Drought Tolerance of Cowpea (*Vigna unguiculata* (L.) Walp.) II. Field Trial in the Dry Season of Sudan Savanna and Dry Matter Production of Potted Plants under Water-stress

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Abstract

A field trial of cowpeas (*Vigna unguiculata* (L.) Walp.) was performed in the dry season at Kano in Sudan Savanna of Nigeria. Grain yield of highly drought-tolerant lines (TVu 11979, 11986, 12348) was around 1 t/ha, while that of highly susceptible ones (TVu 7778, 8256, 9357) was only about 0.2-0.3 t/ha. The productivity of 1 t/ha was similar to that recorded in the rainy season at Kano. This trial confirmed the results of previous evaluation of drought tolerance of cowpea lines. It also suggested that highly tolerant lines could be cultivated in the dry season in farmers' fields. Two cowpea lines (TVu 11979: highly tolerant to drought, TVu 9357: highly susceptible to drought) were cultivated in pots at Tsukuba, Japan. Half of the pots were subjected to water stress (hereafter referred to as stressed plot) and the others were watered periodically (control plot). In the stressed plot, dry matter increase per plant was markedly and equally reduced in both lines and no difference was observed between the highly tolerant line and the highly susceptible one. The distribution of dry matter among plant organs, however, was different at the ripening stage between the two lines. In the highly tolerant line, a larger proportion was distributed to roots, and a smaller proportion to pods in comparison with the highly susceptible one. This characteristic of highly tolerant lines seemed to be very advantageous for collecting residual water from deep soil layers and for dry matter production in the dry season. However, when the

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lines were planted in pots, the root zone was limited. The vigorous growth of roots of these tolerant lines, therefore, could be ineffective in collecting water in potted plants.

Additional key words: cowpea breeding, deep-rooting character, dry matter distribution

In Sudan Savanna, where the crop season is strictly limited by the short duration of precipitation, no crops are cultivated in the dry season except for irrigated crops or legumes in suburban districts. The short duration of the crop season results in an unstable food supply especially in the dry season and a steep rise in the price of staple foods towards the end of an off-season. The development of new cropping systems in the dry season, therefore, may enable to stabilize the annual food supply and alleviate the food shortage in the developing countries of the region.

In the experiment carried out for the field evaluation of drought tolerance in the dry season, reported previously[11], we identified highly tolerant lines bearing several fruits. It was challenging to cultivate such lines in the dry season for developing a new cropping system without irrigation. In this trial, we also expected to confirm the results of previous evaluation of drought tolerance by planting highly tolerant lines, as well as highly susceptible ones.

Dry matter production of potted plants was also compared between a highly tolerant line and a highly susceptible one, and between water-stressed plants and non-stressed ones. Since the root zone of a potted plant is small and limited, we expected to evaluate the deep-rooting character as one of the causal traits for drought tolerance, by comparing the performance under water stress between field cultivation and pot cultivation.

Materials and Methods

1) *Field trial in the dry season*

In the end of the rainy season, on September 28, 1994, three highly tolerant lines (TVu11979, 11986, 12348) and three highlysusceptible ones (TVu 7778, 8256, 9357) were planted at Minjibir Field, International Institute of Tropical Agriculture (IITA), Kano Station, Kano, Nigeria. One line was planted in 3 randomized plots, each of which consisted of 4 rows 4m long (interval between rows 75cm, between hills 40cm, 2 plants per hill). Mature pods were collected from the middle 2 rows by hand successively as they matured. No fertilizer was applied. For pest control, insecticide was sprayed two times in November chiefly to control legume bud thrips (*Megalurothrips sjostedti*). The growth period lasted from October to January (highly susceptible lines) or to February (highly tolerant lines) and monthly average temperature ranged from 21 to 26°C.

2) *Dry matter production of potted plants*

On July 7, 1995, two lines, highly tolerant TVu 11979 and highly susceptible TVu 9357, were planted in pots in a glasshouse of Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Japan. After germination, plants were thinned to one plant per pot.

For the first two samplings, a/5,000 Wagner pots were used and for the latter six samplings, a/2,000 pots were used. No fertilizer was applied. Volcanic ash soil was collected from the field of JIRCAS and was stirred well. The a/5,000 pots and a/2,000 pots were filled with 3.5kg and 10.7kg of fresh soil, respectively. The average soil moisture of several soil samples was 34.2%(w/w), which was used for the estimation of the weight of dry soil in each pot and later for controlling the soil moisture.

Soil moisture was adjusted to 30%(w/w) in half of the pots used in a control plot and to 20% for the other half used in a water-stressed plot. Pots were watered on a balance to keep the levels of soil moisture once every three days.

Eight samplings were performed at intervals of two weeks, the first one starting at 25 days after sowing. In each sampling, 20 plants (5 plants x 2 lines x 2 levels of soil moisture) were harvested ,including roots and litter which had been collected and kept in an envelope in each pot. Sampled plants were cut into organs such as leaf blade, petiole, stem, peduncle, pod, root and litter. Dry weight of the organs was measured after drying for two days in an oven. Leaf area of fresh leaves was also measured to calculate the net assimilation rate.

Results

1) *Field trial in the dry season*

All the lines germinated very well due to the adequate soil moisture in the end of the rainy season. The growth of the highly susceptible lines, however, became depressed at later growth stages in contrast to the vigorous and steady growth of the highly tolerant lines (Plate 1). Average grain yield of tolerant lines was about 1 t/h , whereas that of the highly susceptible ones was less than 0.3 t/h (Table 1). Judging from the large difference in grain yield between the two groups, highly tolerant lines and highly susceptible ones,

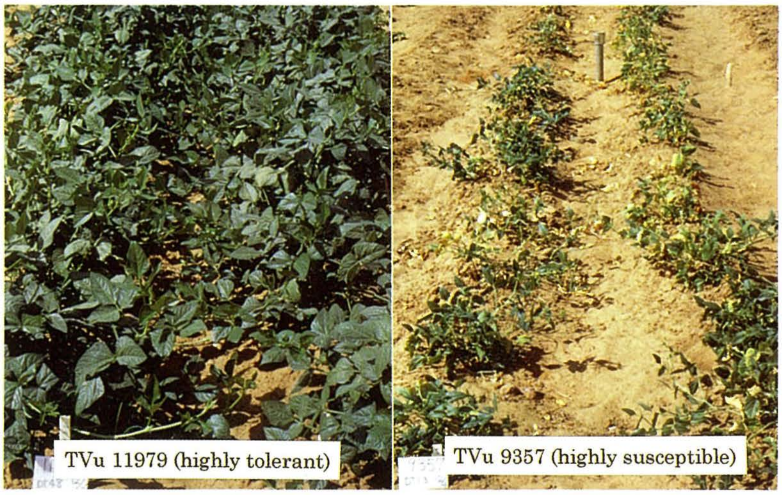

Plate 1. Field trial in the dry season at 67 days after sowing. Sown in the end of the rainy season at Minjibir Field, IITA Kano Station, Kano, Nigeria.

Table 1. Field trial of cowpea lines differing in drought tolerance in the dry season at Kano, Nigeria (1994/1995)

Lines (TVu No.)	Origin	Drought Tolerance score*	Yield (ton/ha)			
			Rep. 1	Rep. 2	Rep. 3	AVG.±SE
11979	Sudan	4.9	1.37	0.67	0.98	1.01±0.35
11986	India	4.9	0.57	0.74	1.46	0.92±0.47
12348	Mozambique	4.7	0.87	0.99	0.87	0.91±0.07
7778	Ivory Coast	1.5	0.24	0.34	0.23	0.27±0.06
8256	Ivory Coast	1.4	0.16	0.24	0.07	0.15±0.09
9357	Ivory Coast	1.3	0.52	0.15	0.15	0.27±0.21

*Highly tolerant: Score≧4.0
Highly susceptible: Score<2.0

the reliability of the evaluation methods reported previously[11] was confirmed. It is worth mentioning that spraying of insecticide twice was sufficient to control pests completely in the dry season due to the small population of important pests such as pod borers, pod-sucking bugs and bruchids.

2) Dry matter production of potted plants

Plate 2 shows the growth of 4 plants at 66 days after sowing (4th sampling), representing highly susceptible TVu 9357(control), highly tolerant TVu 11979 (control), TVu 9357 (stressed) and TVu 11979 (stressed) respectively. The depression of growth by water stress was severe and almost identical in both lines at the level of water stress adopted in this experiment. Branching habit was different between the two lines. TVu 9357 had 4 to 5 long branches, whereas TVu 11979 had 2 to 3 short branches at this stage in the control plot. Stems, peduncles and petioles of TVu 11979 were thicker than those of TVu 9357. Roots of TVu 11979 were also thicker and heavier than those of TVu 9357 as shown in Plate 3.

Time course of total dry weight per plant is shown in Fig. 1-A (control plot) and -B (stressed plot). In the control plot, dry matter production of TVu 9357, whose maturity was earlier than that of

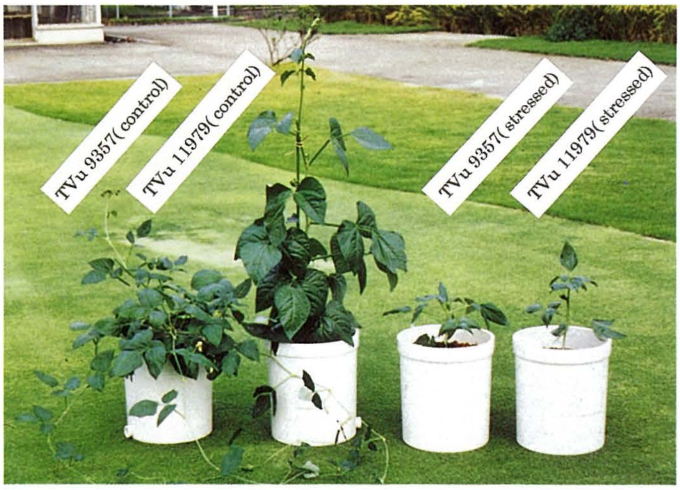

Plate 2. Water-stressed and non-stressed cowpea lines at 66 days after sowing

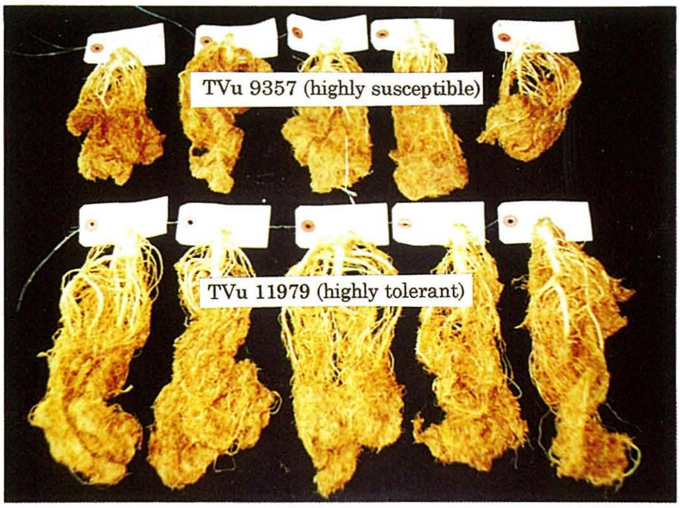

Plate 3. Roots of non-stressed cowpea lines at 67 days after sowing

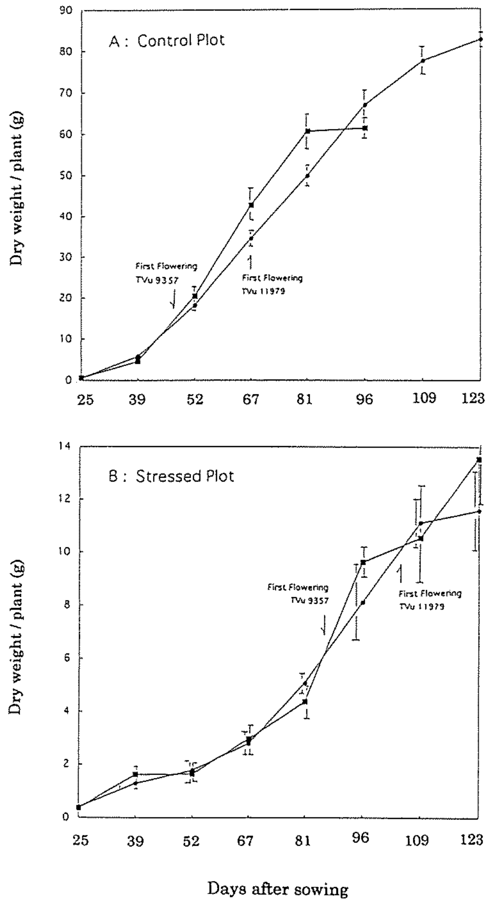

Fig. 1. Time course of dry matter production per plant.
● TVu 11979 ■ TVu 9357

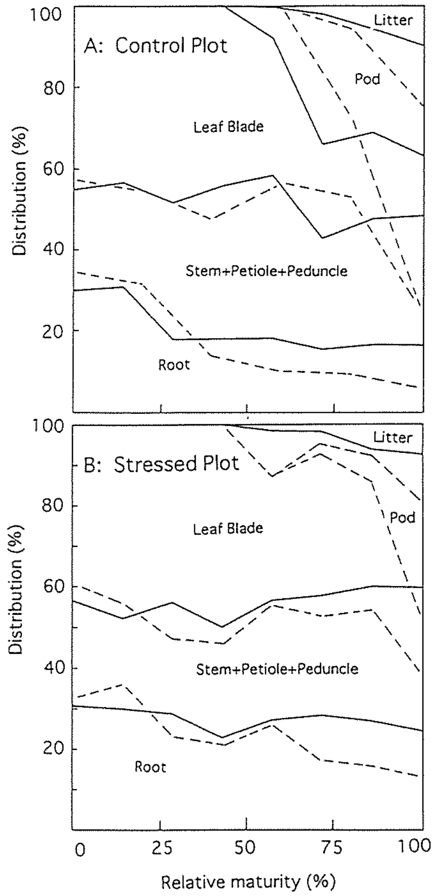

Fig. 2. Dry matter distribution among plant organs.
Relative maturity 0: 25 days after sowing,
100: last sampling
—— TVu 11979 ----- TVu 9357

TVu 11979, was higher than that of TVu 11979 after the first flowering, while at the ripening stage, it was lower than that of TVu 11979. In the stressed plot, dry matter production was lower and growth stages were delayed in both lines. Degree of depression of dry matter production by water stress at the final sampling of control plot (namely Oct. 11 for TVu 9357 and Nov. 7 for TVu 11979) was 84.3% for TVu 9357 and 86.0% for TVu 11979. Therefore, it was concluded that the dry matter production was very severely and equally depressed by the stress in both lines in the pot experiment, in contrast to the field trial described previously.

Time course of dry matter distribution among the plant organs is shown in Fig. 2-A (control plot) and -B (stressed plot). Since it is well known that the distribution of dry matter among plant organs depends on the growth stages, the abscissa expressed here the relative maturity (%) to compare the two lines differing in maturity, rating the date of the first sampling as zero and that of the last as 100.

In the case of highly susceptible TVu 9357, the distribution to vegetative organs decreased sharply after pod formation, with a drastic increase to pods. At the last sampling, pod weight per plant was 31.4 g for the control plot and 4.1 g for the stressed plot, accounting for 51.2% and 30.2% of the total dry weight, respectively. In the case of highly tolerant TVu 11979, on the other hand, the distribution to vegetative organs decreased slowly after pod formation, with a slow increase to pods. At the last sampling, pod weight per plant was 22.4 g (distribution 27.2%) for the control plot and zero (fruits were not produced due to the shedding of buds, flowers and young pods) for the stressed plot.

The most remarkable difference between the two lines was observed in the growth of roots and distribution of dry matter to them. In the case of TVu 9357, root weight decreased at the ripening stage to 3.4 g (5.5%) for the control plot and 1.7 g (12.7%) for the stressed plot. Whereas in the case of TVu 11979, root weight increased continuously even at the ripening stage to 13.5 g (16.4%) for the control plot and 2.8 g (24.4%) for the stressed plot (ref. Plate 3). This continuous growth of roots may account for the vigorous growth of the highly tolerant lines in the field trial described previously.

Time course of assimilation rate in the successive samplings is shown in Table 2. It was affected at the same time by a few factors such as water stress, aging of plants and degree of self-shading. The difference between the control plot and the stressed plot in the average of whole growth period, however, was chiefly due to the effect of water stress. Judging from similar averages between lines and similar degrees of depression by stress, and also from similar rates at earlier growth stages when the effect of aging and self-shading was still limited, it is likely that photosynthesis was equally depressed in the two lines, leading to a similar depression of dry matter production in the two lines.

Discussion

In the field trial carried out in the dry season in Sudan Savanna, highly tolerant lines outyielded highly susceptible ones by far. However, in pot cultivation in a glasshouse at Tsukuba, dry matter production was equally depressed by water stress in the two lines differing in tolerance. The remarkable difference in the results between the field trial and the pot experiment was probably due to the remarkable difference in the root zones in the two experiments. In the field, as the root zone was free, vigorous root growth characterizing the tolerant lines must have been very effective in collecting soil moisture remaining in deep soil layers in the dry season. In pots, on the contrary, since the root zone was restricted and the soil moisture of the pots was controlled, the advantage of this trait could not be revealed.

In the preceding report[11], it was stated that the tolerance scores rated by the two methods, field evaluation method and pot evaluation method, were closely correlated. However, in the pot experiment, no difference was observed in the degree of depression of dry matter production by stress between the lines differing in tolerance to drought. This discrepancy may be due to the difference in the degree of stress in the two pot experiments. That is, in the pot evaluation described in the preceding report, the tolerance was evaluated by the duration of survival under very severe stress conditions leading to death. In the pot experiment for dry matter production in

Plate 2. Time course of net assimilation rate.

mg/dm^2 leaf/day

Lines (TVu No.)	Plot	Soil moisture (%)	Period								Percent against control
			Aug.1-15	16-28	29-Sept.12	13-26	27-Oct.11	12-24	25-Nov.7	AVG.	
11979	Control	30	145.9	82.2	40.6	29.0	27.8	20.9	12.6	51.3	
9357		30	123.3	82.5	44.2	33.8	4.4	—	—	57.6	
11979	Stressed	20	71.6	24.8	27.4	39.3	30.6	26.7	4.0	32.1	62.6
9357		20	90.7	0.9	31.9	27.2	57.5	8.0	34.0	35.7	62.0

this report, on the other hand, dry matter production was measured under relatively mild stress which allowed photosynthesis and dry matter production to occur even though these functions were depressed to some extent. It is concluded, therefore, that the strategy for survival under very severe stress, namely thrifty use of water for instance, is different from the strategy for larger dry matter production in the field, namely deep-rooting trait for instance, by the exploitation of a larger amount of receding soil moisture in the dry season. Since there was no difference in the water use efficiency among cowpea lines[9], dry matter production of potted cowpea under the same level of stress, is expected to be the same among lines differing in tolerance, as was the case in the current pot experiment.

The importance of the deep-rooting trait for drought tolerance has often been reported, by comparing the tolerance among species[2,3,4] and within species[1,5,7,12], which may be related to the fact that a large quantity of soil moisture remains in deep soil layers in the dry season.

The residual and available soil moisture (soil moisture above 4.0% (w/w) below which apparent photosynthesis becomes undetectable in cowpeas in the sandy soil at Kano) at the Minjibir field of IITA Kano Station, in the end of the rainy season (Sept.6, 1991), was 255kg/m^2 and 171kg/m^2 for a soil depth in the range of 0-180cm and 0-120cm respectively[10]. It decreased continuously afterwards by evaporation to a level of 57kg/m^2 and 19kg/m^2 for the respective soil ranges 14 weeks later, when cowpeas planted in the end of the rainy season were assumed to be mature. These amounts of soil moisture were estimated to be equivalent to a biomass of 3.4t/ha and 1.1t/ha respectively, based on the water use efficiency of 6 mg dry matter/g transpiration[9]. Assuming that the distribution percentage of dry matter to grains was 40%, grain yield of cowpeas was estimated to be 1.4 t/ha for a root zone of 0-180cm and 0.5 t/ha for that of 0-120cm. In this calculation, limiting factor for the growth was the amount of residual soil moisture only, which seems to be unrealistic. Still, we can estimate the importance of the deep-rooting trait for drought tolerance, especially in terminal drought[8] in which plants have no other means of survival and further growth than the 'maintenance of water uptake'[8]. One of the specific characteristics of cowpeas is that vegetative growth and reproductive one overlap for a long period of time, which reduces the harvest index and makes it difficult to harvest by machines. The degree of overlapping differs in varieties.

This characteristic is not useful in modern agriculture, while in subsistence agriculture, it is convenient for manual harvesting and for fodder-use of the remaining biomass.

Another important advantage of overlapped growth was found in this experiment. The highly tolerant line, TVu 11979, was less productive (22.4g pod/plant) than the highly susceptible one, TVu 9357 (31.4g pod/plant) in the control plot of the pot experiment. However, in the field trial in the dry season, TVu 11979 was three times more productive than the other line. Continued root growth at the ripening stage secured vigorous growth and a relatively high yield. These results suggest that drought- tolerant cowpeas could be grown for limited and specific use in drought-prone regions or in dry season cultivation.

We appreciate the fact that highly tolerant cowpea lines yielded about one ton of grain per ha in the dry season when fields were usually left unused. This productivity is no less than that in the rainy season[6]. Besides, in this cropping system, pest control is easier than in cultivation in the rainy season due to the smaller population of important pests. We hope that this new cropping system of cowpea will contribute to the stabilization of the annual food supply and to the alleviation of food shortage in developing countries in drought-prone regions.

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ササゲ（*Vigna unguiculata* (L.) Walp）の耐乾性
II．スーダン・サヴァンナの乾季における栽培ならびに水ストレス下でポット栽培した場合の乾物生産

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摘　要

耐乾性極強と評価されたササゲ（*Vigna unguiculata*（L.）Walp.）の遺伝資源を降雨が全くないスーダン・サヴァンナ（Kano, Nigeria）の乾季現地圃場に栽培して生産力を評価した。また耐乾性の機作に関わる深根性の重要度を評価するため，根圏が限定されるポット栽培を行い，耐乾性が異なる系統の水ストレス下での乾物生産を測定し，現地圃場試験の結果と比較した。

現地圃場試験では，極強系統（TVu 11979，11986，12348）はいずれも１t/ha程度の収量性を示したのに対し，極弱系統（TVu 7778, 8256, 9357）では0.2－0.3t/haにとどまった。このことから，耐乾性の評価結果は信頼し得るものであることを確認するとともに，極強の系統を用いれば，乾季にササゲを実用的に栽培することが可能であることがわかった。一方，水ストレス下のポット試験では，乾物生産の阻害程度は耐乾性極弱・極強の系統間で等しく，極強系統での阻害程度が小さいということはなかった。また，登熟期における乾物の諸器官への分配率は系統間で著しく異なり，極強のTVu 11979では根への分配が多く，莢実への分配は少なかったのに対し，極弱のTVu 9357では根への分配が少なく，莢実への分配は多かった。

これらの二つの実験から以下のことが判った。①乾季の現地圃場でTVu 11979等の極強系統の収量性が優れたのは，これらの系統は根の生育が優れるため，下層に残留する土壌水分を利用することができたためである。②水ストレス下のポット栽培では，極強系統の乾物生産が極弱系統と同程度に阻害されたのは，ポットにより根圏が限定され，根の生育が優れるという極強系統の特性が，水収支上，ひいては乾物生産上有利に働かなかったためである。

キーワード：カウピー，乾季，乾物生産，ササゲ，残留土壌水分，深根性，スーダン・サヴァンナ，耐乾性，水ストレス

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