1 INTRODUCTION

1.1 Botany and ecology

Cowpea is one of the most widely adapted, versatile, and nutritious of all the cultivated grain legumes. They are mainly grown in the warm climates since they require warm soil temperatures for good establishment (Kellher, 1994). They are adapted to a wide variety of soils from heavy to light textured and from the humid tropics to the semi-arid tropics. The adaptation of cowpea to West Africa has been studied in reasonable detail; a summary of early findings is in Wien and Summerfield (1980).

Several types of cowpea may be distinguished, broadly, there are the trailing types that may also climb and twine around other vegetation. These are usually indeterminate in growth habits, and may possibly grow over one or two seasons. Breeding and crop improvement efforts have resulted in "erect" non-trailing and determinate types. The duration of cowpea growth varies widely in different genotypes, but environmental conditions also seem to affect it. According to de Moody (1985), the duration from sowing to flowering may range from 38 to 141 days. Most cowpeas are in general photoperiod sensitive, and according to Wien and Summerfield (1980) they are generally quantitative short day plants with a tendency to flower as the days become shorter. The day length above which flowering is delayed considerably may vary with variety but lies close to 13.5 hours.

1.2 Origin and regions of cultivation of cowpea

Cowpea is a native of Africa, with West Africa (Nigeria) being a major centre of diversity (Ng and Padulosi, 1988). As was observed by Pant et al., (1982), India appears to be a secondary centre of diversity since significant genetic variability occurs on the subcontinent and it is likely that the crop was first introduced to India during the Neolithic period. South-eastern Africa is however reported as the centre of diversity of the wild *Vigna* species (Ng and Padulosi, 1988; Padulosi et al., 1997). According to Ehlers and Hall (1997) *Vigna unguiculata* ssp *dekindtiana* is thought to be the immediate progenitor of cultivated cowpea as members of this group can be hybridised with cultivated cowpea. Several studies carried out in recent times suggest narrow genetic variability in cowpea (Panella and Gepts, 1992; Vaillancourt et al., 1993 (genetic variability based on isozymes), Panella et al., 1993 (seed storage protein diversity) and Vaillancourt and Weeden, 1992 (chloroplast DNA). This is surprising considering the extensive variation in morphological and phenological traits among cultivated cowpea accessions, but however it suggests that the crop has undergone a "genetic bottleneck" during domestication. Four cultigroups of cowpea are recognized (Baudoin and Marechal, 1995): (1) unguiculata, which is the common form; (2) biflora or catjang, which is characterised by small erect pods and found mostly in Asia; (3) sesquipedalis, or yard-long bean, also mostly found in Asia and characterised by its very long pods which are consumed as a green snap 'bean'; and (4) textilis, found in West Africa and which was used for fibres which were obtained from its long peduncles.

The crop is grown on about 7 million ha in warm to hot regions of the world (Rachie, 1985). A large percentage of the world cowpea production is grown in the Sudan and Sahel savanna regions of Africa with Nigeria alone accounting for more than 50% (Table 1). Substantial quantities of cowpea are also produced in South America (largely in semiarid north-eastern Brazil), Asia, and the south-eastern and south-western regions of North America. Cowpeas are also grown in some parts of Europe where the highest yields have been reported. Because of its superior nutritional attributes, versatility, adaptability, and productivity, cowpea was chosen by the US National Aeronautical and Space Administration (NASA) as one of few crops worthy of study for cultivation in space stations (Bubenheim et al., 1990; Ehlers and Hall, 1997).

Cowpea yield is highly variable, with yield of up to 4000 kg/ha reported (Table 1).

Table 1: Cowpea production in selected countries of the world.

Country	Area harvested (ha)	Yield (kg / ha)
Sub-Saharan Africa		
Niger	2,600,000	165
Nigeria	2,200,000	864
Mali	260,000	65
Tanzania	140,000	300
Malawi	78,000	679
Senegal	77,000	454
Uganda	55,000	836
Burkina-Faso	10,000	1,000
Oceania		
Australia	7,000	400
America		
USA	2,130	901
Europe		
Bosnia-H	1,400	1,428
Croatia	100	4000
Macedonia	1,600	3,497
Slovenia	30	3,333
FR Yugoslavia	3,700	3,243

Source: Ortiz (1998).

Ortiz (1998) observed that higher yields were further away from the area of the origin of cowpea. Many factors contribute to the lower yield potential of cowpea in the Sub-saharan Africa (centre of origin). Pest and diseases are primary constraints to cowpea production, other factors include economic, inter-cropping and the occasional drought interval encountered during the growing season. Most of the breeding effort so far has been on improved yield and pest and disease resistance. The cowpea improvement programme of IITA has led to the release of many cultivars all over the world. The success of IITA in developing new cowpea cultivars has been attributed to the extensive germplasm collection that they hold (Ortiz, 1998).

1.3 Drought/water deficit in cowpea

Klohn and Wolter, (1998) wrote "Agriculture is globally the major user of water. Moreover, because the production of biomass requires the evaporation of large amounts of water, agriculture is essentially a consumptive user and water-efficient irrigation leaves practically no return water". They argued that at a time when concern about shrinking availability of water per caput hits the headlines, the prevailing trend is for agriculture to produce more food with less water. The global water scarcity is a tremendous problem that puts a huge pressure on agriculture as competition from other users constantly increases. Even rain fed agriculture is not guaranteed.

As was observed by Fussell et al., (1991), rainfall in the Sahelian zone (300-600 mm) is characteristically variable and undependable. Results of other studies have shown coefficients of variation of the annual rainfall ranging from 15 to 30% (reviewed by Fussell et al., 1991) that was inversely related to average annual rainfall (Cochème and Franquin, 1967). Some studies have shown that the standard deviation for the onset and ending of rains has increased constantly since 1960 and that the length of the growing season itself has been reduced (see Fussell et al., 1991). Results from other regions of the world are also saddening, as they all signify changing patterns of rainfall and distribution that put the crops under stress.

Rumney's (1968) classification of deviation from annual average of world precipitation is shown in fig.1.

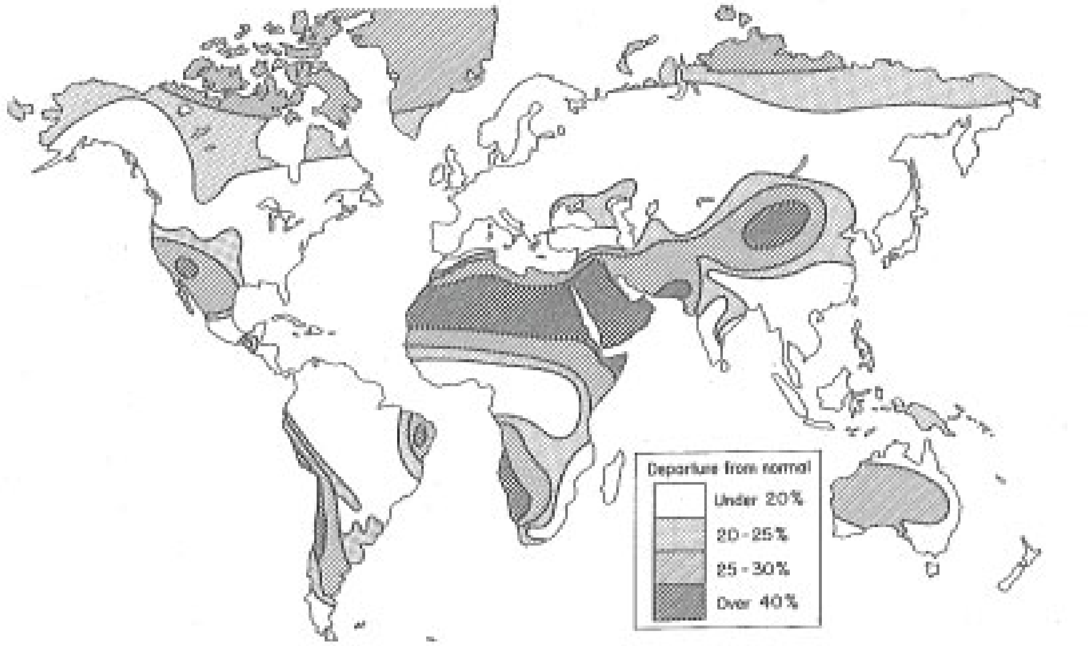

Figure 1: World map showing deviation from annual average of world precipitation (source: Rumney 1968).

The figure indicates that in general the zones with the lowest rainfall tend to have the highest deviation from normal. Nevertheless within any geographical zone, even in a zone of high rainfall there is the possibility of and a randomness to the occurrence of drought that can have widespread and disastrous effects on plant life. This in turn limits all forms of food production.

In a more tropical region where several crops per season may be grown, severe water deficit over period of several weeks can markedly affect crop growth, soil cultivation, and timeliness and success of planting of consecutive or overlapping interrow crops. According to Obeng, (1975), the potential significance of irrigation for achieving further increase in crop productivity in areas otherwise subject to drought stress can be gauged from the fact that of the worlds 3.2 billion hectares of potentially arable land, 2.02 billion hectares are located in the developing regions of Africa, Asia and America, which also have high human populations. About 1.330 billion hectares of this latter area is potentially irrigable land and there is water available in these areas sufficient to irrigate 99% of the land if investment resources and manpower could be made available (Obeng, 1975).

The term drought as it applies to agriculture means water deficit encountered during crop growth. Water deficit may occur in the root or shoot environment of plants, thus the water stress to which a plant is exposed may not be known unless both are known. The two main components of drought resistance in plants are drought avoidance and drought tolerance (Hall et al., 1979; Levitt, 1980; Turner, 1991). Drought avoidance is used to describe the extent to which plant water status is maintained in the presence of water deficit while drought tolerance refers to the extent to which plant function is carried on in the presence of water deficit. Many workers have reported that cowpea is drought-tolerant[1] and show a great deal of drought avoidance under conditions of water deficit. Drought avoidance by cowpeas appears to be mainly due to several mechanisms for regulating rate of water uptake (Turk and Hall, 1980a). In the presence of soil drought, leaf area expansion rates are slow and the rate of leaflet abscission is more rapid resulting in lower ground cover by the crop (Turk and Hall, 1980b). Shackel and Hall (1979) reported that leaflets of cowpea under drought are oriented such that interception of solar radiation is reduced both on individual leaflet and the entire canopy. Conductance of leaflet to water vapour was shown to decrease during soil or atmospheric drought (Wien et al., 1979). According to Turk et al. (1980), cowpea subjected to environmental stresses may become sink limited. They reported that yield under stress was substantially lower than in control and found pods/m² to be the yield component most sensitive to environmental stress. From the foregoing, studies have indicated that cowpea is relatively a drought tolerant crop producing grains in highly water limiting condition under which many crops would fail. On the contrary the high dry seed yield

[1] Drought tolerance is often used to refer to drought resistance by many authors.

(up to 4000 kg / ha) reported for cowpea under irrigated environment suggests that cowpea in addition to being drought tolerant also have high yield potential. As observed by Watanabe et al. (1997), yield of cowpea have remained low and unstable due to scarce and erratic rainfall encountered during the growing season.

1.4 State of research in Physiology and genetics of cowpea drought adaptation

Water stress during critical growth periods reduces yield and quality of crops. The physiological and physiognomical changes that accompany water limitation in plants are well documented in the literature. There are conflicting results on the stages which are more sensitive to water limitation in cowpea. Under field conditions, increasing the frequency or volume of water applied at each irrigation increased seed yield in some studies (Clark and Hiler, 1973; Singh et al., 1975) but did not in others (Malik, 1974; Wien et al. 1979). In the studies of Summerfield et al., (1976a, 1976b), seed yield of cowpea in controlled environment was reduced only when plants were allowed to wilt repeatedly between emergence and first flower. They did not find wilting effect on seed yield during flowering, pod filling and at maturity. Hiler et al. (1972), found seed yield of cowpea to be most sensitive to drought encountered during flowering. This results were further confirmed by Turk et al. (1980) who found cowpea to be more sensitive to drought during flowering and reported up to 44% yield reduction with respect to the irrigated controls. They also found substantial yield reduction due to drought during pod filling. Thus under field conditions, cowpea can recover from water stress encountered during the vegetative stage to produce seed yield equivalent to unstressed controls provided all other conditions are favourable (Turk et al., 1980).

In the search for traits which contribute to drought resistance in cowpea, selection for early flowering[2] and empirical yield testing of breeding lines under dry production conditions have been useful in developing cowpea cultivars adapted to low rainfall areas of the Sahel (Hall and Patel, 1985; Cisse et al., 1995). According to Gwathmey et al., (1992) delay leaf senescence (DLS) is one trait that may contribute to drought adaptation. The trait acts by enhancing plant survival after a mid-season drought has damaged the first flush of pods, and enable a substantial second flush of pods to be produced (Gwathmey and Hall, 1992). Cultivars with DLS also have enhanced production of forage because their leaves remain green and attached to the plant until harvest (Ehlers and

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[2] Early flowering is actually a drought escape response rather than resistance.

Hall, 1997). Another trait that has also been associated with drought resistance in cowpea is indeterminacy in growth habit. This according to Ehlers and Hall, (1997) makes it possible for cultivars to resume vegetative and reproductive growth more quickly once moisture stress is alleviated. Singh et al., (1997) in a review of recent advances in cowpea breeding, reported that drought-tolerant lines were of two types:

a) Lines such as Tvu 11979 and Tvu 11986 that stop growth as soon as drought stress is imposed, probably to conserve moisture and survive for 2-3 weeks.
b) Lines such as Dan 'lla and IT90K-59-2 in which the lower leaves die off one after the other to conserve moisture and remain alive for a longer time. This group have a better regeneration potential than the others after stress release.

Water use efficiency (WUE) has received a greater attention among the major breakthroughs achieved so far. It is defined as the ratio of dry matter production to water use (Hubick et al., 1986). Hubick et al., (1986) observed that WUE might not provide much information about the competitive or yield advantage of one particular species over another, because improved WUE may actually restrict growth. However it is one trait that has been studied so much because it can give an idea of the variation amongst genotypes in ability where water is limiting. This was demonstrated by Passioura (1994) when he defined:

Yield = water transpired * WUE * harvest index

for water limited environment. When it is assumed that these 3 components are independent of each other, an increase in any one of them is likely to increase yield (Passioura, 1994; Hubick, et al., 1986). Few evaluations have been conducted of genotypic differences in WUE since its discovery due mainly to the volume of work involved in direct measurement (Hall et al., 1997)

Relief came with the discovery by Farquhar et al. (1982) that the extent to which C_3 plants discriminate against ^{13}C during carbon assimilation was related to their water use efficiency. Ever since much research has been conducted to investigate the theory. While a large volume of literature is available that collaborate this theory (Wright et al., 1988; Hall et al., 1992; Ismail et al., 1994), some others however did not (Condon et al., 1987; Austin et al., 1990). Ngugi et al. (1996) also did not find sufficient genetic correlation between grain yield and carbon isotope discrimination among field grown genotypes of cowpea. Passioura (1994) attributed the variation to be due apparently to confounding effects of a large variation in vapour pressure deficit (ν) during the season or possibly diurnally. Hall et al. (1997) did not recommend selection for low isotope discrimination in cowpea for now although it was possible to improve WUE using the method. They observed that empirical studies indicate that general adaptability may be associated with high carbon isotope discrimination. Above all it is a very expensive technique to use (about 15 US dollars to analyse a sample) (Hall et al., 1997). In a review of recent advances in cowpea breeding, Singh et al. (1997) also observed that the use of carbon isotope discrimination and assessment of other physiological parameters are too expensive for use in breeding programme. Instead they recommended the wooden box technique as more appropriate for developing countries. The wooden box technique is a special method that involves growing the plants in wooden boxes which permit visual non-destructive study of shoot drought tolerance.

1.5 Statement of problem

The volume of publication on crop performance with respect to water deficit continues to increase on a daily basis. As Loesch (1995) observed, research on plant water relations continues to produce world-wide approximately two papers per day. However the gap between physiology of drought adaptation and breeding for improved performance under water stress is still very wide. This may be due to the difficulties to identify and assess physiological traits conferring drought adaptation. Again most of the results obtained so far have been very conflicting. Turk et al., (1980) suggested that the indeterminacy of cowpeas, differences in drought levels between experiments and other environmental factors could be responsible for the conflicting results. Although cowpea is regarded as drought-resistant, the ever-increasing threat from water scarcity and the erratic rainfall in area of cultivation calls for a higher resistance to drought to get higher and more stable yields. Little information is available regarding genotypic variation for drought tolerance in legumes (Subbarao et al., 1995). In cowpea, the large amount of genetic material available has not been fully exploited to test for variability in drought-resistance. The few studies done so far to compare genotypes have often failed to define the level of drought accurately, most especially; they have failed to compare the genotypes under similar growth stages. Since cowpea growth and development is highly varied among genotypes, it is necessary to test for variation by subjecting different genotypes to the same drought conditions at same growth stages. To adequately study drought responses or resistance of different crops or cultivars, a defined drought of known intensity and duration is necessary.