     | 17   | 30     | 34   | 34     | 54   |
| 17        | 5x7      | 35   | --   | 19     | 14   | 27     | 4    | 22     | 5    | 22     | 18   |
| 18        | 5x8      | 38   | --   | 24     | 27   | 24     | 11   | 26     | 32   | 25     | 29   |
| 19        | 5x9      | 43   | --   | 31     | 35   | 22     | --   | 22     | 28   | 31     | 17   |
| 20        | 5x10     | 36   | --   | 32     | 34   | 13     | --   | 27     | 32   | 27     | 31   |

Table 29. (Continued).

| Entry No.  | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|            |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| 21         | 6x7      | 22   | --   | 12     | 28   | 11     | --   | 7      | 18   | 16     | 26   |
| 22         | 6x8      | 32   | --   | 17     | 34   | 15     | 9    | 6      | 26   | 14     | 34   |
| 23         | 6x9      | 29   | --   | 21     | 34   | 16     | 2    | 20     | 21   | 25     | 23   |
| 24         | 6x10     | 33   | --   | 27     | 33   | 16     | 5    | 24     | 31   | 19     | 27   |
| 25         | 1        | 30   | --   | 16     | 18   | 16     | 6    | 16     | 13   | 22     | 46   |
| 26         | 2        | 47   | --   | 21     | 31   | 30     | 6    | 19     | 25   | 31     | 38   |
| 27         | 3        | 33   | --   | 24     | 25   | 16     | 2    | 25     | 15   | 25     | 14   |
| 28         | 4        | 36   | --   | 19     | 20   | 38     | 2    | 24     | 18   | 27     | 43   |
| 29         | 5        | 62   | --   | 16     | 21   | 27     | 3    | 21     | 25   | 22     | 37   |
| 30         | 6        | 29   | --   | 12     | 28   | 13     | --   | 25     | 9    | 15     | 21   |
| 31         | 7        | 38   | --   | 34     | 43   | 44     | 23   | 24     | 28   | 36     | 37   |
| 32         | 8        | 40   | --   | 20     | 36   | 33     | 8    | 17     | 14   | 22     | 48   |
| 33         | 9        | 38   | --   | 21     | 1    | 14     | 2    | 22     | 2    | 35     | 25   |
| 34         | 10       | 44   | --   | 18     | 25   | 33     | 20   | 21     | 27   | 26     | 35   |
| 35         | Seredo   | --   | --   | --     | 32   | 45     | 24   | --     | 39   | --     | 43   |
| Mean       |          | 33.5 | --   | 22.0   | 29.6 | 29.2   | 9.0  | 21.0   | 24.3 | 23.0   | 32.5 |
| LSD (0.05) |          | 9.7  | --   | 10.2   | 9.4  | 17.7   | ns   | 9.6    | 8.4  | ns     | ns   |

any location. Due to poor establishment in 1991, TX430 produced the lowest number of heads per plot at all locations. Seredo had a high number of heads across all locations in 1991. Among the parental genotypes, IS7254C had the highest number of heads per plot across locations and years. There were differences among hybrids within and across locations. Heterotic response, especially mid-parent heterosis, was positive, but expression varied among hybrids and locations. In 1991, the number of heads harvested at Mumias were higher than the other locations; however, head sizes were very small with very few grains of sorghum per head. Some heads were harvested from nodal tillers contributing to the low yield at this location.

Male GCA means were higher for susceptible males than for tolerant males and, in case of TX432, were higher than the location means; however, significant male GCA effects for TX432 were observed only at Ukwala. Across locations, the tolerant male IS7254C had lower GCA means than other males. The GCA effects for this male were invariably negative, but were only significant at Ukwala in 1991. IA28 and TX430 showed no significant male GCA effects across locations and years. Female GCA means were generally higher for susceptible females. Significant female GCA effects were found for all females. Wheatland was the best female combiner across locations for number of heads. Significant female GCA effects for TX623, (AT-1)-52-2-1-2-1, and (AT-2)-10-6-1-2-1 were also positive, but were limited to the better environments. Significant female GCA effects for B-Yel-PI and (AT-1)-36-4-2-2-1 were negative both in the good and the poor environments. This indicated that GCA effects were important for determining number of heads. Significant SCA was observed with TX623 x

IS7254C at Ukwala in 1991 and with (AT-2)-10-6-1-2-1 x IS7254C at Obambo and Ukwala in 1991, indicating that non-additive gene action was present for number of heads per plot, but was not as important as additive gene action in the genetic control of number of heads.

#### Grain Yield

There were significant differences among genotypes for grain yield at all locations in both years except at Mumias in 1991 (Tables 12-21). Significant differences among parents were observed at all locations except MSU and Buburi in 1990 and Mumias in 1991. Average heterosis ( $F_1$ s vs parents) was expressed for grain yield at Obambo and Buburi in 1990, at Ukwala in 1991, and at MSU in both years. There were significant differences among hybrids at all locations in both years except at Buburi and Mumias in 1991. Significant male GCA effects were expressed for grain yield at all locations in both years except at Ukwala and Mumias in 1990. Significant female GCA effects were observed at all locations in both years except at Buburi and Mumias in 1991. Significant male x female interactions were found at all locations except at Buburi in 1991 and at Mumias in both years. Mumias was the harshest environment for production of grain in both years, but in 1991 it was so severe that no significant differences among the 35 entries could be detected. At Buburi, besides the soil stress conditions on the crop, severe erosion, shoot fly, striga and bird damage made it difficult to detect genetic variation for grain yield, especially in 1991.

Means grain yields of the 35 genotypes are presented in Table 30. There were large differences between the location means of good

Table 30. Mean grain yields of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

| kg plot <sup>-1</sup> |      |      |      |      |      |      |      |      |      |      |      |
|-----------------------|------|------|------|------|------|------|------|------|------|------|------|
| 1                     | 1x7  | 1.46 | 0.58 | 0.60 | 0.71 | 0.40 | 0.25 | 0.60 | 0.25 | 0.02 | 0.04 |
| 2                     | 1x8  | 1.54 | 0.92 | 1.12 | 0.95 | 0.38 | 0.10 | 0.15 | 0.14 | 0.07 | 0.03 |
| 3                     | 1x9  | 1.06 | 0.68 | 0.68 | 0.81 | 0.21 | 0.01 | 0.28 | 0.13 | 0.02 | 0.01 |
| 4                     | 1x10 | 0.99 | 0.61 | 0.62 | 1.14 | 0.35 | 0.01 | 0.18 | 0.06 | 0.04 | 0.02 |
| 5                     | 2x7  | 1.02 | 0.62 | 0.83 | 0.30 | 0.43 | 0.22 | 0.32 | 0.37 | 0.02 | 0.00 |
| 6                     | 2x8  | 1.34 | 0.79 | 1.00 | 0.87 | 0.21 | 0.35 | 0.51 | 0.42 | 0.07 | 0.04 |
| 7                     | 2x9  | 1.03 | 0.53 | 1.03 | 0.75 | 0.12 | 0.21 | 0.43 | 0.28 | 0.01 | 0.01 |
| 8                     | 2x10 | 0.88 | 0.55 | 1.31 | 0.43 | 0.36 | 0.26 | 0.40 | 0.23 | 0.01 | 0.09 |
| 9                     | 3x7  | 0.87 | 0.55 | 0.47 | 0.45 | 0.15 | 0.18 | 0.36 | 0.32 | 0.07 | 0.01 |
| 10                    | 3x8  | 1.28 | 0.85 | 1.00 | 0.89 | 0.19 | 0.48 | 0.42 | 0.46 | 0.05 | 0.04 |
| 11                    | 3x9  | 0.95 | 0.53 | 0.49 | 0.60 | 0.17 | 0.01 | 0.31 | 0.27 | 0.02 | 0.02 |
| 12                    | 3x10 | 0.94 | 0.42 | 0.95 | 0.94 | 0.16 | 0.30 | 0.33 | 0.26 | 0.05 | 0.10 |
| 13                    | 4x7  | 0.95 | 0.32 | 0.87 | 0.33 | 0.16 | 0.19 | 0.42 | 0.30 | 0.01 | 0.09 |
| 14                    | 4x8  | 1.20 | 0.92 | 1.42 | 1.36 | 0.34 | 0.48 | 0.55 | 0.27 | 0.07 | 0.02 |
| 15                    | 4x9  | 1.00 | 0.59 | 1.40 | 0.91 | 0.16 | 0.25 | 0.50 | 0.25 | 0.02 | 0.12 |
| 16                    | 4x10 | 1.03 | 0.64 | 1.51 | 0.48 | 0.35 | 0.46 | 0.47 | 0.29 | 0.09 | 0.15 |
| 17                    | 5x7  | 0.90 | 0.63 | 0.33 | 0.19 | 0.24 | 0.01 | 0.44 | 0.13 | 0.03 | 0.01 |
| 18                    | 5x8  | 1.09 | 1.01 | 0.89 | 0.65 | 0.50 | 0.48 | 0.53 | 0.41 | 0.09 | 0.03 |
| 19                    | 5x9  | 1.16 | 0.75 | 1.08 | 0.87 | 0.39 | 0.00 | 0.34 | 0.36 | 0.02 | 0.05 |
| 20                    | 5x10 | 1.01 | 0.73 | 0.66 | 0.58 | 0.23 | 0.00 | 0.39 | 0.24 | 0.27 | 0.06 |

Table 30. (Continued).

| Entry No.             | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|                       |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| kg plot <sup>-1</sup> |          |      |      |        |      |        |      |        |      |        |      |
| 21                    | 6x7      | 0.42 | 0.38 | 0.31   | 0.41 | 0.15   | 0.00 | 0.22   | 0.28 | 0.01   | 0.01 |
| 22                    | 6x8      | 1.36 | 0.89 | 0.65   | 1.06 | 0.18   | 0.07 | 0.26   | 0.39 | 0.01   | 0.02 |
| 23                    | 6x9      | 0.85 | 0.55 | 0.51   | 0.84 | 0.16   | 0.01 | 0.35   | 0.18 | 0.02   | 0.01 |
| 24                    | 6x10     | 1.23 | 0.71 | 1.25   | 0.66 | 0.26   | 0.07 | 0.54   | 0.19 | 0.04   | 0.02 |
| 25                    | 1        | 0.62 | 0.59 | 0.49   | 0.39 | 0.09   | 0.02 | 0.13   | 0.06 | 0.00   | 0.09 |
| 26                    | 2        | 0.61 | 0.54 | 0.68   | 0.39 | 0.29   | 0.30 | 0.19   | 0.13 | 0.00   | 0.03 |
| 27                    | 3        | 0.59 | 0.47 | 0.57   | 0.24 | 0.03   | 0.03 | 0.30   | 0.17 | 0.01   | 0.00 |
| 28                    | 4        | 0.62 | 0.36 | 0.32   | 0.34 | 0.10   | 0.03 | 0.14   | 0.17 | 0.01   | 0.15 |
| 29                    | 5        | 0.51 | 0.50 | 0.24   | 0.29 | 0.01   | 0.03 | 0.20   | 0.17 | 0.00   | 0.15 |
| 30                    | 6        | 0.67 | 0.46 | 0.16   | 0.42 | 0.03   | 0.00 | 0.22   | 0.06 | 0.00   | 0.02 |
| 31                    | 7        | 0.82 | 0.32 | 0.67   | 0.52 | 0.28   | 0.35 | 0.34   | 0.36 | 0.11   | 0.02 |
| 32                    | 8        | 0.79 | 0.64 | 0.63   | 1.08 | 0.16   | 0.36 | 0.09   | 0.06 | 0.01   | 0.03 |
| 33                    | 9        | 0.74 | 0.46 | 0.67   | 0.02 | 0.19   | 0.03 | 0.18   | 0.03 | 0.00   | 0.07 |
| 34                    | 10       | 0.72 | 0.46 | 0.21   | 0.40 | 0.17   | 0.32 | 0.20   | 0.13 | 0.05   | 0.07 |
| 35                    | Seredo   | --   | --   | --     | 1.00 | 0.54   | 0.28 | --     | 0.43 | --     | 0.08 |
| Mean                  |          |      |      |        |      |        |      |        |      |        |      |
| LSD (0.05)            |          | 0.95 | 0.60 | 0.76   | 0.65 | 0.23   | 0.17 | 0.33   | 0.24 | 0.04   | 0.05 |
|                       |          | 0.29 | 0.13 | 0.29   | 0.27 | 0.15   | 0.35 | 0.16   | 0.11 | 0.09   | ns   |

Male GCA means for grain yield were higher for IA28 than for other male combiners. Significant male GCA effects for grain yield were found for all males. IA28 was the best combiner in both good and poor environments as it had invariably positive GCA effects. In the case of IS7254C, all significant GCA effects were negative. Female GCA means varied with locations and years, so that for most females, GCA effects were both positive and negative depending with location and year with the exception of (AT-1)-52-2-1-2-1. These results suggest that additive genetic variance was important in the control of grain yield. Significant SCA effects, which were both negative or positive, were found. All hybrids except B-Yel-PI x IS7254C; Wheatland x IA28; (AT-1)-52-2-1-2-1 x IA28; and females, TX623, (AT-1)-52-2-1-2-1, B-Yel-PI and (AT-1)-36-4-2-2-1, crossed with male parent TX432 expressed significant SCA effects; however, SCA effects tended to be low in most environments. Significant SCA effects were observed more frequently at MSU, Obambo, and Ukwala. Only one hybrid at Buburi showed significant SCA. SCA effects for a given hybrid were rarely consistent from one year at each location. The existence of both additive and non-additive genetic variance for grain yield were indicated by these data which is in agreement with Wilson *et al.* (1978). Male combiners tended to be more consistent from location to location than female combiners in terms of GCA. Significant SCA effects were less common and tended to be associated with the better environments. These results support Laosuwan and Atkins (1977) who reported that the GCA effects of R-lines accounted for the largest portion of the variation expressed for grain yield.

## One thousand seed weight

There were significant differences among genotypes for 1000 seed weight at all locations except Buburi and Mumias in both years (Tables 12-21). Parental genotypes were significantly different at MSU and Ukwala in both two years and at Obambo in 1991. Mean squares for  $F_1$ s vs Parent were significant only at Obambo in both years and at Buburi in 1991 indicating limited expression of heterosis for 1000 seed weight. There were significant differences among  $F_1$ s at MSU, Obambo and Ukwala in both years. In both years, significant differences among males were found at MSU, Obambo, and Ukwala. Significant differences among females were found at Obambo and Ukwala in both years and at MSU and Buburi in 1991. Male x female interactions were significant in 1991 at MSU and Obambo and in both years at Ukwala.

Means of 1000 seed weight of the 35 genotypes are presented in Table 31. One thousand seed weight in both years at Mumias was significantly lower than the other locations. It was generally observed seed weights were lower at Buburi and Ukwala than at MSU and Obambo in both years. At most locations, parental means were similar. Heterotic response for 1000 seed weight of hybrids above either parent was more observable at Obambo in 1990 than at other sites, although some hybrids did express heterosis for 1000 seed weight in several locations. A number of hybrids maintained higher 1000 seed weight than other genotypes in the poorer environments which supports the findings of Heinrich *et al.* (1983). These data also agree with Nandanwankar (1990), who reported positive heterosis for seed size, and Liang *et al.* (1972) who obtained negative heterobeltiosis for kernel weight. Quinby (1972) also found that male parents had heavier

Table 31. Means of thousand seed weight of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

|    |      |    |    |    |    |    |    |    |    |    |    |
|----|------|----|----|----|----|----|----|----|----|----|----|
| 1  | 1x7  | 31 | 24 | 32 | 35 | 23 | 24 | 33 | 14 | 26 | 22 |
| 2  | 1x8  | 28 | 25 | 21 | 29 | 27 | 10 | 16 | 11 | 22 | 21 |
| 3  | 1x9  | 29 | 24 | 30 | 31 | 27 | 14 | 27 | 12 | 12 | 3  |
| 4  | 1x10 | 26 | 26 | 21 | 27 | 21 | 13 | 22 | 14 | 17 | 13 |
| 5  | 2x7  | 31 | 26 | 38 | 41 | 29 | 26 | 35 | 19 | 29 | 0  |
| 6  | 2x8  | 30 | 26 | 32 | 37 | 27 | 26 | 30 | 21 | 26 | 16 |
| 7  | 2x9  | 31 | 27 | 39 | 41 | 24 | 27 | 33 | 14 | 29 | 0  |
| 8  | 2x10 | 27 | 25 | 30 | 35 | 22 | 13 | 30 | 14 | 22 | 17 |
| 9  | 3x7  | 33 | 25 | 33 | 35 | 31 | 12 | 35 | 17 | 27 | 7  |
| 10 | 3x8  | 27 | 24 | 26 | 28 | 24 | 25 | 26 | 17 | 24 | 12 |
| 11 | 3x9  | 32 | 23 | 28 | 34 | 25 | 11 | 33 | 16 | 15 | 10 |
| 12 | 3x10 | 26 | 23 | 32 | 32 | 22 | 25 | 26 | 14 | 23 | 12 |
| 13 | 4x7  | 31 | 26 | 31 | 36 | 28 | 13 | 33 | 17 | 26 | 20 |
| 14 | 4x8  | 28 | 24 | 27 | 31 | 34 | 25 | 27 | 15 | 29 | 12 |
| 15 | 4x9  | 28 | 24 | 32 | 32 | 25 | 24 | 33 | 16 | 26 | 9  |
| 16 | 4x10 | 28 | 23 | 31 | 32 | 24 | 26 | 30 | 13 | 23 | 17 |
| 17 | 5x7  | 29 | 27 | 32 | 31 | 24 | 11 | 35 | 17 | 29 | 22 |
| 18 | 5x8  | 28 | 26 | 20 | 28 | 25 | 13 | 27 | 14 | 27 | 14 |
| 19 | 5x9  | 29 | 25 | 27 | 31 | 25 | 0  | 33 | 13 | 26 | 10 |
| 20 | 5x10 | 26 | 26 | 27 | 29 | 23 | 0  | 26 | 18 | 27 | 11 |

g

Table 31. (Continued).

| Entry No.  | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|            |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| g          |          |      |      |        |      |        |      |        |      |        |      |
| 21         | 6x7      | 32   | 25   | 24     | 35   | 22     | 0    | 36     | 16   | 28     | 8    |
| 22         | 6x8      | 27   | 25   | 22     | 27   | 21     | 26   | 25     | 15   | 21     | 13   |
| 23         | 6x9      | 31   | 24   | 27     | 31   | 34     | 13   | 29     | 15   | 21     | 15   |
| 24         | 6x10     | 22   | 27   | 25     | 27   | 25     | 27   | 24     | 12   | 11     | 10   |
| 25         | 1        | 25   | 22   | 20     | 23   | 21     | 11   | 22     | 11   | 16     | 9    |
| 26         | 2        | 25   | 21   | 27     | 29   | 20     | 27   | 31     | 15   | 16     | 19   |
| 27         | 3        | 24   | 23   | 29     | 28   | 24     | 14   | 28     | 17   | 21     | 0    |
| 28         | 4        | 26   | 23   | 21     | 26   | 26     | 14   | 29     | 16   | 20     | 17   |
| 29         | 5        | 22   | 30   | 23     | 24   | 22     | 14   | 29     | 16   | 9      | 14   |
| 30         | 6        | 24   | 26   | 25     | 24   | 26     | 0    | 23     | 11   | 8      | 9    |
| 31         | 7        | 28   | 23   | 24     | 29   | 32     | 28   | 29     | 15   | 27     | 16   |
| 32         | 8        | 25   | 22   | 25     | 25   | 24     | 25   | 15     | 9    | 19     | 24   |
| 33         | 9        | 35   | 23   | 28     | 36   | 21     | 13   | 28     | 11   | 0      | 19   |
| 34         | 10       | 27   | 23   | 22     | 28   | 23     | 21   | 21     | 10   | 20     | 17   |
| 35         | Seredo   | --   | --   | --     | 26   | 25     | 27   | --     | 13   | --     | --   |
| Mean       |          | 28.0 | 24.6 | 27.4   | 30.6 | 25.0   | 16.9 | 28.2   | 14.5 | 21.1   | 12.9 |
| LSD (0.05) |          | 3.1  | 1.7  | 4.0    | 2.4  | ns     | ns   | 4.1    | 2.9  | ns     | ns   |

kernels than hybrids. There were discernable differences among hybrids for thousand seed weight in both good and bad environments. Generally, hybrids involving male parent IS7254C had higher means than other hybrids in a number of locations. Some hybrids also exhibited negative heterotic response compared to the lighter seeded parent.

Male GCA means were generally higher for IS7254C than for other male combiners at all locations except Buburi in 1991. Significant male GCA effects were obtained for all males. It was observed that IS7254C and TX430 had positive male GCA effects whereas IA28 and TX432 had negative GCA effects. Generally, female GCA means for Wheatland were higher than for other females. Although significant GCA effects were observed for all females, Wheatland had the highest frequency of significant GCA effects. GCA effects for Wheatland were positive while female GCA effects of the other combiners were generally negative. Significant SCA effects were obtained with TX623 x IA28, Wheatland x IA28, B-Yel-PI x TX432, (AT-2)-10-6-1-2-1 x TX432, and (AT-1)-36-4-2-2-1 x TX432. Of these hybrids, Wheatland X IA28 and (AT-2)-10-6-1-2-1 X TX432 exhibited positive significant SCA effects in poor environments, although the expression was for one location and one year only. These results are in agreement with Bittinger *et al.* (1981) who reported that additive gene effects were greater than dominant gene effects for thousand seed weight.

#### Number of Grains per Head

Significant differences among genotypes were found at MSU and Ukwala in 1990, and at Obambo in both years (Tables 12-21). Differences among parents existed at Buburi in 1991 and at Obambo in both years. Average

heterosis for number of grains was significant only at Obambo and Ukwala in 1990. Significant differences among hybrids were expressed at MSU, Obambo and Ukwala in 1990 and at Obambo in 1991. Mean squares for males were significant at MSU, Obambo, and Ukwala in 1990 and at Obambo in 1991. Significant differences among females were expressed at MSU, Obambo and Mumias in single years. Male x female interactions for number of grains were significant only at Obambo and Ukwala in single years.

Mean numbers of grains per head of the 35 sorghum genotypes are presented in Table 32. Generally, location means for the stress environments were lower than location means of the better environments. Parents generally exhibited a lower number of grains per head than hybrids. Parents differed from each other within locations. Parents, (AT-2)-10-6-1-2-1 and TX432, had comparable performances across locations except at Mumias. Parent IA28 had particularly high numbers of seeds per head at Obambo in both years and at Buburi in 1991. Hybrids exhibited a higher number of grains per head than the highest parent; however, heterosis was expressed more often in better environments than in poor environments. There were a number of hybrids that exhibited heterosis across locations, except at Mumias. Nandanwankar (1990) and Rubaihayo and Makumbi (1976) also reported consistent significant increases in number of grains per head due to heterotic effects. Differences among hybrids were evident both in the good and poor environments. Hybrids involving all females crossed with male parent IA28 had generally higher numbers of seeds per head across locations than other hybrids. Hybrid Wheatland x IS7254C had 4110 seeds per head at Ukwala in 1991 which was the highest of

Table 32. Mean number of grains per head of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

|                   |      |      |   |      |      |   |      |      |      |   |      |
|-------------------|------|------|---|------|------|---|------|------|------|---|------|
| ----- x1000 ----- |      |      |   |      |      |   |      |      |      |   |      |
| 1                 | 1x7  | 1.42 | — | 0.79 | 0.60 | — | 0.73 | 0.73 | 0.69 | — | 0.09 |
| 2                 | 1x8  | 1.39 | — | 2.49 | 1.02 | — | 0.68 | 0.47 | 0.60 | — | 0.02 |
| 3                 | 1x9  | 0.94 | — | 1.49 | 0.85 | — | 0.03 | 0.67 | 0.44 | — | 0.03 |
| 4                 | 1x10 | 1.11 | — | 1.98 | 1.38 | — | 0.05 | 0.39 | 0.21 | — | 0.02 |
| 5                 | 2x7  | 1.23 | — | 0.81 | 0.26 | — | 0.44 | 0.35 | 4.11 | — | —    |
| 6                 | 2x8  | 1.33 | — | 1.71 | 0.70 | — | 0.80 | 0.62 | 0.60 | — | 0.09 |
| 7                 | 2x9  | 1.07 | — | 1.12 | 0.63 | — | 0.83 | 0.43 | 0.68 | — | —    |
| 8                 | 2x10 | 1.43 | — | 1.87 | 0.33 | — | 0.59 | 0.47 | 0.42 | — | 0.09 |
| 9                 | 3x7  | 1.34 | — | 1.02 | 0.39 | — | 1.50 | 0.84 | 1.10 | — | 0.02 |
| 10                | 3x8  | 1.87 | — | 2.13 | 1.03 | — | 2.37 | 1.36 | 0.90 | — | 0.03 |
| 11                | 3x9  | 1.47 | — | 1.04 | 0.71 | — | 0.02 | 0.93 | 0.60 | — | 0.08 |
| 12                | 3x10 | 1.78 | — | 2.10 | 0.80 | — | 0.81 | 0.63 | 0.60 | — | 0.15 |
| 13                | 4x7  | 1.15 | — | 0.96 | 0.25 | — | 2.39 | 0.82 | 0.62 | — | 0.17 |
| 14                | 4x8  | 1.52 | — | 2.22 | 1.34 | — | 2.73 | 0.87 | 0.82 | — | 0.03 |
| 15                | 4x9  | 1.06 | — | 1.89 | 1.12 | — | 1.06 | 0.81 | 0.94 | — | 0.26 |
| 16                | 4x10 | 1.30 | — | 1.84 | 0.56 | — | 1.07 | 0.56 | 0.68 | — | 0.17 |
| 17                | 5x7  | 0.98 | — | 0.55 | 0.47 | — | 0.05 | 0.57 | 1.47 | — | 0.06 |
| 18                | 5x8  | 1.02 | — | 2.03 | 0.86 | — | 1.76 | 0.89 | 0.97 | — | 0.08 |
| 19                | 5x9  | 0.94 | — | 1.52 | 0.82 | — | 0.00 | 0.49 | 1.24 | — | 0.15 |
| 20                | 5x10 | 1.11 | — | 0.78 | 0.60 | — | 0.00 | 0.64 | 0.43 | — | 0.12 |

Table 32. (Continued).

| Entry No.         | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-------------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|                   |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- x1000 ----- |          |      |      |        |      |        |      |        |      |        |      |
| 21                | 6x7      | 0.61 | --   | 1.08   | 0.41 | --     | 0.0  | 0.98   | 1.07 | --     | 0.01 |
| 22                | 6x8      | 1.61 | --   | 2.10   | 1.20 | --     | 0.28 | 2.04   | 0.96 | --     | 0.05 |
| 23                | 6x9      | 1.00 | --   | 0.96   | 0.76 | --     | 0.13 | 0.65   | 0.61 | --     | 0.02 |
| 24                | 6x10     | 1.72 | --   | 1.87   | 0.72 | --     | 0.50 | 0.94   | 0.53 | --     | 0.05 |
| 25                | 1        | 0.89 | --   | 1.74   | 0.87 | --     | 0.18 | 0.55   | 0.37 | --     | 0.12 |
| 26                | 2        | 0.52 | --   | 1.35   | 0.43 | --     | 2.04 | 0.36   | 0.44 | --     | 0.04 |
| 27                | 3        | 0.78 | --   | 0.81   | 0.38 | --     | 0.50 | 0.50   | 0.84 | --     | --   |
| 28                | 4        | 0.69 | --   | 0.83   | 0.80 | --     | 0.67 | 0.22   | 0.70 | --     | 0.13 |
| 29                | 5        | 0.36 | --   | 0.76   | 0.66 | --     | 0.40 | 0.33   | 0.44 | --     | 0.18 |
| 30                | 6        | 1.00 | --   | 0.58   | 0.64 | --     | 0.0  | 0.42   | 0.86 | --     | 0.08 |
| 31                | 7        | 0.81 | --   | 0.82   | 0.41 | --     | 0.57 | 0.61   | 0.95 | --     | 0.05 |
| 32                | 8        | 0.79 | --   | 1.41   | 1.24 | --     | 1.83 | 0.41   | 0.47 | --     | 0.04 |
| 33                | 9        | 0.55 | --   | 1.13   | 0.64 | --     | 0.54 | 0.34   | 0.46 | --     | 0.13 |
| 34                | 10       | 0.60 | --   | 0.59   | 0.60 | --     | 0.77 | 0.58   | 0.51 | --     | 0.15 |
| 35                | Seredo   | --   | --   | --     | 1.24 | --     | 0.44 | --     | 0.93 | --     | --   |
| -----             |          |      |      |        |      |        |      |        |      |        |      |
| Mean              |          | 1.10 | --   | 1.37   | 0.73 | --     | 0.94 | 0.66   | 0.82 | --     | 0.09 |
| ISD (0.05)        |          | 0.41 | --   | 0.80   | 0.31 | --     | ns   | 0.47   | ns   | --     | ns   |

all hybrids in any location or year. Hybrid (AT-1)-52-2-1-2-1 x TX430 also had a higher number of seeds per head over locations than some other hybrids. Wheatland x TX432 was a relatively poor hybrid in poor environments compared to many of the other hybrids.

Male GCA means for number of grains per head were generally higher for IA28 than other males. No significant male GCA effects were found for TX432. IA28 had positive significant male GCA effects in both years at Obambo, and in 1990 at MSU and Ukwala, whereas other male combiners had significant GCA effects only in better environments and these effects were negative indicating poor general combining ability. Female GCA means were higher for (AT-1)-52-2-1-2-1 than for other females. Depending on the location, females, TX623, B-Yel-PI, and (AT-1)-36-4-2-2-1, exhibited both negative and positive GCA effects; however, only the positive female GCA effects were significant. Both Wheatland and (AT-2)-10-6-1-2-1 had negative significant female GCA effects. It was observed that females combiners had expressed significant GCA effects at low frequency. It appeared that additive genetic effects controlled the number of grains per head which agrees with Laosuwan and Atkins (1977) who reported that GCA effects of males controlled the largest portion of the variation expressed for number of grains per head. Significant positive SCA effects were expressed at Ukwala by (AT-1)-36-4-2-2-1 x IA28 in 1990 and by TX623 x TX432 and B-Yel-PI x IA28 at Obambo in 1991. These results are in agreement with Laosuwan and Atkins (1977) that while non-additive gene effects contributed to the variation in single hybrids they played a lesser role than additive gene effects.

### Total Dry Weights

Total dry weight were not measured at Obambo and Ukwala in 1990 nor at MSU in 1991. There were significant differences among genotypes at MSU, Obambo and Mumias (Tables 12-21). Differences among parents were significant at Obambo, Buburi, Ukwala, and Mumias in some years. Mean squares for  $F_1$ s vs parents were only significant at Obambo in 1991 and Mumias in 1990. Differences among  $F_1$ s were significant at MSU and Mumias in single years and at Obambo in both two years. Males were significant at MSU, Obambo and Mumias in 1990. Mean squares for females were significant at MSU and Mumias in 1990 and Obambo in both years. Male x female interactions were significant at MSU and Obambo in 1990.

Location means for total dry weights from good environments were at least twice as high as location means from the poor environments in 1990 (Table 33). Total dry weights at Obambo in 1991 were low and were not much different from the poor environments except for Mumias. Differences among parents were more obvious when they were compared between Obambo and the stress environments. Large differences were exhibited by TX623, and IA28 which had low total dry weights across locations as compared to the tall IS7254C. Parents generally had lower dry matter weights than hybrids; however, this was not as obvious at MSU and Buburi. There was inconsistency in expression of heterosis and also fluctuations in total dry weights of particular hybrids at a given location. These inconsistencies were attributed to differences in soil pH and genotype. Fluctuations also existed between years. Furlani *et al.* (1986) have reported that in ferric and aluminum phosphate soils, low shoot dry matter yields were obtained. Johnson and Ohki (1984) reported similar findings

Table 33. Mean total dry weights of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

| kg plot <sup>-1</sup> |      |   |    |     |     |    |     |    |     |     |     |
|-----------------------|------|---|----|-----|-----|----|-----|----|-----|-----|-----|
| 1                     | 1x7  | 7 | -- | 1.5 | 2.3 | -- | 1.2 | -- | 1.5 | 2.2 | 0.8 |
| 2                     | 1x8  | 6 | -- | 2.6 | 2.1 | -- | 0.8 | -- | 1.1 | 2.2 | 1.3 |
| 3                     | 1x9  | 6 | -- | 1.9 | 1.9 | -- | 0.7 | -- | 0.7 | 1.0 | 0.3 |
| 4                     | 1x10 | 4 | -- | 1.9 | 2.5 | -- | 0.5 | -- | 0.6 | 1.2 | 0.4 |
| 5                     | 2x7  | 5 | -- | 2.1 | 1.2 | -- | 1.5 | -- | 1.1 | 2.2 | 0.4 |
| 6                     | 2x8  | 5 | -- | 2.7 | 1.6 | -- | 1.1 | -- | 1.7 | 2.4 | 0.5 |
| 7                     | 2x9  | 4 | -- | 3.0 | 1.4 | -- | 1.5 | -- | 1.5 | 1.2 | 0.3 |
| 8                     | 2x10 | 3 | -- | 3.0 | 1.2 | -- | 1.5 | -- | 0.9 | 0.8 | 0.7 |
| 9                     | 3x7  | 4 | -- | 2.6 | 1.5 | -- | 0.8 | -- | 1.4 | 1.6 | 0.1 |
| 10                    | 3x8  | 5 | -- | 2.8 | 1.6 | -- | 1.2 | -- | 2.0 | 2.8 | 0.4 |
| 11                    | 3x9  | 3 | -- | 1.9 | 1.4 | -- | 0.9 | -- | 1.2 | 1.2 | 0.5 |
| 12                    | 3x10 | 3 | -- | 2.1 | 1.9 | -- | 1.2 | -- | 1.1 | 0.7 | 0.5 |
| 13                    | 4x7  | 7 | -- | 2.3 | 1.5 | -- | 1.3 | -- | 1.7 | 4.0 | 0.5 |
| 14                    | 4x8  | 4 | -- | 3.5 | 2.4 | -- | 1.9 | -- | 2.0 | 2.6 | 0.5 |
| 15                    | 4x9  | 4 | -- | 2.8 | 1.4 | -- | 1.8 | -- | 1.2 | 2.0 | 0.5 |
| 16                    | 4x10 | 4 | -- | 3.1 | 1.2 | -- | 3.9 | -- | 1.5 | 2.6 | 0.8 |
| 17                    | 5x7  | 5 | -- | 1.9 | 0.7 | -- | 1.1 | -- | 0.6 | 3.6 | 0.6 |
| 18                    | 5x8  | 5 | -- | 1.9 | 1.4 | -- | 2.3 | -- | 1.9 | 2.6 | 0.4 |
| 19                    | 5x9  | 5 | -- | 2.7 | 1.7 | -- | 0.9 | -- | 1.5 | 2.6 | 0.3 |
| 20                    | 5x10 | 5 | -- | 2.5 | 1.2 | -- | 0.5 | -- | 1.1 | 3.0 | 0.5 |

Table 33. (Continued).

| Entry No.                         | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------------------------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|                                   |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- kg plot <sup>-1</sup> ----- |          |      |      |        |      |        |      |        |      |        |      |
| 21                                | 6x7      | 3    | --   | 1.0    | 1.4  | --     | 0.3  | --     | 1.8  | 2.2    | 0.1  |
| 22                                | 6x8      | 6    | --   | 1.7    | 2.0  | --     | 1.5  | --     | 2.0  | 1.6    | 0.7  |
| 23                                | 6x9      | 4    | --   | 1.5    | 1.8  | --     | 0.6  | --     | 1.1  | 1.2    | 0.2  |
| 24                                | 6x10     | 5    | --   | 2.6    | 1.8  | --     | 0.8  | --     | 1.1  | 1.4    | 0.3  |
| 25                                | 1        | 3    | --   | 1.2    | 0.8  | --     | 0.5  | --     | 0.6  | 0.2    | 0.5  |
| 26                                | 2        | 3    | --   | 1.4    | 1.3  | --     | 0.6  | --     | 0.7  | 1.0    | 0.5  |
| 27                                | 3        | 3    | --   | 2.3    | 0.7  | --     | 0.6  | --     | 0.8  | 1.4    | 0.1  |
| 28                                | 4        | 4    | --   | 1.5    | 0.8  | --     | 0.5  | --     | 1.3  | 2.2    | 0.6  |
| 29                                | 5        | 3    | --   | 1.4    | 0.6  | --     | 0.5  | --     | 1.0  | 2.6    | 0.7  |
| 30                                | 6        | 4    | --   | 0.6    | 1.2  | --     | 0.2  | --     | 0.7  | 1.2    | 0.3  |
| 31                                | 7        | 4    | --   | 2.0    | 1.4  | --     | 2.1  | --     | 1.1  | 2.5    | 0.5  |
| 32                                | 8        | 4    | --   | 1.8    | 1.8  | --     | 1.2  | --     | 0.6  | 1.4    | 0.8  |
| 33                                | 9        | 4    | --   | 1.9    | 0.1  | --     | 0.3  | --     | 0.2  | 0.4    | 0.5  |
| 34                                | 10       | 3    | --   | 1.1    | 1.1  | --     | 1.2  | --     | 0.8  | 1.2    | 0.6  |
| 35                                | Seredo   | -    | --   | --     | 2.3  | --     | 1.6  | --     | 2.2  | --     | 0.3  |
| -----                             |          |      |      |        |      |        |      |        |      |        |      |
| Mean                              |          | 4.3  | --   | 2.1    | 1.5  | --     | 1.1  | --     | 1.2  | 1.8    | 0.5  |
| LSD (0.05)                        |          | 1.7  | --   | 1.0    | 0.7  | --     | ns   | --     | ns   | 1.1    | ns   |

with wheat where low soil pH significantly reduced dry weight. There were significant differences among hybrids for total dry weight. Dry weights were considerably higher at MSU compared to the other locations; however, dry weight means differences among genotypes were fairly consistent, for (AT-1)-52-2-1-2-1 x IA28, and (AT-1)-52-2-1-2-1 x TX432 as compared to lower means of TX623 x TX430 and B-Yel-PI x TX430, across locations. Hybrid (AT-1)-52-2-1-2-1 x IS7254C had means comparable to the other hybrids at Obambo, Buburi, and Ukwala, yet had the highest total dry weight means at MSU and Mumias in 1990.

Male GCA means were highest for IA28. Isolated significant male GCA effects were also obtained for males, IS7254C, TX430 and TX432. Significant male effects were negative at MSU and Obambo and positive at Mumias. The positive significant male GCA effects for total dry weight were found for IS7254C and TX430. High female GCA means were found for TX623 in the better environments. (AT-1)-52-2-1-2-1 had high female GCA means for total dry weight. (AT-2)-10-6-1-2-1 had significant negative GCA effects in the better environments and positive effects in the poor environment of Mumias. Significant male and female GCA effects were expressed in the poor environments by IS7254C, TX430, (AT-1)-52-2-1-2-1, and (AT-2)-10-6-1-2-1 which implies a significant role for additive gene effects in the inheritance of tolerance to stress conditions of soil acidity. Wheatland and B-Yel-PI did not exhibit any significant female GCA effects. Significant SCA effects were expressed only at MSU by (AT-1)-52-2-1-2-1 x IS7254C and (AT-1)-36-4-2-2-1 x IS7254C which were positive and negative, respectively. These data are in agreement with Modi and Dabholkar (1989) who reported significant GCA and SCA effects for

dry weight, but in the present study additive gene effects were more important, particularly, in stress environments.

#### Harvest Index

Harvest index was not measured at Obambo and Ukwala in 1990 nor at MSU in 1991. Significant differences among genotypes for harvest index were found at MSU, Buburi, Ukwala, and Mumias in individual years and at Obambo in both years (Table 12-21). There were significant differences among parents at Obambo in both years and at Ukwala, Buburi and Mumias in individual years. Significant differences between hybrids and parents were found at Obambo, Buburi and Ukwala in individual years. Differences among  $F_1$ s were significant at Obambo in both years, at Buburi in 1991, and at MSU in 1990. Mean squares for males were significant at Obambo for two years, and at MSU, Buburi, and Mumias in individual years. Significant female mean squares were limited to individual years at Obambo, Buburi and Ukwala. Significant male x female interactions existed only at Obambo.

Mean harvest indices of 35 sorghum genotypes are presented in Table 34. The location means for MSU in 1990 and for Obambo for two years were far higher than for the other locations and reflect the stress due to soil acidity at these other sites. Low soil pH has been shown to reduce harvest index by lower shoot dry matter yield and grain yield in sorghum growing in acid soils (Furlani *et al.*, 1986; and John and Ohki, 1984). Parental differences existed in both the good and poor environments; however, fluctuations were very high in the poor environments. Some parental genotypes, as well as Seredo, had fairly acceptable means for harvest index, across all locations, including Mumias; however, Wheatland,

Table 34. Mean harvest indices of 35 sorghum genotypes grown at five locations in 1990 and 1991.

| Entry No. | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

|                  |      |      |    |      |      |    |      |    |      |      |      |
|------------------|------|------|----|------|------|----|------|----|------|------|------|
| ----- x100 ----- |      |      |    |      |      |    |      |    |      |      |      |
| 1                | 1x7  | 0.23 | -- | 0.37 | 0.38 | -- | 0.17 | -- | 0.16 | 0.01 | 0.07 |
| 2                | 1x8  | 0.27 | -- | 0.42 | 0.47 | -- | 0.08 | -- | 0.13 | 0.03 | 0.02 |
| 3                | 1x9  | 0.18 | -- | 0.32 | 0.43 | -- | 0.01 | -- | 0.18 | 0.03 | 0.05 |
| 4                | 1x10 | 0.24 | -- | 0.35 | 0.47 | -- | 0.02 | -- | 0.11 | 0.03 | 0.03 |
| 5                | 2x7  | 0.20 | -- | 0.41 | 0.29 | -- | 0.14 | -- | 0.18 | 0.02 | 0.01 |
| 6                | 2x8  | 0.27 | -- | 0.38 | 0.61 | -- | 0.35 | -- | 0.25 | 0.01 | 0.08 |
| 7                | 2x9  | 0.27 | -- | 0.36 | 0.56 | -- | 0.17 | -- | 0.19 | 0.03 | 0.00 |
| 8                | 2x10 | 0.30 | -- | 0.46 | 0.35 | -- | 0.10 | -- | 0.27 | 0.01 | 0.12 |
| 9                | 3x7  | 0.20 | -- | 0.18 | 0.31 | -- | 0.13 | -- | 0.26 | 0.02 | 0.03 |
| 10               | 3x8  | 0.30 | -- | 0.39 | 0.55 | -- | 0.40 | -- | 0.23 | 0.04 | 0.11 |
| 11               | 3x9  | 0.30 | -- | 0.27 | 0.46 | -- | 0.00 | -- | 0.24 | 0.02 | 0.03 |
| 12               | 3x10 | 0.29 | -- | 0.49 | 0.49 | -- | 0.26 | -- | 0.24 | 0.01 | 0.17 |
| 13               | 4x7  | 0.14 | -- | 0.40 | 0.20 | -- | 0.10 | -- | 0.18 | 0.06 | 0.20 |
| 14               | 4x8  | 0.27 | -- | 0.41 | 0.57 | -- | 0.25 | -- | 0.13 | 0.01 | 0.04 |
| 15               | 4x9  | 0.24 | -- | 0.53 | 0.70 | -- | 0.14 | -- | 0.24 | 0.02 | 0.12 |
| 16               | 4x10 | 0.27 | -- | 0.50 | 0.39 | -- | 0.18 | -- | 0.21 | 0.01 | 0.23 |
| 17               | 5x7  | 0.19 | -- | 0.17 | 0.33 | -- | 0.00 | -- | 0.20 | 0.03 | 0.03 |
| 18               | 5x8  | 0.20 | -- | 0.47 | 0.47 | -- | 0.12 | -- | 0.23 | 0.01 | 0.08 |
| 19               | 5x9  | 0.24 | -- | 0.41 | 0.55 | -- | 0.00 | -- | 0.25 | 0.04 | 0.09 |
| 20               | 5x10 | 0.23 | -- | 0.28 | 0.51 | -- | 0.00 | -- | 0.21 | 0.01 | 0.08 |

Table 34. (Continued).

| Entry No.        | Genotype | MSU  |      | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------------|----------|------|------|--------|------|--------|------|--------|------|--------|------|
|                  |          | 1990 | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- x100 ----- |          |      |      |        |      |        |      |        |      |        |      |
| 21               | 6x7      | 0.19 | --   | 0.30   | 0.32 | --     | 0.00 | --     | 0.16 | 0.09   | 0.02 |
| 22               | 6x8      | 0.26 | --   | 0.38   | 0.54 | --     | 0.05 | --     | 0.19 | 0.01   | 0.03 |
| 23               | 6x9      | 0.23 | --   | 0.34   | 0.44 | --     | 0.01 | --     | 0.17 | 0.01   | 0.05 |
| 24               | 6x10     | 0.27 | --   | 0.48   | 0.38 | --     | 0.11 | --     | 0.18 | 0.01   | 0.04 |
| 25               | 1        | 0.19 | --   | 0.43   | 0.50 | --     | 0.04 | --     | 0.09 | 0.02   | 0.10 |
| 26               | 2        | 0.21 | --   | 0.40   | 0.31 | --     | 0.48 | --     | 0.20 | 0.01   | 0.04 |
| 27               | 3        | 0.25 | --   | 0.24   | 0.35 | --     | 0.03 | --     | 0.22 | 0.00   | 0.00 |
| 28               | 4        | 0.17 | --   | 0.23   | 0.45 | --     | 0.04 | --     | 0.13 | 0.01   | 0.16 |
| 29               | 5        | 0.15 | --   | 0.17   | 0.57 | --     | 0.04 | --     | 0.19 | 0.01   | 0.12 |
| 30               | 6        | 0.21 | --   | 0.30   | 0.35 | --     | 0.00 | --     | 0.10 | 0.00   | 0.06 |
| 31               | 7        | 0.19 | --   | 0.35   | 0.35 | --     | 0.17 | --     | 0.33 | 0.00   | 0.04 |
| 32               | 8        | 0.23 | --   | 0.37   | 0.62 | --     | 0.33 | --     | 0.10 | 0.05   | 0.04 |
| 33               | 9        | 0.19 | --   | 0.36   | 0.20 | --     | 0.07 | --     | 0.15 | 0.00   | 0.12 |
| 34               | 10       | 0.23 | --   | 0.19   | 0.37 | --     | 0.26 | --     | 0.17 | 0.04   | 0.13 |
| 35               | Seredo   | --   | --   | --     | 0.42 | --     | 0.17 | --     | 0.19 | --     | 0.25 |
| -----            |          |      |      |        |      |        |      |        |      |        |      |
| Mean             |          | 0.23 | --   | 0.36   | 0.44 | --     | 0.13 | --     | 0.19 | 0.02   | 0.08 |
| LSD (0.05)       |          | 0.09 | --   | 0.14   | 0.17 | --     | 0.20 | --     | 0.09 | 0.04   | ns   |

IS7254C, IA28, and TX432 expressed large differences at most locations except Mumias. Genotypic expression of this character, at Mumias in both years and at Buburi in 1991, was extremely variable within locations. Heterosis was not expressed uniformly by hybrids either within or across locations. In the poor environments, heterosis was generally suppressed; however, some hybrids such as Wheatland x TX432, B-Yel-PI x IA28, and (AT-1)-52-2-1-2-1 x TX430 were able to express significant heterosis over the higher parent at Ukwala and Mumias. Significant differences among hybrids were observed at most sites. Some hybrids such as (AT-1)-52-2-1-2-1 x TX432 had consistently high harvest indices even in the poor environments. Flores *et al.* (1988) also reported higher harvest indices for genotypes tolerant to acid soil stress.

Male GCA means for harvest index were generally higher for IA28 than for other males; however, all males exhibited significant male GCA effects at some locations. Only males, IA28 and TX430, had significant positive GCA effects in stress environments. High variation for female GCA means across locations was observed. Significant positive female GCA effects occurred only with B-Yel-PI and (AT-1)-52-2-1-2-1 in the better environments. No significant female GCA effects for harvest index were expressed for Wheatland or (AT-1)-36-4-2-2-1. TX623 and (AT-2)-10-6-1-2-1 expressed significant negative GCA effects in poor environments. Significant positive SCA effects were expressed for harvest index by (AT-1)-52-2-1-2-1 x TX430 at Obambo in 1991. These results are in agreement with Modi and Dabholkar (1989) who also reported significant additive and non-additive genetic effects for harvest index.

### Leaf mineral concentrations

The combined analyses of variance of the twelve leaf mineral concentrations of 34 sorghum genotypes measured in 1990 and 35 sorghum genotypes measured in 1991 at four locations in Kenya are presented in Tables 35 and 36. Genotype x location interactions were significant for K, Ca, Mn, Cu, and Zn in 1990 and for all minerals except Mg in 1991. There were significant differences among genotypes for all leaf mineral concentrations that had no significant G x L interaction. Location differences were significant for all minerals except P, S, and Cl in 1990 and for all minerals except P in 1991. Due to numerous genotype x location interactions, all minerals were analyzed separately by location.

### Magnesium

There were significant differences among genotypes for Mg content at Buburi for two years and at Ukwala and Mumias in single years (Tables 37-44). In 1990, parents differed significantly only at Mumias; however, in 1991, significant differences among parents existed at all locations except Mumias. It was only at Buburi and Mumias in 1990 that the contrast of  $F_1$ s vs Parents was significant for Mg content. Differences among  $F_1$ s were found at Obambo and Mumias in 1990, at Ukwala in 1991, and at Buburi in both years. Mean squares for both males and females were significant at Obambo and Mumias in 1990, and at Buburi in both years. A significant male x female interaction for Mg occurred at Buburi in 1990.

Magnesium contents of leaves for the 35 genotypes are presented in Table 45. In both years, the location means for Obambo were higher than all other locations. Location means for Ukwala, Buburi, and Mumias were

Table 35. Analyses of variance for leaf mineral concentrations of 34 sorghum genotypes measured in four locations, 1990.

| Mean Squares  |     |          |         |            |          |          |          |
|---------------|-----|----------|---------|------------|----------|----------|----------|
| Source        | df  | Mg       | Al      | Si         | P        | S        | Cl       |
| Locations (L) | 3   | 0.630 ** | 1.92 ** | 1006.14 ** | 0.141 ** | 0.099 ** | 0.330 ** |
| Rep / L       | 8   | 0.008    | 0.15    | 14.05      | 0.006    | 0.004    | 0.032    |
| Genotypes (G) | 33  | 0.013 ** | 0.07 *  | 5.55 **    | 0.003 ** | 0.001 *  | 0.008 ** |
| G x L         | 99  | 0.006 ** | 0.06    | 3.41 **    | 0.001    | < 0.001  | 0.005 *  |
| Error         | 249 | 0.003    | 0.04    | 2.20       | 0.001    | < 0.001  | 0.004    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 35. (Continued).

| Source        | df  | Mean Squares |         |              |                |            |             |
|---------------|-----|--------------|---------|--------------|----------------|------------|-------------|
|               |     | K            | Ca      | Mn           | Fe             | Cu         | Zn          |
| Locations (L) | 3   | 4.95 **      | 2.85 ** | 129918.56 ** | 40044493.03 ** | 7365.25 ** | 22843.68 ** |
| Rep / L       | 8   | 0.30         | 0.08    | 13193.26     | 3738966.61     | 3504.62    | 1590.13     |
| Genotypes (G) | 33  | 0.36 **      | 0.15 ** | 11473.39 **  | 679276.54      | 182.53 **  | 937.25 **   |
| G x L         | 99  | 0.12 **      | 0.05 ** | 5478.15 **   | 700190.12      | 184.16 **  | 349.02 **   |
| Error         | 264 | 0.06         | 0.02    | 2812.24      | 567503.06      | 96.16      | 185.64      |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 36. Analyses of variance for leaf mineral concentrations of 35 sorghum genotypes measured in four locations, 1991.

| Source        | df  | Mean Squares |          |            |           |           |          |
|---------------|-----|--------------|----------|------------|-----------|-----------|----------|
|               |     | Mg           | Al       | Si         | P         | S         | Cl       |
| Locations (L) | 3   | 0.338 **     | 0.234 ** | 1217.47 ** | 0.0037    | 0.1082 ** | 0.264 ** |
| Rep / L       | 9   | 0.022        | 0.023    | 5.89       | 0.0060    | 0.0021    | 0.034    |
| Genotypes (G) | 34  | 0.022 **     | 0.076 ** | 4.74 **    | 0.0018 ** | 0.0007 *  | 0.012 ** |
| G x L         | 99  | 0.012        | 0.053 ** | 3.29 **    | 0.0018 ** | 0.0007 ** | 0.011 ** |
| Error         | 306 | 0.012        | 0.005    | 1.53       | 0.0005    | 0.0003    | 0.005    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 36. (Continued).

| Source        | df  | Mean Squares |          |             |               |             |            |
|---------------|-----|--------------|----------|-------------|---------------|-------------|------------|
|               |     | K            | Ca       | Mn          | Fe            | Cu          | Zn         |
| Locations (L) | 3   | 4.33 **      | 0.713 ** | 89916.05 ** | 5026954.01 ** | 17042.35 ** | 6516.14 ** |
| Rep / L       | 9   | 0.14         | 0.046    | 9127.84     | 152747.53     | 994.35      | 310.42     |
| Genotypes (G) | 34  | 0.26 **      | 0.100 ** | 7750.97 **  | 382700.55 **  | 164.42      | 556.45 **  |
| G x L         | 95  | 0.11 **      | 0.026 ** | 2896.59 **  | 260756.77 **  | 219.86 **   | 372.17 **  |
| Error         | 306 | 0.03         | 0.007    | 1512.08     | 64854.10      | 139.04      | 139.40     |

\*, \*\* significant at the 0.01 levels of probability, respectively.

Table 37. Analyses of variance for leaf mineral concentrations of 34 sorghum genotypes measured at Obambo, 1990.

| Mean Squares (MS) |    |          |          |          |           |           |
|-------------------|----|----------|----------|----------|-----------|-----------|
| Source            | df | Mg       | Al       | Si       | P         | S         |
| Rep (R)           | 3  | 0.009    | 0.041 ** | 1.89 *   | 0.0050 ** | 0.0011 ** |
| Genotypes (G)     | 33 | 0.021 ** | 0.011 ** | 7.79 **  | 0.0010 ** | 0.0002    |
| Parents (P)       | 9  | 0.033 ** | 0.024 ** | 9.04 **  | 0.0020 ** | 0.0002    |
| F1's vs Parent    | 1  | < 0.001  | 0.009    | 2.44     | 0.0004    | < 0.0001  |
| F1's              | 23 | 0.017 ** | 0.005 ** | 7.29 **  | 0.0010 ** | 0.0003    |
| Male (M)          | 3  | 0.066 ** | 0.007 *  | 30.08 ** | 0.0040 ** | 0.0003    |
| Female (F)        | 5  | 0.020 *  | 0.015 ** | 6.75 **  | 0.0006    | 0.0003    |
| M X F             | 15 | 0.006    | 0.002    | 3.24 *   | 0.0009    | 0.0003    |
| Error             | 84 | 0.005    | 0.003    | 1.64     | 0.0005    | 0.0002    |
| Error (P)         | 21 | 0.004    | 0.007    | 1.48     | 0.0005    | 0.0001    |
| Error (F1's)      | 60 | 0.006    | 0.002    | 1.74     | 0.0005    | 0.0002    |
| Residual          | 3  | 0.03     | 0.017    | 57.84    | 0.004     | 0.003     |
|                   |    |          |          |          |           | 0.003     |
|                   |    |          |          |          |           | 0.003     |
|                   |    |          |          |          |           | 0.002     |
|                   |    |          |          |          |           | 0.004     |
|                   |    |          |          |          |           | 0.024     |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 37. (Continued).

|                |    | MS      |          |             |              |            |            |
|----------------|----|---------|----------|-------------|--------------|------------|------------|
| Source         | df | K       | Ca       | Mn          | Fe           | Cu         | Zn         |
| Rep (R)        | 3  | 0.34 ** | 0.148 ** | 6772.94 **  | 33922.18 **  | 1104.28 ** | 1605.69 ** |
| Genotypes (G)  | 33 | 0.22 ** | 0.073 ** | 4629.94 **  | 131845.07 ** | 67.64      | 489.77 **  |
| Parents (P)    | 9  | 0.19 ** | 0.124 ** | 8638.08 **  | 331658.97 *  | 60.20      | 588.26 **  |
| F1's vs Parent | 1  | < 0.01  | 0.011    | 346.21      | 245573.33    | 6.59       | 107.00     |
| F1's           | 23 | 0.25 ** | 0.057 ** | 3260.71 **  | 49272.78     | 76.09      | 479.88     |
| Male (M)       | 3  | 1.06 ** | 0.350 ** | 11839.09 ** | 48152.39     | 92.57      | 1915.00 ** |
| Female (F)     | 5  | 0.31 ** | 0.028    | 5426.25 **  | 89343.14     | 110.33     | 778.70 **  |
| M X F          | 15 | 0.07    | 0.007    | 823.19      | 36140.07     | 61.38      | 93.24      |
| Error          | 99 | 0.04    | 0.011    | 1389.52     | 61238.47     | 65.93      | 126.68     |
| Error (P)      | 27 | 0.03    | 0.011    | 1426.56     | 111345.95    | 59.67      | 67.52      |
| Error (F1's)   | 69 | 0.04    | 0.012    | 1408.99     | 41454.02     | 60.65      | 140.74     |
| Residual       | 3  | 0.13    | 0.010    | 608.35      | 65313.50     | 243.71     | 335.74     |

\*,\*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 38. Analyses of variance for leaf mineral concentrations of 35 sorghum genotypes measured at Obambo, 1991.

| Source          | df  | Mean Squares (MS) |          |          |           |           |          |
|-----------------|-----|-------------------|----------|----------|-----------|-----------|----------|
|                 |     | Mg                | Al       | Si       | P         | S         | Cl       |
| Rep (R)         | 3   | 0.05              | 0.004    | 10.91 ** | 0.0013 ** | 0.0005 *  | 0.083 ** |
| Genotypes (G)   | 34  | 0.04              | 0.004 ** | 5.06 **  | 0.0015 ** | 0.0002 ** | 0.010 ** |
| Parents         | 9   | 0.02 **           | 0.005 *  | 8.49 **  | 0.0027 ** | 0.0002    | 0.013 ** |
| F1's vs Parents | 1   | < 0.01            | 0.002    | 11.95 ** | 0.0020 ** | 0.0003    | 0.005    |
| F1's            | 23  | 0.05              | 0.003    | 3.35 **  | 0.0010 ** | 0.0003    | 0.008 *  |
| Male (M)        | 3   | 0.03              | 0.004    | 9.19 **  | 0.0035 ** | 0.0001    | 0.010 *  |
| Female (F)      | 5   | 0.07              | 0.004    | 5.49 **  | 0.0008 ** | 0.0009 ** | 0.013 ** |
| M X F           | 15  | 0.05              | 0.002    | 1.47 *   | 0.0006 ** | 0.0001    | 0.006    |
| Error           | 102 | 0.03              | 0.002    | 0.94     | 0.0003    | 0.0001    | 0.004    |
| Error (P)       | 27  | < 0.01            | 0.002    | 1.40     | 0.0003    | 0.0001    | 0.003    |
| Error (F1's)    | 69  | 0.05              | 0.002    | 0.78     | 0.0002    | 0.0001    | 0.003    |
| Residual        | 6   | 0.06              | 0.002    | 0.71     | 0.0015    | 0.0001    | 0.020    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 38. (Continued).

| MS              |     |          |          |             |              |           |
|-----------------|-----|----------|----------|-------------|--------------|-----------|
| Source          | df  | K        | Ca       | Mn          | Fe           | Cu Zn     |
| Rep (R)         | 3   | 0.764 *  | 0.080 ** | 1624.06 *   | 2685.62      | 187.89 *  |
| Genotypes (G)   | 34  | 0.116 ** | 0.050 ** | 2268.03 **  | 49543.42 **  | 224.94 ** |
| Parents (P)     | 9   | 0.107 ** | 0.060 ** | 1713.29 *   | 396720.90 *  | 211.28 ** |
| F1's vs Parents | 1   | 0.003    | 0.150 ** | 14849.47 ** | 7642.86      | 40.83     |
| F1's            | 23  | 0.121 ** | 0.043 ** | 1714.76 **  | 54957.38 **  | 239.30 ** |
| Male (M)        | 3   | 0.517 ** | 0.265 ** | 1267.78     | 66157.17 *   | 883.76 ** |
| Female (F)      | 5   | 0.188 ** | 0.027 ** | 5235.45 **  | 108333.40 ** | 429.25 ** |
| M X F           | 15  | 0.019 *  | 0.004    | 630.60      | 34925.40     | 47.09     |
| Error           | 102 | 0.012    | 0.003    | 581.29      | 18951.63     | 65.07     |
| Error (P)       | 27  | 0.015    | 0.003    | 600.95      | 12747.45     | 44.42     |
| Error (F1's)    | 69  | 0.009    | 0.003    | 581.13      | 22657.06     | 77.04     |
| Residual        | 6   | 0.033    | 0.003    | 494.66      | 4258.00      | 20.34     |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 39. Analyses of variance for leaf mineral concentrations of 34 sorghum genotypes measured at Buburi, 1990.

| Source          | df | Mean Squares (MS) |          |         |          |           |          |
|-----------------|----|-------------------|----------|---------|----------|-----------|----------|
|                 |    | Mg                | Al       | Si      | P        | S         | Cl       |
| Rep (R)         | 1  | 0.014 **          | 0.188 ** | 0.15 ** | 0.0044 * | 0.0057 ** | 0.029    |
| Genotypes (G)   | 33 | 0.005 **          | 0.016    | 1.41    | 0.0012   | 0.0003    | 0.012    |
| Parents         | 9  | 0.006             | 0.022 *  | 0.91    | 0.0007   | 0.0003 ** | 0.013    |
| F1's vs Parents | 1  | 0.008 **          | < 0.001  | 2.04    | 0.0018   | 0.0008    | 0.017    |
| F1's            | 23 | 0.004 **          | 0.014    | 1.58    | 0.0014   | 0.0003    | 0.011    |
| Male (M)        | 3  | 0.013 **          | 0.007    | 0.96    | 0.0020   | 0.0004    | 0.041 ** |
| Female (F)      | 5  | 0.004 **          | 0.019    | 1.17    | 0.0010   | 0.0004    | 0.008    |
| M X F           | 15 | 0.002 *           | 0.014    | 1.83    | 0.0010   | 0.0002    | 0.006    |
| Error           | 33 | 0.001             | 0.011    | 1.65    | 0.0008   | 0.0003    | 0.008    |
| Error (P)       | 9  | 0.002             | 0.005    | 1.61    | 0.0006   | 0.0001    | 0.012    |
| Error (F1's)    | 23 | 0.001             | 0.013    | 1.66    | 0.0010   | 0.0004    | 0.006    |
| Residual        | 1  | 0.002             | 0.019    | 1.78    | 0.0030   | 0.0001    | 0.018    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 39. (Continued).

| MS              |    |          |          |            |               |                        |
|-----------------|----|----------|----------|------------|---------------|------------------------|
| Source          | df | K        | Ca       | Mn         | Fe            | Cu Zn                  |
| Rep (R)         | 1  | 0.255 ** | 0.099 *  | 38513.16 * | 7323389.21 ** | 24305.40 ** 6928.60 ** |
| Genotypes (G)   | 33 | 0.223 ** | 0.039 ** | 9908.81 *  | 231845.72     | 556.80 1023.48         |
| Parents         | 9  | 0.189 ** | 0.051 *  | 17354.95 * | 327833.98     | 408.43 599.45          |
| F1's vs Parents | 1  | 0.003    | 0.001    | 7141.24    | 3560.30       | 145.73 1066.11         |
| F1's            | 23 | 0.246 ** | 0.036 ** | 7115.44    | 204210.54     | 632.72 1187.55         |
| Male (M)        | 3  | 1.142 ** | 0.126 ** | 20430.22 * | 52846.14      | 298.30 3693.28 *       |
| Female (F)      | 5  | 0.140    | 0.035    | 10840.12   | 308511.70     | 135.93 721.96          |
| M X F           | 15 | 0.102    | 0.018    | 3210.92    | 199716.37     | 865.21 841.60          |
| Error           | 33 | 0.068    | 0.017    | 5475.33    | 180541.71     | 528.76 826.64          |
| Error (P)       | 9  | 0.033    | 0.012    | 4777.59    | 151849.84     | 362.71 346.81          |
| Error (F1's)    | 23 | 0.082    | 0.016    | 4405.51    | 189732.80     | 607.82 1027.62         |
| Residual        | 1  | 0.061    | 0.085    | 36360.85   | 2883632.67    | 204.83 522.57          |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 40. Analyses of variance for leaf mineral concentrations of 35 sorghum genotypes measured at Buburi, 1991.

| Mean Squares (MS) |    |          |          |        |           |           |          |
|-------------------|----|----------|----------|--------|-----------|-----------|----------|
| Source            | df | Mg       | Al       | Si     | P         | S         | Cl       |
| Rep (R)           | 1  | 0.014 ** | 0.030 ** | 1.11   | 0.0147 ** | 0.0036 ** | 0.025 *  |
| Genotypes (G)     | 34 | 0.005 ** | 0.004 *  | 2.45 * | 0.0011    | 0.0003 ** | 0.017 ** |
| Parents (P)       | 9  | 0.010 ** | 0.007    | 0.73   | 0.0018    | 0.0007 ** | 0.021 *  |
| F1's vs Parents   | 1  | 0.001    | < 0.001  | 1.84   | 0.0004    | 0.0003    | 0.039 *  |
| F1's              | 23 | 0.004 *  | 0.003    | 2.86   | 0.0008    | 0.0002    | 0.016 *  |
| Male (M)          | 3  | 0.014 ** | 0.003 *  | 1.64   | 0.0002    | 0.0002    | 0.067 ** |
| Female (F)        | 5  | 0.002 ** | 0.002    | 6.00 * | 0.0012    | 0.0003    | 0.009    |
| M X F             | 15 | 0.003    | 0.003    | 2.06   | 0.0008    | 0.0002    | 0.008    |
| Error             | 34 | 0.002    | 0.002    | 1.82   | 0.0008    | 0.0001    | 0.006    |
| Error (P)         | 9  | 0.001    | 0.002    | 1.28   | 0.0006    | 0.0001    | 0.005    |
| Error (F1's)      | 23 | 0.002    | 0.002    | 2.12   | 0.0010    | 0.0002    | 0.006    |
| Residual          | 1  | 0.013    | 0.004    | 1.60   | 0.0002    | 0.0004    | 0.021    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 40. (Continued).

| MS              |    |          |          |             |             |            |
|-----------------|----|----------|----------|-------------|-------------|------------|
| Source          | df | K        | Ca       | Mn          | Fe          | Zn         |
| Rep (R)         | 1  | 0.135    | 0.147 ** | 24583.13 ** | 63246.24 *  | 1430.13 ** |
| Genotypes (G)   | 34 | 0.116 ** | 0.034 ** | 3037.98     | 29755.39 *  | 65.74      |
| Parents (P)     | 9  | 0.152 ** | 0.059 ** | 3213.63     | 44091.35 ** | 99.15      |
| F1's vs Parents | 1  | < 0.001  | 0.007    | 1891.90     | 4759.56     | 12.11      |
| F1's            | 23 | 0.109 *  | 0.025    | 2469.96     | 25222.72    | 52.13      |
| Male (M)        | 3  | 0.149 *  | 0.098 ** | 5935.05     | 38985.17    | 13.21      |
| Female (F)      | 5  | 0.239 ** | 0.026    | 4241.45     | 25568.39    | 51.33      |
| M X F           | 15 | 0.057    | 0.010    | 1186.44     | 22355.00    | 60.18      |
| Error           | 34 | 0.040    | 0.011    | 3087.75     | 14273.75    | 88.67      |
| Error (P)       | 9  | 0.026    | 0.004    | 2077.82     | 5260.22     | 51.36      |
| Error (F1's)    | 23 | 0.048    | 0.014    | 3142.04     | 18731.76    | 110.46     |
| Residual        | 1  | 0.022    | 0.016    | 14016.20    | 7135.04     | 7147.00    |
|                 |    |          |          |             |             | 246.97     |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 41. Analyses of variance for leaf mineral concentrations of 34 sorghum genotypes measured at Mumias, 1990.

| Source          | df | Mean Squares (MS) |         |          |          |           |           |
|-----------------|----|-------------------|---------|----------|----------|-----------|-----------|
|                 |    | Mg                | Al      | Si       | P        | S         | Cl        |
| Rep (R)         | 1  | 0.005 *           | 0.015   | 80.18 ** | 0.024 ** | 0.0172 ** | 0.0131    |
| Genotypes (G)   | 33 | 0.004 **          | 0.128   | 4.39     | 0.002    | 0.0006    | 0.0013 *  |
| Parents         | 9  | 0.005 *           | 0.217   | 8.22 **  | 0.003    | 0.0080    | 0.0022    |
| F1's vs Parents | 1  | 0.009 **          | 0.485 * | 0.20     | 0.005    | 0.0005    | < 0.0001  |
| F1's            | 23 | 0.003 **          | 0.078   | 3.07     | 0.001    | 0.0005    | 0.0010 ** |
| Male (M)        | 3  | 0.006 **          | 0.206 * | 13.94 ** | < 0.001  | 0.0001    | 0.0016 ** |
| Female (F)      | 5  | 0.005 **          | 0.086   | 1.47     | 0.001    | 0.0004    | 0.0011 *  |
| M X F           | 15 | 0.002             | 0.050   | 1.43     | 0.002    | 0.0006    | 0.0008 *  |
| Error           | 33 | 0.001             | 0.078   | 2.77     | 0.002    | 0.0005    | 0.0006    |
| Error (P)       | 9  | 0.002             | 0.135   | 2.77     | 0.005    | 0.0006    | 0.0014    |
| Error (F1's)    | 23 | 0.001             | 0.056   | 2.79     | 0.001    | 0.0005    | 0.0003    |
| Residual        | 1  | 0.002             | 0.071   | 2.31     | 0.001    | 0.0003    | 0.0003    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 41. (Continued).

| MS              |    |          |          |             |               |          |           |
|-----------------|----|----------|----------|-------------|---------------|----------|-----------|
| Source          | df | K        | Ca       | Mn          | Fe            | Cu       | Zn        |
| Rep (R)         | 1  | 1.058 ** | 0.023    | 1631.70     | 436529.01     | 58.00 *  | 16.70     |
| Genotypes (G)   | 33 | 0.159 *  | 0.129 ** | 6540.94     | 1294873.20    | 19.04 ** | 202.40 ** |
| Parents         | 9  | 0.261    | 0.182    | 6864.61     | 2502829.65    | 12.17    | 530.07 *  |
| F1's vs Parents | 1  | 0.337    | 0.026    | 1632.36     | 3493661.58    | 2.94     | 222.74 *  |
| F1's            | 23 | 0.112 ** | 0.112 ** | 6627.70 **  | 726595.09     | 22.42 ** | 73.30 *   |
| Male (M)        | 3  | 0.315 ** | 0.396 ** | 20898.41 ** | 2911748.50 ** | 60.87 ** | 328.39 ** |
| Female (F)      | 5  | 0.163 ** | 0.148 ** | 9601.96 **  | 420545.96     | 33.60 ** | 42.99     |
| M X F           | 15 | 0.054    | 0.044 *  | 2782.13     | 391580.79     | 11.01    | 32.39     |
| Error           | 33 | 0.084    | 0.036    | 3718.90     | 1050611.56    | 8.13     | 52.07     |
| Error (P)       | 9  | 0.201    | 0.074    | 7760.18     | 2790160.78    | 12.36    | 113.42    |
| Error (F1's)    | 23 | 0.041    | 0.020    | 2239.69     | 414252.54     | 5.87     | 28.00     |
| Residual        | 1  | 0.020    | 0.082    | 1369.21     | 30933.06      | 22.04    | 53.53     |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 42. Analyses of variance for leaf mineral concentrations of 31 sorghum genotypes measured at Mumias, 1991.

| Mean Squares (MS) |    |         |       |      |         |          |
|-------------------|----|---------|-------|------|---------|----------|
| Source            | df | Mg      | Al    | Si   | P       | S        |
| Rep (R)           | 1  | < 0.001 | 0.007 | 1.80 | 0.001   | 0.0013   |
| Genotypes (G)     | 30 | 0.004   | 0.095 | 3.69 | 0.002   | 0.0008   |
| Parents (P)       | 9  | 0.001   | 0.265 | 3.67 | 0.002   | 0.0011   |
| F1's vs Parents   | 1  | 0.021   | 0.033 | 3.84 | < 0.001 | < 0.0001 |
| F1's              | 19 | 0.005   | 0.019 | 3.54 | 0.001   | 0.0007   |
| Male (M)          | 3  | 0.004   | 0.003 | 3.02 | 0.004 * | 0.0011   |
| Female (F)        | 5  | 0.003   | 0.022 | 4.06 | 0.001   | 0.0005   |
| M X F             | 11 | 0.006   | 0.020 | 2.73 | 0.001   | 0.0006   |
| Error             | 25 | 0.005   | 0.091 | 7.05 | 0.001   | 0.0005   |
| Error (P)         | 7  | 0.003   | 0.265 | 7.44 | 0.001   | 0.0004   |
| Error (F1's)      | 16 | 0.007   | 0.013 | 7.34 | 0.001   | 0.0004   |
| Residual          | 2  | 0.001   | 0.106 | 3.37 | 0.005   | 0.0017   |

\* significant at the 0.05 level of probability.

Table 42. (Continued).

| MS              |    |       |         |         |           |       |
|-----------------|----|-------|---------|---------|-----------|-------|
| Source          | df | K     | Ca      | Mn      | Fe        | Zn    |
| Rep (R)         | 1  | 0.044 | 0.026   | 3549.16 | 178483.89 | 0.10  |
| Genotypes (G)   | 30 | 0.118 | 0.071   | 4963.84 | 432711.93 | 75.18 |
| Parents (P)     | 9  | 0.043 | 0.032   | 4322.59 | 804375.88 | 98.04 |
| F1's vs Parents | 1  | 0.013 | 0.186 * | 1.11    | 24886.27  | 50.86 |
| F1's            | 19 | 0.162 | 0.083   | 4928.99 | 293578.59 | 65.66 |
| Male (M)        | 3  | 0.250 | 0.062   | 7039.07 | 34962.54  | 61.55 |
| Female (F)      | 5  | 0.142 | 0.086   | 1297.49 | 235913.28 | 78.27 |
| M X F           | 11 | 0.159 | 0.104   | 6601.76 | 317521.72 | 44.33 |
| Error           | 25 | 0.160 | 0.073   | 4564.76 | 402365.49 | 66.27 |
| Error (P)       | 7  | 0.077 | 0.031   | 4037.08 | 796785.99 | 64.50 |
| Error (F1's)    | 16 | 0.216 | 0.097   | 4766.90 | 203631.51 | 64.08 |
| Residual        | 2  | 0.003 | 0.028   | 4794.52 | 611765.58 | 89.99 |

\* significant at the 0.05 level of probability.

Table 43. (Continued).

| Source          | df | MS    |       |             |               |           |           |
|-----------------|----|-------|-------|-------------|---------------|-----------|-----------|
|                 |    | K     | Ca    | Mn          | Fe            | Cu        | Zn        |
| Rep (R)         | 3  | 0.035 | 0.017 | 15027.47 ** | 7044016.05 ** | 120.24 ** | 319.55 ** |
| Genotypes (G)   | 33 | 0.085 | 0.019 | 3966.76     | 1032351.53    | 13.13     | 67.91     |
| Parents (P)     | 9  | 0.147 | 0.015 | 4009.98     | 1116033.12    | 13.98     | 67.44     |
| Fl's vs Parents | 1  | 0.016 | 0.011 | 9722.38     | 463515.55     | 19.13     | 19.13     |
| Fl's            | 23 | 0.064 | 0.021 | 3699.60     | 1024338.55    | 12.53     | 12.53     |
| Male (M)        | 3  | 0.057 | 0.018 | 2257.29     | 1028967.27    | 17.70     | 13.18     |
| Female (F)      | 5  | 0.135 | 0.033 | 7310.60     | 832148.35     | 11.74     | 20.19     |
| M X F           | 15 | 0.042 | 0.018 | 2784.40     | 1087476.21    | 11.76     | 98.90     |
| Error           | 99 | 0.083 | 0.027 | 3045.05     | 1041718.60    | 11.53     | 75.46     |
| Error (P)       | 27 | 0.080 | 0.042 | 2385.27     | 710212.39     | 9.72      | 50.04     |
| Error (Fl's)    | 69 | 0.085 | 0.022 | 3375.35     | 1204430.18    | 11.71     | 83.96     |
| Residual        | 3  | 0.064 | 0.071 | 1386.17     | 282908.15     | 23.68     | 108.74    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 44. Analyses of variance for leaf mineral concentrations of 35 sorghum genotypes measured at Ukwala, 1991.

| Source          | df  | Mean Squares (MS) |          |         |          |           |          |
|-----------------|-----|-------------------|----------|---------|----------|-----------|----------|
|                 |     | Mg                | Al       | Si      | P        | S         | Cl       |
| Rep (R)         | 3   | 0.007 **          | 0.047 ** | 3.55    | 0.012 ** | 0.0043 ** | 0.007    |
| Genotypes (G)   | 34  | 0.006 **          | 0.020 ** | 2.77 *  | 0.003 ** | 0.0013 ** | 0.017 ** |
| Parents (P)     | 9   | 0.008 **          | 0.017 *  | 1.33    | 0.004 ** | 0.0018 ** | 0.030 ** |
| F1's vs Parents | 1   | < 0.001           | 0.004    | 10.40 * | 0.001    | 0.0010    | 0.001    |
| F1's            | 23  | 0.004 **          | 0.012    | 2.97 *  | 0.002 ** | 0.0008    | 0.009 *  |
| Male (M)        | 3   | 0.003             | 0.021 *  | 8.47 ** | 0.002 ** | 0.0003    | 0.005    |
| Female (F)      | 5   | 0.003             | 0.031 ** | 2.88    | 0.005 ** | 0.0010    | 0.021 ** |
| M X F           | 15  | 0.004             | 0.003    | 1.89    | 0.001 ** | 0.0008    | 0.006    |
| Error           | 102 | 0.001             | 0.009    | 1.53    | 0.001    | 0.0006    | 0.005    |
| Error (P)       | 27  | 0.001             | 0.005    | 1.15    | 0.001    | 0.0003    | 0.008    |
| Error (F1's)    | 69  | 0.002             | 0.007    | 1.72    | 0.001    | 0.0007    | 0.004    |
| Residual        | 6   | 0.002             | 0.050    | 1.06    | 0.001    | 0.0008    | 0.003    |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

Table 44. (Continued).

| MS              |     |          |          |            |              |            |
|-----------------|-----|----------|----------|------------|--------------|------------|
| Source          | df  | K        | Ca       | Mn         | Fe           | Zn         |
| Rep (R)         | 3   | 0.227 ** | 0.007    | 7663.67 ** | 239507.69    | 2198.33 ** |
| Genotypes (G)   | 34  | 0.189 ** | 0.047 ** | 2822.44 ** | 414633.27 ** | 492.40 *   |
| Parents (P)     | 9   | 0.195 ** | 0.090 ** | 4511.92 ** | 312067.46 ** | 426.56 *   |
| F1's vs Parents | 1   | 0.014    | 0.001    | 447.82     | 121346.16    | 519.34     |
| F1's            | 23  | 0.139 *  | 0.034 ** | 2375.56 *  | 189968.60 ** | 497.91 *   |
| Male (M)        | 3   | 0.348 ** | 0.132 ** | 5879.82 ** | 346577.24 ** | 1427.62 ** |
| Female (F)      | 5   | 0.267 ** | 0.055 ** | 5160.32 ** | 490889.87 ** | 883.72 *   |
| M X F           | 15  | 0.054    | 0.008    | 746.46     | 58339.78     | 183.36     |
| Error           | 102 | 0.036    | 0.006    | 1233.99    | 115000.75    | 270.19     |
| Error (P)       | 27  | 0.032    | 0.005    | 790.11     | 69227.31     | 175.49     |
| Error (F1's)    | 69  | 0.031    | 0.006    | 1390.02    | 65105.37     | 291.11     |
| Residual        | 6   | 0.112    | 0.011    | 1437.11    | 894778.10    | 455.76     |
|                 |     |          |          |            |              | 102.25     |

\*, \*\* significant at the 0.05 and 0.01 levels of probability, respectively.

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Table 45. Mean magnesium concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No. | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

| %  |      |      |      |      |      |      |      |      |      |
|----|------|------|------|------|------|------|------|------|------|
| 1  | 1x7  | 0.42 | 0.29 | 0.22 | 0.20 | 0.15 | 0.16 | 0.17 | —    |
| 2  | 1x8  | 0.34 | 0.19 | 0.15 | 0.13 | 0.15 | 0.13 | 0.10 | 0.12 |
| 3  | 1x9  | 0.34 | 0.27 | 0.17 | 0.14 | 0.15 | 0.18 | 0.16 | 0.15 |
| 4  | 1x10 | 0.37 | 0.23 | 0.20 | 0.15 | 0.15 | 0.15 | 0.15 | 0.07 |
| 5  | 2x7  | 0.38 | 0.22 | 0.18 | 0.19 | 0.12 | 0.14 | 0.10 | 0.27 |
| 6  | 2x8  | 0.23 | 0.20 | 0.13 | 0.12 | 0.13 | 0.17 | 0.11 | 0.11 |
| 7  | 2x9  | 0.32 | 0.24 | 0.19 | 0.17 | 0.14 | 0.13 | 0.14 | 0.13 |
| 8  | 2x10 | 0.31 | 0.22 | 0.14 | 0.15 | 0.12 | 0.13 | 0.15 | 0.07 |
| 9  | 3x7  | 0.38 | 0.26 | 0.16 | 0.24 | 0.14 | 0.22 | 0.15 | 0.13 |
| 10 | 3x8  | 0.22 | 0.23 | 0.12 | 0.12 | 0.13 | 0.20 | 0.10 | 0.17 |
| 11 | 3x9  | 0.19 | 0.23 | 0.19 | 0.14 | 0.20 | 0.17 | 0.14 | 0.10 |
| 12 | 3x10 | 0.23 | 0.17 | 0.16 | 0.11 | 0.14 | 0.13 | 0.10 | 0.19 |
| 13 | 4x7  | 0.38 | 0.25 | 0.24 | 0.19 | 0.20 | 0.16 | 0.14 | 0.12 |
| 14 | 4x8  | 0.19 | 0.19 | 0.17 | 0.12 | 0.19 | 0.16 | 0.11 | 0.12 |
| 15 | 4x9  | 0.34 | 0.25 | 0.16 | 0.17 | 0.13 | 0.16 | 0.20 | 0.10 |
| 16 | 4x10 | 0.26 | 0.18 | 0.10 | 0.09 | 0.15 | 0.13 | 0.12 | —    |
| 17 | 5x7  | 0.40 | 0.30 | 0.26 | 0.22 | 0.20 | 0.12 | 0.22 | 0.13 |
| 18 | 5x8  | 0.28 | 0.23 | 0.15 | 0.16 | 0.15 | 0.20 | 0.16 | 0.18 |
| 19 | 5x9  | 0.43 | 0.37 | 0.26 | 0.15 | 0.15 | 0.22 | 0.13 | —    |
| 20 | 5x10 | 0.30 | 0.21 | 0.19 | 0.13 | 0.16 | 0.15 | 0.16 | 0.11 |



comparable in each year. With few exceptions, parental genotypes lacked consistency between years and among locations. (AT-1)-52-2-1-2-1 had the lowest and IS7254C the highest Mg content in most environments. At most of the locations in the two years, there was negative expression of heterosis, in that hybrids had lower mean Mg contents than their midparent and/or lower parent. A few hybrids such as (AT-2)-10-6-1-2-1 x IS7254C, (AT-1)-36-4-2-2-1 x IS7254C, and (AT-1)-36-4-2-2-1 x TX430, had higher means than their higher parent at Buburi. There were differences among hybrids for Mg content, but hybrids showed large fluctuations between years within locations. Hybrids, Wheatland x IA28 and (AT-1)-36-4-2-2-1 x IA28, had consistently lower means than (AT-2)-10-6-1-2-1 x IS7254C hybrids across locations and years. Clark and Gourley (1987) also reported lower concentrations of Mg in the leaves of plants grown on an acid soil compared to leaves of plants grown on a neutral soil.

The significant male GCA means for Mg content were highest for IS7254C and TX430. Both had significant positive male GCA effects. IA28 had the lowest male GCA means and its GCA effects were significantly negative at Buburi and Mumias in 1990. No significant male GCA effects were found for TX432. Females, (AT-2)-10-6-1-2-1 and (AT-1)-36-4-2-2-1, had higher GCA means than other females. B-Yel-PI exhibited a significant GCA effect at Mumias in 1990. Females, TX623, Wheatland, and (AT-1)-52-2-1-2-1, invariably showed no significant female GCA effects for Mg content. Specific combining ability effects were not significant, indicating that additive effects were predominant for Mg content. These results are in agreement with Gorz *et al.* (1987) who observed that GCA effects exceeded SCA effects for Mg content in sorghum plant tissue. In this study,

hybrids which had a higher concentration of Mg in leaves than the higher parent were generally those which had either one or two tolerant parents. Duncan (1987) reported that Al-tolerant genotypes accumulated higher levels of Mg than other genotypes. In this study, tolerant parents and hybrids from some tolerant combinations had higher Mg concentrations than other genotypes, especially in the poorer environments.

#### Aluminum

There were significant differences among genotypes for Al content only at Buburi and Ukwala in 1991 and at Obambo in both years (Tables 37-44). Significant differences among parents existed in both years at Obambo and in single years at Buburi and Ukwala. Mean squares for  $F_1$ s vs Parents were only significant at Mumias in 1990, indicating a lack of average heterosis for Al content. Significant differences among hybrids were observed only at Obambo in 1990. Mean squares for males were significant at all locations in single years while mean squares for females were only significant at Obambo in 1990 and at Ukwala in 1991. There were no significant male x female interactions suggesting that non-additive genetic effects were not important for Al content.

Means of aluminum content of the 35 genotypes are presented in Table 46. There were differences among genotypes only at Obambo in 1990. Significant differences among genotypic means were observed at all locations, except Mumias in 1991. Location means for 1990 were generally higher than for 1991. The lowest Al contents were found at Buburi in 1991. Mean fluctuations between years for various parents at individual locations was high, except for a few parents such as (AT-1)-52-2-1-2-1,

Table 46. Mean aluminum concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No.     | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|---------------|----------|--------|------|--------|------|--------|------|--------|------|
|               |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- % ----- |          |        |      |        |      |        |      |        |      |
| 1             | 1x7      | 0.32   | 0.28 | 0.39   | 0.26 | 0.54   | 0.23 | 0.40   | —    |
| 2             | 1x8      | 0.33   | 0.29 | 0.36   | 0.25 | 0.54   | 0.26 | 0.69   | 0.44 |
| 3             | 1x9      | 0.29   | 0.31 | 0.42   | 0.22 | 0.49   | 0.31 | 0.80   | 0.41 |
| 4             | 1x10     | 0.33   | 0.28 | 0.37   | 0.30 | 0.53   | 0.24 | 1.03   | 0.38 |
| 5             | 2x7      | 0.43   | 0.34 | 0.34   | 0.30 | 0.52   | 0.29 | 0.45   | 0.27 |
| 6             | 2x8      | 0.39   | 0.35 | 0.46   | 0.27 | 0.47   | 0.38 | 0.77   | 0.49 |
| 7             | 2x9      | 0.37   | 0.32 | 0.52   | 0.34 | 0.63   | 0.43 | 0.73   | 0.52 |
| 8             | 2x10     | 0.38   | 0.33 | 0.49   | 0.27 | 0.33   | 0.42 | 1.01   | 0.33 |
| 9             | 3x7      | 0.35   | 0.28 | 0.36   | 0.23 | 0.41   | 0.33 | 0.44   | 0.36 |
| 10            | 3x8      | 0.29   | 0.32 | 0.49   | 0.29 | 0.48   | 0.29 | 0.63   | 0.36 |
| 11            | 3x9      | 0.29   | 0.30 | 0.53   | 0.30 | 0.39   | 0.35 | 0.58   | 0.39 |
| 12            | 3x10     | 0.30   | 0.32 | 0.56   | 0.23 | 0.44   | 0.38 | 0.62   | 0.40 |
| 13            | 4x7      | 0.36   | 0.32 | 0.46   | 0.27 | 0.85   | 0.27 | 0.49   | 0.66 |
| 14            | 4x8      | 0.26   | 0.29 | 0.50   | 0.29 | 0.46   | 0.25 | 0.49   | 0.50 |
| 15            | 4x9      | 0.35   | 0.30 | 0.26   | 0.28 | 0.56   | 0.31 | 0.81   | 0.48 |
| 16            | 4x10     | 0.30   | 0.31 | 0.37   | 0.24 | 0.59   | 0.28 | 0.56   | —    |
| 17            | 5x7      | 0.36   | 0.32 | 0.42   | 0.31 | 0.89   | 0.30 | 0.42   | 0.34 |
| 18            | 5x8      | 0.32   | 0.35 | 0.37   | 0.31 | 0.46   | 0.31 | 0.58   | 0.38 |
| 19            | 5x9      | 0.33   | 0.26 | 0.38   | 0.23 | 0.43   | 0.38 | 0.47   | —    |
| 20            | 5x10     | 0.32   | 0.28 | 0.46   | 0.17 | 0.66   | 0.34 | 0.39   | 0.64 |

Table 46. (Continued).

| Entry<br>No.                          | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|---------------------------------------|----------|--------|------|--------|------|--------|------|--------|------|
|                                       |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| <hr style="border-top: 1px dashed;"/> |          |        |      |        |      |        |      |        |      |
| %                                     |          |        |      |        |      |        |      |        |      |
| 21                                    | 6x7      | 0.29   | 0.31 | 0.32   | 0.27 | 0.52   | 0.29 | 0.44   | 0.36 |
| 22                                    | 6x8      | 0.27   | 0.30 | 0.27   | 0.27 | 0.57   | 0.29 | 0.45   | 0.35 |
| 23                                    | 6x9      | 0.32   | 0.25 | 0.49   | 0.26 | 0.57   | 0.30 | 1.00   | 0.35 |
| 24                                    | 6x10     | 0.31   | 0.28 | 0.33   | 0.26 | 0.66   | 0.33 | 0.58   | —    |
| 25                                    | 1        | 0.34   | 0.28 | 0.53   | 0.19 | 0.42   | 0.27 | 1.14   | 0.32 |
| 26                                    | 2        | 0.59   | 0.32 | 0.62   | 0.31 | 0.56   | 0.38 | 1.03   | 0.39 |
| 27                                    | 3        | 0.29   | 0.27 | 0.36   | 0.32 | 0.09   | 0.30 | 0.73   | 0.34 |
| 28                                    | 4        | 0.35   | 0.29 | 0.31   | 0.21 | 0.52   | 0.27 | 0.41   | 0.39 |
| 29                                    | 5        | 0.31   | 0.36 | 0.45   | 0.32 | 0.44   | 0.42 | 0.65   | 0.32 |
| 30                                    | 6        | 0.26   | 0.29 | 0.45   | 0.24 | 0.59   | 0.22 | 0.69   | 1.48 |
| 31                                    | 7        | 0.38   | 0.31 | 0.30   | 0.29 | 0.52   | 0.34 | 0.54   | 0.32 |
| 32                                    | 8        | 0.39   | 0.33 | 0.44   | 0.31 | 0.57   | 0.42 | 1.50   | 0.47 |
| 33                                    | 9        | 0.35   | 0.25 | 0.28   | 0.29 | 0.39   | 0.34 | 0.79   | 0.22 |
| 34                                    | 10       | 0.29   | 0.25 | 0.41   | 0.17 | 0.45   | 0.32 | 0.56   | 0.35 |
| 35                                    | Seredo   | —      | 0.24 | —      | 0.21 | —      | 0.57 | —      | 0.23 |
| <hr/>                                 |          |        |      |        |      |        |      |        |      |
| Mean                                  |          | 0.33   | 0.30 | 0.41   | 0.26 | 0.54   | 0.33 | 0.67   | 0.43 |
| LSD (0.05)                            |          | 0.09   | 0.06 | ns     | 0.08 | ns     | 0.14 | ns     | ns   |

(AT-2)-10-6-1-2-1, B-Yel-PI, and IS7254C. Means for Seredo were generally low at most locations except Ukwala in 1991. Wheatland and IA28 had higher mean Al content across locations and over years than other parents. Means for hybrids were consistently lower than their respective midparent, or their lower parent at Mumias in 1990, indicating negative heterotic response for this trait; however, there were a few hybrids involving male parents, TX432 and TX430, that had higher means than their midparent or higher parent. Mean differences among hybrids across locations could not be ascertained due to fluctuations between years; however, Wheatland x TX432 had higher Al content at Buburi, Ukwala and Mumias than a number of hybrids, especially those involving male parent, IS7254C. In 1990, hybrids of female parents, TX623, Wheatland, B-Yel-PI, (AT-2)-10-6-1-2-1, and (AT-1)-36-4-2-2-1, crossed with male parent, IS7254C, had lower Al contents than hybrids of females, TX623, Wheatland, and (AT-1)-36-4-2-2-1, crossed with male parent TX432 at Mumias.

Male GCA means were lowest for IS7254C and IA28; however, no significant male GCA effects were observed, except for TX432 at Buburi in 1991. Lowest female GCA means were recorded for (AT-2)-10-6-1-2-1 at Mumias in 1990 and at Buburi in 1991. The only significant female GCA effects were for Wheatland at Obambo in 1990 and at Ukwala in 1991. Female GCA effects were positive for Wheatland. These data agree, in part, with Boye-Goni and Marcarian (1985) who found that Al-tolerance showed predominantly additive genetic effects. No significant male x female interactions were found in this study, indicating that nonadditive genetic effects were not significant in these materials.

### Silicon

Significant differences among genotypes for silicon content were found at Obambo in both years and at Buburi and Ukwala in 1991 (Tables 37-44). Significant differences were found among parents at Obambo and Mumias in 1990 and at Buburi in 1991. The contrast of  $F_1$ s vs parents was not significant at any location except Obambo and Ukwala in 1991. Differences among  $F_1$ s were significant at Ukwala in 1991 and at Obambo in both years. Mean squares for males were significant at Mumias in 1990; at Buburi, and Ukwala in 1991; and at Obambo in both years. Females were significant at Obambo in 1990 and 1991. The only significant male x female interaction occurred at Obambo in 1991. In general, more variation in silicon content occurred in 1991 than in 1990, with the exception of Mumias.

Genotypic means for Si content, by location, are presented in Table 47. Means of Si content at Obambo were much higher than at other low soil pH locations in both years, suggesting that low soil pH significantly reduced Si content in leaves. Clark and Gourley (1987) also reported that leaf concentrations of Si were lower on acid soil compared to leaves of plants grown on neutral soil. Except at Ukwala in 1990 and Obambo in 1991, Si means for parent (AT-1)-36-4-2-2-1 were lower than IS7254C, TX623, and Wheatland. Seredo had low Si means across all low pH locations. Si content of hybrids was generally higher than the midparent or the higher parent at Obambo in 1991; however, a few hybrids had lower means than their midparent or lower parent. Differences in Si content among hybrids were not consistent over locations. The effect of Si in overcoming Mn and Fe toxicity (Clark and Gourley, 1987) could not be

Table 47. Mean silicon concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry<br>No. | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|--------------|----------|--------|------|--------|------|--------|------|--------|------|
|              |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
|              |          | %      |      |        |      |        |      |        |      |
| 1            | 1x7      | 15.5   | 11.5 | 4.1    | 6.5  | 6.9    | 4.9  | 6.9    | —    |
| 2            | 1x8      | 12.6   | 11.2 | 5.0    | 5.4  | 5.8    | 3.8  | 6.2    | 2.6  |
| 3            | 1x9      | 13.0   | 12.5 | 6.5    | 6.5  | 6.2    | 5.1  | 5.0    | 6.2  |
| 4            | 1x10     | 11.0   | 12.1 | 5.0    | 7.5  | 6.5    | 3.0  | 7.5    | 4.8  |
| 5            | 2x7      | 15.4   | 13.5 | 5.0    | 8.0  | 6.6    | 5.2  | 7.9    | 2.8  |
| 6            | 2x8      | 12.8   | 12.4 | 4.8    | 6.2  | 7.9    | 6.1  | 6.9    | 4.6  |
| 7            | 2x9      | 11.9   | 11.1 | 5.1    | 6.7  | 7.1    | 5.4  | 4.0    | 4.5  |
| 8            | 2x10     | 12.4   | 12.8 | 6.5    | 7.4  | 7.8    | 4.2  | 5.9    | 3.2  |
| 9            | 3x7      | 12.9   | 11.3 | 4.7    | 7.0  | 6.6    | 4.8  | 9.1    | 2.8  |
| 10           | 3x8      | 11.2   | 10.0 | 5.3    | 6.7  | 5.7    | 3.6  | 6.9    | 6.6  |
| 11           | 3x9      | 10.1   | 10.1 | 5.7    | 6.8  | 5.8    | 4.0  | 5.3    | 6.4  |
| 12           | 3x10     | 11.0   | 11.2 | 4.2    | 7.0  | 5.8    | 4.2  | 5.8    | 6.0  |
| 13           | 4x7      | 14.5   | 12.6 | 6.3    | 8.0  | 7.0    | 5.2  | 7.6    | 3.9  |
| 14           | 4x8      | 11.2   | 11.0 | 5.2    | 8.5  | 7.0    | 4.1  | 6.4    | 3.6  |
| 15           | 4x9      | 12.8   | 11.1 | 4.4    | 9.1  | 6.2    | 5.7  | 7.2    | 5.4  |
| 16           | 4x10     | 12.0   | 12.1 | 6.2    | 9.0  | 7.0    | 4.9  | 7.1    | —    |
| 17           | 5x7      | 14.1   | 13.2 | 5.9    | 8.8  | 7.2    | 6.3  | 8.7    | 4.0  |
| 18           | 5x8      | 10.5   | 11.0 | 3.5    | 6.4  | 6.4    | 3.5  | 6.7    | 2.1  |
| 19           | 5x9      | 11.1   | 10.3 | 3.7    | 5.9  | 7.5    | 5.3  | 5.0    | —    |
| 20           | 5x10     | 11.6   | 11.7 | 4.8    | 3.9  | 7.2    | 4.2  | 6.5    | 3.2  |

Table 47. (Continued).

| Entry No.  | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------|----------|--------|------|--------|------|--------|------|--------|------|
|            |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| %          |          |        |      |        |      |        |      |        |      |
| 21         | 6x7      | 12.4   | 12.3 | 4.4    | 7.6  | 6.6    | 5.5  | 8.6    | 5.6  |
| 22         | 6x8      | 11.3   | 11.7 | 3.9    | 7.7  | 6.4    | 5.1  | 6.3    | 5.6  |
| 23         | 6x9      | 12.5   | 11.1 | 6.2    | 8.0  | 5.6    | 5.0  | 6.7    | 4.5  |
| 24         | 6x10     | 13.4   | 11.7 | 4.6    | 6.9  | 5.9    | 3.7  | 7.9    | ---  |
| 25         | 1        | 13.2   | 11.7 | 4.7    | 7.2  | 5.6    | 3.9  | 10.0   | 3.5  |
| 26         | 2        | 14.4   | 12.8 | 5.7    | 7.1  | 6.5    | 3.2  | 4.3    | 7.3  |
| 27         | 3        | 11.2   | 9.4  | 5.3    | 6.3  | 7.1    | 3.5  | 7.4    | 2.4  |
| 28         | 4        | 12.8   | 11.2 | 4.4    | 6.9  | 6.9    | 4.3  | 5.8    | 6.3  |
| 29         | 5        | 11.0   | 11.9 | 3.9    | 7.0  | 4.2    | 3.6  | 4.2    | 6.9  |
| 30         | 6        | 10.7   | 10.7 | 4.2    | 7.1  | 7.8    | 4.1  | 5.9    | 4.3  |
| 31         | 7        | 15.2   | 13.2 | 5.7    | 7.4  | 5.3    | 5.2  | 10.2   | 5.8  |
| 32         | 8        | 11.5   | 11.0 | 4.5    | 6.5  | 6.2    | 4.5  | 6.5    | 4.1  |
| 33         | 9        | 12.1   | 9.0  | 4.0    | 7.1  | 6.7    | 4.2  | 7.2    | 3.9  |
| 34         | 10       | 9.3    | 9.3  | 4.4    | 5.4  | 6.5    | 4.4  | 7.2    | 6.3  |
| 35         | Seredo   | ---    | 10.2 | ---    | 4.9  | ---    | 5.5  | ---    | 3.4  |
| Mean       |          |        |      |        |      |        |      |        |      |
| LSD (0.05) |          | 12.3   | 11.4 | 4.9    | 7.0  | 6.5    | 4.6  | 6.8    | 4.7  |
|            |          | 1.9    | 1.4  | ns     | ns   | ns     | 1.7  | ns     | ns   |

ascertained due to the high fluctuations in Si content among genotypes, and lack of significant differences among genotypes in low soil pH locations. These data failed to show any clear distinction in Si content between tolerant and susceptible genotypes under acid soil stress conditions. Galvez *et al.* (1987) viewed Si effects as not sufficient, in themselves, to completely surmount the toxic effects of Mn and Al. Gorz *et al.* (1987) reported a significant association of Si with Ca, and also a significant association of Mg with Si and Cu. Hybrids of females, Wheatland, (AT-2)-10-6-1-2-1, and (AT-1)-52-2-1-2-1, crossed with male IS7254C; and females, Wheatland, and (AT-1)-52-2-1-2-1, crossed with male parent TX432 had higher concentrations at most locations than hybrids, (AT-2)-10-6-1-2-1 x IA28 and (AT-2)-10-6-1-2-1 x TX432.

Male GCA means were invariably higher for IS7254C at Mumias in 1990, at Buburi and Ukwala in 1991, and at Obambo in both years than for other male combiners; however, male GCA effects were only significant for IS7254C and TX430 at Obambo. Male GCA effects for TX430 were negative. There was lack of consistency in female GCA means. Nonetheless, B-Yel-PI had lower female GCA means than other female combiners except at Mumias in 1990. Significant female GCA effects were found only at Obambo and Ukwala in 1991 for Wheatland, B-Yel-PI and (AT-1)-52-2-1-2-1. Both Wheatland and (AT-1)-52-2-1-2-1 had positive significant GCA effects at Obambo and Ukwala, respectively. Specific combining ability effects were not significant. This is similar to Gorz *et al.* (1987) in that additive gene effects were predominant for Si content.

### Phosphorus

There were significant differences among genotypes for P content at Ukwala in 1991 and at Obambo in both years (Tables 37-44). Differences among parents were significant in 1991 at Ukwala and in both years at Obambo. The contrast of  $F_1$ s vs parents was only significant at Obambo in 1991. Significant differences among  $F_1$ s were observed at Obambo in both years and at Ukwala in 1991. Mean squares for males were significant in 1991 at Ukwala and Mumias and in both years at Obambo. Females were significant only at Obambo and Ukwala in 1991. Significant male x female interactions were seen at Obambo and Ukwala in 1991. No source of variation for P was significant at Buburi in either year.

Table 48 shows mean P concentrations in the leaves of 35 genotypes grown at four locations in Kenya for two years. Means of locations were comparable between years, except for Buburi which was lower in 1990 than 1991. There was no evidence in this study to support previous findings (Clark and Gourley, 1987) reporting a decrease in P content due to low soil pH. Few parental differences in P content were found; however, TX430 differed from TX623 and B-Yel-PI in some locations and years. At Obambo in 1991, hybrid means were above midparent values in most cases, and some hybrids expressed heterosis above the higher parent. Differences among hybrids were most evident at Obambo and Ukwala. Hybrids of male parent TX430 generally had higher P content than other hybrids. At Ukwala in 1991, hybrids of female parents, TX623, Wheatland, and (AT-2)-10-6-1-2-1, crossed to male parent IS7254C generally had higher P contents than other hybrids; however, these data failed to show any clear distinction in P content between tolerant and susceptible genotypes under acid soil

Table 48. Mean phosphorus concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry<br>No.  | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|---------------|----------|--------|------|--------|------|--------|------|--------|------|
|               |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- % ----- |          |        |      |        |      |        |      |        |      |
| 1             | 1x7      | 0.13   | 0.14 | 0.12   | 0.17 | 0.17   | 0.20 | 0.17   | --   |
| 2             | 1x8      | 0.15   | 0.16 | 0.13   | 0.17 | 0.17   | 0.18 | 0.20   | 0.14 |
| 3             | 1x9      | 0.16   | 0.18 | 0.17   | 0.18 | 0.19   | 0.20 | 0.25   | 0.19 |
| 4             | 1x10     | 0.15   | 0.16 | 0.13   | 0.20 | 0.20   | 0.22 | 0.22   | 0.20 |
| 5             | 2x7      | 0.15   | 0.18 | 0.12   | 0.17 | 0.15   | 0.18 | 0.25   | 0.12 |
| 6             | 2x8      | 0.14   | 0.16 | 0.15   | 0.17 | 0.20   | 0.13 | 0.25   | 0.16 |
| 7             | 2x9      | 0.22   | 0.22 | 0.13   | 0.17 | 0.18   | 0.16 | 0.24   | 0.17 |
| 8             | 2x10     | 0.14   | 0.16 | 0.09   | 0.15 | 0.17   | 0.14 | 0.23   | 0.21 |
| 9             | 3x7      | 0.14   | 0.17 | 0.10   | 0.17 | 0.19   | 0.17 | 0.17   | 0.07 |
| 10            | 3x8      | 0.15   | 0.17 | 0.17   | 0.23 | 0.21   | 0.15 | 0.26   | 0.16 |
| 11            | 3x9      | 0.15   | 0.19 | 0.16   | 0.17 | 0.19   | 0.16 | 0.22   | 0.15 |
| 12            | 3x10     | 0.16   | 0.18 | 0.16   | 0.18 | 0.19   | 0.13 | 0.18   | 0.17 |
| 13            | 4x7      | 0.14   | 0.15 | 0.13   | 0.18 | 0.19   | 0.14 | 0.23   | 0.14 |
| 14            | 4x8      | 0.14   | 0.17 | 0.10   | 0.15 | 0.17   | 0.17 | 0.22   | 0.15 |
| 15            | 4x9      | 0.15   | 0.16 | 0.12   | 0.20 | 0.17   | 0.18 | 0.21   | 0.17 |
| 16            | 4x10     | 0.15   | 0.18 | 0.12   | 0.21 | 0.16   | 0.15 | 0.24   | --   |
| 17            | 5x7      | 0.14   | 0.16 | 0.12   | 0.19 | 0.15   | 0.19 | 0.22   | 0.14 |
| 18            | 5x8      | 0.15   | 0.17 | 0.12   | 0.20 | 0.20   | 0.15 | 0.23   | 0.15 |
| 19            | 5x9      | 0.18   | 0.18 | 0.21   | 0.17 | 0.17   | 0.17 | 0.25   | --   |
| 20            | 5x10     | 0.15   | 0.17 | 0.14   | 0.18 | 0.19   | 0.15 | 0.25   | 0.17 |

Table 48. (Continued).

| Entry<br>No. | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|--------------|----------|--------|------|--------|------|--------|------|--------|------|
|              |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| %            |          |        |      |        |      |        |      |        |      |
| 21           | 6x7      | 0.14   | 0.15 | 0.15   | 0.17 | 0.18   | 0.16 | 0.24   | 0.14 |
| 22           | 6x8      | 0.15   | 0.17 | 0.11   | 0.17 | 0.21   | 0.17 | 0.20   | 0.17 |
| 23           | 6x9      | 0.17   | 0.18 | 0.12   | 0.15 | 0.17   | 0.15 | 0.26   | 0.10 |
| 24           | 6x10     | 0.13   | 0.18 | 0.11   | 0.15 | 0.18   | 0.12 | 0.19   | —    |
| 25           | 1        | 0.12   | 0.14 | 0.09   | 0.16 | 0.21   | 0.22 | 0.21   | 0.13 |
| 26           | 2        | 0.13   | 0.11 | 0.14   | 0.16 | 0.17   | 0.15 | 0.22   | 0.22 |
| 27           | 3        | 0.15   | 0.17 | 0.12   | 0.12 | 0.16   | 0.17 | 0.24   | 0.17 |
| 28           | 4        | 0.14   | 0.15 | 0.11   | 0.19 | 0.17   | 0.13 | 0.22   | 0.19 |
| 29           | 5        | 0.17   | 0.18 | 0.14   | 0.22 | 0.22   | 0.15 | 0.18   | 0.15 |
| 30           | 6        | 0.13   | 0.18 | 0.14   | 0.16 | 0.17   | 0.16 | 0.30   | 0.13 |
| 31           | 7        | 0.14   | 0.14 | 0.12   | 0.21 | 0.17   | 0.18 | 0.23   | 0.14 |
| 32           | 8        | 0.18   | 0.15 | 0.14   | 0.15 | 0.20   | 0.16 | 0.27   | 0.14 |
| 33           | 9        | 0.20   | 0.20 | 0.11   | 0.20 | 0.19   | 0.22 | 0.27   | 0.12 |
| 34           | 10       | 0.14   | 0.17 | 0.10   | 0.16 | 0.18   | 0.15 | 0.21   | 0.14 |
| 35           | Seredo   | —      | 0.15 | —      | 0.15 | —      | 0.12 | —      | 0.16 |
| Mean         |          |        |      |        |      |        |      |        |      |
| LSD (0.05)   |          | 0.15   | 0.17 | 0.13   | 0.17 | 0.18   | 0.16 | 0.18   | 0.16 |
|              |          | 0.03   | 0.02 | ns     | ns   | ns     | 0.03 | ns     | ns   |

conditions. This is in contrast to previous reports of P content under acid soil conditions (Clark and Gourley, 1987; Andrew *et al.* 1973).

Significant male GCA effects for P content were observed at Obambo for IS7254C in 1991 and for TX430 in both years. Effects were negative for IS7254C and positive for TX430. Female GCA effects were significant only for TX623 at Obambo and Ukwala in 1991. At Obambo, hybrids of Wheatland crossed with males, IS7254C, TX430, and TX432, and (AT-1)-52-2-1-2-1 x TX430 demonstrated significant SCA effects in 1991. The SCA effects were positive for Wheatland X IS7254C and Wheatland X TX430. Significant SCA effects were also found for TX623 x TX432 and (AT-1)-52-2-1-2-1 x IS7254C at Ukwala in 1991. The latter hybrid had a negative SCA effect. These data indicate that both GCA and SCA were important in controlling P content which agrees with Gorz *et al.* (1987).

### Sulfur

Significant differences among genotypes for sulfur content were found at Obambo, Buburi, and Ukwala in 1991 (Tables 37-44). Differences among parents occurred existed at Buburi in 1990 and at Buburi and Ukwala in 1991. Mean squares for  $F_1$ s vs parents and  $F_1$ s were not significant at any location in either year. Mean squares for males were significant only at Ukwala in 1990 while differences due to females were significant only at Obambo in 1991. No significant male x female interactions were found. No source of variation for S content was significant at Mumias in either year.

Means for S content are presented in Table 49. Sulfur content at Obambo was relatively lower than at locations with lower soil pH in both

Table 49. Mean sulfur concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No.     | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|---------------|----------|--------|------|--------|------|--------|------|--------|------|
|               |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- % ----- |          |        |      |        |      |        |      |        |      |
| 1             | 1x7      | 0.09   | 0.11 | 0.17   | 0.14 | 0.16   | 0.19 | 0.18   | --   |
| 2             | 1x8      | 0.09   | 0.11 | 0.15   | 0.16 | 0.16   | 0.18 | 0.16   | 0.14 |
| 3             | 1x9      | 0.11   | 0.11 | 0.17   | 0.15 | 0.16   | 0.18 | 0.22   | 0.17 |
| 4             | 1x10     | 0.12   | 0.11 | 0.16   | 0.14 | 0.17   | 0.20 | 0.16   | 0.19 |
| 5             | 2x7      | 0.11   | 0.14 | 0.14   | 0.16 | 0.15   | 0.20 | 0.20   | 0.15 |
| 6             | 2x8      | 0.10   | 0.12 | 0.15   | 0.17 | 0.15   | 0.16 | 0.18   | 0.15 |
| 7             | 2x9      | 0.13   | 0.14 | 0.16   | 0.14 | 0.16   | 0.19 | 0.19   | 0.15 |
| 8             | 2x10     | 0.11   | 0.13 | 0.13   | 0.14 | 0.15   | 0.18 | 0.18   | 0.18 |
| 9             | 3x7      | 0.11   | 0.13 | 0.14   | 0.14 | 0.16   | 0.18 | 0.17   | 0.21 |
| 10            | 3x8      | 0.11   | 0.13 | 0.15   | 0.16 | 0.19   | 0.20 | 0.18   | 0.14 |
| 11            | 3x9      | 0.11   | 0.13 | 0.16   | 0.14 | 0.19   | 0.20 | 0.17   | 0.13 |
| 12            | 3x10     | 0.11   | 0.13 | 0.16   | 0.15 | 0.17   | 0.18 | 0.18   | 0.16 |
| 13            | 4x7      | 0.11   | 0.11 | 0.17   | 0.15 | 0.17   | 0.18 | 0.19   | 0.14 |
| 14            | 4x8      | 0.11   | 0.12 | 0.13   | 0.13 | 0.18   | 0.22 | 0.18   | 0.14 |
| 15            | 4x9      | 0.10   | 0.12 | 0.15   | 0.15 | 0.16   | 0.20 | 0.17   | 0.17 |
| 16            | 4x10     | 0.11   | 0.13 | 0.15   | 0.14 | 0.16   | 0.20 | 0.19   | --   |
| 17            | 5x7      | 0.09   | 0.13 | 0.16   | 0.15 | 0.14   | 0.19 | 0.17   | 0.15 |
| 18            | 5x8      | 0.11   | 0.13 | 0.15   | 0.15 | 0.16   | 0.21 | 0.15   | 0.15 |
| 19            | 5x9      | 0.11   | 0.13 | 0.17   | 0.15 | 0.17   | 0.19 | 0.19   | --   |
| 20            | 5x10     | 0.11   | 0.13 | 0.16   | 0.16 | 0.17   | 0.21 | 0.17   | 0.16 |

Table 49. (Continued).

| Entry<br>No. | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|--------------|----------|--------|------|--------|------|--------|------|--------|------|
|              |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| %            |          |        |      |        |      |        |      |        |      |
| 21           | 6x7      | 0.11   | 0.12 | 0.17   | 0.15 | 0.16   | 0.19 | 0.19   | 0.14 |
| 22           | 6x8      | 0.11   | 0.12 | 0.15   | 0.14 | 0.18   | 0.21 | 0.22   | 0.15 |
| 23           | 6x9      | 0.11   | 0.13 | 0.15   | 0.13 | 0.16   | 0.19 | 0.17   | 0.11 |
| 24           | 6x10     | 0.11   | 0.13 | 0.15   | 0.14 | 0.16   | 0.22 | 0.18   | —    |
| 25           | 1        | 0.10   | 0.11 | 0.14   | 0.13 | 0.17   | 0.19 | 0.16   | 0.17 |
| 26           | 2        | 0.11   | 0.12 | 0.13   | 0.16 | 0.16   | 0.19 | 0.18   | 0.19 |
| 27           | 3        | 0.11   | 0.12 | 0.14   | 0.13 | 0.14   | 0.20 | 0.17   | 0.17 |
| 28           | 4        | 0.10   | 0.12 | 0.15   | 0.15 | 0.15   | 0.16 | 0.16   | 0.14 |
| 29           | 5        | 0.10   | 0.13 | 0.16   | 0.16 | 0.16   | 0.20 | 0.21   | 0.16 |
| 30           | 6        | 0.10   | 0.12 | 0.16   | 0.15 | 0.17   | 0.18 | 0.20   | 0.10 |
| 31           | 7        | 0.11   | 0.12 | 0.16   | 0.19 | 0.15   | 0.23 | 0.20   | 0.16 |
| 32           | 8        | 0.11   | 0.11 | 0.14   | 0.14 | 0.18   | 0.16 | 0.19   | 0.15 |
| 33           | 9        | 0.12   | 0.13 | 0.14   | 0.16 | 0.17   | 0.20 | 0.21   | 0.16 |
| 34           | 10       | 0.11   | 0.13 | 0.13   | 0.15 | 0.19   | 0.17 | 0.18   | 0.13 |
| 35           | Seredo   | —      | 0.13 | —      | 0.16 | —      | 0.15 | —      | 0.16 |
| Mean         |          |        |      |        |      |        |      |        |      |
| LSD (0.05)   |          | 0.11   | 0.12 | 0.15   | 0.15 | 0.16   | 0.19 | 0.18   | 0.15 |
|              |          | ns     | 0.02 | ns     | 0.02 | ns     | 0.03 | ns     | ns   |

years. The highest location means for S content were found at Mumias in 1990 and Ukwala in 1991. In general, S contents of the parental genotypes were lower at Obambo than at the other locations. Parental genotype (AT-1)-52-2-1-2-1 had relatively low means compared to other parents across all locations in both years, while TX430 had a relatively higher S content across locations and years. Differences between hybrids and parents were not significant; however, at Obambo in 1990, male parents generally had higher S contents than hybrids. Hybrids involving Wheatland had higher S contents than their higher parent with the exception of IA28 at Obambo in 1991. While some hybrids exhibited heterosis, the expression of heterosis was not consistent across environments. Differences among hybrids for S content were not significant. Hybrids, TX623 x TX430 and TX623 x TX432, had low S content at Obambo and high S content at other locations in both years. (AT-2)-10-6-1-2-1 x IA28 exhibited low S content across locations in both years. Wheatland x IS7254C and B-Yel-PI x TX432 had higher S values than other hybrids across all environments. These data show a general lack of agreement with Clark and Gourley (1987) in that S content was generally lower in genotypes at Obambo than it was in leaves of sorghum plants from low soil pH environments.

There was significant variation among male GCA means only at Ukwala in 1990; however, no significant male GCA effects were detected. Significant female GCA effects for S content were found for TX623 and Wheatland at Obambo in 1991. The female GCA effects were negative and positive for TX623 and Wheatland, respectively. No significant SCA effects were observed for S content. This study indicated that female GCA effects were more important in controlling S content than male GCA effects

while SCA effects were not significant. Gorz *et al.* (1987) also reported that GCA effects exceeded SCA effects for S content.

### Chlorine

There were significant differences among genotypes at Mumias in 1990, and at Obambo, Buburi, and Ukwala in 1991 (Tables 37-44). Differences among parents were significant at Obambo in 1990 and at all locations except Mumias in 1991. The  $F_1$ s vs parents contrast was significant only at Buburi in 1991. Differences among  $F_1$ s were significant only at Mumias in 1990, but were significant at all locations except Mumias in 1991. Differences among males were significant at Buburi in both years, at Mumias in 1990, at Ukwala in 1991, and at Obambo in both years. Differences among females were significant at Mumias in 1990 and at Obambo in both years. Male x female interaction was significant only at Mumias in 1990.

Mean Cl contents of the 35 sorghum genotypes are presented in Table 50. Mean Cl concentrations in male parents was generally higher than in female parents across locations except for female parents, Wheatland and B-Yel-PI. This trend was not seen at Obambo in 1990. Parent (AT-1)-36-4-2-2-1 had lower, and IS7254C had higher Cl content than other parents across locations. Location means were lower in 1990 than 1991 except for Buburi. Mumias had the lowest Cl content in both years.

At Buburi in 1991, all hybrids except TX623 X IA28 and TX623 X TX430 demonstrated positive heterotic responses for Cl content either on a midparent or the high-parent basis. Hybrids, TX623 x IS7254C, Wheatland x IS7254C, B-Yel-PI x IA28, and (AT-2)-10-6-1-2-1 x IA28, had higher Cl

Table 50. Mean chlorine concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry<br>No. | Genotype | Obambo        |      | Buburi |      | Ukwala |      | Mumias |      |
|--------------|----------|---------------|------|--------|------|--------|------|--------|------|
|              |          | 1990          | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
|              |          | ----- % ----- |      |        |      |        |      |        |      |
| 1            | 1x7      | 0.10          | 0.29 | 0.27   | 0.45 | 0.12   | 0.32 | 0.08   | --   |
| 2            | 1x8      | 0.06          | 0.22 | 0.33   | 0.14 | 0.19   | 0.29 | 0.06   | 0.06 |
| 3            | 1x9      | 0.13          | 0.16 | 0.18   | 0.14 | 0.17   | 0.26 | 0.07   | 0.06 |
| 4            | 1x10     | 0.06          | 0.25 | 0.24   | 0.18 | 0.15   | 0.30 | 0.05   | 0.08 |
| 5            | 2x7      | 0.09          | 0.18 | 0.28   | 0.37 | 0.11   | 0.23 | 0.12   | 0.04 |
| 6            | 2x8      | 0.16          | 0.20 | 0.30   | 0.27 | 0.13   | 0.18 | 0.10   | 0.10 |
| 7            | 2x9      | 0.09          | 0.15 | 0.17   | 0.29 | 0.10   | 0.23 | 0.07   | 0.07 |
| 8            | 2x10     | 0.09          | 0.15 | 0.13   | 0.35 | 0.13   | 0.20 | 0.05   | 0.14 |
| 9            | 3x7      | 0.15          | 0.23 | 0.25   | 0.36 | 0.17   | 0.23 | 0.09   | 0.03 |
| 10           | 3x8      | 0.20          | 0.27 | 0.32   | 0.31 | 0.20   | 0.36 | 0.11   | 0.13 |
| 11           | 3x9      | 0.17          | 0.24 | 0.30   | 0.22 | 0.13   | 0.24 | 0.10   | 0.08 |
| 12           | 3x10     | 0.10          | 0.27 | 0.28   | 0.25 | 0.16   | 0.38 | 0.11   | 0.04 |
| 13           | 4x7      | 0.09          | 0.20 | 0.36   | 0.38 | 0.12   | 0.23 | 0.09   | 0.05 |
| 14           | 4x8      | 0.08          | 0.29 | 0.27   | 0.25 | 0.13   | 0.23 | 0.10   | 0.09 |
| 15           | 4x9      | 0.10          | 0.20 | 0.16   | 0.28 | 0.09   | 0.27 | 0.07   | 0.07 |
| 16           | 4x10     | 0.07          | 0.21 | 0.25   | 0.26 | 0.09   | 0.24 | 0.06   | --   |
| 17           | 5x7      | 0.07          | 0.17 | 0.28   | 0.36 | 0.09   | 0.23 | 0.07   | 0.10 |
| 18           | 5x8      | 0.13          | 0.27 | 0.18   | 0.34 | 0.11   | 0.27 | 0.08   | 0.04 |
| 19           | 5x9      | 0.07          | 0.27 | 0.16   | 0.17 | 0.16   | 0.23 | 0.11   | --   |
| 20           | 5x10     | 0.10          | 0.23 | 0.18   | 0.16 | 0.10   | 0.26 | 0.08   | 0.06 |

Table 50. (Continued).

| Entry No.     | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|---------------|----------|--------|------|--------|------|--------|------|--------|------|
|               |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- % ----- |          |        |      |        |      |        |      |        |      |
| 21            | 6x7      | 0.08   | 0.24 | 0.39   | 0.37 | 0.10   | 0.23 | 0.07   | 0.11 |
| 22            | 6x8      | 0.07   | 0.23 | 0.32   | 0.16 | 0.12   | 0.23 | 0.13   | 0.04 |
| 23            | 6x9      | 0.08   | 0.16 | 0.12   | 0.27 | 0.11   | 0.21 | 0.06   | 0.08 |
| 24            | 6x10     | 0.08   | 0.18 | 0.21   | 0.16 | 0.17   | 0.25 | 0.07   | --   |
| 25            | 1        | 0.07   | 0.22 | 0.08   | 0.17 | 0.15   | 0.25 | 0.06   | 0.06 |
| 26            | 2        | 0.08   | 0.18 | 0.20   | 0.24 | 0.12   | 0.28 | 0.09   | 0.08 |
| 27            | 3        | 0.15   | 0.28 | 0.24   | 0.20 | 0.12   | 0.28 | 0.08   | 0.04 |
| 28            | 4        | 0.11   | 0.18 | 0.18   | 0.17 | 0.13   | 0.25 | 0.08   | 0.10 |
| 29            | 5        | 0.06   | 0.17 | 0.21   | 0.14 | 0.20   | 0.26 | 0.12   | 0.07 |
| 30            | 6        | 0.09   | 0.23 | 0.14   | 0.15 | 0.10   | 0.14 | 0.05   | 0.04 |
| 31            | 7        | 0.12   | 0.34 | 0.32   | 0.47 | 0.10   | 0.47 | 0.15   | 0.11 |
| 32            | 8        | 0.19   | 0.21 | 0.34   | 0.28 | 0.15   | 0.22 | 0.08   | 0.08 |
| 33            | 9        | 0.06   | 0.23 | 0.14   | 0.23 | 0.15   | 0.18 | 0.10   | 0.08 |
| 34            | 10       | 0.04   | 0.29 | 0.26   | 0.11 | 0.10   | 0.27 | 0.04   | 0.05 |
| 35            | Seredo   | --     | 0.31 | --     | 0.26 | --     | 0.08 | --     | 0.08 |
| -----         |          |        |      |        |      |        |      |        |      |
| Mean          |          | 0.10   | 0.23 | 0.24   | 0.25 | 0.13   | 0.28 | 0.08   | 0.07 |
| LSD (0.05)    |          | ns     | 0.08 | ns     | 0.15 | ns     | 0.10 | 0.05   | ns   |

contents than other hybrids at most locations in both years. At many locations, hybrids of male parent TX430 had a relatively low Cl content. These data indicate that Cl content is subject to considerable environmental variation which disagrees with previous findings by Clark and Gourley (1987).

Significant male GCA effects for Cl content were observed for all male combiners. Tolerant males, IA28 and IS7254C, showed positive male effects at Mumias in 1990 and Buburi in 1991. Susceptible males, TX430 at Buburi in 1990 and TX432 at Mumias in 1990, demonstrated significant negative male GCA effects. All tolerant female combiners did not show significant female GCA effects for Cl content. Susceptible females, TX623 at Mumias in 1990, Wheatland at Obambo in 1991, and B-Yel-PI at Mumias and Obambo in 1990, and B-Yel-PI at Ukwala in 1991, had significant female GCA effects. The effects were negative for TX623 and Wheatland. Female GCA effects for Cl content of B-Yel-PI were invariably positive across locations and years. General combining ability appeared to be the main source of genetic variation Cl content. Gorz *et al.* (1987) also reported predominantly GCA effects for Cl content.

#### Potassium

There were significant differences among genotypes for K content at all locations except for Mumias and Ukwala in 1991 and 1990, respectively (Tables 37-44). Differences among parents occurred at Buburi in 1990, Ukwala in 1991, and Obambo in both years. There was a significant difference between  $F_1$ s and parents at any location in either year. Differences among  $F_1$ s and among males were significant at all locations

with the exceptions of Ukwala and Mumias in 1990 and 1991, respectively. Differences among females were significant in both years at Obambo and in single years at Buburi, Mumias, and Ukwala. The only significant male x female interaction occurred at Obambo in 1991.

Mean potassium contents in leaves of the 35 sorghum genotypes are presented in Table 51. The location means for Obambo were below unity and were lower than all other locations in both years. Parents, IA28 and Wheatland, exhibited consistently high K values across locations. Female (AT-1)-36-4-2-2-1 showed low K content at Obambo and high K contents in the low pH areas; however, most of the parents had low k values for both years at Obambo and high values in acid soil locations. The K contents of parental genotypes fluctuated considerably between years at Mumias. It appeared that hybrids of females, TX623, Wheatland, B-Yel-PI, (AT-2)-10-6-1-2-1, and (AT-1)-52-2-1-2-1, crossed with male parent IS7254C had lower K content than other hybrids, in general. There was no consistent effect of soil acidity on K content in leaves in this study. Some tolerant and susceptible genotypes showed increases in K content under acid soil; however, some tolerant genotypes showed increased and others decreases K contents in acid soils. Nonetheless, female (AT-1)-36-4-2-2-1 met Duncan's (1987) criterion to be classified as a tolerant genotype.

Male IA28 invariably had higher male GCA means across locations than other male combiners. Only the two tolerant males, IA28 and IS7254C, had significant male GCA effects for K content. The male GCA effects for IS7254C were significant at Obambo for two years and at Mumias in 1990. IA28 showed significant positive male GCA effects at Obambo in both years, at Buburi and Mumias in 1990, and at Ukwala in 1991. Significant female

Table 51. Mean potassium concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No. | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

| %  |      |      |      |      |      |      |      |      |      |
|----|------|------|------|------|------|------|------|------|------|
| 1  | 1x7  | 0.57 | 0.75 | 1.18 | 1.06 | 0.98 | 1.13 | 1.17 | --   |
| 2  | 1x8  | 1.18 | 1.11 | 1.91 | 1.00 | 1.31 | 1.33 | 1.30 | 0.97 |
| 3  | 1x9  | 1.06 | 0.90 | 1.30 | 1.15 | 1.27 | 1.09 | 1.13 | 0.93 |
| 4  | 1x10 | 0.81 | 0.85 | 1.88 | 1.22 | 1.20 | 1.48 | 1.06 | 1.36 |
| 5  | 2x7  | 0.74 | 0.79 | 0.93 | 1.12 | 1.04 | 1.43 | 1.27 | 0.84 |
| 6  | 2x8  | 1.21 | 1.05 | 1.80 | 1.41 | 1.05 | 1.35 | 1.33 | 0.93 |
| 7  | 2x9  | 1.08 | 1.03 | 1.73 | 1.35 | 1.12 | 1.43 | 1.45 | 0.95 |
| 8  | 2x10 | 1.15 | 0.94 | 1.71 | 1.34 | 1.12 | 1.49 | 1.22 | 1.85 |
| 9  | 3x7  | 0.76 | 0.79 | 1.10 | 0.95 | 1.28 | 1.24 | 0.80 | 0.88 |
| 10 | 3x8  | 1.07 | 1.16 | 1.88 | 1.61 | 1.21 | 1.44 | 1.30 | 1.02 |
| 11 | 3x9  | 1.15 | 1.04 | 1.58 | 0.94 | 1.02 | 1.31 | 1.44 | 0.63 |
| 12 | 3x10 | 1.28 | 1.01 | 1.95 | 1.25 | 1.15 | 1.60 | 1.25 | 0.75 |
| 13 | 4x7  | 0.58 | 0.63 | 1.28 | 1.06 | 1.18 | 1.18 | 0.89 | 0.77 |
| 14 | 4x8  | 1.29 | 1.07 | 1.79 | 1.32 | 1.14 | 1.55 | 1.33 | 1.34 |
| 15 | 4x9  | 0.99 | 0.88 | 1.07 | 1.29 | 1.11 | 1.28 | 1.15 | 1.16 |
| 16 | 4x10 | 1.03 | 0.86 | 1.16 | 1.28 | 1.10 | 1.29 | 1.04 | --   |
| 17 | 5x7  | 0.72 | 0.63 | 1.23 | 1.23 | 0.79 | 1.32 | 0.91 | 1.24 |
| 18 | 5x8  | 1.43 | 1.19 | 2.17 | 1.72 | 1.01 | 1.75 | 1.39 | 1.17 |
| 19 | 5x9  | 1.24 | 1.00 | 1.60 | 1.16 | 1.00 | 1.35 | 1.40 | --   |
| 20 | 5x10 | 1.16 | 0.89 | 1.84 | 1.37 | 0.95 | 1.67 | 1.52 | 1.26 |

Table 51. (Continued).

| Entry No.  | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------|----------|--------|------|--------|------|--------|------|--------|------|
|            |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| <hr/>      |          |        |      |        |      |        |      |        |      |
| <hr/>      |          |        |      |        |      |        |      |        |      |
| %          |          |        |      |        |      |        |      |        |      |
| <hr/>      |          |        |      |        |      |        |      |        |      |
| 21         | 6x7      | 0.71   | 0.59 | 1.46   | 1.05 | 1.00   | 1.18 | 0.68   | 1.30 |
| 22         | 6x8      | 0.85   | 0.72 | 1.90   | 0.86 | 1.18   | 1.32 | 1.36   | 0.71 |
| 23         | 6x9      | 0.73   | 0.72 | 1.12   | 0.75 | 1.10   | 0.97 | 0.83   | 0.45 |
| 24         | 6x10     | 0.69   | 0.72 | 1.38   | 0.87 | 1.32   | 1.15 | 0.86   | —    |
| 25         | 1        | 0.88   | 0.90 | 1.26   | 1.15 | 1.38   | 1.36 | 0.80   | 1.25 |
| 26         | 2        | 1.06   | 1.00 | 1.46   | 1.65 | 1.02   | 1.83 | 1.44   | 0.98 |
| 27         | 3        | 1.13   | 0.94 | 1.45   | 0.98 | 0.91   | 1.40 | 0.84   | 1.31 |
| 28         | 4        | 0.92   | 0.83 | 1.16   | 1.11 | 1.10   | 1.25 | 0.82   | 1.10 |
| 29         | 5        | 0.90   | 0.75 | 1.81   | 1.14 | 1.34   | 1.41 | 1.84   | 0.86 |
| 30         | 6        | 0.76   | 0.72 | 1.31   | 0.86 | 0.93   | 1.20 | 0.81   | 0.81 |
| 31         | 7        | 0.59   | 0.62 | 1.42   | 1.09 | 1.06   | 1.19 | 0.92   | 1.07 |
| 32         | 8        | 1.40   | 1.06 | 2.10   | 1.41 | 1.30   | 0.98 | 1.14   | 1.09 |
| 33         | 9        | 0.98   | 1.05 | 1.63   | 0.85 | 1.02   | 1.37 | 0.88   | 1.04 |
| 34         | 10       | 1.08   | 1.11 | 1.92   | 1.56 | 0.82   | 1.23 | 0.67   | 0.86 |
| 35         | Seredo   | —      | 1.11 | —      | 1.40 | —      | 0.72 | —      | 1.23 |
| <hr/>      |          |        |      |        |      |        |      |        |      |
| Mean       |          | 0.98   | 0.90 | 1.54   | 1.19 | 1.10   | 1.32 | 1.12   | 1.02 |
| LSD (0.05) |          | 0.28   | 0.15 | 0.53   | 0.41 | ns     | 0.27 | 0.59   | ns   |

GCA effects were recorded for B-Yel-PI, (AT-2)-10-6-1-2-1, and (AT-1)-36-4-2-2-1. Both B-Yel-PI and (AT-2)-10-6-1-2-1 showed significant positive female GCA effects at Obambo and Ukwala in 1991. Significant female GCA effects for K content in (AT-1)-36-4-2-2-1 were invariably negative. Specific combining ability effects were not significant. Gorz *et al.* (1987) also found that additive effects were predominant for K content.

#### Calcium

There were significant differences among genotypes for calcium content at all locations except Mumias in 1991 and Ukwala in 1990 (Tables 37-44). Differences among parents were significant at Obambo and Buburi in both years and at Ukwala in 1991. The contrast of  $F_1$ s vs parents was only significant at Obambo and Mumias in 1991. There were significant differences among  $F_1$ s at Obambo in both years and in single years at Buburi, Mumias, and Ukwala. Mean squares for males were significant at all locations except Mumias in 1991 and Ukwala in 1990; however, females were only significant at Mumias in 1990 and at Obambo and Ukwala in 1991. The only significant male x female interaction occurred at Mumias in 1990.

Calcium concentrations in leaves of the 35 genotypes of sorghum are presented in Table 52. Location means for Buburi and Ukwala were comparable in magnitude and were lower than the other locations. The 1990 location mean for Mumias was significantly higher than any of the other location means. Parental genotypes, TX623, (AT-1)-36-4-2-2-1, and IS7254C, had high Ca concentrations compared to IA28 across locations. At Obambo in 1991, the Ca contents of males, with the exception of IA28, were higher than any of the female parents. Seredo consistently exhibited a

Table 52. Mean calcium concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No. | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|--------|------|--------|------|--------|------|--------|------|
|           |          |        |      |        |      |        |      |        |      |
|           |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| <hr/>     |          |        |      |        |      |        |      |        |      |
| <hr/>     |          |        |      |        |      |        |      |        |      |
| %         |          |        |      |        |      |        |      |        |      |
| <hr/>     |          |        |      |        |      |        |      |        |      |
| 1         | 1x7      | 0.91   | 0.73 | 0.56   | 0.63 | 0.50   | 0.47 | 0.97   | —    |
| 2         | 1x8      | 0.59   | 0.54 | 0.41   | 0.44 | 0.44   | 0.34 | 0.79   | 0.87 |
| 3         | 1x9      | 0.79   | 0.70 | 0.71   | 0.74 | 0.44   | 0.45 | 1.42   | 0.81 |
| 4         | 1x10     | 0.80   | 0.72 | 0.64   | 0.60 | 0.48   | 0.48 | 0.98   | 0.49 |
| 5         | 2x7      | 0.84   | 0.63 | 0.39   | 0.63 | 0.55   | 0.41 | 0.59   | 0.87 |
| 6         | 2x8      | 0.59   | 0.44 | 0.32   | 0.44 | 0.58   | 0.38 | 0.70   | 0.50 |
| 7         | 2x9      | 0.76   | 0.71 | 0.45   | 0.54 | 0.67   | 0.49 | 1.00   | 0.54 |
| 8         | 2x10     | 0.72   | 0.57 | 0.62   | 0.58 | 0.56   | 0.53 | 1.08   | 0.32 |
| 9         | 3x7      | 0.80   | 0.68 | 0.49   | 0.60 | 0.49   | 0.50 | 0.89   | 1.25 |
| 10        | 3x8      | 0.57   | 0.45 | 0.36   | 0.40 | 0.43   | 0.34 | 0.59   | 0.53 |
| 11        | 3x9      | 0.71   | 0.70 | 0.52   | 0.57 | 0.56   | 0.52 | 0.81   | 0.57 |
| 12        | 3x10     | 0.74   | 0.63 | 0.46   | 0.63 | 0.43   | 0.46 | 0.85   | 0.97 |
| 13        | 4x7      | 0.86   | 0.73 | 0.62   | 0.67 | 0.48   | 0.50 | 0.81   | 0.71 |
| 14        | 4x8      | 0.56   | 0.55 | 0.33   | 0.45 | 0.47   | 0.33 | 0.53   | 0.54 |
| 15        | 4x9      | 0.86   | 0.73 | 0.39   | 0.56 | 0.56   | 0.43 | 0.80   | 0.60 |
| 16        | 4x10     | 0.82   | 0.72 | 0.51   | 0.61 | 0.64   | 0.44 | 0.83   | —    |
| 17        | 5x7      | 0.95   | 0.77 | 0.64   | 0.69 | 0.55   | 0.51 | 1.00   | 0.70 |
| 18        | 5x8      | 0.57   | 0.46 | 0.34   | 0.39 | 0.56   | 0.34 | 0.47   | 1.03 |
| 19        | 5x9      | 0.79   | 0.74 | 0.46   | 0.60 | 0.64   | 0.48 | 0.90   | —    |
| 20        | 5x10     | 0.83   | 0.65 | 0.47   | 0.42 | 0.43   | 0.46 | 0.78   | 0.90 |

Table 52. (Continued).

| Entry No.  | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|------------|----------|--------|------|--------|------|--------|------|--------|------|
|            |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| <hr/>      |          |        |      |        |      |        |      |        |      |
| <hr/>      |          |        |      |        |      |        |      |        |      |
| %          |          |        |      |        |      |        |      |        |      |
| <hr/>      |          |        |      |        |      |        |      |        |      |
| 21         | 6x7      | 0.85   | 0.74 | 0.54   | 0.61 | 0.61   | 0.57 | 1.08   | 0.55 |
| 22         | 6x8      | 0.66   | 0.55 | 0.35   | 0.57 | 0.49   | 0.41 | 0.62   | 0.95 |
| 23         | 6x9      | 0.87   | 0.76 | 0.79   | 0.81 | 0.47   | 0.69 | 1.28   | 0.59 |
| 24         | 6x10     | 0.91   | 0.71 | 0.71   | 0.75 | 0.42   | 0.67 | 1.23   | --   |
| 25         | 1        | 0.71   | 0.54 | 0.88   | 0.58 | 0.51   | 0.45 | 0.81   | 0.45 |
| 26         | 2        | 0.55   | 0.40 | 0.52   | 0.47 | 0.49   | 0.36 | 0.68   | 0.59 |
| 27         | 3        | 0.63   | 0.54 | 0.46   | 0.49 | 0.41   | 0.48 | 0.72   | 0.66 |
| 28         | 4        | 0.65   | 0.46 | 0.36   | 0.40 | 0.56   | 0.30 | 0.54   | 0.65 |
| 29         | 5        | 0.87   | 0.59 | 0.41   | 0.52 | 0.43   | 0.37 | 0.46   | 0.58 |
| 30         | 6        | 0.79   | 0.64 | 0.51   | 0.61 | 0.57   | 0.53 | 1.02   | 0.61 |
| 31         | 7        | 1.03   | 0.79 | 0.59   | 0.82 | 0.46   | 0.77 | 1.10   | 0.59 |
| 32         | 8        | 0.46   | 0.46 | 0.34   | 0.28 | 0.46   | 0.30 | 0.50   | 0.42 |
| 33         | 9        | 0.89   | 0.65 | 0.42   | 0.83 | 0.54   | 0.57 | 1.18   | 0.51 |
| 34         | 10       | 0.84   | 0.71 | 0.62   | 0.59 | 0.57   | 0.61 | 1.30   | 0.88 |
| 35         | Seredo   | --     | 0.55 | --     | 0.41 | --     | 0.47 | --     | 0.51 |
| <hr/>      |          |        |      |        |      |        |      |        |      |
| Mean       |          | 0.76   | 0.63 | 0.50   | 0.57 | 0.51   | 0.47 | 0.86   | 0.67 |
| LSD (0.05) |          | 0.15   | 0.08 | 0.26   | 0.22 | ns     | 0.11 | 0.38   | ns   |

low Ca concentration across locations. At Obambo and Mumias in 1991, there was some heterotic expression for Ca concentration. Consistently low Ca contents were observed in all hybrids from tolerant male parent IA28 across locations and years and these hybrids were lower than the other hybrids except at Ukwala in 1990. The obtained results are in agreement with Clark and Gourley (1987) in that there was a reduction in Ca concentration on acid soils at Buburi and Ukwala as compared to Obambo. Due to the fact that some tolerant genotypes had K contents as high as some susceptible genotypes, while other tolerant genotypes had low Ca content, these data do not confirm or refute the findings of Duncan (1987). Andrew *et al.* (1973) reported that reduction in Ca concentration in tolerant species was balanced by reciprocal increases in K and Mg.

Male GCA means were higher for susceptible males, TX430 and TX432, than for tolerant male IA28. All significant male GCA effects for TX430, TX432, and IS7254C were positive. Tolerant male IA28 showed significant negative GCA effects at Obambo and Buburi in both ears, and at Mumias and Ukwala in 1990 and 1991, respectively. Significant female GCA effects were observed for all females except (AT-2)-10-6-1-2-1; however, significant female GCA effects for Wheatland and B-Yel-PI were confined to the better environments. TX623 and (AT-1)-36-4-2-2-1 had significant positive female GCA effects in both good and poor environments (AT-1)-52-2-1-2-1 expressed significant negative female GCA effects in stressed environment. None of the hybrids expressed significant SCA effects. The obtained results indicate that additive gene effects were predominant for Ca which supports the findings of Gorz *et al.* (1987).

### Manganese

There were significant differences among genotypes for Mn concentrations at Buburi in 1990, Ukwala in 1991, and Obambo in both years (Tables 37-44). Significant differences among parents occurred at Obambo in both years and at Buburi and Ukwala in 1990 and 1991, respectively. There was a significant difference between  $F_1$ s and parents only at Obambo in 1990 indicating a general lack of heterosis for Mn content in this material. Differences among  $F_1$ s were significant at Obambo in both years and at Mumias and Ukwala in 1990 and 1991, respectively. There were significant differences among males at all locations except Ukwala in 1990, but males were significant only at Ukwala in 1991. Mean squares for females were significant at Obambo in both years and at Mumias and Ukwala in 1990 and 1991, respectively. The male x female interaction was not significant at any location indicating that SCA effects were not important in the inheritance of Mn content.

Manganese concentrations in leaves of the 35 sorghum genotypes are presented in Table 53. Location means for Mn at Obambo were less than the other locations in both years while Mumias had the highest means in both years. The means for 1990 were higher than for 1991 at all locations. These results obtained in this study are in agreement with Clark and Gourley (1987) a Mn content increase in leaves of sorghum plants grown on acid soils as compared to plants grown in neutral soils. Parental differences existed Mn concentration at all locations except Mumias, although differences were observed only in single years at Ukwala and Buburi. Parents, TX623, IS7254C, and TX432, generally had higher Mn content than other parents, except at Mumias. Mean Mn contents for Seredo

Table 53. Mean manganese concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No. | Genotype | Obambo |       | Buburi |       | Ukwala |       | Mumias |       |
|-----------|----------|--------|-------|--------|-------|--------|-------|--------|-------|
|           |          | 1990   | 1991  | 1990   | 1991  | 1990   | 1991  | 1990   | 1991  |
|           |          | ppm    |       |        |       |        |       |        |       |
| 1         | 1x7      | 238.4  | 174.3 | 330.4  | 192.6 | 211.7  | 179.5 | 353.0  | —     |
| 2         | 1x8      | 176.7  | 134.4 | 200.0  | 173.2 | 242.5  | 148.9 | 200.6  | 222.7 |
| 3         | 1x9      | 210.6  | 152.2 | 337.6  | 207.2 | 207.2  | 166.3 | 326.8  | 190.8 |
| 4         | 1x10     | 239.8  | 159.5 | 314.8  | 226.4 | 227.2  | 182.6 | 344.2  | 190.5 |
| 5         | 2x7      | 190.0  | 109.7 | 223.5  | 218.1 | 214.3  | 113.7 | 226.8  | 269.8 |
| 6         | 2x8      | 161.5  | 93.5  | 194.6  | 145.3 | 182.3  | 107.0 | 266.5  | 181.0 |
| 7         | 2x9      | 178.4  | 128.2 | 175.2  | 191.5 | 222.3  | 035.8 | 280.2  | 178.6 |
| 8         | 2x10     | 201.3  | 130.6 | 262.0  | 159.6 | 216.3  | 160.9 | 344.3  | 145.3 |
| 9         | 3x7      | 197.4  | 116.6 | 228.6  | 168.6 | 233.3  | 138.8 | 218.9  | 303.9 |
| 10        | 3x8      | 130.6  | 125.9 | 167.6  | 109.0 | 209.9  | 123.0 | 206.4  | 135.6 |
| 11        | 3x9      | 163.0  | 139.7 | 222.0  | 175.0 | 224.4  | 133.8 | 191.0  | 138.8 |
| 12        | 3x10     | 175.0  | 136.1 | 181.4  | 181.0 | 187.6  | 137.4 | 235.4  | 275.9 |
| 13        | 4x7      | 190.6  | 143.1 | 288.2  | 219.2 | 244.4  | 137.5 | 319.4  | 255.7 |
| 14        | 4x8      | 147.5  | 116.6 | 151.3  | 160.5 | 266.3  | 93.0  | 202.9  | 174.0 |
| 15        | 4x9      | 181.4  | 146.0 | 174.6  | 155.4 | 253.8  | 143.2 | 360.9  | 217.3 |
| 16        | 4x10     | 191.2  | 152.1 | 199.2  | 106.7 | 252.6  | 117.1 | 321.0  | —     |
| 17        | 5x7      | 209.8  | 168.9 | 295.4  | 206.3 | 279.7  | 148.5 | 259.5  | 266.2 |
| 18        | 5x8      | 159.4  | 177.0 | 163.7  | 164.7 | 272.7  | 113.6 | 174.9  | 240.2 |
| 19        | 5x9      | 227.8  | 167.6 | 181.3  | 203.0 | 286.4  | 169.7 | 302.2  | —     |
| 20        | 5x10     | 208.2  | 152.5 | 243.5  | 178.3 | 229.0  | 158.3 | 284.5  | 188.5 |

Table 53. (Continued).

| Entry No.  | Genotype | Obambo |       | Buburi |       | Ukwala |       | Mumias |       |
|------------|----------|--------|-------|--------|-------|--------|-------|--------|-------|
|            |          | 1990   | 1991  | 1990   | 1991  | 1990   | 1991  | 1990   | 1991  |
|            |          | ppm    |       |        |       |        |       |        |       |
| 21         | 6x7      | 164.5  | 143.8 | 251.2  | 237.9 | 248.3  | 136.7 | 314.6  | 135.5 |
| 22         | 6x8      | 156.0  | 138.3 | 160.6  | 178.1 | 223.2  | 143.0 | 224.6  | 260.2 |
| 23         | 6x9      | 169.9  | 134.7 | 320.0  | 231.0 | 197.2  | 176.6 | 291.5  | 185.4 |
| 24         | 6x10     | 217.5  | 153.3 | 277.7  | 224.2 | 213.5  | 173.1 | 310.9  | —     |
| 25         | 1        | 218.9  | 137.7 | 434.4  | 199.8 | 171.8  | 194.5 | 347.4  | 301.8 |
| 26         | 2        | 189.0  | 93.4  | 219.0  | 154.8 | 233.3  | 93.1  | 226.1  | 174.9 |
| 27         | 3        | 130.5  | 103.3 | 162.7  | 163.8 | 248.7  | 160.5 | 245.0  | 279.3 |
| 28         | 4        | 137.9  | 99.9  | 180.0  | 133.3 | 247.3  | 96.6  | 216.4  | 156.9 |
| 29         | 5        | 192.7  | 141.7 | 210.0  | 236.8 | 162.7  | 124.4 | 231.3  | 193.4 |
| 30         | 6        | 119.4  | 89.9  | 210.4  | 173.6 | 250.7  | 138.3 | 341.7  | 168.5 |
| 31         | 7        | 235.8  | 127.4 | 164.6  | 215.0 | 216.7  | 180.9 | 263.3  | 222.5 |
| 32         | 8        | 132.7  | 117.8 | 123.1  | 107.6 | 192.7  | 120.3 | 293.8  | 189.2 |
| 33         | 9        | 210.9  | 128.4 | 106.3  | 167.6 | 209.3  | 149.5 | 288.2  | 235.3 |
| 34         | 10       | 248.0  | 145.8 | 274.8  | 140.6 | 221.3  | 164.7 | 387.8  | 180.6 |
| 35         | Seredo   | —      | 91.1  | —      | 90.7  | —      | 150.4 | —      | 100.0 |
| Mean       |          |        |       |        |       |        |       |        |       |
| LSD (0.05) |          | 185.9  | 133.5 | 224.4  | 177.9 | 228.5  | 142.3 | 276.5  | 203.0 |
|            |          | 52.4   | 33.8  | 150.5  | ns    | ns     | 49.3  | ns     | ns    |

at Obambo, Buburi, and Mumias were comparable in magnitude and were lower than most genotypes. At Obambo, male parents generally had higher Mn contents than female parents with the exception of TX623 and (AT-2)-10-6-1-2-1. Hybrids expressed positive heterosis over the midparent and, in some cases, over the high parent at Obambo. Hybrids from tolerant male parent IA28 had lower Mn contents than most other hybrids at a number of locations.

The only significant male GCA effects for Mn content occurred with tolerant male IA28. The GCA effects for IA28 were significant at Obambo, Buburi, and Mumias in 1990 and at Ukwala in 1991 and were invariably negative. Significant female GCA effects were found for TX623, Wheatland, B-Yel-PI, and (AT-2)-10-6-1-2-1. Only B-Yel-PI exhibited significant female GCA effects under the stress conditions of Mumias and these effects were negative. At Obambo, female GCA effects for TX623 and (AT-2)-10-6-1-2-1 were positive and female GCA effects for Wheatland were negative. General combining ability was the main source of genetic variation for Mn content. Gorz *et al.* (1987) also found that GCA effects for Mn were more important than SCA effects.

### Iron

There were significant differences among genotypes for Fe concentration at Buburi and Ukwala in 1991 and at Obambo in both years (Tables 37-44). Differences among parents followed the same pattern as genotypes. The contrast of  $F_1$ s vs parents was not significant at any location indicating that average heterosis was not important for Fe content. There were no significant differences among hybrids in 1990, but

differences were found at Obambo and Ukwala in 1991. Males were significant at Mumias in 1990 and at Obambo and Ukwala in 1991. Mean squares for females were significant only at Obambo and Ukwala in 1991. Male x female interactions were not significant at any locations, indicating that specific combining ability was not important for Fe concentration.

Means for iron concentration in leaves of the 35 genotypes are presented in Table 54. The mean Fe contents Obambo were consistently lower than the other location means, except for Buburi in 1991. Location means for Ukwala, Mumias, and Buburi were two to three times higher in 1990 than the respective location means in 1991, and there were no significant differences among genotypes for the Fe content at these three locations in 1990 levels. Parents, (AT-1)-52-2-1-2-1 and TX430, in general, had lower Fe concentrations than IA28 and B-Yel-PI across locations and years. Seredo had lower Fe concentrations than most genotypes at all locations except Ukwala. These data are in agreement with Clark and Gourley (1987) in that Fe concentrations in leaves of plants grown on acid soil were higher than those grown on neutral soil. At Obambo in 1991, hybrids expressed positive heterosis over the midparent and, in some cases, over the higher parent. Hybrids, Wheatland x IS7254C, B-Yel-PI x IS7254C, and (AT-1)-36-4-2-2-1 x IS7254C, had lower Fe concentrations than other hybrids across locations.

None of the males had significant male GCA effects, except IS7254C. Male GCA effects negative and significant at Mumias and Ukwala in 1990 and 1991. None of the females showed significant GCA effects, except Wheatland. Female GCA effects for Wheatland were positive at Ukwala in

Table 54. Mean iron concentrations in the leaves of plants of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No. | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

|    |      |     |     |      |     |      |      |      |      |
|----|------|-----|-----|------|-----|------|------|------|------|
| 1  | 1x7  | 235 | 202 | 1626 | 297 | 1402 | 379  | 896  | —    |
| 2  | 1x8  | 299 | 173 | 1058 | 369 | 1992 | 551  | 1374 | 1123 |
| 3  | 1x9  | 248 | 189 | 1165 | 279 | 1495 | 721  | 2131 | 655  |
| 4  | 1x10 | 650 | 184 | 1092 | 417 | 1317 | 443  | 2323 | 497  |
| 5  | 2x7  | 395 | 252 | 890  | 329 | 1922 | 543  | 810  | 316  |
| 6  | 2x8  | 602 | 532 | 1313 | 490 | 1165 | 973  | 1873 | 1298 |
| 7  | 2x9  | 418 | 399 | 1252 | 610 | 1945 | 1034 | 2242 | 1367 |
| 8  | 2x10 | 574 | 273 | 1298 | 392 | 571  | 1280 | 1958 | 419  |
| 9  | 3x7  | 421 | 237 | 1045 | 295 | 1034 | 656  | 724  | 457  |
| 10 | 3x8  | 346 | 407 | 1508 | 357 | 1138 | 667  | 2142 | 381  |
| 11 | 3x9  | 324 | 445 | 1837 | 763 | 1150 | 789  | 1127 | 512  |
| 12 | 3x10 | 344 | 292 | 1607 | 300 | 1236 | 844  | 1382 | 768  |
| 13 | 4x7  | 332 | 301 | 1456 | 314 | 2340 | 429  | 1135 | 1601 |
| 14 | 4x8  | 270 | 239 | 1879 | 326 | 1390 | 470  | 1551 | 757  |
| 15 | 4x9  | 322 | 225 | 842  | 344 | 1454 | 609  | 2863 | 1120 |
| 16 | 4x10 | 364 | 227 | 1276 | 319 | 1459 | 506  | 2033 | —    |
| 17 | 5x7  | 278 | 403 | 1113 | 260 | 3107 | 573  | 876  | 397  |
| 18 | 5x8  | 383 | 609 | 1027 | 375 | 1059 | 635  | 1657 | 546  |
| 19 | 5x9  | 334 | 213 | 1234 | 395 | 1005 | 782  | 1856 | —    |
| 20 | 5x10 | 306 | 249 | 1280 | 418 | 1763 | 886  | 868  | 1095 |

ppm

Table 54. (Continued).

| Entry No.       | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------------|----------|--------|------|--------|------|--------|------|--------|------|
|                 |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- ppm ----- |          |        |      |        |      |        |      |        |      |
| 21              | 6x7      | 344    | 220  | 682    | 358  | 1411   | 451  | 1075   | 452  |
| 22              | 6x8      | 264    | 204  | 766    | 315  | 1516   | 560  | 1279   | 542  |
| 23              | 6x9      | 242    | 208  | 1402   | 291  | 1349   | 515  | 2466   | 444  |
| 24              | 6x10     | 268    | 198  | 829    | 320  | 1731   | 670  | 1165   | ---  |
| 25              | 1        | 276    | 221  | 1604   | 236  | 891    | 636  | 2960   | 502  |
| 26              | 2        | 1248   | 387  | 1945   | 421  | 1696   | 953  | 1904   | 504  |
| 27              | 3        | 332    | 337  | 1263   | 653  | 2640   | 705  | 2065   | 463  |
| 28              | 4        | 394    | 255  | 920    | 339  | 1657   | 416  | 870    | 366  |
| 29              | 5        | 337    | 480  | 1445   | 567  | 1228   | 1016 | 1490   | 415  |
| 30              | 6        | 295    | 202  | 1206   | 265  | 1967   | 417  | 2957   | 2468 |
| 31              | 7        | 378    | 228  | 646    | 268  | 2024   | 480  | 1047   | 478  |
| 32              | 8        | 462    | 430  | 1251   | 547  | 1586   | 1260 | 4508   | 713  |
| 33              | 9        | 319    | 278  | 696    | 331  | 945    | 612  | 1740   | 335  |
| 34              | 10       | 448    | 214  | 1465   | 280  | 1417   | 815  | 1187   | 551  |
| 35              | Seredo   | ---    | 172  | ---    | 253  | ---    | 2007 | ---    | 359  |
| -----           |          |        |      |        |      |        |      |        |      |
| Mean            |          | 384    | 288  | 1233   | 374  | 1515   | 722  | 1722   | 724  |
| LSD (0.05)      |          | 348    | 193  | ns     | ns   | ns     | 476  | ns     | ns   |

1991. Additive gene effects were predominant for Fe content which is in partial agreement with Gorz *et al.* (1987). Nonadditive effects were not significant for Fe concentration in this study.

### Copper

Significant differences among genotypes for Cu content in leaves occurred at Mumias in 1990 and at Obambo and Ukwala in 1991 (Table 37-44). Differences among parents were observed only at Obambo and Ukwala in 1991. Significant differences between hybrids and parents were not found at any location in the two years indicating a general lack of heterosis for Cu concentration. Differences among  $F_1$ s, males, and females were significant at Mumias in 1990 and at Obambo and Ukwala in 1991. No significant male x female interactions were detected in this study, indicating that nonadditive genetic effects were not important for Cu concentration.

Means for copper concentration are presented in Table 55. The location means for Cu content at Obambo, Ukwala and Mumias in 1990 were comparable in magnitude and were lower than the respective location means in 1991. Copper concentrations at Buburi in 1990 and 1991 were similar. With the exception of Ukwala in 1991, these data are in agreement with Clark and Gourley (1987) as it was observed that Cu concentration in leaves of sorghum plants was decreased in the more acid soil locations as compared to Obambo within each year. Parent (AT-1)-52-2-1-2-1 had low Cu concentrations at Obambo, Ukwala, and Mumias in 1990 which were lower than other parents for the same period. Mean Cu contents of IA28 at Ukwala in 1990 and Mumias in 1990 and 1991 were comparable and were lower than at Obambo in 1990. Parent TX430 had lower means in the acid soil locations

Table 55. Mean copper concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No. | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------|----------|--------|------|--------|------|--------|------|--------|------|
|           |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |

| ppm |      |      |      |      |      |      |      |      |      |
|-----|------|------|------|------|------|------|------|------|------|
| 1   | 1x7  | 20.1 | 26.9 | 27.8 | 33.5 | 15.5 | 46.5 | 14.7 | --   |
| 2   | 1x8  | 16.6 | 39.4 | 37.7 | 39.0 | 11.5 | 66.1 | 15.2 | 25.0 |
| 3   | 1x9  | 27.9 | 34.4 | 42.3 | 38.3 | 13.7 | 41.4 | 11.7 | 38.8 |
| 4   | 1x10 | 15.6 | 27.2 | 18.3 | 28.2 | 14.5 | 35.2 | 11.2 | 43.3 |
| 5   | 2x7  | 9.3  | 26.5 | 18.9 | 26.1 | 12.7 | 63.3 | 15.8 | 19.9 |
| 6   | 2x8  | 14.1 | 46.7 | 12.7 | 36.7 | 12.0 | 75.5 | 14.2 | 18.8 |
| 7   | 2x9  | 18.9 | 45.9 | 17.3 | 31.6 | 14.3 | 58.2 | 12.7 | 21.9 |
| 8   | 2x10 | 14.2 | 36.4 | 80.4 | 28.2 | 12.2 | 77.1 | 7.3  | 32.9 |
| 9   | 3x7  | 10.6 | 37.8 | 39.4 | 19.4 | 11.2 | 53.5 | 11.8 | 11.2 |
| 10  | 3x8  | 16.6 | 52.5 | 25.1 | 31.4 | 13.0 | 67.5 | 15.2 | 23.0 |
| 11  | 3x9  | 15.3 | 49.2 | 17.3 | 29.3 | 13.5 | 39.4 | 11.3 | 16.8 |
| 12  | 3x10 | 11.3 | 46.2 | 29.9 | 31.4 | 12.5 | 57.2 | 12.7 | 27.7 |
| 13  | 4x7  | 14.3 | 36.4 | 20.4 | 32.4 | 17.3 | 48.3 | 14.7 | 27.1 |
| 14  | 4x8  | 11.8 | 52.1 | 35.7 | 25.0 | 11.5 | 64.4 | 17.3 | 31.8 |
| 15  | 4x9  | 14.5 | 43.2 | 22.0 | 40.5 | 11.8 | 47.6 | 9.2  | 31.2 |
| 16  | 4x10 | 13.3 | 37.5 | 63.2 | 38.4 | 10.5 | 49.3 | 13.2 | --   |
| 17  | 5x7  | 16.4 | 36.7 | 22.6 | 35.8 | 15.0 | 57.6 | 9.8  | 18.3 |
| 18  | 5x8  | 14.6 | 48.4 | 15.8 | 27.7 | 12.7 | 71.1 | 13.7 | 21.9 |
| 19  | 5x9  | 10.6 | 42.1 | 64.1 | 25.6 | 13.2 | 55.6 | 12.7 | --   |
| 20  | 5x10 | 19.5 | 47.8 | 15.3 | 35.0 | 17.2 | 61.1 | 7.3  | 23.0 |

Table 55. (Continued).

| Entry No.       | Genotype | Obambo |      | Buburi |      | Ukwala |      | Mumias |      |
|-----------------|----------|--------|------|--------|------|--------|------|--------|------|
|                 |          | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 | 1990   | 1991 |
| ----- ppm ----- |          |        |      |        |      |        |      |        |      |
| 21              | 6x7      | 14.0   | 29.0 | 36.6   | 32.4 | 12.5   | 65.5 | 18.8   | 27.8 |
| 22              | 6x8      | 21.0   | 39.4 | 50.0   | 30.8 | 11.2   | 54.8 | 20.9   | 23.5 |
| 23              | 6x9      | 22.7   | 41.8 | 46.9   | 28.2 | 12.7   | 44.3 | 11.2   | 22.0 |
| 24              | 6x10     | 11.5   | 38.6 | 23.6   | 30.8 | 13.0   | 56.1 | 17.3   | ---  |
| 25              | 1        | 9.7    | 31.0 | 24.6   | 29.8 | 12.7   | 55.2 | 11.2   | 53.6 |
| 26              | 2        | 13.8   | 48.9 | 46.6   | 27.1 | 11.0   | 52.9 | 12.7   | 22.5 |
| 27              | 3        | 14.5   | 46.7 | 56.0   | 30.5 | 10.5   | 47.9 | 14.7   | 24.5 |
| 28              | 4        | 10.2   | 38.8 | 45.2   | 42.8 | 9.5    | 55.7 | 10.7   | 18.8 |
| 29              | 5        | 18.1   | 37.8 | 39.6   | 30.4 | 12.3   | 70.0 | 14.2   | 29.7 |
| 30              | 6        | 11.0   | 36.1 | 18.9   | 28.2 | 12.5   | 46.5 | 16.8   | 20.4 |
| 31              | 7        | 14.7   | 32.1 | 49.3   | 41.0 | 11.5   | 44.3 | 18.3   | 30.9 |
| 32              | 8        | 20.1   | 53.1 | 39.9   | 31.9 | 14.0   | 68.5 | 14.3   | 16.8 |
| 33              | 9        | 20.0   | 44.3 | 14.3   | 18.8 | 16.0   | 38.0 | 13.7   | 24.0 |
| 34              | 10       | 17.4   | 44.0 | 24.1   | 25.1 | 13.2   | 53.4 | 11.2   | 30.6 |
| 35              | Seredo   | ---    | 33.2 | ---    | 23.0 | ---    | 70.7 | ---    | 20.9 |
| -----           |          |        |      |        |      |        |      |        |      |
| Mean            |          | 15.5   | 40.2 | 33.5   | 31.0 | 12.9   | 55.7 | 13.5   | 25.7 |
| LSD (0.05)      |          | ns     | 11.3 | ns     | ns   | ns     | 23.1 | 5.8    | ns   |

than at Obambo. In 1991, Cu contents of TX430 were generally lower than other parent means at all locations. Hybrids ranged from low to high for Cu concentration. Hybrids, TX623 x TX432 and Wheatland x IA28, in general, had lower Cu contents than most hybrids. Copper concentration of B-Yel-PI x TX430 remained consistent in both good and stress environments.

Male GCA means for tolerant male IA28 were consistently higher than other males. These effects were significant and positive at Mumias in 1990 and at Obambo and Ukwala in 1991. Tolerant male IS7254C had a significant negative GCA effect at Obambo in 1991. Susceptible male combiners showed no significant male GCA effects. Significant GCA effects were found for all females except (AT-1)-52-2-1-2-1 and (AT-2)-10-6-1-2-1. TX623 and B-Yel-PI had significant female GCA effects only Obambo in 1991, while females, Wheatland and (AT-1)-36-4-2-2-1, showed significant positive GCA effects at Ukwala in 1991 and Mumias in 1990, respectively. The results obtained in this study indicated predominantly additive gene effects for Cu which agrees with the data of Gorz *et al.* (1987).

#### Zinc

There were significant differences for Zn concentration in sorghum leaves among the 35 genotypes and among the parental genotypes at all locations except Buburi and Ukwala in 1990 and Mumias in 1991 (Tables 37-44). There was a significant difference between  $F_1$ s and parents at Mumias in 1990 and Ukwala in 1991 indicating limited heterotic response for Zn concentration. Significant differences among hybrids were expressed at Mumias in 1990 and at Obambo and Buburi in 1991. Males were significant

at Obambo in both years, at Buburi in 1991, and at Mumias in 1990. Mean squares for females were significant at Buburi and Ukwala in 1991, and at Obambo in both years. There were no significant male x female interaction for Zn content, indicating that nonadditive genetic effects were not important for Zn.

Means for Zn content in leaves of the 35 sorghum genotypes are presented in Table 56. Zinc content at Obambo was higher than at Ukwala in both years. Zinc content was consistently high at Buburi in both years, and was higher than the respective values at Obambo in each year. Mean Zn content at Ukwala, was inconsistent for the two years. Clark and Gourley (1987), however, reported Zn content to remain unchanged in both acid and neutral soils.

Zinc contents among parents varied. Mean Zn contents of parents B-Yel-PI were comparable in magnitude at Obambo, Ukwala, and Mumias in 1990, and at Buburi and Mumias in 1991. Parents, TX623, (AT-2)-10-6-1-2-1, IS7254C, TX430, and TX432, generally showed higher Zn contents than other parents at most locations. Parent IA28 exhibited low Zn concentrations across locations. At Mumias in 1990, all male parents, except IA28, had higher Zn contents than female parents. Positive heterotic responses over the midparent and, in some cases, over the higher parent, for Zn content were expressed at Mumias in 1990, and at Ukwala in 1991. On the other hand, some hybrids expressed negative heterotic response for Zn content. Since the expression of heterosis for Zn content occurred in only one location per year it appeared that heterosis was not a major factor in determining Zn content in the leaves. Among hybrids, it appeared that hybrids of female parents, with the exception of B-Yel-PI, crossed common

Table 56. Mean zinc concentrations in the leaves of 35 sorghum genotypes grown at four locations in Kenya, 1990 and 1991.

| Entry No. | Genotype | Obambo |      | Buburi |       | Ukwala |      | Mumias |      |
|-----------|----------|--------|------|--------|-------|--------|------|--------|------|
|           |          | 1990   | 1991 | 1990   | 1991  | 1990   | 1991 | 1990   | 1991 |
|           |          | ppm    |      |        |       |        |      |        |      |
| 1         | 1x7      | 65.9   | 40.4 | 106.0  | 69.0  | 25.4   | 72.3 | 43.8   | —    |
| 2         | 1x8      | 29.6   | 35.5 | 46.6   | 35.5  | 32.2   | 58.4 | 18.5   | 26.3 |
| 3         | 1x9      | 54.4   | 43.7 | 122.0  | 50.3  | 23.2   | 55.2 | 32.7   | 41.0 |
| 4         | 1x10     | 38.6   | 39.4 | 61.4   | 112.6 | 26.4   | 52.7 | 29.5   | 33.5 |
| 5         | 2x7      | 43.9   | 34.4 | 55.4   | 43.9  | 22.9   | 55.0 | 28.9   | 21.1 |
| 6         | 2x8      | 27.6   | 39.6 | 37.8   | 31.1  | 26.0   | 59.7 | 24.7   | 20.1 |
| 7         | 2x9      | 42.4   | 45.5 | 56.6   | 48.1  | 27.1   | 54.8 | 27.9   | 23.7 |
| 8         | 2x10     | 36.0   | 40.2 | 115.9  | 45.0  | 27.0   | 63.4 | 22.1   | 28.9 |
| 9         | 3x7      | 36.9   | 40.2 | 63.5   | 36.8  | 24.7   | 44.0 | 28.5   | 28.9 |
| 10        | 3x8      | 21.9   | 39.9 | 43.9   | 44.4  | 25.0   | 50.5 | 24.2   | 27.3 |
| 11        | 3x9      | 36.7   | 44.5 | 62.1   | 41.0  | 28.5   | 41.9 | 22.1   | 25.3 |
| 12        | 3x10     | 32.2   | 47.1 | 51.0   | 45.6  | 21.3   | 52.8 | 27.4   | 42.8 |
| 13        | 4x7      | 38.7   | 36.6 | 76.9   | 57.9  | 34.3   | 42.4 | 32.2   | 24.2 |
| 14        | 4x8      | 22.5   | 40.8 | 36.1   | 31.6  | 29.6   | 46.7 | 19.5   | 27.8 |
| 15        | 4x9      | 40.7   | 42.5 | 56.6   | 66.2  | 21.1   | 48.8 | 31.6   | 27.4 |
| 16        | 4x10     | 28.7   | 44.2 | 85.0   | 76.5  | 24.8   | 51.2 | 27.4   | —    |
| 17        | 5x7      | 53.4   | 45.7 | 80.1   | 69.7  | 21.6   | 52.2 | 34.9   | 22.1 |
| 18        | 5x8      | 26.4   | 41.0 | 32.1   | 36.7  | 24.4   | 57.9 | 22.1   | 28.4 |
| 19        | 5x9      | 45.1   | 43.1 | 77.6   | 47.2  | 36.2   | 57.0 | 31.6   | —    |
| 20        | 5x10     | 43.6   | 49.0 | 65.3   | 50.8  | 28.7   | 69.0 | 29.0   | 25.8 |

Table 56. (Continued).

| Entry No.       | Genotype | Obambo |      | Buburi |       | Ukwala |      | Mumias |      |
|-----------------|----------|--------|------|--------|-------|--------|------|--------|------|
|                 |          | 1990   | 1991 | 1990   | 1991  | 1990   | 1991 | 1990   | 1991 |
| ----- ppm ----- |          |        |      |        |       |        |      |        |      |
| 21              | 6x7      | 31.3   | 32.2 | 90.4   | 48.4  | 32.1   | 59.2 | 39.5   | 26.4 |
| 22              | 6x8      | 23.4   | 30.0 | 47.4   | 25.2  | 28.5   | 44.3 | 22.1   | 30.1 |
| 23              | 6x9      | 34.7   | 39.4 | 78.4   | 34.4  | 20.1   | 44.1 | 27.4   | 28.8 |
| 24              | 6x10     | 25.1   | 37.7 | 49.7   | 36.7  | 28.6   | 53.6 | 32.2   | —    |
| 25              | 1        | 34.5   | 37.9 | 75.0   | 53.2  | 28.6   | 51.6 | 30.6   | 39.4 |
| 26              | 2        | 29.2   | 41.0 | 71.0   | 36.1  | 23.4   | 50.5 | 25.8   | 38.6 |
| 27              | 3        | 25.8   | 41.6 | 49.2   | 26.4  | 24.3   | 47.6 | 25.2   | 25.7 |
| 28              | 4        | 22.4   | 34.1 | 48.0   | 39.9  | 22.6   | 42.0 | 20.5   | 27.9 |
| 29              | 5        | 40.3   | 41.1 | 54.6   | 36.5  | 22.1   | 61.2 | 30.0   | 27.8 |
| 30              | 6        | 16.8   | 32.8 | 41.7   | 23.7  | 32.4   | 40.0 | 25.3   | 19.5 |
| 31              | 7        | 59.9   | 48.1 | 96.0   | 117.8 | 22.7   | 59.2 | 77.5   | 29.0 |
| 32              | 8        | 29.6   | 38.0 | 47.3   | 33.3  | 33.0   | 46.2 | 25.3   | 19.5 |
| 33              | 9        | 46.5   | 45.1 | 51.7   | 36.0  | 27.7   | 39.2 | 31.1   | 34.3 |
| 34              | 10       | 36.2   | 60.8 | 44.4   | 78.4  | 23.7   | 56.4 | 31.6   | 34.9 |
| 35              | Seredo   | —      | 40.2 | —      | 41.3  | —      | 55.5 | —      | 22.2 |
| -----           |          |        |      |        |       |        |      |        |      |
| Mean            |          | 36.1   | 40.9 | 64.0   | 48.8  | 26.5   | 52.5 | 29.5   | 28.4 |
| LSD (0.05)      |          | 15.8   | 8.8  | ns     | 26.0  | ns     | 16.1 | 14.7   | ns   |

male parent IA28 had lower Zn contents than other hybrids at most locations.

Significant male GCA effects were found for tolerant males. The male GCA effects for Zn content in male IS7254C were positive at Obambo and Mumias in 1990. In the case of male IA28, significant male effects were negative at Obambo and Mumias in 1990, and at Buburi in 1991. Female GCA effects were significant only for TX623 and (AT-1)-36-4-2-2-1. Significant female GCA effects were negative for (AT-1)-36-4-2-2-1 at Obambo in 1991 and positive for TX623 combiners at Obambo in 1990, and Buburi in 1991. There were no significant SCA effects. These data indicated that additive genetic effects were predominant for Zn content. Gorz *et al.* (1987) reported similar findings for Zn content; however, in they found some nonadditive genetic effects.

### Heritability

#### Agronomic Characters

Broad-sense and narrow-sense heritabilities for agronomic characteristics are presented in Table 57. MSU and Obambo, the more favorable environments, had high estimates for both broad-sense and narrow-sense heritability for days to flower in both years; however, in 1991, Ukwala also showed high heritabilities. In both years, the lowest estimates were from Mumias. Heritability estimates at Mumias were uniformly low for days to flower. Ekeobil *et al.* (1977) and Liang *et al.* (1972) also reported high heritabilities for this character, while Bittinger *et al.* (1981) found intermediate heritability estimates for days to flower.



Table 57. (Continued).

| Location | Year | Trait       |      |            |      |           |      |            |      |
|----------|------|-------------|------|------------|------|-----------|------|------------|------|
|          |      | Leaf Length |      | Leaf Width |      | Leaf Area |      | Heads/Plot |      |
|          |      | HB          | HN   | HB         | HN   | HB        | HN   | HB         | HN   |
| MSU      | 1990 | 0.60        | 0.55 | 0.21       | 0.21 | 0.35      | 0.35 | 0.45       | 0.45 |
| Obambo   | 1990 | 0.67        | 0.56 | 0.11       | 0.11 | 0.20      | 0.15 | 0.29       | 0.23 |
| Buburi   | 1990 | 0.27        | 0.27 | 0.21       | 0.21 | 0.23      | 0.23 | 0.30       | 0.30 |
| Ukwala   | 1990 | 0.56        | 0.49 | 0.46       | 0.46 | 0.51      | 0.49 | 0.56       | 0.39 |
| Mumias   | 1990 | 0.28        | 0.08 | 0.13       | 0.13 | 0.17      | 0.13 | 0.24       | 0.24 |
| MSU      | 1991 | --          | --   | --         | --   | --        | --   | --         | --   |
| Obambo   | 1991 | 0.69        | 0.69 | 0.14       | 0.14 | 0.31      | 0.31 | 0.30       | 0.00 |
| Buburi   | 1991 | 0.08        | 0.08 | 0.20       | 0.20 | 0.13      | 0.13 | 0.19       | 0.19 |
| Ukwala   | 1991 | 0.21        | 0.21 | 0.31       | 0.31 | 0.33      | 0.31 | 0.55       | 0.16 |
| Mumias   | 1991 | 0.06        | 0.00 | 0.23       | 0.00 | 0.18      | 0.00 | 0.16       | 0.16 |

Table 57. (Continued).

| Location | Year | Trait       |      |               |      |             |      |               |      |               |      |
|----------|------|-------------|------|---------------|------|-------------|------|---------------|------|---------------|------|
|          |      | Grain Yield |      | 1000 Seed Wt. |      | Grains/Head |      | Total Dry Wt. |      | Harvest Index |      |
|          |      | HB          | HN   | HB            | HN   | HB          | HN   | HB            | HN   | HB            | HN   |
| MSU      | 1990 | 0.46        | 0.20 | 0.51          | 0.46 | 0.41        | 0.30 | 0.38          | 0.20 | 0.27          | 0.27 |
| Obambo   | 1990 | 0.73        | 0.51 | 0.46          | 0.43 | 0.43        | 0.42 | 0.41          | 0.26 | 0.41          | 0.18 |
| Buburi   | 1990 | 0.77        | 0.22 | 0.01          | 0.01 | 0.13        | 0.01 | --            | --   | --            | --   |
| Ukwala   | 1990 | 0.40        | 0.02 | 0.80          | 0.73 | 0.49        | 0.33 | --            | --   | --            | --   |
| Mumias   | 1990 | 0.44        | 0.20 | 0.25          | 0.25 | 0.07        | 0.07 | 0.66          | 0.60 | 0.30          | 0.23 |
| MSU      | 1991 | 0.78        | 0.64 | 0.54          | 0.26 | --          | --   | --            | --   | --            | --   |
| Obambo   | 1991 | 0.71        | 0.46 | 0.87          | 0.79 | 0.72        | 0.51 | 0.33          | 0.26 | 0.47          | 0.35 |
| Buburi   | 1991 | 0.31        | 0.31 | 0.26          | 0.15 | 0.39        | 0.39 | 0.13          | 0.13 | 0.41          | 0.38 |
| Ukwala   | 1991 | 0.58        | 0.34 | 0.60          | 0.20 | 0.05        | 0.05 | 0.01          | 0.01 | 0.19          | 0.19 |
| Mumias   | 1991 | 0.21        | 0.21 | 0.02          | 0.02 | 0.46        | 0.36 | 0.00          | 0.00 | 0.21          | 0.21 |

High heritability estimates were observed for plant height except at Buburi in 1990 and Mumias in 1991. These estimates are in agreement with Ekebil *et al.* (1977) who reported high broad-sense heritability estimates and Liang *et al.* (1972) who reported high narrow-sense heritability estimates for plant height.

Broad-sense and narrow-sense heritability estimates for head length were high at Ukwala in both years. Bittinger *et al.* (1981) also reported high heritability estimates for panicle length. Intermediate broad-sense heritability estimates were measured at MSU for two years; however narrow-sense heritability was lower in 1990 than in 1991. Heritability estimates varied considerably with years at the other three locations.

Heritability estimates for peduncle length were high to intermediate at MSU and Obambo, but varied with years at the other locations. As with days to flower and plant height heritability estimates were higher in the locations with higher soil pH.

Heritability estimates for leaf length were high at MSU and Obambo, but varied greatly with years at the other locations. Again, the highest heritability were seen in the better environments. Heritabilities were lower in 1991 than 1990 in the more acid soil locations.

Leaf width heritability estimates for leaf width and leaf area were generally low at all sites. The highest heritabilities for these two traits occurred at Ukwala in 1990, but these estimates were only intermediate.

Low broad-sense and narrow-sense heritability estimates (Table 56) were found at all locations, except at MSU and Ukwala in 1990 where the estimates were intermediate. Ekebil *et al.* (1977) also obtained low

broad-sense heritability estimates for heads per plant.

Broad-sense heritability for grain yield (Table 56) was high at Obambo in both years, and at Buburi and MSU in 1990 and 1991, respectively. Intermediate broad-sense heritability estimates were recorded at Ukwala in both two years. Heritability estimates were obtained at Mumias and Buburi in 1991. Narrow-sense heritability estimates were, in general, considerably lower than broad-sense heritability, indicating a more important role for non-additive gene effects. Ekebil *et al.* (1977) also obtained high broad-sense heritability estimates for grain yield. Comparable estimates of narrow-sense heritability of 44% were also reported by Finkner *et al.* (1981). Bittinger *et al.* (1981) obtained low heritability estimates for grain yield.

High broad-sense and narrow-sense heritabilities for 1000 seed weight were found only at Ukwala in 1990 and Obambo in 1991. Low broad-sense and narrow-sense heritability estimates for 1000 seed weight were obtained at Buburi and Mumias in both years. Heritability estimates varied considerably between years. There was also a large difference between broad-sense and narrow-sense heritabilities at Ukwala in 1991. Ekebil *et al.* (1977) reported high broad-sense heritability estimates for kernel weight while Bittinger *et al.* (1981) found heritability estimates to be intermediate for the this trait. Liang *et al.* (1972) obtained high narrow-sense heritability estimates for kernel weight.

Low and intermediate broad-sense and narrow-sense heritability estimates for number of grains per head were realized at all locations except at Obambo, in 1991, where there was a high broad-sense estimate.

This trait was subject to a great deal of environmental variation and would, consequently, be difficult to select for.

Low broad-sense and narrow-sense heritability estimates for total dry weight were obtained at all locations except at Mumias in 1991. Heritabilities at the four Kenyan locations were particularly low in 1991. Low broad-sense and narrow-sense heritability estimates for harvest index existed at all locations in both years.

#### Leaf Mineral Concentrations

Broad-sense and narrow-sense heritabilities for leaf mineral element concentrations are presented in Table 58. Intermediate broad-sense and low narrow-sense heritability estimates for Mg concentrations were measured at Buburi in both years, and at Mumias and Obambo in 1990. Estimates were very low at the other locations. In several environments, it appeared all variation for Mg content was environmental.

Broad-sense and narrow-sense heritability estimates for Al content were invariably low at all locations. Boye-Goni and Marcarian (1985), on the other hand, reported high broad-sense and narrow-sense heritability estimates for Al content.

Low broad-sense and narrow-sense heritability estimates for Si content were found at all locations. The highest estimates were found at Obambo in both years, but these were only intermediate.

Low broad-sense and narrow-sense heritability estimates for P content were obtained at all locations, except for Obambo and Ukwala, in 1991, where the estimates were intermediate.

Table 58. Broad-sense (HB) and narrow-sense (HN) heritabilities for leaf mineral concentrations measured at four locations in Kenya, 1990 and 1991.

|          |      | Trait |      |      |      |      |      |      |      |
|----------|------|-------|------|------|------|------|------|------|------|
| Location | Year | Mg    |      | Al   |      | Si   |      | P    |      |
|          |      | HB    | HN   | HB   | HN   | HB   | HN   | HB   | HN   |
| Obambo   | 1990 | 0.37  | 0.37 | 0.32 | 0.32 | 0.51 | 0.39 | 0.37 | 0.23 |
| Buburi   | 1990 | 0.62  | 0.38 | 0.08 | 0.04 | 0.05 | 0.00 | 0.21 | 0.08 |
| Ukwala   | 1990 | 0.00  | 0.00 | 0.02 | 0.02 | 0.07 | 0.07 | 0.05 | 0.05 |
| Mumias   | 1990 | 0.52  | 0.38 | 0.24 | 0.24 | 0.27 | 0.27 | 0.31 | 0.00 |
| Obambo   | 1991 | 0.04  | 0.03 | 0.12 | 0.12 | 0.49 | 0.38 | 0.53 | 0.30 |
| Buburi   | 1991 | 0.44  | 0.28 | 0.32 | 0.00 | 0.19 | 0.19 | 0.05 | 0.05 |
| Ukwala   | 1991 | 0.27  | 0.00 | 0.26 | 0.26 | 0.18 | 0.16 | 0.50 | 0.32 |
| Mumias   | 1991 | 0.00  | 0.00 | 0.29 | 0.07 | 0.07 | 0.07 | 0.23 | 0.21 |

Table 58. (Continued).

| Location | Year | Trait |      |      |      |      |      |      |      |
|----------|------|-------|------|------|------|------|------|------|------|
|          |      | S     |      | Cl   |      | K    |      | Ca   |      |
|          |      | HB    | HN   | HB   | HN   | HB   | HN   | HB   | HN   |
| Obambo   | 1990 | 0.11  | 0.02 | 0.15 | 0.15 | 0.58 | 0.53 | 0.56 | 0.56 |
| Buburi   | 1990 | 0.11  | 0.11 | 0.34 | 0.34 | 0.55 | 0.50 | 0.45 | 0.38 |
| Ukwala   | 1990 | 0.15  | 0.15 | 0.10 | 0.10 | 0.07 | 0.07 | 0.04 | 0.04 |
| Mumias   | 1990 | 0.17  | 0.00 | 0.57 | 0.15 | 0.51 | 0.43 | 0.73 | 0.57 |
| Obambo   | 1991 | 0.25  | 0.25 | 0.27 | 0.12 | 0.78 | 0.73 | 0.79 | 0.77 |
| Buburi   | 1991 | 0.15  | 0.05 | 0.50 | 0.42 | 0.42 | 0.36 | 0.40 | 0.40 |
| Ukwala   | 1991 | 0.07  | 0.01 | 0.22 | 0.00 | 0.50 | 0.41 | 0.61 | 0.56 |
| Mumias   | 1991 | 0.28  | 0.09 | 0.32 | 0.00 | 0.04 | 0.04 | 0.04 | 0.00 |

Table 58. (Continued).

| Location | Year | Trait |      |      |      |      |      |      |      |
|----------|------|-------|------|------|------|------|------|------|------|
|          |      | Mn    |      | Fe   |      | Cu   |      | Zn   |      |
|          |      | HB    | HN   | HB   | HN   | HB   | HN   | HB   | HN   |
| Obambo   | 1990 | 0.35  | 0.35 | 0.08 | 0.08 | 0.07 | 0.07 | 0.46 | 0.46 |
| Buburi   | 1990 | 0.35  | 0.35 | 0.09 | 0.07 | 0.17 | 0.00 | 0.19 | 0.19 |
| Ukwala   | 1990 | 0.08  | 0.08 | 0.00 | 0.00 | 0.02 | 0.02 | 0.04 | 0.00 |
| Mumias   | 1990 | 0.54  | 0.48 | 0.34 | 0.34 | 0.62 | 0.45 | 0.50 | 0.46 |
| Obambo   | 1991 | 0.36  | 0.35 | 0.28 | 0.19 | 0.43 | 0.43 | 0.30 | 0.30 |
| Buburi   | 1991 | 0.20  | 0.20 | 0.16 | 0.08 | 0.00 | 0.00 | 0.57 | 0.36 |
| Ukwala   | 1991 | 0.26  | 0.26 | 0.37 | 0.37 | 0.25 | 0.25 | 0.16 | 0.66 |
| Mumias   | 1991 | 0.18  | 0.00 | 0.27 | 0.04 | 0.33 | 0.33 | 0.18 | 0.18 |

Low broad-sense and narrow-sense heritability estimates for S content were found at all locations. Broad-sense estimates were generally higher in 1991 than in 1990.

Intermediate broad-sense heritabilities for Cl concentration were obtained at Mumias and Buburi in both years. Narrow-sense heritabilities were generally low for Cl content with the exception of Buburi.

Intermediate to high broad-sense and narrow-sense heritability estimates for K concentration were expressed at Obambo and Buburi in both years. Heritabilities fluctuated tremendously between years at Ukwala and Mumias.

Heritabilities for Ca content were high at Obambo and intermediate at Buburi in both years. As with potassium there were large differences in heritability estimates between years at Ukwala and Mumias. The highest heritability estimates were obtained at Mumias and Obambo in 1990 and 1991, respectively.

Low broad-sense and narrow-sense heritability estimates for Mn concentrations were received at all locations and years except at Mumias in 1990 where the estimates were intermediate. Lowest estimates were at Ukwala and Mumias in 1990 and 1991, respectively.

Low broad-sense and narrow-sense heritability estimates for Fe content were expressed at all locations in both years. Heritabilities were particularly low in 1990.

Low broad-sense and narrow-sense heritability for Cu content were measured at all locations, except at Mumias and Obambo in 1990 and 1991, respectively. The heritability estimates for these latter two locations were only intermediate, however.

Low broad-sense and narrow-sense heritability estimates for Zn content were measured at all locations, except at Obambo and Mumias in 1990 and at Buburi in 1991, where estimates were intermediate.

## CHAPTER V

### SUMMARY AND CONCLUSIONS

Acid infertile tropical soils are considered marginal for agricultural production. The major constraints to crop production on these soils are mineral stress, low organic matter content, acidity, shallow soil depth which affects rooting depth, and drought. Using plants tolerant to acidity is an important complementary approach to soil management on these soils. In subsistence agriculture, stable performance is more important than high yields in favorable environments. The objectives of this study were to: identify attributes of acid soil tolerance for transfer to high yielding agronomically acceptable cultivars; determine the influence of soil acidity limitations on the performance of sorghum in low fertile acid soils; evaluate combining ability for tolerance to soil acidity; and examine heritability and heterosis in relation to soil acidity.

Thirty-four genotypes consisting of six cytoplasmic genetic male sterile A-lines, represented by their respective maintainer B-lines, as female parents, four restorer R-lines, as male parents, and their twenty four  $F_1$  hybrids from a North Carolina Mating Design II were utilized in this study. In Kenya, 'Seredo', an improved cultivar from Uganda, was included as a local check.

Four locations were selected in Kenya on the basis of soil pH. One additional site was established at the Plant Science Research Center

(PSRC) Mississippi State, MS. Kenyan locations were situated in Western Province, in low altitude, low fertile acid soil, where sorghum is an important crop in the subsistence farming systems. Three sites, Buburi, Mumias, and Ukwala, were chosen for low soil pH ( $<5.2$ ) while the Obambo trial site was selected to test performance at a soil pH above 5.2.

At each trial site in Kenya, soil samples were taken at two depths for physical and chemical analysis to determine the nutrient status of the soil. The following characteristics were determined: sand, clay, and silt percentages; soil classification; soil pH; organic carbon; total N; P, K, Mg, Na, Ca, Mn, Zn, Cu, and Fe contents. Carbon to nitrogen (C:N) ratio and exchangeable acidity (Hp) were also determined.

Trials were grown in 1990 and 1991 during the long rains season in Kenya and during the summers of 1990 and 1991 in Mississippi. The experimental design for each location was a randomized complete block design with four replicates. Agronomic characters measured included: days to flower; plant height; peduncle length; head length; leaf length, leaf width, and leaf area of the fourth leaf from the top of the plant; number of heads per plot; grain yield per plot; thousand seed weight; number of grains per heads; total dry weight per plot; and harvest index.

Dried leaf samples from the four trial sites in Kenya were analyzed for mineral concentrations using energy dispersive x-ray fluorescence. The minerals evaluated included Mg, K, Al, Ca, Si, P, S, Cl, Mn, Fe, Cu, and Zn.

Data for each plant character measured were analyzed in accordance with North Carolina mating design II with a random model to determine GCA and SCA effects and estimate broad-sense and narrow-sense heritabilities.

The locations selected for the study varied in terms of soil acidity, levels of fertility stresses, and physical properties. Obambo had a mean pH of 5.6 in both years and was considered the most favorable site for sorghum production. Obambo had relatively higher concentrations of K, Mg, Ca, Na, and Mn than the other locations in Kenya. Soil pH at Buburi, Ukwala, and Mumias ranged from 4.3 to 5.0 in 1990 and from 4.7 to 4.9 in 1991. Mumias and Ukwala were characterized by low soil pH, high Fe content, high Hp, and deficient levels of Mg and Ca. The Hp levels at these two locations were in the toxic range. In 1990, subsoils (20-40 cm) had significantly lower levels of K, Na, Ca, Mn, Zn, and Cu and higher (toxic) levels of Hp than top soils at Buburi. Similar results were obtained for K, and Mn at Mumias in 1990; for K and Mg at Buburi in 1991; and for Mn at Mumias in 1991. The consequence of declining soil pH was a reduction in fertility of the subsoil. The significantly higher levels of Hp and Mn in the subsoils at Buburi and Mumias, respectively, represented additional toxicities to the developing roots of crops in the subsoil.

A significantly lower pH was observed at planting than at harvest in some years at all locations except Ukwala. The significant changes in the mineral content over time were attributed to pH changes in the soil profile which affected pH sensitive minerals such as Mg at Obambo and Buburi, P at Mumias, and Mn at Obambo, Buburi and Mumias in 1990. In those cases where no significant soil pH differences between the two time periods were observed, there were significant changes in the concentrations of P, Mg, Ca, Mn, Zn, and Fe. Reduction in mineral content at harvest time may have been partially due to crop utilization. Carbon

concentration and C:N ratio were significantly higher at Buburi than at the other three locations in Kenya in 1990.

There were significant differences among genotypes for days to flower, plant height, head length, peduncle length, number of grains per head, grain yield, and thousand seed weight at most of the locations in both years. Significant differences among genotypes were found in some locations, particularly MSU, Obambo, and occasionally Ukwala, for leaf length, leaf width, leaf area, number of grains per head, total dry weight, and harvest index. There were significant differences among the ten parental genotypes for plant height, number of heads per plot, grain yield, total dry weights, and harvest index at most of the locations; however, significant differences among parents for most of other characteristics, were generally confined to the better environments of MSU and Obambo. Significant average heterosis for plant height, head length, peduncle length, and grain yield, was expressed at most locations, but for other characteristics, heterotic expression was limited mainly to Obambo and Ukwala. Significant male effects (GCA) were expressed for most agronomic characteristics at MSU, Obambo, and Ukwala. Significant female effects (GCA) were expressed for most agronomic characteristics at MSU, Obambo, Ukwala, and occasionally Buburi. Significant male x female interactions (SCA) occurred most frequently for days to flower, and plant height. Male x female interactions were mostly confined to the better environments, MSU, Obambo, and occasionally Ukwala.

Generally, low soil pH had an adverse effect on most agronomic characteristics; however, a number of superior hybrids were identified in acid soil environments. Tolerant males, IS7254C and IA28, consistently

imparted good agronomic characteristics to their hybrids under low pH conditions. IS7254C produced hybrids which were characterized by early flowering, long heads, tall plant height, large seeds, and high total dry weight. Hybrids of IA28 had shorter plant height, longer heads, longer leaves, greater leaf area, higher grain yield, more grains per head, increased total dry weight, and higher harvest index than hybrids from the other males. Female combiners, however, were inconsistent in their performance. Females expressed significant GCA effects more often in the better environments than in poor environments. Significant female GCA effects were mostly negative which had an adverse effect on performance; however, negative GCA effects for flowering and plant height would be desirable from a production standpoint. Wheatland appeared to be the best combiner among the females.

There were significant differences among genotypes for mineral contents. Significant differences for Mg, Al, Si, P, S, and Cl, were measured at Obambo, Buburi, and Ukwala in 1991. Potassium, Ca, Mn, Fe, Cu and Zn showed large differences in both years, especially at Obambo and Mumias. Significant differences among parents were found for all mineral concentrations at all locations, except Mumias; however, most significant differences were measured in 1990. The contrast of  $F_1$ s vs parents was significant for most mineral contents, except S, K, Fe, and Cu. The expression of average heterosis for any given mineral was limited to two locations per year and was more frequent at Ukwala and Mumias; however, heterosis for Cl content, was expressed at all locations. Males were significant for all mineral concentrations, particularly at Obambo, Ukwala, and Mumias. Females were significant for all mineral

concentrations, especially at Obambo, and Ukwala. Significant male x female interactions for Mg, Si, P, Cl, K, and Ca were measured during single years. Male x female interactions were mainly observed at Obambo.

Mean concentrations of Mg, Si, Cu, and Zn were higher; S, K, Ca, Mn, and Fe were lower; and Al, P, and Cl were variable in leaves of plants grown at Obambo compared to plants grown at the three locations with low soil pH. Iron concentrations at Ukwala, Mumias, and Buburi were at least twice as high as the concentrations at Obambo. Phosphorus concentration in the leaves showed few differences as a result of P deficiency at all locations, including Obambo. Significant nonadditive genetic effects were found only for P, although analysis of variance indicated significant male x female interactions for several minerals. Tolerant males, IA28 and IS7254C, were good general combiners for most mineral concentrations, even in poor environments. Tolerant females expressed significant GCA effects in the better environments. Among females, TX623 and Wheatland were the best general combiners. Broad-sense and narrow-sense heritabilities for days to flower, plant height, head length, peduncle length, and thousand seed weight were high; grain yield and leaf length were intermediate; and leaf width, leaf area, number of heads per plot, number of grains per head, and total dry weight were low. The high and intermediate heritability estimates were mainly observed at MSU, Obambo and Ukwala; and low heritability estimates were mainly at Buburi and Mumias except for total dry weight.

Intermediate broad-sense and narrow-sense heritability estimates for Mg, P, K, and Ca, were found at Obambo, and Ukwala, but were low at other locations. High and intermediate broad-sense and narrow-sense

heritability estimates for Al, Si, Cu, Zn, and Mn were observed at Mumias while heritabilities were low at other locations.

This study has shown that sorghum genotypes grown under good environment can exhibit their potential performance to a high degree. Plants adapted to soils of low fertility appear to have characteristics different from those adapted to optimal nutrient supply. Low fertility and soil acidity, which were a feature of Buburi, Ukwala, and Mumias, and P-deficiency which was a problem even at Obambo, affected crop performance adversely through various agronomic traits. The main consideration in breeding for the sub-optimal environment of soil acidity should be geared towards breeding sorghum genotypes that are tolerant to soil acidity, and which are early to medium maturing, as it was observed that late maturing genotypes were lacking in performance and were not stable.

The following conclusions and recommendations were drawn based on the results of this study:

- 1) Germplasm evaluation of acid soil tolerance should be conducted in the field at representative sub-optimal acid soil locations. Some genotypes in this study that had been previously selected for acid soil/aluminum tolerance proved to be less tolerant under the field conditions encountered in Kenya.
- 2) Evaluation for tolerance to soil acidity should also include an evaluation of P-efficiency. Phosphorous deficiency was a common problem at all locations in Kenya, including the higher pH site at Obambo.

- 3) Agronomic traits which appeared to be good indicators of tolerance to acid soil conditions included earlier maturity, taller plants, longer heads, and higher yield; however, taller plants may not be desirable to the producer.
- 4) Most of the characteristics which were good indicators of acid soil tolerance were primarily controlled by GCA. Therefore, these traits should respond rapidly to selection and could be utilized in either a cultivar or an  $F_1$  hybrid.
- 5) Among the mineral elements, the two which showed the most promise as indicators of tolerance to acid soil were calcium and magnesium; however, mineral element concentrations are expensive and time consuming to measure; require specialized equipment and training; and are subject to considerable environmental and sampling variation. Consequently, agronomic traits would be more efficient evaluators of acid soil tolerance, particularly in developing countries where much of the world's acid soils are found.
- 6) Hybridization and selection programs should be initiated to incorporate other desirable characteristics such as early to medium maturity; shootfly resistance, tillering capacity; tolerance to striga, drought, and diseases; high yield; and grain quality into acid soil tolerant genotypes. This could be accomplished through the use of a selection index or another multiple trait selection technique.

## LITERATURE CITED

- Allison, F. E. 1973. Soil organic matter and its role in crop production. Elsevier, London.
- Alva, A. K., D. C. Edwards, C. J. Asher, and F.P.C. Blamey. 1986. Effects of phosphorus/aluminum molar ratios and calcium concentration on plant response to aluminum. Soil Sci. Soc. Am. Proc 50:133-137.
- Andrew, C. S., A. D. Johnson, and R. L. Sandland. 1973. Effect of aluminum on the growth and chemical composition of some tropical and temperate pasture legumes. Aust. J. Agric. Res. 24:325-339.
- Andrew, C. S., and P. J. Vandenberg. 1973. The influence of aluminum on phosphate sorption by whole plants and excised roots of some pasture legumes. Aust. J. Agric. Res. 24:341-351.
- Aniol, A., R. D. Hill, and E. N. Larter. 1980. Aluminum tolerance of spring rye inbred lines. Crop Sci. 20:341-351.
- Atlin, G. N., and K. J. Frey. 1989. Breeding crop varieties for low-input agriculture. Am. J. Alternative Agric. 4:53-58.
- Bittinger, T. S., R. P. Cantrell, J. D. Axtell, and W. E. Nyquist. 1981. Analysis of quantitative traits in PP9 random mating sorghum population. Crop Sci. 21:664-669.
- Borgonovi, R. A., R. E. Schaffert, and G. V. E. Pitta. 1987. Breeding aluminum-tolerant sorghums. p. 271-292. In: L. M. Gourley, and J. G. Salinas (ed.) Sorghum for acid soils. Proc. workshop on evaluating sorghum for tolerance to Al-toxic tropical soils in Latin America. Cali, Columbia. 28 May-2 June 1984. CIAT. Cali, Columbia.
- Boye-Goni, S. R., and V. Marcarian. 1985. Diallel analysis of aluminum tolerance in selected lines of grain sorghum. Crop Sci. 25:749-759.
- Bruce, R. C., L. A. Warrell, D. G. Edwards, and L. C. Bell. 1988. Effects of aluminum and calcium in the soil solution of acid soils on root elongation of *Glycine max* Forrest. Aust. J. Agric. Res. 38:319-338.

- Buring, P. 1979. Introduction to the study of soils in tropical and subtropical regions. 3rd ed. Center for Agricultural Publishing and Documentation, Wageningen, The Netherlands.
- Cammussi, A., E. Ottaviano, B. Basso, and E. Pirillo. 1989. Photosynthetic rate as a yield component of maize in environmental restrictive conditions. J. Genet. Breed. 43:3743.
- Clark, R. B., and L. M. Gourley. 1987. Evaluation of mineral elements in sorghum grown on acid tropical soils. p. 251-270. In L. M. Gourley and J. G. Salinas (ed.) Sorghum for acid soils. Proc. workshop in evaluating sorghum for tolerance to Al-toxic tropical soils in Latin America. Cali, Columbia. 28 May-2 June 1984. CIAT. Cali, Columbia.
- Comstock, R. E., and H. F. Robinson. 1948. The components of genetic variance in populations of biparental progenies and their use in estimating the average degree of dominance. Biometrics 4:254-266.
- Culvenor, R. A. 1985. Tolerance of *Phalaris aquatica* L. lines and some other agricultural species to excess manganese, and the effect of aluminum on manganese tolerance in *P. aquatica*. Aust. J. Agric. Res. 36:695-708.
- Doggett, H. 1970. Sorghum. Longmans, Green and Co. Ltd., London, England.
- Doggett, H. 1988. Sorghum. 2nd ed. Longman Scientific and Technical, Harlow, England.
- Duncan, R. R., R. B. Clark, and P. R. Furlani. 1983. Laboratory and field evaluations of sorghum for response to aluminum on acid soil. Agron. J. 75:1023-1026.
- Duncan, R. R., and L. M. Shuman. 1990. Level of acid soil field stress for sorghum (*Sorghum bicolor*) tolerance development: comparison among locations. p. 425-428. In M. L. van Beusichen (ed.) Plant nutrition-physiology and applications. Proc. 11th Inter. Plant Nutr. Colloq. Plant Soil Sci. 41. Kluwer Academic Publ., Dordrecht, Netherlands.
- Duncan, R. R., and J. D. Sutton. 1987. Influence of field sampling techniques on the Al, Mn, Mg, and Ca nutritional profiles for acid soil tolerant and susceptible sorghum genotypes. p. 99-110. In W.H. Gabelman and B. C. Loughman (ed.) Genetic aspects of plant mineral nutrition. Martinus Nijhoff, Dordrecht, Netherlands.
- Eberhart, S. A., and W. A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.

- Eckebil, J. P., W. M. Ross, C. O. Gardner, and J. W. Maranville. 1977. Heritability estimates, genetic correlations, and predicted gains from  $S_1$  progeny tests in three grain sorghum random-mating populations. *Crop Sci.* 18:373-377.
- FAO. 1974. Soil classification. FAO/UNESCO, Rome, Italy.
- Faris, M. A., M. R. A. de Araujo, and M. de A. Lira. 1981. Yield stability of forage sorghum in Northeastern Brazil. *Crop Sci.* 21:132-134.
- Finkner, R. E., M. D. Finkner, R. M. Glaze, and G. Maese. 1981. Genetic control of percentage grain protein and grain yield in grain sorghum. *Crop Sci.* 21:139-142.
- Flores, C. I., R. B. Clark, and L. M. Gourley. 1988. Growth and yield traits of sorghum grown on acid soil at varied aluminum saturation. *Plant Soil* 106:49-57.
- Foy, C. D., and A. L. Flemming. 1978. The physiology of plant tolerance to excess available aluminum and manganese in acid soils. p. 301-328. In G. A. Jung (ed.) *Crop tolerance to suboptimal land conditions*. ASA Special Publ. 32. Amer. Soc. Agron., Madison, WI.
- Foy, C. D., R. L. Chaney, and M. C. White. 1978. The physiology of metal toxicity in plants. *Ann. Rev. Plant Physiol.* 29:5-66.
- Francis, T. R., and L. W. Kannenberg. 1978. Yield stability studies in short-season maize I. A descriptive method for grouping genotypes. *Can. J. Plant Sci.* 58:1029-1034.
- Furlani, P. R., and R. B. Clark. 1981. Screening sorghum for aluminum tolerance in nutrient solutions. *Agron. J.* 73:587-594.
- Furlani, A. M. C., R. B. Clark, C. Y. Sullivan, and J. W. Maranville. 1986. Induction of leaf red-speckling by phosphorus on sorghum grown under controlled conditions. *Crop Sci.* 26:551-557.
- Galvez, L., R. B. Clark, L. M. Gourley, and J. W. Maranville. 1987. Silicon interactions with manganese and aluminum toxicity in sorghum. *J. Plant Nutr.* 10:1139-1147.
- Goldman, I. L., T. E. Carter, Jr., and R. P. Patterson. 1989. A detrimental interaction of subsoil aluminum and drought stress on the leaf water status of soybean. *Agron. J.* 81:461-463.
- Gorz, H. J., F. A. Haskins, J. F. Pedersen, and W. M. Ross. 1987. Combining ability effects for mineral elements in forage sorghum hybrids. *Crop Sci.* 27:216-219.

- Gourley, L. M. 1987a. Identifying aluminum tolerance in sorghum genotypes grown on tropical acid soil. p. 89-98. In H. W. Gabelman and B. C. Loughman (ed.) Genetic aspects of plant mineral nutrition. Martinus Nijhoff Publ., Boston, USA.
- Gourley, L. M. 1987b. Finding and utilizing exotic Al-tolerant sorghum germplasm. p. 293-309. In L. M. Gourley and J.G. Salinas (ed.) Sorghum for acid soils. Proc. workshop on evaluating sorghum for tolerance to Al-toxic tropical soils in Latin America. Cali, Columbia. 28 May-2 June 1984. CIAT, Cali, Columbia.
- Gourley, L. M. 1987c. Breeding sorghum for acid soils of the humid tropics. p. 261-273. In M. Latham, P. Ahn, and C. R. Elliot (ed.) Africaland-land development and management of acid soils in Africa II. Proc. 2nd regional workshop. IBSRAM, Bangkok, Thailand.
- Gourley, L. M., S. A. Rogers, C. Ruiz-Gomez, and R. B. Clark. 1990. Genetic aspects of aluminum tolerance in sorghum. Plant Soil 123:211-216.
- Grundon, N. J., D. G. Edwards, P. N. Takkar, C. J. Asher, and R. B. Clark. 1987. Nutritional disorders of grain sorghum. ACIAR monograph No. 2, Canberra, Australia.
- Guiragossian, V. 1986. Food quality: Beverages prepared from high tannin sorghums. Rep. SAFGRAD/ICRISAT/EARSAM.
- Haynes, R. J. 1984. Lime and phosphate in the soil-plant system. Adv. Agron. 37:249-315.
- Helyar, K. R., and W. M. Porter. 1989. Soil acidification, its measurement and the processes involved. p. 61-101. In A. D. Robson (ed.) Soil acidity and plant growth. Academic Press, San Diego, CA.
- Heinrich, G. M., C. A. Francis, and J. D. Eastin. 1983. Stability of grain sorghum yield components across diverse environments. Crop Sci. 23:209-212.
- Howeler, R. H. 1987. Effective screening techniques for tolerance to aluminum toxicity. p. 173-186. In L. M. Gourley and J. D. Salinas (ed.) Sorghum for acid soils. Proc. workshop on evaluating sorghum for tolerance to Al-toxic tropical soils in Latin America. Cali, Columbia. 28 May-2 June 1984. CIAT, Cali, Columbia.
- Huang, P. M. 1988. Ionic effects affecting aluminum transformations and the impact on soil and environmental sciences. Adv. Soil Sci. 8:1-78.

- Jaetzold, R., and H. Schmidt. 1982. Farm management handbook of Kenya. Vol. II.A. Natural conditions and farm management information Part A. West Kenya (Nyanza and Western Provinces). Min. Agric., Kenya in cooperation with the German Agric. Team (GAT) of the German Agency for Technical Cooperation (GTZ).
- Johnson, J. W., and K. Ohki. 1984. The influence of soil pH on leaf area and yield of wheat. *Crop Sci.* 24:377-378.
- Jowett, D. 1972. Yield stability parameters for sorghum in East Africa. *Crop Sci.* 12:314-317.
- Juo, A. S. R. 1987. Mineral characteristics of lateritic soils with special reference to site selection for soil management research. p. 125-134. *In* M. Latham (ed.) Land development management of acid soils. Proc. regional seminar on lateritic soils, materials and ores. IBSRAM, Bangkok, Thailand.
- Kerven, G. L., D. G. Edwards, C. J. Asher, P. S. Hallman, and S. Kokot. 1989. Aluminum determination in soil solution. I. Evaluation of existing colorimetric and separation methods for the determination of inorganic monomeric aluminum in the presence of organic acid ligands. *Aust. J. Res.* 27:79-90.
- Kononova, M. M. 1966. Soil organic matter, its nature, its role in soil formation and in soil fertility. 2nd English ed. Pergamon Press, London, England.
- Laosuwan, P., and R. E. Atkins. 1977. Estimates of combining ability and heterosis in converted exotic sorghums. *Crop Sci.* 17:47-50.
- Larson, W. E. 1986. Problems of management under intensive agriculture in developing countries. p. 1-12. *In* M. K. Magunda, W. E. Fenster, D. S. Muduuli, M. Silver, and J. K. Zake (ed.) Proc. 8th Annual General Meeting of Soil Science of East Africa. AGMSSEA. Kampala, Uganda.
- Liang, G. H., C. R. Reddy, and A. D. Dayton. 1972. Heterosis, Inbreeding depression and heritability estimates in a systematic series of grain sorghum genotypes. *Crop Sci.* 12:409-411.
- Lopes, A. S., T. J. Smyth, and N. Curi. 1987. The need for a soil fertility reference base and nutrient dynamics studies. p. 147-166. *In* Pedro A. Sanchez, E. R. Stoner, and E. Pushparajah (ed.) Management of acid tropical soils for sustainable agriculture. Proc. Inaugural workshop. IBSRAM, Bangkok, Thailand.
- Macfie, S. M., and G. J. Taylor. 1989. Differential tolerance of manganese among cultivars of *Triticum aestivum*. *Can. J. Bot.* 67:1305-1308.

- Majisu, B. N., and H. Doggett. 1972. The yield stability of sorghum varieties and hybrids in East African environments. *East Afr. Agric. For. J.* 38:179-192.
- Mann, A. W. 1983. Hydrogeochemistry and weathering on the Yilgarn block, Western Australia-ferrolysis and heavy metals in continental brines. *Geochimica et Cosmochimica Acta* 47:170-181.
- Matsumoto, G., S. Monimura, and E. Takahashi. 1977. Binding of aluminum to DNA or DNP in pea root nuclei. *Plant Cell Physiol.* 18:987-993.
- Mbagwu, J. S. C., R. Lal, and T. W. Scott. 1984. Effects of desurfacing of Alfisols and Ultisols in Southern Nigeria. I. Crop performance. *Soil Sci. Soc. Am. J.* 48:828-833.
- Ministry of Agriculture, NAL, FURP (Phase I). 1987. Description of the first priority sites in various districts. Final Report, Annex III. Vols. 4, 5, and 7. Nairobi, Kenya.
- Modi, N., and A. R. Dabholkar. 1989. Combining ability analysis of harvest index and some components of harvest index in sorghum. *Ind. J. Genet.* 49:281-285.
- Mosquera, O. V. 1987. Analysis methodology for tropical soils. p.73-84. In L. M. Gourley and J. G. Salinas (ed.) *Sorghum for acid soils. Proc. workshop on evaluating sorghum for tolerance to Al-toxic tropical soils in Latin America.* Cali, Columbia. 28 May-2 June 1984. CIAT. Cali, Columbia.
- Muchow, R. C. 1990. Effect of nitrogen on partitioning and yielding in grain sorghum under differing environmental conditions in the semi-arid tropics. *Field Crops Res.* 25:265-278.
- Nandanwankar, K. G. 1990. Heterosis studies for grain yield characters in rabi sorghum [*Sorghum bicolor* (L.) Moench]. *Ind. J. Genet.* 50:83-85.
- Nayeem, K. A., and D. R. Bapat. 1989. Phenotypic adaptability of characters related to productivity in grain sorghum, *Sorghum bicolor*. *Ind. J. Genet.* 49:195-201.
- Nelson, L. E. 1983. Tolerances of 20 rice cultivars to excess Al and Mn. *Agron. J.* 75:134-138.
- Ohki, K. 1986. Photosynthesis, chlorophyll and transpiration responses in aluminum stressed wheat and sorghum. *Crop Sci.* 26:572-575.
- Pedersen, A. R., E. H. Everson, and J. E. Grafius. 1978. The gene pool concept as a basis for cultivar selection and recommendation. *Crop Sci.* 18:883-886.

- Petr, F. C., and K. J. Frey. 1966. Genotypic correlations, dominance and heritability of quantitative characters in oats. *Crop Sci.* 6:259-268.
- Pieri, C. 1987. Management of acid tropical soils in Africa. p.41-61. In Pedro A. Sanchez, Eric R. Stoner, and E. Pushparajah (ed.) Management of acid tropical soils for sustainable agriculture: Proc. Inaugural workshop. IBSRAM, Bangkok, Thailand.
- Pushparajah, E., and A. T. Bachik. 1987. Management of acid tropical soils in Southeast Asia. p. 13-39. In Pedro A. Sanchez, Eric R. Stoner, and E. Pushparajah (ed.) Management of acid tropical soils for sustainable agriculture. Proc. Inaugural workshop. IBSRAM, Bangkok, Thailand.
- Quinby, J.R. 1972. Grain filling period of sorghum parents and hybrids. *Crop Sci.* 12:690-691.
- Quinby, J.R. 1974. Sorghum improvement and the genetics of growth. Texas A & M Univ. Press, College Station, TX.
- Raju, P. S., R. B. Clark, J. R. Ellis, and J. W. Maranville. 1988. Effects of VA mycorrhizae on mineral uptake in sorghum genotypes grown on acid soil. *Commun. Soil Sci.* 19:7-12.
- Reich, V. H., and R. E. Atkins. 1970. Yield stability of four population types of grain sorghum [*Sorghum bicolor* (L.) Moench] in different environments. *Crop Sci.* 10:511-517.
- Rhue, R. D., C. O. Crogan, E. W. Stockmeyer, and H. L. Everett. 1978. Genetic control of aluminum tolerance in corn. *Crop Sci.* 18:1063-1067.
- Ritchie, G. S. P. 1989. The chemical behavior of aluminum, hydrogen and manganese in acid soils. p. 1-60. In A. D. Robson (ed.) Soil acidity and plant growth. Academic Press, San Diego, CA.
- Robson, A. D., and L. K. Abbott. 1989. The effect of soil acidity on microbial activity in soils. p. 139-160. In A. D. Robson (ed.) Soil acidity and plant growth. Academic Press, San Diego, CA.
- Rooney, L. W., A. W. Kirleis, and D. S. Murty. 1986. Traditional foods from sorghum: Their production, evaluation and nutritional values. p. 317-353. In Y. Pomeranz (ed.) Advances in cereal science and technology. Vol. VIII. Am. Assoc. Cereal Chemistry, St. Paul, MN.
- Rosielle, A. A., and J. Hamblin. 1981. Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Sci.* 21:943-946.

- Ross, W. M., H. J. Gorz, F. A. Haskins, G. H. Hookstra, J. K. Rutto, and R. Ritter. 1983. Combining ability effects for forage residue traits in grain sorghum hybrids. *Crop Sci.* 23:97-101.
- Rubaihayo, P. R., and V. Makumbi. 1976. Heterosis, inbreeding depression and correlation coefficients of yield and yield components of sorghum. *Z. Pflanzenzüchtung.* 77:286-295.
- Saeed, M., and C. A. Francis. 1983. Yield stability in relation to maturity in grain sorghum. *Crop Sci.* 23:683-687.
- SAS Institute. 1985. SAS/STAT user's guide. SAS Institute, Cary, NC.
- Scott, B. J., and J. A. Fisher. 1989. Selection of genotypes tolerant of aluminum and manganese. p. 167-207. *In* A. D. Robson (ed.) Soil acidity and plant growth. Academic Press, San Diego, CA.
- Sharma, S. P., P. K. Sharma, and B. R. Tripathi. 1990. Forms of acidity in some acid soils of India. *J. Ind. Soc. Soil Sci.* 38:189-195.
- Shuman, L. M., E. L. Ramseur, and R. R. Duncan. 1990. Soil aluminum effects on the growth and aluminum concentration of sorghum. *Agron. J.* 82:313-318.
- Stickler, F. C., S. Wearden, and A. W. Pauli. 1961. Leaf area determination in grain sorghum. *Agron. J.* 53:187-188.
- Sutton, P., and W. A. Dick. 1987. Reclamation of acidic mined lands in humid areas. *Agron. J.* 41:377-405.
- Taylor, G. J. 1989. Multiple metal stress in *Triticum aestivum*. Differentiation between additive, multiplicative, antagonistic, and synergistic effects. *Can. J. Bot.* 67:2272-2277.
- Wilson, N. D., D. E. Weibel, and R. W. McNew. 1978. Diallel analyses of grain yield, percent protein, and protein yield in grain sorghum. *Crop Sci.* 18:491-495.