CHAPTER I

LITERATURE REVIEW
HETEROSIS

It has long been known that in cross-fertilizing species, inbreeding leads to deterioration in the progeny, especially after a few generations. The general result is loss of vigour and reduced fertility, productivity and greater vulnerability to diseases. These deleterious effects can be avoided and the vigour and fertility can be restored by crossing the inbred lines. The hybrid, thus produced are generally taller, sturdier and more productive than the parents. This superiority of the hybrid is known as hybrid vigour or heterosis. Hybrid vigour occurs both in animals and plants and it is not a newly discovered phenomenon. The mule, a hybrid between jack and mare, was used by ancient man for its well-known qualities of strength and stubborn endurance. Darwin also had observed that inbreeding resulted in the degeneration of vigour while cross breeding induced hybrid vigour. The best example of heterosis in plant is hybrid maize (corn). The use of hybrid corn in the United States has resulted in substantial increase in yield. Degree of heterosis is difficult to estimate statistically. However, when F₁ is found better than either parent (P) the existence of heterosis is indicated. In the studies on heterosis, the objective is to measure the level or the behaviour pattern of hybrids. As per the hypothesis of complementation at cellular and subcellular levels, growth and yield are considered to be the result of a series of reactions. Any change in even a
single reaction can alter the final product. Here the behaviour pattern is compared with the better parent or lower parent.

The term heterosis has been used to define a broader range of phenomena. For example, heterosis per se denotes a superiority of trait in the progeny over both the parents. When heterosis is based on mid-parent value, the progeny is not superior to both the parents, but considered superior to the mean of both the parents. The hybrid follows the better parent, if the behaviour pattern is heterotic on the basis of mid-parent value, and is close to the value of the better parent; obviously it becomes superior to the lower parent. Likewise the hybrid is said to follow the lower parent, when it is close to the lower parent and in this case, it is not considered to be heterotic.

Several workers have developed methods to express heterosis. Walton (1971) and Khanna (1974) held mid-parent value as the basis.

\[
\text{Heterosis} = \frac{F_1}{(P_1 + P_2)/2} \times 100
\]

The mid-parent value has been used to assess heterosis in nitrate reductase activity (Bhatt et al. 1979) and grain yield (Dhonukshe 1979, Paschal and Wilcox 1975, Paterniani 1980, Major et al. 1972, Turner 1953). However, Liang et al. (1972), Rao and Murthy (1970), Bailey et al. (1980), and Shrivas and Singh (1982) attempted to quantify heterosis on the basis of the value of the better parent.

\[
\text{Heterosis} = \frac{F_1 - \text{better parent}}{\text{better parent}} \times 100
\]
Theories

The present-day explanations of heterosis are based on the following main theories.

1) Dominance hypothesis:

In this theory (Brewbaker 1964), it is assumed that the parental inbreds could be dominant in some factors. If these differences in two parents existed at different loci then the hybrid could be benefited by having all dominant loci and hence better than the parents as in the following example.

<table>
<thead>
<tr>
<th>Parent I</th>
<th>Parent II</th>
</tr>
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<tbody>
<tr>
<td>aa, BB, cc DD</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>AA, bb, CC dd</td>
</tr>
</tbody>
</table>

F1

Aa, Bb, Cc, Dd

2) Complementation at cellular and subcellular levels:

The growth and yield of a plant are the result of a series of reactions. Lack or poor potential of even one reaction in the long chain can influence the final product. If it is considered that the synthesis of substance "X" has four steps A, B, C, D and if one step, say B, is completely missing or less efficient then the synthesis of "X" will be poor. If two parents having less efficient synthesis because of less efficiency at B in one parent and D in another parent are crossed the hybrid will be efficient in B and D. Thus there
will be higher rate of synthesis than its parents, and hence heterosis (Robbins 1952, Brewbaker 1964).

3) Physiological stimulus and initial capital:

It was suggested long ago by East and Shull (1908) that heterozygosity provided some physiological stimulus that resulted in enlarged size, vigour, and higher yield in hybrids. Ashby (1932, 1937) concluded that the hybrids had larger embryo and thus started with a higher initial capital to provide a physiological stimulus. However this theory was not accepted by others.

An important point to remember is that hybrid vigour decreases rapidly in F2 generation, and diminishes in each succeeding generation. In order to obtain higher yields therefore, fresh hybrid seed must be used for each season (Paterniani 1980, Jataasra et al. 1980). Furthermore, crossing of dissimilar plants does not always lead to heterosis. Dhanukhe and Rao (1979) observed that out of 36 hybrids only 24 showed significant heterosis in grain yield. Paschal and Wilcox (1975) obtained heterosis for yield in 12 hybrids out of 30. Mishra et al. (1981) found heterosis in nitrate reductase activity in 14 hybrids out of 21. Shrivas and Singh (1982) studied 10 sesame cultivars and their 45 hybrids. They observed that 10 crosses were taller than their better parent and 16 were shorter. Rao and Vankateswarlu (1971) grouped the hybrids as heterotic and non-heterotic based on their yield performance.
Griffus (1959) discussed several aspects of heterosis in barley and concluded that there is no single gene system operating for yield. Yield is an end product of multiple interactions between several yield components. Therefore heterosis obtained in yield should be the result of many heterotic factors. Paschal and Wilcox (1975) noted in soybean that heterosis for yield was greater than any other character. Number of pods per plant was the most heterotic. Number of seeds/pod and seedsize of F$_1$, was intermediate to parental value. Jost and Hayward (1980) observed heterosis in grain yield of wheat eventhough 2 of the 3 yield components were intermediate to parental value. Jensen and Jonsson (1981) found no heterotic effect on root growth whereas shoot weight of rye wheat significantly exceeded those of both rye and wheat. Hence they concluded that heterosis was localized mainly to the shoots of the hybrids. Likewise, Shrivas and Singh (1982) found in sesame that a cross which showed high degree of heterosis for one trait did not show heterosis in other traits.

Physiological analysis of heterosis:

A simplified explanation for hybrid vigour has not been found so far. The favourable phenotypic expression of heterosis is important from the crop production point of view. The physiological analysis of heterosis will help elucidate the phenomenon of heterosis.

1) Heterosis in growth:

F$_1$ hybrids were found to be superior to the parents for height in maize, bean and sorghum. The percent heterosis over
better parent was 22.4, 31.7 and 41.5 respectively (Sinha and Khanna 1975). The number of nodes and length of internodes determine plant height. Analysis of sorghum hybrids CSH-1, CSH-2 and CSH-3 (Rao and Venkateswarlu 1971) revealed that the node number and internode length was dominant in CSH-2, whereas topmost internode length was equal to that of higher parent in all hybrids. Shivas and Singh (1982) examined 45 hybrids with their parents and found that 10 crosses were taller than their better parent, and 16 were shorter which indicated that not all hybrids showed heterosis for plant height. Heterosis in plant height was also observed by Singh and Singh (1979), Lodhi and Sangwan (1979), Paschal and Wilcox (1975).

Leaf area is an important factor for dry matter accumulation and grain yield. Heterosis in leaf area was observed in sorghum, bean and maize (Sinha and Khanna 1975). Duarate and Adams (1963) made a genetic analysis of the components of leaf area in Phaseolus vulgaris. It was found that $F_1$ dominated in leaf number, but leaf size was intermediate between parents. Nösberger (1970) noted heterosis in leaf area of the plant, but in number of leaves the $F_1$ hybrid followed one of the parents, while for width of leaves the $F_1$ was intermediate. Quinby (1970) observed no heterosis in number of leaves in sorghum. Harer and Bapat (1982) examined heterosis in sorghum and found heterosis in plant height, leaf width, leaf area, but there was no heterosis in leaf number.
2) Heterosis in dry matter accumulation:

Heterosis to the extent of 124 and 195% of the better-parent was recorded in forage sorghum for green fodder yield and dry matter yield respectively (Lodhi et al. 1978). The total dry matter production of the two heterotic hybrids G3H-1 and G3H-2 was greater than the parents at all stages of growth, whereas other non-heterotic hybrids were superior only up to 90 days (Rao and Venkateswarlu 1971). Initial differences in dry matter are small, but they go on enlarging as time passes (Nösberger 1970). The two major components of dry matter production are the leaf area and the net photosynthesis rate per unit area or the net assimilation rate. Nösberger (1970) observed heterosis in net assimilation rate (NAR) over the mid parent. However, when expressed on the basis of unit amount of chlorophyll, there was heterosis. Voldeng and Blackman (1973) Donaldson and Blackman (1973), Beauchampet et al. (1976), Nielsen and Barber (1978) had also reported heterosis in dry matter production.

3) Heterosis in the rate of photosynthesis and chlorophyll content:

Heterosis in the rate of photosynthesis was observed by Khanna and Sinha (1975). Protsenk et al. (1964) suggested that the photosynthetic process in the hybrids is controlled by a successful heritable combination of chlorophyll content of the parents. The amount of chlorophyll was examined in
maize (Nosberger 1970) and sorghum (Khanna 1974); and on plant basis there was heterosis, but on unit weight basis the hybrid followed better parent. Flanchon (1976) recorded higher concentration of chlorophyll in hybrids than in parental lines, and he concluded that at least one parent should have higher chlorophyll content to expect new progress in the hybrid. He further found that yield potential was not always related to the concentration of chlorophyll in leaves. Bhatt et al. (1981) analysed very young shoots (96 hour) of sorghum hybrids CSH-1, CSH-5, CSH-6 and their parents for chlorophyll "a", chlorophyll "b" and ascorbic acid. In all hybrids both chlorophylls and ascorbic acid turn over showed better parental and/or mid-parent heterosis.

4) Heterosis in yield:

Remarkable improvement in crop yield has occurred due to heterosis. Heterosis in yield was found in sorghum (Harer and Bapat 1982, Quinby 1974, Singhania 1980, Maranville et al. 1980a); maize (Eweida et al. 1980, Bhalla et al. 1980, Schuster and Rojc 1980); rice (Singh and Singh 1978); wheat (Jatasa et al. 1980); soybean (Paschal and Wilcox 1970); and barley (Fejer and Fedak 1980). The main components of yield in sorghum are 1) number of grains per panicle and 2) 1000 grain weight. Heterosis in yield is manifested through heterosis in yield
components. Jatasra et al. (1980) observed hybrid vigour for yield and yield components in wheat. Bhalla et al. (1980) observed that the crosses of maize showing superior heterotic value for yield also showed hybrid vigour with respect to ear length and ear diameter. Singh and Singh (1978) observed heterosis in rice for number of productive tillers and grain weight; whereas there was negative heterosis for panicle length and 1000 grain weight.

The relationship between dry matter production and its partitioning which is responsible for yield is important. In other words a balance between source or the photosynthate supply and sink has to be maintained to increase the yield. Rao and Venkateswarlu (1971) examined dry matter production and grain yield in two heterotic and two non-heterotic sorghum hybrids. The non-heterotic hybrids were heterotic in dry matter production, but the sink potential was not enhanced and therefore were non-heterotic in grain yield.

5) Heterosis in seedling growth:

Bhatt et al. (1981) examined the growth pattern unto 96 hour of germination and observed that the shoot growth of sorghum hybrids CSH-1, CSH-5, CSH-6 was greater than parents. In heterotic hybrids, early germination of seed and early leaf emergence were noticed (Edje and Burris 1971, Lowe et al. 1972). Demirlicakmak et al. (1963) noted that plants grown from large seeds have a faster growth rate, produce more tillers and have high grain yield.
The germination proceeds with the absorption of water, followed by the activation and synthesis of enzymes. Ghose et al. (1974) found that the hybrid followed the better parent in water absorption. Hageman et al. (1967) indicated that the hybrid utilizes its endosperm reserve at the same rate as does one of the parent.

6) Heterosis in root growth:

Heterosis in root growth was reported by Ashby (1937), Robbins (1940, 1941), Paddick (1944), Whaley (1939, 1952), Sarikissian and Srivastava (1967) and Sinha and Ghildiyal (1971). Murphy and Long (1979) observed that oat hybrids have greater shoot and root length as compared to their parents. Root growth is dependent on shoot growth and the two maintained a particular ratio for genotype (Troughton and Whittington 1969). Photosynthates are translocated from shoot to root (Stoy 1969). Hattrick and Bowling (1973) found a close correlation between root respiration and carbohydrate transport from the shoot. Crapo and Ketelapper (1981) observed that reduction in photosynthates to roots reduced root growth. Hence enhancement of photosynthetic potential could lead to enhanced root growth.

Heterosis in root morphological characters was also noted. Balko and Russell (1980) pointed out that maize inbreds have less root growth in clump than hybrids and therefore will extract less N from the soil. Blum et al. (1977) found that heterosis was significant in all sorghum hybrids for length of
seminal roots, growth rate of adventitious roots, and root volume. Consistent heterosis was not revealed in the number of adventitious roots per plant nor in seminal and adventitious root dry matter. Nielsen and Barber (1978) found that hybrids followed mid-parent in root length. Genotypes showed negative correlation between root length and I-max (maximum P influx) which revealed that genotypes with longer, finer roots absorbed P more slowly per cm of root.

7) Heterosis and nutrient uptake:

Heterosis in the uptake of N, P, K was reported by Rabideau et al. (1950), Nosberger (1970), Rao and Venkateshwarlu (1971). Beauchamp et al. (1976) observed greater N accumulation rate (q N/plant/day) in one of the three corn hybrids than in parental inbreds. In many of these instances, the data were expressed on plant basis. As early as 1934, Smith reported that no heterosis existed if data were calculated on unit weight basis. Even the data of Nosberger (1970), Rao and Venkateshwarlu (1971) and Sinha and Ghildiyal (1971) showed that there was no heterosis in nutrient uptake on unit weight basis. The same view was expressed by Sinha and Khanna (1975) in their review article.

There are few articles after 1975 which deals with the problem of heterosis in mineral uptake. To understand the physiological basis of heterosis in nutrient uptake, it was felt very necessary to know the cultivar differences from the viewpoint of mineral absorption, translocation and requirement. (The review of cultivar differences is presented separately). The "heterosis" in nutrient
uptake can be split into the following components.

Nutrient uptake = Root weight \times Absorption per unit weight.

Epstein and Jefferies (1964) concluded that variation in nutrient uptake can be due to variation in root morphology and also uptake mechanisms. Knowledge of ion absorption kinetics of roots in genotypes is important to understand the efficiency in ion absorption from soil.

For evaluating heterosis in mineral uptake, Frick and Bauman (1978) suggested a criterion, "Augmentation potential", which was greater in hybrids than in the parents. They further claimed that hybrids with greater than 225% augmentation potential were positively heterotic.

8) Heterosis in relation to its female and male parents:

The term heterosis has its origin in heterozygosis, which indicates the consequence of hybridity. Naturally the hybridity gives better possibility for expression by the two parents. Moll et al. (1962) indicated that greater genetic diversity of the parental varieties provides greater heterosis in the varietal crosses. Warner et al. (1968) observed that for nitrate reductase in maize, the F₁ resembled one parent in the rate of enzyme synthesis and other parent in the rate of in vivo decay. The interspecific hybrid, pearl millet x napier grass, has the leaf and high quality characteristic of pearl millet and short day sensitivity of napier grass (Wayne and Warren 1980).
Harer and Bapat (1982) examined 15 parents and their 50 grain sorghum hybrids and observed that hybrids of 36A female were high yielding, similarly the hybrids involving the male parent SC 120 were also high yielding and early maturing. Maranville et al. (1980a) found that the response of sorghum hybrids was more closely related to female parent in grain and stover yield and for grain N concentration. For percent stover nitrogen, the influence of male and female parents was equal.

These observations revealed that a hybrid may resemble male or female parents or both. It is also possible that it may acquire some components of character from female and some from male parents.

CULTIVARS

The wild species are said to be well adapted for the environment in which they thrive. The individuals better adapted or more fit for their environment, make successive generations. Such individuals of species, showing a certain amount of variation in form, size, colour and physiological processes, and are distinctly different from each other are said to form variety. When two varieties differ in respect to absorption of certain elements but not in other elements, the differences are due to genetically controlled mechanisms of mineral nutrition. When the differences are quantitative, the process is probably controlled by a number of loci. The concept "that gene influences
chemical reactions, specially synthesis of enzymes and thus exert their effect", was first put forth by Garrod (1909).

Beadle and Tatum (1959) demonstrated numerous deficiencies resulting from single gene mutation and made the Garrod's concept significantly understood. Graham (1978) noted genetic differences in nutrient efficiency among crop plants for phosphorus, copper and zinc. Some genotypes do not have the capacity to extract nutrient from the soil, even when present in sufficient quantity. Harvey (1939) noted that many of the differences in corn lines for nutrients were inherited. Strains, varieties, and inbred lines of crop species differ in the physiological mechanisms of ion transport and also root morphology (Epstein and Jefferies 1964).

Varietal differences in root growth and its significance:

Root is the plant organ that comes in direct contact with soil and absorbs required nutrients from it. Most nutrients move by mass flow and/or diffusion through soil to the root surface and thus become positionally available for absorption by the root. Variation in root growth amongst hybrids and cultivars has been recorded in many crop species (Zartman and Woywodzie 1979, Jorden et al. 1979, Raper and Barber 1970). Schenk and Barber (1980) studied root morphological characters in three corn genotypes. One genotype had most of its roots in top soil where K and P supply was higher. It also had the largest root surface per unit of shoot; this caused the higher P content in
shoot. Nielsen (1979) noted that the efficiency of nutrient uptake increased with an increase in root length per unit weight of plant. Andrew and Hageman (1980) obtained differences in nitrate uptake due to differences in the sizes of root system. Gerloff (1976) noted varietal differences in shoot : root ratio. The shoot : root ratio changed in snap bean varieties when grown under different levels of P. An early development of an extensive root system makes a variety more efficient in absorbing nutrients from a limited availability source, and thereby gains an advantage over other varieties. The uptake of N, P, K, Ca, Mg per meter of root was greatest for the early growth stage and decreased with plant age (Lee 1960). Similar results in corn were noted by Warncke and Barber (1974), Mengel and Barber (1974a, 1974b). Blair and Cordeo (1978) on the contrary, found that the legumes having greater efficiency produced a smaller root system than the inefficient ones. The greater root efficiency may have been associated with a difference in root distribution and root hair density. Nye (1966) observed that for phosphorus the more efficient root anatomy appears to be thin roots covered with root hairs.

Varieties differ in the effect of root-stock on the mineral composition of scion. Epstein and Jefferies (1964) reviewed numerous instances, illustrating that the root-stock markedly affected the concentration of nutrients and other elements in the scion. Pearse (1940) found the quantities of nitrogen and potassium significantly different in the shoots
grafted on two root-stocks of different varieties of apple.

Brown et al. (1958) produced evidence that the roots are responsible for the differential susceptibility of two soybean varieties to iron chlorosis.

**Varietal differences in mineral uptake:**

Genetic differences in cultivars are important in developing cultivars with differing responses. Epstein and Jafferies (1964) referred to many experiments in which soil grown plants of one variety were found to contain higher or lower amount of particular elements per unit weight than did plants of another variety grown under identical conditions.

1) Potassium:

Walker and Schillinger (1975) observed that soybean genotypes usually yield about the same under high as well as moderate K fertility. However, one variety responded better for high K. Gerloff (1976) and Shea et al. (1968) found differences amongst soybean varieties for efficiency in K utilisation, especially under K stress. Duncan (1981) compared 17 different grain sorghum genotypes for their leaf K, P content and observed that each genotype was unique in its capability to extract P and K from soil. Pandey and Kannan (1982) observed varietal differences in Rb uptake pattern among rice cultivars in laboratory studies. Schenk and Barber (1980) studied three genotypes of corn and observed higher P content in one genotype.
than in others. However, K concentration did not differ between varieties. It has been noted however that cultivars differed in their efficiency of nutrient utilization, i.e., dry weight produced per gm of element absorbed. Jensen and Pettersson (1980) showed differences in utilization of K amongst 11 varieties of barley. They also suggested that there could be wide differences in such properties as ion influx and efflux, and net ion transport to shoot.

2) Phosphate:

Varietal differences in phosphate uptake were observed by several workers (Smith 1934, Howell and Bernard 1961, Epstein and Jeffries 1964, Kleese et al. 1968, Rao et al. 1979, Kovacevic 1980). Estes and Bruetsch (1973) noted differences in P uptake by roots which was attributed as due to the morphological differences in the root (Rabideau et al. 1960). Clark et al. (1978) recorded marked differences amongst sorghum genotypes for uptake, accumulation and distribution of P. Fox (1978) studied a number of corn inbreds and hybrids and found only one of them to have a greater ability to absorb P from soil.

These varietal differences in mineral content were correlated with dry matter production. Rasmusson et al. (1971) found varietal differences in P, K, Ca, Mg (percent dry matter) in grain and leaves of barley and wheat. However, these varieties did not appear to differ in efficiency of converting P and K into yield. Bruetth and Estes (1976) observed that genotypes differ in dry matter production per gram of N, P, K, Ca and Mg absorbed.
He further elucidated that the efficiency of dry matter production per unit of P absorbed was greatest for late maturing hybrids than early maturing. Blair and Corder (1978) used different criteria for determining P efficiency. They noted differences in efficiency and the order of efficiency varied according to the criteria used. Clark and Brown (1974) defined efficient plants as those plants that accumulate higher concentration of phosphorus when they are grown at a given level of phosphorus. Lyness (1936) found that the strains which are most efficient under P stress would not be the most effective under optimal P supply. Whiteaker et al. (1976) observed similar findings in snap bean at three levels of phosphorus.

3) Varietal differences in other elements:

Hay et al. (1953) examined the accumulation and translocation of nitrogen in two corn hybrids. The data show that the proportion of N translocated to grain from other plant parts depends upon the hybrid. Similar varietal differences in translocation of N from individual leaf blade were noted by Beauchamp et al. (1976), Halloran (1981). Maranville et al. (1980b) found 20% difference between the least and most efficient sorghum hybrid in N efficiency, when calculated as total dry matter per unit of N uptake (NE1). The other criteria used were total grain yield per unit of N uptake (NE2) and the product of NE2 and grain : stover N ratio (NE3). It was noted that each N efficiency criterion ranked the hybrids differently.
Variatual differences in mineral uptake for elements other than N, P, K, were also observed. Varietal differences for Fe were noted in sorghum (Brown and Jones 1977 b, Kannan 1980), in corn (Estes and Bruetch 1973), soybean (Wei 1943), and rice (Panney and Kannan 1982). Varietal differences for Zn were observed by Brown and Jones (1977 b) in sorghum, Halim et al. (1968) and Peaslee et al. (1981) in corn and Kannan and Ramani (1982) in sorghum.

4) Varietal differences in absorption kinetics:

Pettersson (1978) examined the uptake efficiency for Rb and SO₄ in genotypes of barley. He observed that in two cultivars though the root weight was same they were extreme in uptake. Further experiments indicated that the differences in Rb uptake efficiency were due to variation in Rb influx at the plasmalemma of the root cell. Andrew (1966) measured Kₘ and Vₘₐₓ values for roots of different species and suggested that the effectiveness of the uptake mechanism vary among species. Baligar and Barber (1979) studied the influx characteristic of Florida and Indiana corn genotypes. Florida genotypes had significantly higher Iₘₐₓ values for Ca and P. Kₘ value for K was higher in Indiana genotypes than for Florida where Indiana genotypes had lower Kₘ for P. Schenk and Barber (1980) observed that uptake parameters and Iₘₐₓ, Kₘ, Cₘₐₜ varied several fold between genotypes. They further found that a genotype having favourable properties for absorption of K was not necessarily also superior in P uptake parameters.
Glass and Perley (1980) observed that barley varieties differed significantly with respect to $K_m$ and $V_{max}$ for influx. The efficiency of nutrient uptake (Nielsen 1979) increases as $I_{max}$ and root length unit of plant weight increased and as $K_m$ and $C_{min}$ decreased. Plant should have higher $I_{max}$ in order to absorb rapidly at high nutrient level and a small $K_m$ and $C_{min}$ to recover the nutrient supply of soil at low nutrient level.

**SORGHUM**

Sorghum (*Sorghum bicolor* (Linn.) Moench), popularly known as "Jowar" in India, is the most important food and fodder crop of dry land agriculture. The area under sorghum cultivation in India is 17-18 million hectares and the annual production is 8-10 million tonnes. On the basis of area under cultivation and production, sorghum stands as the third major crop in India and first in the state of Maharashtra. The average yield is around 500 Kg/ha; however the hybrids and high yielding varieties yield 2000 - 3000 Kg/ha under normal growing conditions; but have a maximum yield potential of 6000 - 7000 Kg/ha under highly favourable conditions. In the State of Maharashtra the area under hybrid sorghum cultivation is about 2.5 million hectares out of total cultivated land of 5.8 million hectares. The average yield of hybrid is about 1536 Kg/ha while that of local cultivars is about 650 Kg/ha. The introduction of hybrids in sorghum has revolutionized the grain production in the country.
Out of 15 cultivars released by All India Sorghum Improvement Project, eight are hybrids CSH-1 to CSH-8. The important point to be remembered about hybrids is their good response to fertilizers. In Maharashtra the normal recommendations for hybrids are, 100 Kg N, 50 Kg P₂O₅ and 40 Kg K per hectare against the 25 Kg N, 15 Kg P₂O₅ and no K for local varieties. Pawar and Narkhede (1980, 1981) compared the sorghum hybrid CSH-1 with the best local cultivar M35-1 and found that dry matter per plant was more in the latter than the former, although the harvest index for these was 30.6 and 39.2 respectively. It was further found that the removal of N P K per hectare was more in CSH-1 than M35-1. Von Vexxull (1982) observed that hybrid rice accumulated large quantities of potassium: 34-36 Kg K₂O/100 Kg grain as against 25-27 Kg K₂O by inbred lines.

STRESS PHYSIOLOGY

1) Salinity:

Salinity is generally caused by the presence of excessive concentrations of soluble salts which restrict the growth of plants. Sodium and chloride are the most prominent ions of the saline substrate. The other ions which play important role in soils are sulphate, bicarbonate, borate and lithium. Salinity is characterized by two unique features: low osmotic potential and high concentration of sodium and other ions which can be toxic. Thus the plant growth in saline soils is
affected mostly by physiological unavailability of water and in some cases, by ion toxicity.

Some plants, namely the halophytes do grow in saline conditions and possess mechanisms for tolerating high levels of salts. In some species, salts are excluded from absorption. In others, uptake occurs but the salt is excreted by special glands in the leaves. Some plant species take the salts but prevent it from reaching the active metabolic sites.

2) Moisture stress:

Water stress is the main problem in agriculture affecting crop production. A water loss from plant causes a water deficit in the cells and cell growth is affected. The lack of turgor pressure hampers the cell enlargement. A depression in cell elongation in maize leaves when the water availability of root medium decreased from 0.16 - 0.2 bars was noted by Acevedo et al. (1971). If stress is prolonged cell division is also inhibited (Hsaio 1973). Karlen et al. (1982) observed that even short term drought reduced K uptake by plants. A reduction in the concentration of phosphate in tomato leaves by drought was noticed by Gates (1957).

3) Mineral stress:

We consider that wild plants are well adapted to their native habitats on the basis that if they were not, they would not be there. Plants adapt to low nutrient availability (Epstein
1972) by two ways. They have greater ability to absorb elements from the low levels of nutrient medium. Alternatively, some possess greater efficiency in the utilization of the elements. There are marked differences among species in their ability to grow in low concentration medium (Loneragan and Asher 1967, Blair and Cordero 1978, Fox 1978). Ranking of species in terms of efficiency vary according to the definition of efficiency used. Clark and Brown (1974) define P efficient plants as those that accumulate higher concentrations of phosphorus when they are grown at a given level of phosphorus. Loneragan and Asher (1967) used the term P utilization efficiency in terms of the amount of dry matter produced per unit of P absorbed. According to Fox (1978) an efficient plant is one that produces a large quantity of harvestable dry matter per unit time and area growing in a medium that has less than sufficient P available for maximum yield.