Water Use Efficiency of Selected Cowpea Cultivars (*Vigna unguiculata* (L.) Walp) Grown on Residual Soil Moisture in Northeast Nigeria

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Abstract— *A field experiment was carried out in the Fadama of Jere bowl to assess the water extraction and water use efficiency of two improved (IT 86D-719 and IT88D-867-11) and one local (Borno Brown) cowpea cultivars grown on residual soil moisture. The three cowpea cultivars and a control were laid out in a randomized complete block design and replicated three times. The result showed that yield and growth parameters were significantly (P< 0.05) different amongst the three cowpea cultivars. The improved cultivars gave significantly (P< 0.05) higher seed yields than the local cultivar. Cultivar IT 86D-719 had the highest seed yield of 893.0 kg ha^{-1} while the cultivar Borno Brown had the lowest seed yield of 675.3 kg ha^{-1}. On the other hand the cultivar Borno Brown had the highest 100 seed weight compared to the improved cultivars. The result also showed that water extraction in all the cultivars increased with depth, with maximum extraction occurring at the depth of 80-100 cm, suggesting that the lower soil layers were more effective in supplying water as the hydraulic conductivities of surface layers decreased. The water use efficiency of the two improved varieties of IT86D-719 (63.56 kg/m^3) and IT88D-867-11(70.06 kg/m^3), were higher compared to the local variety (45.69 kg/m^3). Borno brown and IT 88D-867-11 are good water extractors at field capacity but low extractors at moisture stress. IT 88D-867-11 displayed sign of higher extraction rate than IT 86D-719 at field capacity, but IT86D-719 displayed a higher extraction capacity at moisture stress (20WAS).*

Keywords— Cowpea Cultivars, Soil Moisture, Northern Nigeria.

I. INTRODUCTION

Cowpea production under residual moisture is currently gaining popularity in *Fadama* areas in Northern Nigeria where water is a major limiting factor. Wetlands are referred to as *Fadama* in the Hausa language, which is widely spoken throughout the West African Sahel (Oyebande, 2002) and similar environment elsewhere. Crop production in the *Fadama* depends not only on residual moisture but also on the ability of crops to extract the available soil water (Miller and Arstad, 1974). Jere bowl is one of the *Fadama* areas, a confluence catchment for Ngadda and Alau rivers in Borno State, which spans an area of 200 km^2. Rice is the dominant crop grown during the wet season, and is immediately followed with cowpea in the dry season under residual moisture cultivation. In this type of dual production system, the study of moisture dynamics becomes critical in the formulation of sound intervention strategies.

Cowpea is an important food and cash crop in Nigeria with an annual production of 4.33 million tonnes (CBN, 2005). This has placed Nigeria as the largest producer of cowpea globally. Nigeria, together with Niger and Chad Republics, accounts for about 70% of the global cowpea production (FAO, 2008). The benefit of cultivating cowpea includes fixation of atmospheric nitrogen to the soil as well as soil cover against land degradation. This is in addition to its rich protein which makes it the principal source of protein supply to the peasant communities and second only to meat in protein supply to the urban populace. Also, its haulms and pods serve as animal feeds (Grema and Hess, 1994).

In the past, cowpea was exclusively cultivated under rain fed conditions, but currently the residual moisture production shores up the deficit supply of rain-fed production and will help stabilize the price of cowpea out of season. Dry land crops grown during the cool harmatan season on the *Fadama* depend primarily on residual moisture. The extraction of the receding water depends on the amount stored in the profile, the ability of crops to extract the available soil water, and the rooting characteristics of the crops and their abilities to extract the available store soil water and in some cases, the upward capillary movement from shallow ground water table (Miller and Arstad, 1974).

Several studies in dry land areas have shown that dry land crops grown after rice can extract substantial amounts of stored soil water (Angus *et al*., 1983; Klodpeng and Morris, 1984). Agriculture in dry land areas is very vulnerable to failure and the use of *Fadama* lands to complement upland farming becomes very vital (Kundiri, 1995). *Fadama* farming increases food security by serving as an alternative when rain fed crops fail and also expands production in the off season (Kundiri, 1995). In addition, *Fadama* lands are more contiguous niche than the rain fed production sites, which would ensure a more stable production.

Rainfall in the drier cowpea production region of the country is often unpredictably erratic, but within the *Fadama* areas, the farming systems can reliably utilize the seasonal flood water, shallow ground water for irrigation or residual soil moisture. Residual moisture agriculture is strictly reliant on moisture vis-à-vis the inherent moisture content, water use and the crop water use efficiency (De Tar, 2009). Thus, different crops and even different crop varieties are bound to display different water use efficiency as observed by Amato and Ritchie (2002) for maize, Abidoye (2004) for Soya bean, and Gui-Rui-Yu *et.al*, (2007) for tomato. Evidences exist in maize for varietal differences in water use efficiency, but there is paucity of research on the potential of growing cowpea and other short duration crop species in the *Fadama* area in north east Nigeria. Proper soil and water management practices are considered to be the key factors for sustainable crop production.

The clear understanding of soil water dynamics in the *Fadama* could suggest profitable direction for applied soil and water management research on efficient residual soil moisture utilization for cowpea production. The water table recession rates after rice harvest have obvious implications for cropping systems research in the *Fadama* as well as recession farming. In view of the limited water resources of the arid and semi-arid environments, it is considered desirable to assess the water extraction pattern and water use efficiency of cowpea grown using residual soil moisture.

II. MATERIALS AND METHODS

The study area

The study was carried out at Jere bowl located about 5.5 km north east of Maiduguri, the Borno state capital between latitudes 11º 51´and 12º 05´ N and longitudes 13º11´ and 13º 27´ E. The Jere bowl has an altitude of 305.5 meters above sea level, while the surrounding has an altitude that varies between 309.5 m and 311.5 m above sea level. The soils are sandy loam in texture with high organic matter content and generally high in fertility. The area has a semi-arid climate with a short unimodal rainy season that starts in June and ends in September and long dry season, starting around November and lasting till April/May. Average annual rainfall in Maiduguri is 568 mm and average maximum temperature of about of 34°c and minimum of 19.6°c is a common occurrence in the study area. The average relative humidity in the area is quite low especially during the dry season. The area receives a high radiation load (except during the cool Harmattan season from November to February) of 40.2% at 0900Z (10:00 am) and 26.1% at 1500Z (4:00 pm). Mean annual sunshine duration was 8.5 hrs/day with mean solar radiation of 14.2 ML.

Treatments, Experimental Design and Cultural Practice

The treatments comprised of four experimental plots planted to three cowpea cultivars (two improved IT86D-719, IT88D-867-11, and a local cultivar, Borno Brown), assigned to the three plots and a control plot with no cowpea planted in it. The three cowpea cultivars and the control were replicated three times, giving a total of twelve plots laid out in a randomized complete block design (RCBD) in experimental plots measuring 2 m × 3 m with an alley of 1 m between replicates. Cowpea seeds were sown at the rate of two seeds per hole at a spacing of 50 cm × 30 cm. No fertilizer application was made in line with farmers practice in the study area. Weed control was done manually using hand hoe as at when due. Insect pests control was done by spraying with karate (cypermethrin) 100g/ai at the rate of 1L/ha at 25, 45 and 55 days after sowing (DAS). Matured pods were harvested by hand picking when the pods were dried.

Collection and Preparation of Soil Samples

Composite soil samples (0-15 cm depth) were collected from the field for routine physico-chemical analysis prior to land preparation. The soil samples were air dried, ground and passed through a 2mm sieve and used for the analysis following standard analytical procedures. Particle size analysis was carried out using the hydrometer (Gee and Bourder, 1986). Soil bulk density at depths of 0-10 cm, 10-20 cm and 20-60 cm was determined by the undisturbed core sample method (Black and Hartage, 1986), while total porosity was calculated from the average bulk density value (0-60 cm depth) based on a particle density value of 2.65Mg m^{-3}. Soil pH was measured in 1:2.5 soil water suspension using glass electrode digital pH meter (model Kent Eil 7045/48) as described by Page *et al*.

(1982). Organic carbon and total nitrogen contents were determined by dichromate wet oxidation and regular macro-Kjeldhal methods, respectively while the available phosphorus was determined by Bray-1 method (Page *et al*. 1982). Exchangeable bases were determined using 1N neutral ammonium acetate (NH_4OA_C) saturation method (Page *et al*., 1982). Exchangeable calcium and magnesium were determined titrimetrically with 0.02N Na_2 EDTA, while the exchangeable potassium and sodium were determined with a flame photometer (model FGA 330C) at wavelengths of 767 and 589 nm, respectively.

Determination of Field Water Content

The field water content was determined gravimetrically at 20 cm depth intervals to a depth of 100 cm on each plot. Soil samples were collected at planting and subsequently at four weeks interval. The samples were brought to the laboratory, weighed and oven dried at105^o C for 24 hours and reweighed. The gravimetric moisture content was determined by the difference. Subsequently, the values were converted to volumetric moisture content by multiplying with the appropriate value of the bulk density.

Measurement of Plant Parameters

The plant parameters measured include total grain yield at harvest and root length measurements. The cowpea grains were harvested when the grains were fully matured. The mature pods were hand-picked per individual plot, threshed and weighed to obtain the yield per plot and subsequently converted to yield per hectare.

Soil core technique that permits quantitative analysis of the root system described by Raper and Barber (1970) was used to measure the root length density. Soil cores of 5.4 cm diameter and 10 cm height were removed for measurement of cowpea root distribution. Cores were taken at 5 cm from the cowpea row on a line perpendicular to a cowpea plant. The cores were sub-divided into segments of 0-10, 10-20, 20-40, 40-60 and 60-80 cm depth increments. Root samples, one per plot were collected per replication. Cores were collected at 50% flowering and at harvest. The soil root cores were placed in plastic bags and stored in the refrigerator until roots could be separated from the soil. Each sample was washed through three sets of sieves arranged in decreasing order of diameter (i.e. 4, 2 and 1 mm), then the roots remaining in the sieves were transferred into large Petri dishes with the aid of a tweezer and magnifying glass. Direct method of estimating root length (millimeter per unit volume of soil) as described by Reicosky *et al*. (1970) was used. The root samples in the large Petri dishes were placed over millimeter–graph paper. The roots were strengthened with tweezers, observations were made through a magnifying glass and the length of a given root segment was estimated to the nearest millimeter. The individual root lengths were summed up to give estimate of the total root length. Dead roots were not included in measurements of root length. Calculations of root lengths per unit volume of soil (RLD) were made at the end of the growing season.

Water Use Efficiency

The crop water use efficiency, defined as yield of plant produced per unit of water used was determined using the equation developed by Power (1983) for estimating water use efficiency as follows: $WUE = \frac{Y}{ET}$

Where, WUE is the crop water use efficiency, Y is the total yield per given area during the growing season and ET is the evapotranspiration. WUE is expressed as yield produced per unit volume of water (kg/m^3). Water use is restricted to that removed from soil by evaporation and transpiration excluding non-productive losses that might have occurred through deep drainage and surface run-off.

III. RESULTS AND DISCUSSION

Physico-Chemical Properties of the Soil

The selected properties of the soil of the experimental site are presented in Table 1. The soil has a sandy loam texture comprising 72.8, 10.0 and 17.2 % sand, silt and clay, respectively. The soil is moderately acidic with a pH value of 5.88 and electrical conductivity of 0.03 dSm^{-1}. The soil has low organic carbon and total nitrogen contents of 0.02 and 0.05 g kg^{-1}, respectively and low phosphorus value of 4.25 mg kg^{-1}. In general, the soil has low fertility status having exchangeable K, Ca, Mg and Na of 0.28, 1.00, 0.40 and 0.21 Cmolkg-^{1}, respectively. The bulk density at 0-10 cm was 1.83 Mg m^{-3} then decreased to 1.73 Mg m^{-3} at 10-20 cm depth and increased to 1.86 Mg m^{-3} at 20-60 cm depth.

Moisture Content at Different Sampling Depths

Results on soil moisture content at five sampling depths and six sampling periods were shown in Figure 2. The highest moisture content of 0.6267 (cm^3/cm^3) was consistently obtained from soil samples at 80-100 cm depth, while the lowest moisture content of 0.4967 (cm^3/cm^3) was recorded at 0-20 cm depth at sowing. The moisture contents at the end of the experiment were 0.3450 (cm^3/cm^3) and 0.0442 (cm^3/cm^3) at 80-100 cm depth and 0-20 cm depths, respectively.

Results at all sampling periods showed that soil moisture content significantly increased with each successive increase in sampling depth. The general trend was soil moisture content at 80-100 cm depth > 60-80 cm depth > 40-60 cm depth >20-40 cm depth > 0-20 cm depth. The result also indicated decrease in soil moisture over time, this corroborate with the result of Arya *et al*. (1975) who reported that since root growth is a continuing process and hydraulic properties of a drying soil change substantially, water depletion patterns are markedly time dependent.

Effects of Cowpea Cultivars on Moisture Content

There was significant difference in moisture content among cultivars at all sampling periods (Table 2). At all sampling periods, soil moisture content in plots cropped to IT88D-867-11 and Borno Brown were significantly ($P < 0.05$) lower than that of the uncropped plots. During the crop growth at 4 and 8 WAS there was no significant difference in soil moisture content between the uncropped field and that cropped to IT86D -719. Subsequent result from 12 and 16 WAS however revealed significantly lower soil moisture content in plots cropped to IT86D -719 than in the other cropped plots. Plots cropped to these cowpea cultivars also had significantly lower moisture content in comparison to that cropped to IT86D-719 at 4 WAS. In addition, plots cropped to IT88D-867-11 and IT86D-719 showed significantly higher soil moisture content compared to plots cropped to Borno Brown at 8 WAS. However, the terminal result at 16 WAS did not show significant difference in soil moisture content among all plots cropped to the cowpea cultivars.

The result generally suggests decline in soil moisture content over time as reported by Safir *et al*. (1972) who said that initially the hydraulic factors favour water uptake by roots in the surface layers. As the soil dries rhizosphere resistance to water flow increases more rapidly near the surface and a downward shift in the uptake pattern would be expected.

Grain yield of Cowpea Cultivars

The highest grain yield of 893 kg/ha was obtained from IT86D-719. This was followed by IT 88D-867-11 with mean yield of 846 kg/ha. There was no significant ($P > 0.05$) difference between the yield of the two improved varieties. However, both varieties significantly ($P<0.05$) out-yielded the local cultivar, Borno Brown which recorded 675.3 kg/ha.

Root Length Density of Cowpea Cultivars at Different Depths

The root length density of the three cowpea cultivars investigated during the sixteen weeks of experimentation is presented on Table 5. The root length density at 50% flowering indicated that Borno Brown has the highest concentration compared to both IT86D-719 and IT88D-867-11. The root length density at 100% flowering followed similar pattern. The result revealed that there were no significant ($P>0.05$) differences among the cowpea varieties at flowering (RL 50%) and at harvest (RL 100%). In respect to the depth, there was significant difference for 60-80cm depth and 80-100cm at both RL 50% and RL100%. The highest concentration of root (0.183 g/cm^3) was obtained at 0-20 cm at 50% flowering, while lowest concentration of 0.027 (g/cm^3) was obtained at 80-100 cm depth. Similar root concentration pattern was obtained at 100% flowering. No significant difference was observed for interaction between variety and depth for root length density at 50%. However, there was highly significant ($P<0.05$) for variety and depth at 100%

Water Extraction Rate (Water Use) by Different Cultivars of Cowpea

Figure 1 shows the rate of water extraction by the roots of the three cowpea cultivars during 20 weeks growth periods. The initial extraction rate at 4 WAS was generally low for all cultivars, but increased with time. When cultivars were compared extraction rate was highest in Borno Brown (0.8 cm/day), followed by IT88D-867-11 (0.48cm/day) and then IT88D-719 (0.32cm/day). The result revealed similar extraction trend at 8 WAS, with extraction rate of 0.30, 0.31 and 0.18 cm/day, for Borno Brown, IT88D-867-11 and IT88D-719, respectively. The peak extraction rate for Borno Brown (0.80cm) and IT88D-867-11(0.48cm) occurred at 12 WAS as against 20 WAS for IT86D-719 (0.45cm/day).

The result at 12 WAS indicated substantially higher extraction rate for Borno Brown. For IT86D-719, the extraction rate increased throughout the growth cycle with peak extraction rate at 20 WAS. In contrast, for IT88D-867-11 and Borno Brown, an early increase in the extraction rate was followed by a sharp decrease later in the crop growth cycle to 0.33 cm and 0.37cm at 16 WAS and 0.48 cm and 0.38 cm at 20 WAS, respectively. Borno Brown and IT88D-867-11 were good water extractors at field capacity but low extractors at moisture stress. IT88D-867-11 displayed sign of higher extraction rate than IT86D-719 at field capacity. IT86D-719 displayed higher extraction capacity at moisture stress (20 WAS).

Water extraction generally increased with depth with highest extraction at 80-100 cm followed by 60-80 cm and then 40-60 cm in that order, indicating that lower soil layers became more effective in supplying water as the hydraulic conductivities of the surface layers decreased (Figure 2). Water extraction increased with depth and peaked at 12 WAS. For the 80-100 cm layers, the extraction rate was followed by a substantial decrease later in the drying cycle as shown in Figure 2.

The root water extraction efficiency of the 3 cowpea cultivars at flowering and at podding across depth are presented in Figure 3 and 4, respectively. In general, the results indicated increase in water extraction efficiency with increase in depths (at lower depths). However, water extraction efficiency at podding almost doubled that at flowering.

IV. CONCLUSION

The study revealed that there was significant ($p<0.05$) difference in yield of the three cowpea cultivars. The IT 86D-719 produced the highest grain yield. However, there was no significant ($p>0.05$) differences in the yield between the two improved cultivars. Low initial rate of water extraction for all cultivars was observed, however, extraction rate increased with time with highest by IT 88D-867-11 > Borno brown > IT 86D-71. The peak extraction rate for Borno brown and IT 88D -867-11 occurred at 12 WAS as against 20 for IT 86D-719. Moisture content from the cropped and uncropped plots increased with increase in depth at 80-100 cm depth > 60-80 cm depth > 40-60cm depth >20-40 cm depth>0-20 cm depth. Decrease in soil moisture content over time from planting to harvest was also observed. Borno Brown and IT 88D-867-11 are good water extractors at field capacity, but low extractors at moisture stress. IT 88D-867-11 displayed sign of higher extraction rate than IT 86D-719 at field capacity, but IT86D-719 displayed a higher extraction capacity at moisture stress.

Table.1: Physico-chemical Properties of the Soil of the Experimental Site

CHARACTERISTICS	VALUES
Soil $pH_{1:2.5}$ (H_2O)	5.88
Electrical Conductivity (EC) dsm^{-1}	0.03
Organic Carbon (g kg^{-1})	0.20
Nitrogen (g kg^{-1})	0.05
C:N ratio	4.00
Phosphorus (mg kg^{-1})	4.20
Exchangeable bases (Cmol Kg^{-1})	
Na	0.21
K	0.28
Ca	1.00
Mg	0.40
Total exchangeable bases (Cmol Kg^{-1})	1.89
Particle size distribution (%)	
Sand	72.80
Silt	10.00
Clay	17.20
Texture	Sandy loam
Bulk Density (Mg m^{-3})	
0-10 cm	1.83
10-20 cm	1.73
20-60 cm	1.86
Total Porosity (%)	30.94

Table.2: Soil Moisture Content (cm^3/cm^3) of Cropped and Uncropped Plots at Sampling Intervals

Cultivars	At Planting	4 WAS	8 WAS	12 WAS	16 WAS	20 WAS
IT86D-719	0.57	0.51	0.38	0.22	0.17	0.11
IT88D-867-11	0.54	0.47	0.34	0.19	0.17	0.12
Borno Brown	0.54	0.47	0.34	0.22	0.18	0.12
Control	0.57	0.53	0.39	0.29	0.24	0.18
SE±	**0.0046**	**0.0077**	**0.0077**	**0.0072**	**0.0086**	**0.0078**
$LSD_{(0.05)}$	***	***	***	***	***	***

Table.3: Grain Yield for the Three Cowpea Cultivars

Cultivar	Grain yield (kg/ha)
IT 86D-719	893.00
IT 88D-867-11	846.00
Borno Brown	675.30
Mean	804.80
SE±	**26.50**
$LSD_{(0.05)}$	**104.10**

Table.4: Root Length Density as Affected by Cultivar and Depths

Treatment	Root length at 50%	Root length at 100%
Cultivar		
IT86D-719	0.079	0.061
IT88D- 867-11	0.070	0.068
Borno Brown	0.113	0.100
SE±	**0.0176**	**0.0074**
$LSD_{(0.05)}$	*	***
Depth (cm)		
0-20	0.183	0.151

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20-40	0.108	0.128
40-60	0.078	0.073
60-80	0.041	0.026
80-100	0.027	0.007
SE±	**0.0227**	**0.0095**
$LSD_{(0.05)}$	***	***
V×D	**NS**	***

Table.6: Water Use Efficiency of Three Cowpea Cultivars

Variety	Water Use (cm/day)	Water Use Efficiency (kg/ha/cm)
IT86D-719	14.93	63.56
IT88D-867-11	12.80	70.06
Borno brown	14.44	45.69
SE±	**1.103**	**10.936**
$LSD_{(0.05)}$	**4.331**	**42.940**

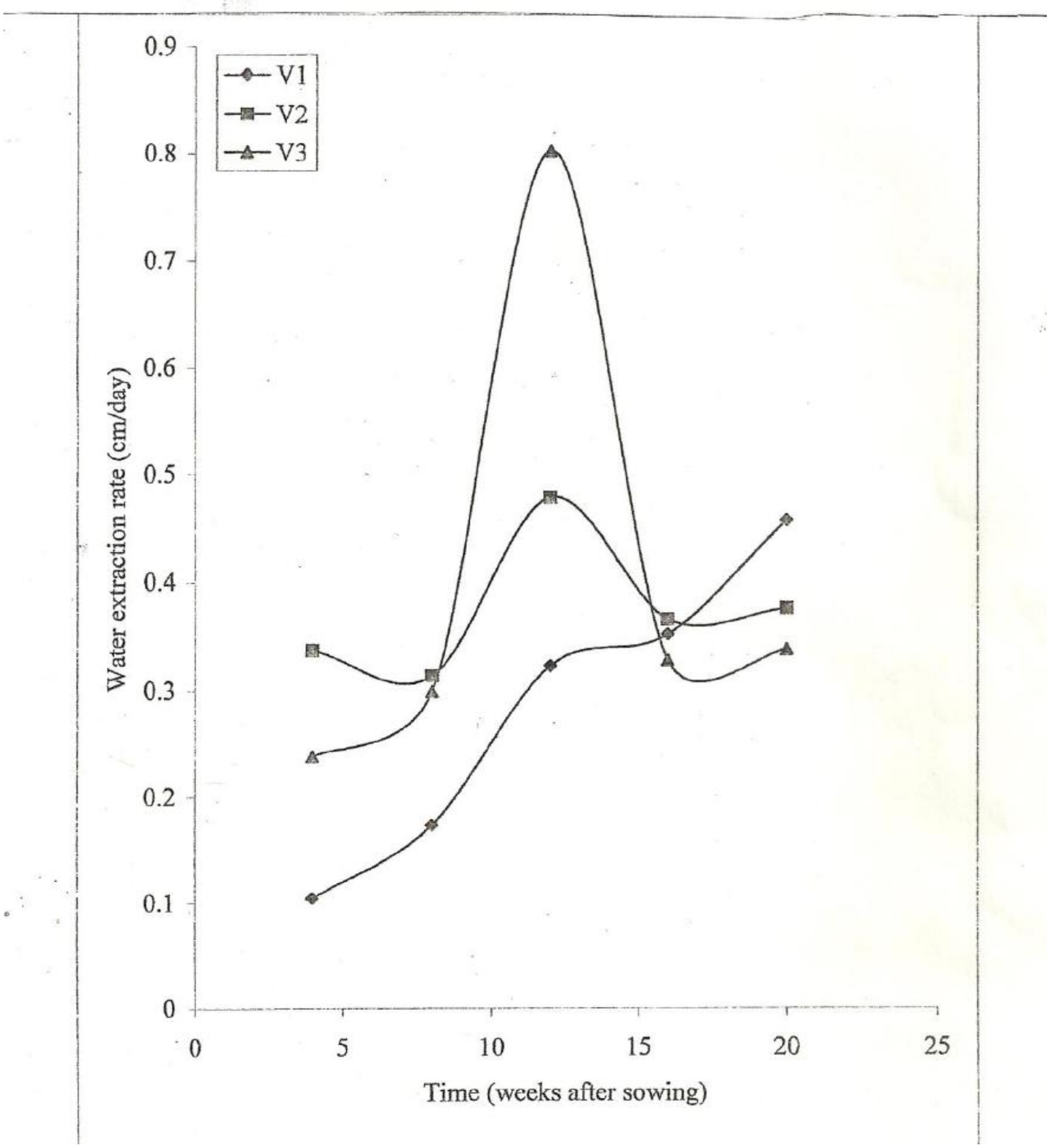
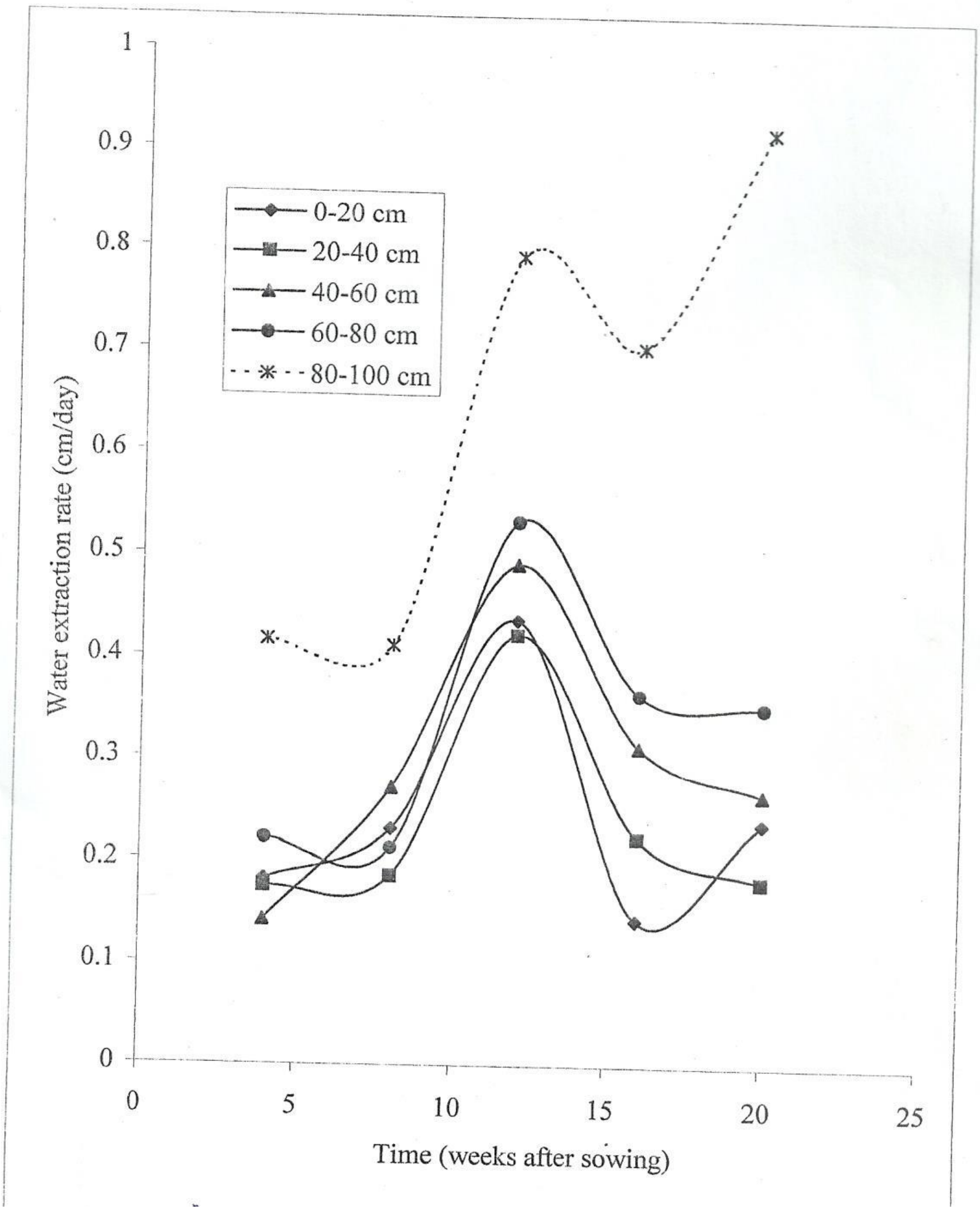
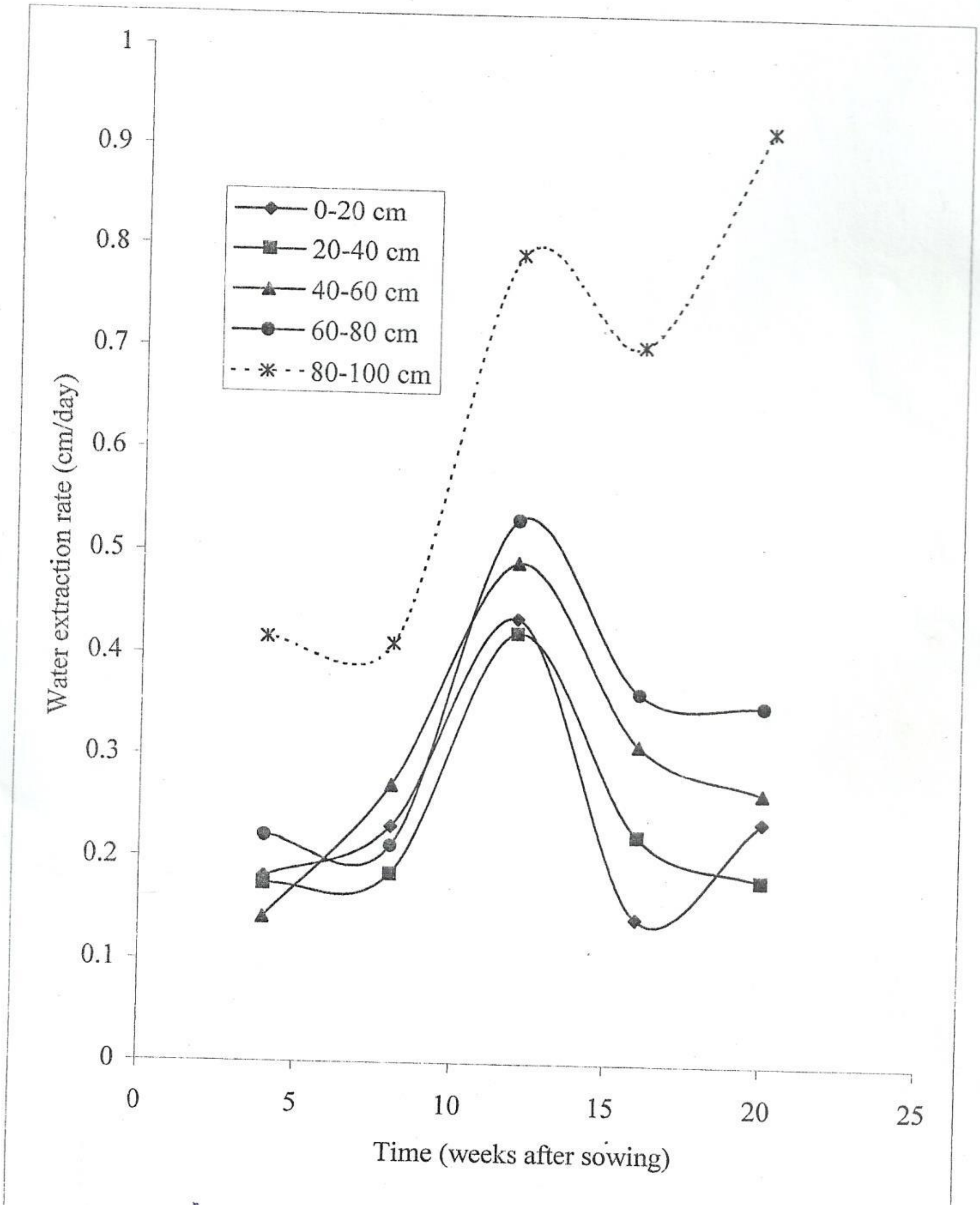
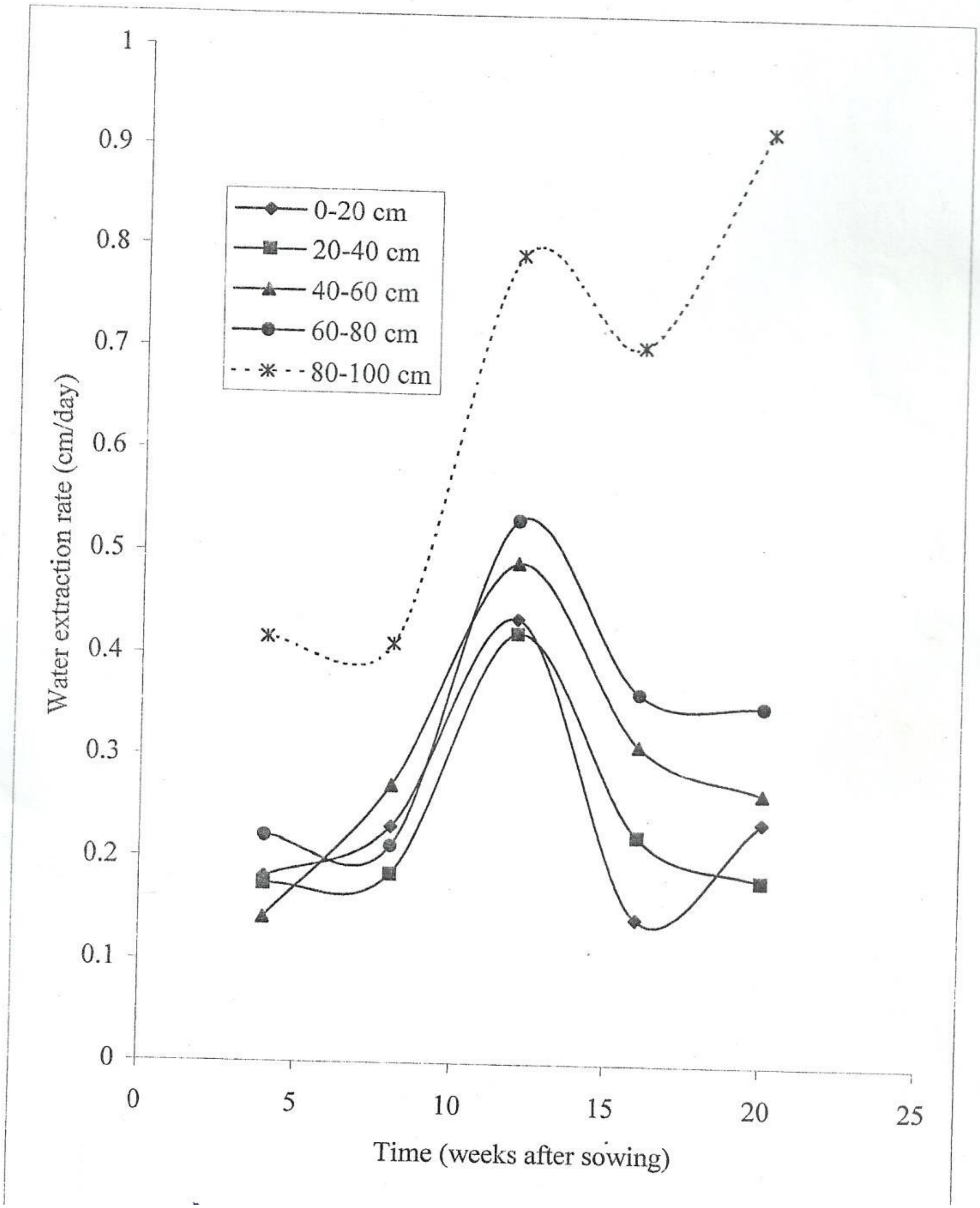


Fig.1: Rate of water extraction by cowpea cultivars at 4 weeks interval


Water extraction rate (cm/day)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20 cm
20-40 cm
40-60 cm
60-80 cm
80-100 cm
0
5
10
15
20
25
Time (weeks after sowing)


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Water extraction rate (cm/day)
0-20 cm
20-40 cm
40-60 cm
60-80 cm
80-100 cm
0
5
10
15
20
25
Time (weeks after sowing)


0-20 cm
20-40 cm
40-60 cm
60-80 cm
80-100 cm
Water extraction rate (cm/day)
Time (weeks after sowing)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5
10
15
20
25

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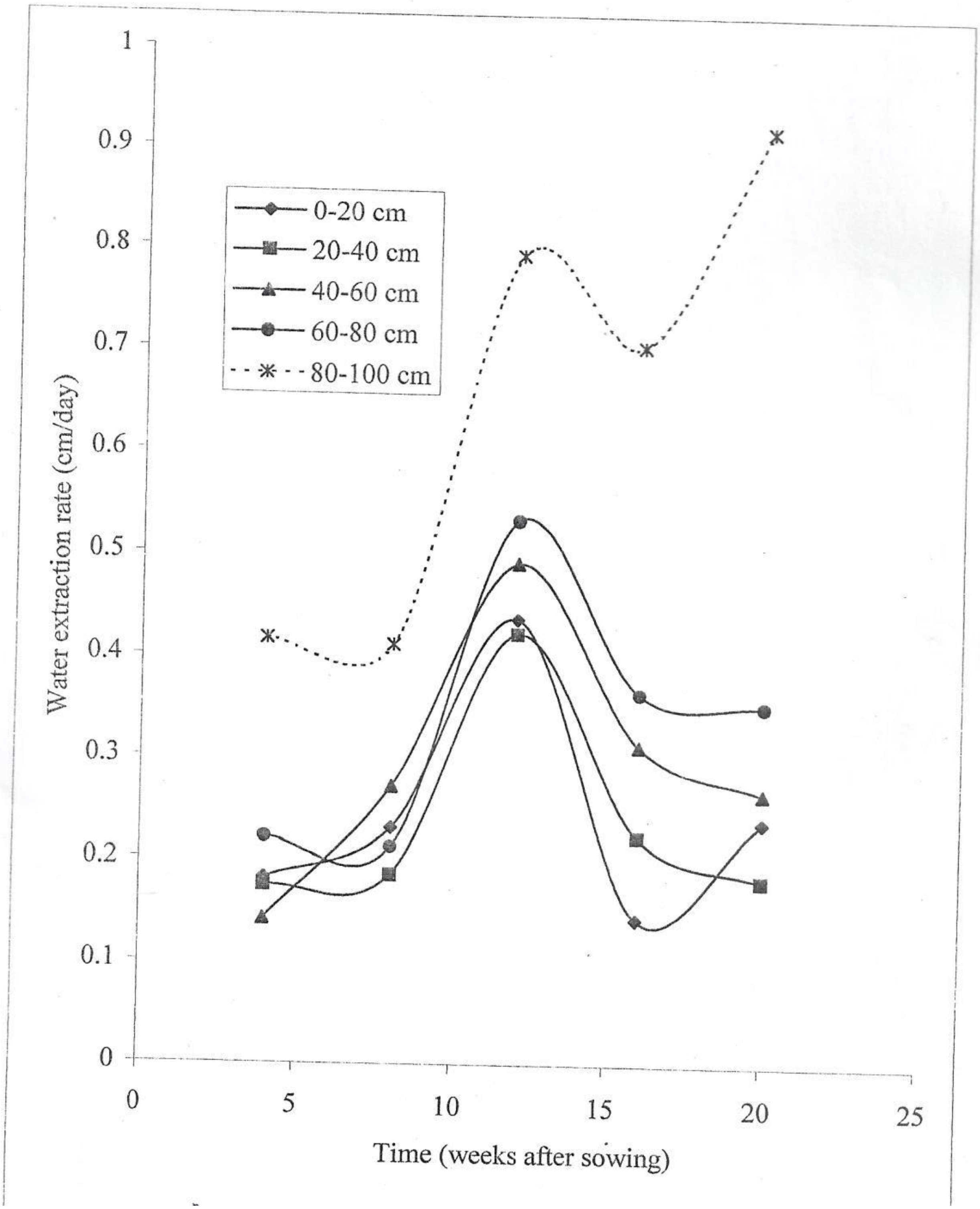

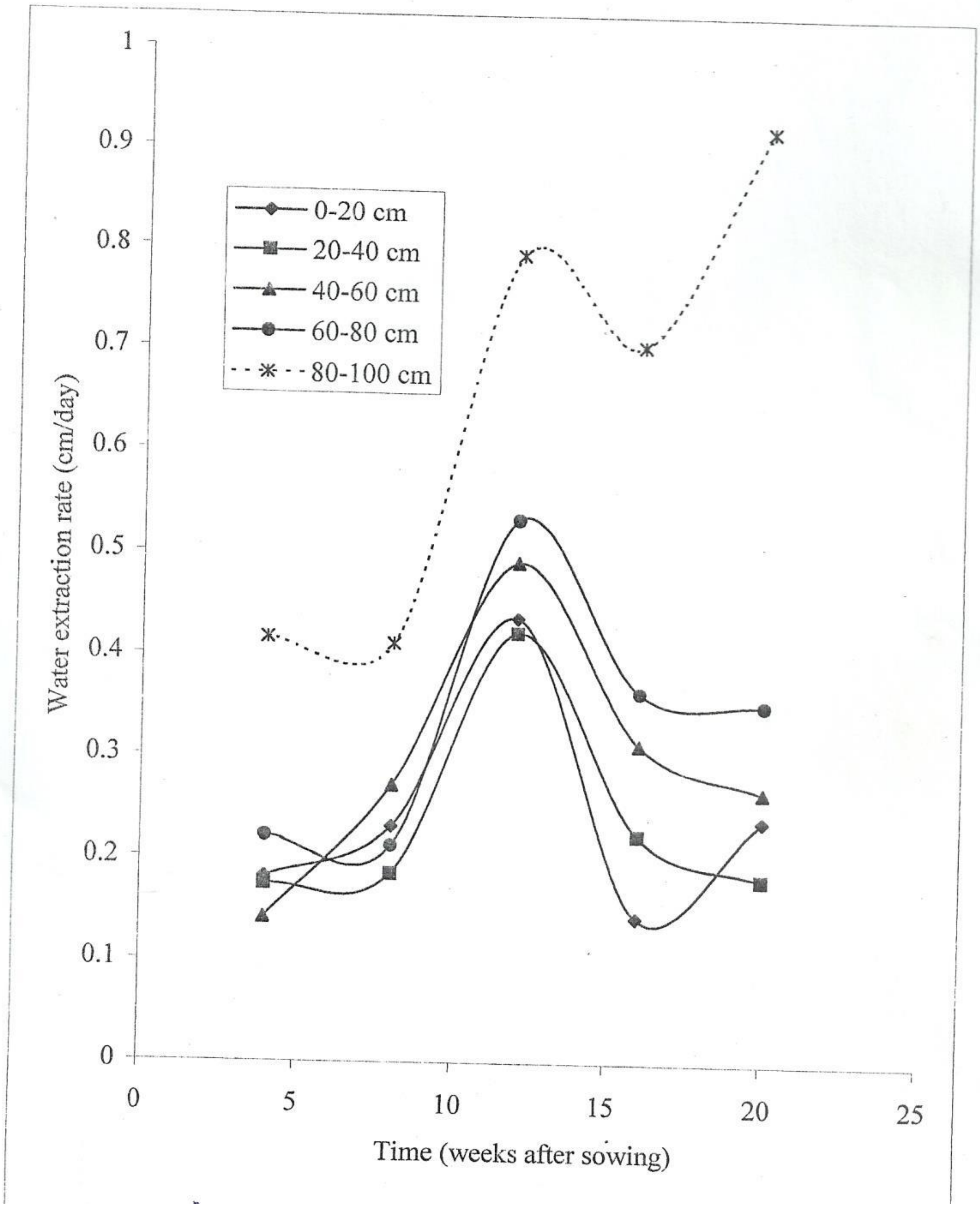

Fig.2: Rate of water extraction by cowpea cultivars at different depths

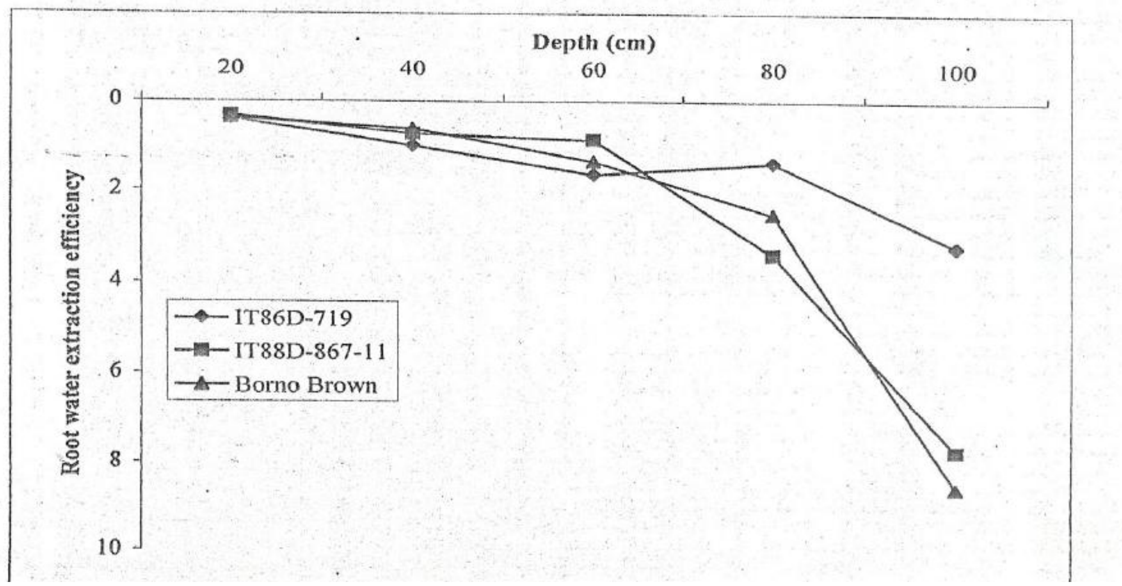

Fig.3: Root water extraction efficiency at flowering

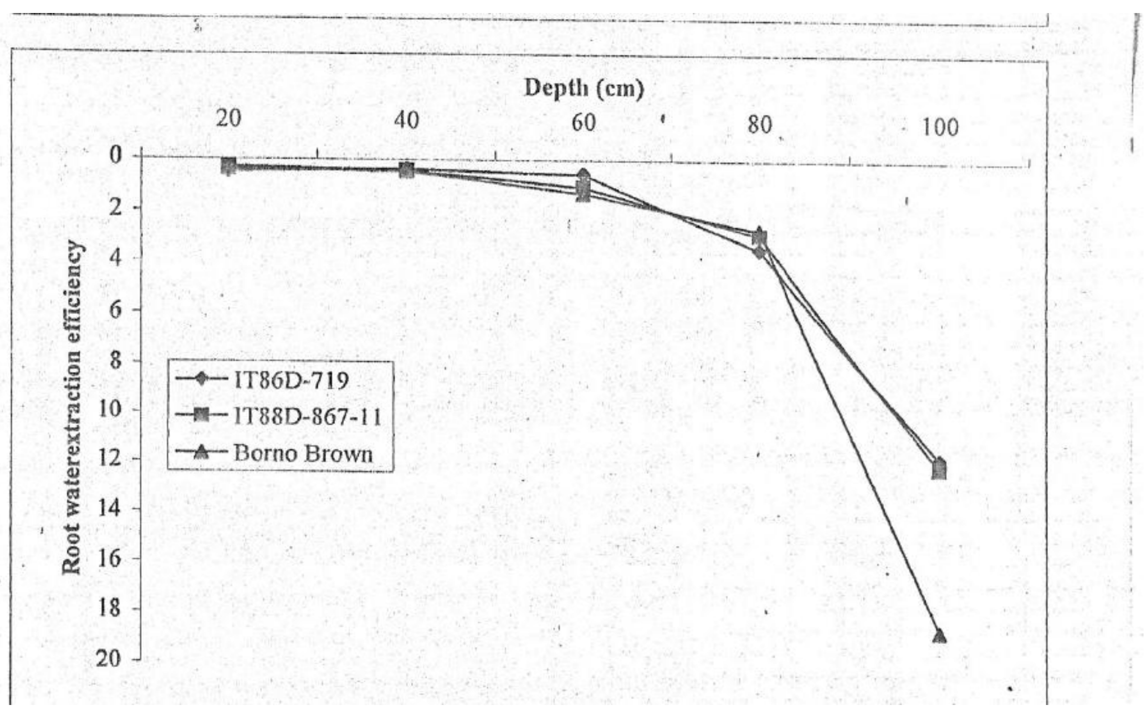

Fig.4: Root water extraction efficiency at podding

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