
**Physiological Plant Studies in
South Africa.**

**Part I.—Wilting and Osmotic Phenomena of
Grasses and other Plants under Arid
Condition.**

**By MARGUERITE HENRICI, Ph.D., Plant Physiologist,
Veterinary Research Laboratory, Vryburg.**

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THE present study represents part of an investigation into the physiological behaviour of plants under the hot arid conditions of Bechuanaland; more particularly into the causes of "grass wilting." Later papers will deal with the biochemical changes involved in the metabolism of wilting plants.

The phenomenon of wilting of course depends primarily upon the "water balance" of the plant under any given climatic and edaphic conditions, and the present paper may, therefore, be divided into (a) a general description of the Bechuanaland veld and of the local climatic conditions; and (b) a determination of suction force and osmotic values for certain grasses and other plants. A determination of the transpiration of selected local grasses, and of other plants of the same habitat, appears as a companion paper and may be regarded as "Part II" of the present article.

Inclusion of direct measurements of the water intake of the plants studied was also planned, but the late arrival of the requisite apparatus from Europe prevented the acquisition of the desired data in time for the present report.

The investigations now recorded were carried out on the Government farm, Armoedsvlakte, a few miles from Vryburg (formerly included in Bechuanaland, but now within the Cape Province), and about 80 miles east of the Kalahari Desert. The plants coming under observation were taken from the vicinity of laboratory buildings erected for the study of the cattle disease "lamsiekte." Botanical identification of plant species was kindly undertaken by the Division of Botany, Pretoria.

CLIMATIC AND EDAPHIC DESCRIPTION OF ARMOEDSVLAKTE.

Rainfall.—Vryburg District is characterized by a very irregular, localized, seasonal rainfall, varying considerably at different places not far removed from one another. The annual precipitation for the last five years, measured at Armoedsvlakte itself, and therefore valid for the investigations now recorded, is as follows:—

September, 1919-September, 1920	17.89 inches.
" 1920	"	1921 21.71 "
" 1921	"	1922 9.13 "
" 1922	"	1923 18.29 "
" 1923	"	1924 13.78 "

The town of Vryburg itself, about five miles away, has generally rather more rain than Armoedsvlakte, and averages 18 inches. This amount in itself would allow of "dry farming" but for the fact that other factors, to be mentioned presently, render much of it valueless.

Season of Rainfall.—The rains occur during the warm season of the year, but vary greatly in their relative distribution over individual months. In 1920-21 precipitation occurred at intervals over the whole growing period of the grasses; from September to November, and again from January until the end of April. Such a distribution is considered a "good year" in the district, but unfortunately is not to be relied upon. In 1923-24, useful rains fell towards the end of October and in November, and again in March, with drought between, broken by occasional useless light showers. In April and May substantial precipitation again occurred, but this was valueless. Coming after the long drought and at the time of nocturnal frost, it was too late to benefit the plants. The year was, therefore, a bad one from the point of view of pasture, and the little grass available was further reduced by locust invasion.

Distribution of Rainfall.—It is generally recognized that the significance of rain depends upon the nature of the fall. American authorities point out that in semi-arid regions a precipitation of less than one-tenth of an inch in one fall is useless, since the extent of penetration, and the subsequent surface evaporation, leave it without influence upon the soil moisture. At Armoedsvlakte a year may be dry in spite of moderate total rainfall, since the actual distribution so often consists of light showers without effect upon the soil, on the one hand, and very heavy downpours for brief periods on the other. Real general "soaking rains," which penetrate the soil, slowly but continuously, are rare, and during 1923 and 1924 only occurred on three occasions. The greater part of the total precipitation occurred in short gushes, forming surface pools from which much water was lost by subsequent evaporation in a blazing sun, or which drained through the shallow soil into crevices in the underlying rocks. The exceptionally low general "relative humidity" of the air also causes rapid evaporation after rain.

Relative Humidity.—In considering this, the data derived from wet and dry bulb thermometers may be ignored in favour of readings taken with the Assmann psychrometer directly over the plants. From August, 1923, to May, 1924, such readings were taken, almost daily, at intervals of one or two hours. The air over the plants should be moister owing to transpiration, and low relative humidity at such points therefore be of greater significance. The psychrometer readings were reckoned either directly from the Assmann tables, extended when necessary by using Sprung's formula (*Aspiration-Psychrometer Tafeln*, 1914, S. VIII). From 1st September to 11th November, 1923, the relative humidity during the day-time was below 20 per cent., more frequently below 15 per cent., and sometimes approached even zero. By night it never exceeded 60 per cent. and seldom passed 30 per cent. Dew was therefore quite excluded.

The relatively heavy rains of November effected a temporary increase of atmospheric moisture, but even ten days later the diurnal humidity had fallen to 30 per cent. (Table I, Appendix) and the nocturnal value to the point of irregular dew. In December, day

values sank below 20 per cent. and below 10 per cent. on hotter days; while the general early morning values (60 per cent.) again precluded dew. The few short sudden downpours of January effected corresponding temporary increases in air moisture, but the general influence was not great and no dew was noticeable until March. During February, rains fell in the neighbourhood although not over the farm itself. As a consequence, the relative humidity over the plants fluctuated around 40 per cent., although on many days it did not even reach 20 per cent. In March the day-time humidity varied between 30 per cent. and 60 per cent., with early morning dews and a general day-break humidity of 92 per cent. By the beginning of April a general diurnal decline to 20 per cent., never exceeding 40 per cent., was recorded; with a dewless early morning average of about 60 per cent. In the middle of the month several days showed as low a value as 2 per cent. A late rain in April increased the relative humidity for the moment, but after a few days the figure 30 per cent. again prevailed.

In considering these figures it should be emphasized that the higher relative humidity of early morning only holds for an hour or two, and the season 1923-24 can be regarded as very bad from the point of view of dew-formation. In the preceding period of January to June (1923), deposition of dew occurred every night upon which observations were made; indeed frequently twice—shortly after midnight and again around 6 a.m.

Although the Assmann psychrometer was not available during this earlier period, occasional readings on a Lambrecht polymeter indoors, gave usually below 30 per cent. relative humidity during the day-time, rising to 50 per cent. after spasmodic rains.

Insolation.—Evaporation of rain at Armoedsvlakte is much favoured by intense insolation, as well as by high temperatures and strong winds. The insolation is so extreme that in summer the sunshine cards record about fifteen hours. Cloudy days are so rare that over the twenty months of observation recorded in this paper, only one single day could be described as without sunshine. The very lack of atmospheric moisture of course itself contributes to the intensity of insolation. The rainfall, especially in 1923-24, generally occurred during the night.

During the long dry winter the sky may remain for weeks without sign of cloud, and the average duration of bright sunshine is over ten hours.

Temperature.—The range of temperature over Bechuanaland is very wide, not only for the year, but also for single days. The shade extremes for Armoedsvlakte generally range from 20° to 106° F. or -6.5° to 41° C., although an occasional even wider divergence may occur.

Observations taken over the actual plants ranged from 15° C. to 34° C. from January to March, 1923, with a daily amplitude of about 15° C. In autumn, April to June, the range lay between 0° C. to 27° C., decreasing gradually from summer to autumn; daily amplitude about 20° C.

In the second half of 1923 and beginning of 1924, the temperature was considerably higher than during the previous year. From October to January, temperatures up to 38° C. were not uncommon, while during the night a lower limit of 15° C. was seldom reached.

Subsequent months corresponded more closely to those of the previous year, although even in April and May a day temperature of 30° C. was sometimes reached.

Further details, particularly in regard to soil temperatures, are given later in considering appropriate experimental protocols.

Wind.—Fairly strong winds prevail at Armoedsvlakte throughout the year, and the use of windmills over boreholes provides the water supply for the stock and for farm purposes. August to November is generally the period of most wind. Systematic readings of the velocity of the wind have only recently been taken (Cassella anemograph), but during March and April, 1924, a record of 240 miles per day was frequent, i.e. an average velocity of 10 miles per hour, or about five yards a second.

The wind occurs for the most part during the day-time, while the sunshine is most intense, and hence has a powerfully drying effect. Frequently, also, it carries dust which tends to block the stomata of the leaves. A large proportion of the Armoedsvlakte plants possess glandular hairs, and dust adheres to the leaves very easily.

THE ARMOEDSVLAKTE VELD.

The geological formation of the Vryburg District consists largely of dolomitic limestone, and at Armoedsvlakte the soil is so shallow that the underlying rock is struck at a depth of anything from a few inches to a few feet. Outcrop is frequent, and many parts are only covered by a thin layer of silt and dust. Although varying in colour and composition, the main soil characters are low permanent retentive capacity for water, deficiency in phosphate and humus, and richness in lime. Some parts of the farm are completely sandy; either reddish-brown and moderately coarse or grey-brown and fine. Particularly the latter type shows a peculiar behaviour under variations of water-content; being easily worked when wet, but forming a firm crust when dry, offering considerable resistance to shovel or pick. At a water-content of 1 per cent. to 2 per cent., reckoned on the sampled soil, the crust splits under the spade into pieces which can be crushed to small sandy particles. When the moisture-content falls still lower (December, 1922, until the rains of January, 1923), the soil again disintegrates on the surface, so that plants with superficial roots can be easily dug out.

The water-content of the saturated soil is about 30 per cent., but the dry soil does not absorb water easily, and rain water penetrates slowly. As soon as water reaches the underlying rock, however, it seems to disappear quickly to lower depths. Water is found all over the farm at a depth of about 40 metres, but annual variations in the water table were not actually observed. The observed moisture in the surface soil was higher in winter than in summer, but this was probably due to the influence of temperature and lower evaporation.

Data showing moisture-content in the soil during a vegetative period are shown in Table 1.

Unfortunately, only occasional determinations were made from January to April, 1923, under specific veld conditions. From August, 1923 to May, 1924, however, regular determinations were made at weekly intervals; and at longer intervals throughout the succeeding winter months. Since soil moisture depends upon temperature as well as upon rainfall, both factors are indicated in the table. The

rainfall is given in the form of totals over the periods shown, and the temperature, in the form of average maximum and average minimum readings, for the same periods.

The soil samples, for moisture determination, were taken about 100 yards from the laboratory, at a depth of 10 cm. below the surface. Triplicate samples, taken at a distance of about 30 yards apart, were used for each determination. In successive weeks sampling was conducted by digging small holes a short distance away from the preceding sampling points. All samples were at once removed to the laboratory, a suitable aliquot (usually 1 gm.) rapidly weighed out and dried to constant weight at 104° C. The loss in weight was taken as moisture, and the average of the three determinations is indicated as percentage in the table. As would be expected, perfect agreement in the triplicate determinations on the unsieved soil was rarely obtained, the extreme variation being about 0.4 per cent. with low water-content to about 2 per cent. with high water-content. In the last column of the table remarks are included on the state of the veld at any given date. The absence of the type of soil particles which persistently retain water allows of rapid evaporation after rain, but, on the other hand, enables the plants to utilize existing soil moisture at very low actual percentages. The chemical composition of the soil is not discussed in this paper, but a few analytical data will be found in a paper, "Phosphorus in the Live Stock Industry," published in the *Journal of the Department of Agriculture*, May, 1924 (Theiler, Green, and Du Toit).

The veld of Armoedsvlakte, and of the Vryburg District generally, is open, flat, and almost without trees. It is a "grass veld" with a number of characteristic bushes, such as *Grewia cana*, Sond., *Tarchonanthus camphoratus*, Linn., and various species of *Rhus*. The accompanying photograph (1-3) conveys some impression of its general appearance.

When first observed personally in November, 1922, after a drought period of about ten months, it looked more like a desert than a ranching country. *Elephantorrhiza Burchellii*, Benth., *Cassia obovata*, Collad., *Stachys spathulata*, Benth., and *Salvia rugosa*, Thumb., were growing sparsely at intervals of a few yards. Everywhere in between were dead grass-tufts; *Eragrostis superba*, Peyr., and *Tragus racemosus*, All., being developed here and there as dwarfed forms without proper haulms. The veld remained like this until January, 1923, when the first rains of the season fell. It then changed with great rapidity. A large number of Karroo weeds (*Giesekia* and *Limeum*) appeared. Grasses developed with incredible speed by shooting from the margins of old tufts, but not as new individual young plants. A large variety of other plants appeared later in the season, but since a complete list is being compiled by another investigator there is no need to note them all here. For the purposes of the present investigation, mention need only be made of plants actually studied: good representatives of the Armoedsvlakte flora as a whole.

During the main season of rain in this year (February) the bare spaces between the grass tufts became populated with numerous creepers, especially Convolvulaceae and Cucurbitaceae, but these, together with *Giesekia* and *Limeum*, died down again in March. As illustrating, however, the thinly populated character of the veld, it should here be emphasized that, even at the best time of the year, bare soil spaces constituted about 80 per cent. of the total soil area.

After the January and February rains the grasses dominated the veld as a whole, but apparently were not so profuse as in previous years. At the time of ripening they reached six feet or more in height. Among the grasses, *Anthephora pubescens*, Nees, predominated. *Digitaria eriantha* Stend. was also prominent. On the limestone ridges *Chrysopogon serrulatus*, Trin., grew more freely; with *Cymbopogon excavatus*, Stapf., and *Cymbopogon plurinodis* more scattered. *Themeda triandra*, Stack., appeared surprisingly late, only towards the end of January. *Fingerhuthia africana*, Lehm., and various species of *Eragrostis*, *Chloris*, and *Panicum* were visible everywhere, but nowhere prominent. *Brachiaria Marlothii* was widespread, but died down immediately after the rains, although *Tragus racemosus*, also an annual, remained green much longer. Towards autumn *Aristida congesta* R. and S. dominated more and more.

In February most of the grasses flowered, although the subsequent seed was found incapable of germinating. Seeds were gathered as ripe in April and May. In May the haulms became yellow, but the leaves remained green until the middle of June. By the end of June the grasses were dry.

Later on a few insignificant showers fell, and during the latter half of August beautiful dark green grass shoots again appeared, especially *Themeda*. Annual grasses, however, were not apparent. In the beginning of September many old haulms of various species (*Aristida uniplumis*, *Eragrostis superba*, *Digitaria*, *Themeda*) became green, at least in their basal regions. This phenomenon was so peculiar that it is worthy of special comment and further investigation. Two species of *Aristida*, *uniplumis* and *stipoides*, were specially examined and showed the phenomenon in remarkable fashion. *Uniplumis*, for instance, showed the green colour at the end of the winter and again after every moderate rain. The haulms were often yellowish green up to the spike after rain, but faded down during the ensuing weeks of drought; first to the top node, then to the one below, and so on until the colour finally vanished. Microscopical sections, cut at the time, showed normal chlorophyll grains with enclosed starch, besides the large proportion of destroyed cellular material. The cells could be plasmolysed and deplasmolysed, and were therefore alive. The nucleus itself was not visible in freehand sections, being probably covered with chlorophyll granules.

Towards the end of September less green grass could be found than in August on account of the drought, and only *Eragrostis superba* was in flower. The old haulms became yellow again and grass leaves dried out. At this time some of the grasses showed red leaves. In October the grasses dried out so quickly that the process of withering could scarcely be observed. On 1st November over half an inch of rain fell and new green leaves appeared, becoming abundant after the rainfall of over two inches in the middle of the month. At the same time the old haulms of *Aristida uniplumis* became green up to the spike, and until the end of the month the grasses in general grew with extraordinary rapidity. At the beginning of December, however, the green colour of the *Aristida* haulms receded, and a few days later leaf-wilting occurred. On 11th December a locust invasion occurred and destroyed the veld so completely that very few green leaves were again visible until the end of January, 1924. The damage from locusts can perhaps be best illustrated by mentioning

that, after their visit, it took three people several hours to collect 50 grams of green leaves of a species of grass wanted for analytical purposes.

The January rains (Table I) caused a fresh shooting of the veld, but unfortunately the grasses dried out in February, with the exception of *Cymbopogon excavatus*, Stapf. The March rains brought on new leaves and the haulms developed, but remained short and flowered by the time they reached 1 to 2 feet in height. Some then showed intercalary growth and reached a fair height by the end of April, but never reached the dimensions of the previous year. In March, also, the annual creepers appeared, but in much smaller numbers than in 1923. None of the grasses ordinarily counted upon to supply feed for cattle could be regarded as dominant throughout this period. By the end of April various species of *Aristida*, particularly *Aristida congesta*, were the most prominent.

During the earlier part of April the veld was parched, and, although the rains later in the month effected rapid improvement, the frost of 1st May intervened before the seeds could become solid and ripe. During May, probably on account of the frequent frosts, the haulms and leaves rapidly turned yellow and the plants showed only unripe seeds. By the beginning of June no green leaves could be found on any of the grasses except Themeda.

The most striking feature of the veld throughout the whole season was the complete absence of young plants. Indeed, over two years of observation young perennial grass-plants were never seen except for a few *Pogonarthria falcata* Rendl. in April, 1923. The roots of even these plants, however, had apparently not developed frost-resistance, since they were not observed in 1924.

During the period of repeated withering and recovery of the grasses quite a large number of other veld plants grew normally under the same veld conditions. The question therefore arises: What factors cause the wilting of the grasses and prevention of withering of the other plants?

Wilting.—First of all the phenomenon of wilting may be considered in some detail. The description of the veld, already given, best illustrates the influence of the irregular rainfall. In the beginning of 1923 the normal "rainy season" was interrupted by hot sunny days, on which the grass opened early, but wilted by 8 a.m. during January and by noon later in the season. In the course of the evening it recovered again, without suffering permanent withering. At the end of 1923, and in February, 1924, however, permanent wilting occurred and the factors which control temporary wilting could therefore not be studied. Under the extreme conditions producing "permanent wilting" the grasses withered so quickly that drooping could scarcely be observed. Desiccation occurred during rolling, the leaves did not unroll again, and in a few days were completely dried out. Under the less extreme conditions of the preceding year, the process of "temporary wilting" could be more closely observed. In the early morning the grass leaves were bright green and open. Between 8 a.m. and 11 a.m., according to temperature, relative humidity, and conditions of soil moisture, the leaves began to fold, curl, and wither. As first sign of wilting, *Digitaria*, *Anthephora*, and *Chrysopogon* showed a "drooping," not clearly shown by other grasses, probably on account of a different disposition of the sclerenchyme tissue. The final shape of the wilted leaves is

quite specific. *Digitaria* curls, *Eragrostis superba* first folds then rolls, while *Aristida uniplumis*, *Eragrostis lehmaniana*, and *Aristida congesta* roll up very rapidly. *Cymbopogon plurinodis* and *Themeda* show a simple folding, and with the latter only the completely dry leaves are curled. *Chrysopogon* also shows a shrinking in certain parts of the folded leaf resulting in serrated or rake-like edges.

During wilting the grass leaves lose their fresh colour and become grey green. During the evening, or night, recovery follows if the process has not gone too far, and the controlling factors of temperature and moisture are sufficiently favourable. The influence of these factors may be best illustrated by specific example. In January, 1923, when grass leaves appeared after the first rains, a subsequent wilting was observed as early as 8 a.m. and the ensuing recovery was only marked for a few hours late at night. At this time the soil was exceedingly dry, the temperature high, and atmospheric moisture low. The following month soil moisture was higher, temperature lower, and wilting less frequent. The leaves then only withered towards noon and by late evening were quite fresh again. After 17th March, 1923, little wilting was recorded, the last occurring at a soil moisture-content of about 0.5 per cent. In the following much hotter summer of 1924, however, wilting frequently occurred at soil moisture much above this, and comparison of the data given in Table I shows that temperature and atmospheric humidity play an important part. Apparently the moisture-content of the soil at which wilting occurs varies directly with temperature and inversely with relative humidity; the higher the air temperature, and the lower the air moisture, the higher may be the soil moisture which still allows of withering. The quantitative relationships between these factors in the season 1923-24 are brought out in the appendix tables and require no further comment.

The difference between "temporary" and "permanent" wilting is, of course, not a fundamental one, and a continuance of conditions occasioning the former leads inevitably to the latter. The difference between the two processes actually observed in 1923 and 1924 was largely a matter of rate, the water loss in the summer of the latter year being much faster than in the former. In regard to the actual loss of water which the grasses can stand before wilting occurs, it may be mentioned that, from a large number of data secured in connexion with another portion of the investigation into veld conditions, a loss of 20 per cent. of the fresh weight of the leaves need not be accompanied by any sign of withering. Even in temporary wilting, from which recovery follows during the night, a water-loss equivalent of 50 per cent. of the fresh weight may take place daily. These figures are interesting in comparison with those of Knight (1922, S. 377), in which drooping is recorded on European plants at a water loss of 2 per cent.

Comparison of the Grasses with Other Plants.—In comparison with the behaviour of the grasses a few comparative observations upon other plants of the same area are of interest. Different plants are of course adapted to resist drought by different means, and the mechanism involved may be anatomical, or physiological, or both. The flora of the Vryburg District provides an interesting illustration of the various methods adopted by nature to guard against desiccation and some of these may next be considered:—

Root System.—Amongst the Armoedsvlakte flora a tremendous development of water storing root system is common, and this may take the form of subterranean stem as in *Elephantorrhiza Burchellii*, Benth., and *Menadora africana*, Hook; or simply the form of a large rhizome as in *Cassia abovata*, Collad. These big roots develop horizontally since vertical penetration is soon limited by the solid rock beneath the shallow soil. Some individual bushes may have deeper roots passing down clefts in the underlying rock, but opportunity for observing these was limited, and in any case it is the lateral root growth which is characteristic. A large number of monocotyledons, but also several dicotyledons (*Euphorbia*, *Convolvulaceae*, *Asclepiadaceae*, for instance), show big bulbs or tubers which serve for water storage. Most of these plants are in evidence in spring, or towards winter when the veld as a whole becomes dry.

Succulence.—It is a peculiar fact that succulent plants are rare on Armoedsvlakte, the only ones observed being three species of *Mesembryanthemum*, a *Portulaca*, and a *Gnaphalium*. The two latter are leaf-succulents, the former stem and leaf succulents.

Leaf Size.—More frequent than succulence is diminution in size of leaf, which in some cases goes to complete reduction. A large number of Compositae show this behaviour, amongst which may be mentioned *Nolletia ciliaris*, Steetz, *Felicia fascicularis*, D.C., several *Helichrysum*, *Pentzia*. Of other plants may be cited *Polygala rarifolia*, *Hermbsbaedtia elegans*, *Semonvillea fenestrata*, and various *Oldenlandia*. Completely without leaves are *Pituranthos Burchellii* B. and H., a *Thesium*, and *Arthrosolen gymnostachya* C. A. Mey. Except in the rainy season, big leaves are never found.

Leaf Epidermis.—Special formation of the leaf epidermis is characteristic of many Armoedsvlakte plants:—

- (a) *Stomata.* Some of the plants show an unusually small number of stomata, and the stomata themselves may be very small, e.g. *Elephantorrhiza* and various *Amarantaceae*. Generally speaking, however, this protective device is much less frequent than might have been anticipated.
- (b) *Cuticle.* A thick cuticle is common on monocotyledons and dicotyledons such as *Rhus* and *Grewia*. An epidermis several layers thick is shown by several monocotyledons, e.g. *Dipcadi*.
- (c) *Hairs.* A thick covering of hairs is characteristic of several species of *Helichrysum*; also of *Stachys spathulata* Burch., various *Convolvulaceae*, *Melhania Rehmanni*, Szysz. It is noteworthy that many plants are only covered with hairs when young, becoming smooth again as they grow older, e.g. *Indigofera hololeuca*, *Vernonia kraussii*, Sch. Bip. It is also noteworthy that glandular hairs are very common in the vegetation of Armoedsvlakte, but it is difficult to say whether this fact is of any significance in regard to protection against excessive transpiration (*cf.* Marloth).

The corresponding leading features of the grasses may be briefly summarized. The grasses in general have exceedingly small roots which are devoid of hairs, except in the rainy season. Some grass roots, however, have the cortex tissue developed in a peculiar way as a cover which can be stripped off round the central cylinder, e.g. *Eragrostis superba*, *Pogonathria*, *Aristida uniplumis* (Photo 4).

During drought this cover is shrivelled, but after rain it swells up like a sponge. It has not yet been studied from the anatomical point of view, but macroscopically it is an interesting structure. Apart from their unbranched suction roots, all the grasses have branched fixation roots, often corky. The leaves of all the grasses investigated were found very similar, being formed on the "wreath type" of Haberlandt (1918, p. 264). All show much sclerenchyme tissue, and all show numerous blunt papilli on their surface. Many leaves (e.g. *Digitaria*, *Sporobolus*, *Themeda*) show numerous hairs when young, which, however, are reduced to the region of the ligula when old. The stomata are generally numerous and nearly always (excepting *Chrysopogon*) on both sides of the leaf. They are indeed often more numerous on the under side, a disadvantage when the lower surface is exposed to the sun by folding of the leaf. The stomata themselves are large and arranged in long rows over the green tissue of the leaf. The distribution is very surprising in view of the fact that grasses of dry habitat have frequently no stomata on the under surface of the leaf at all (Volkens, 1887, p. 63). It would therefore seem that the grasses of Vryburg are not specially adapted to the climate, and although a special study of their anatomy might reveal much more of interest in various connexions, such investigation is beyond the scope of the present work.

Behaviour of Plants other than Grasses.—From the anatomical sketch just given it is apparent that most of the plants other than grasses are protected against wilting by various morphological features. Indeed, a wilted perennial has not been observed in the open veld, although of course all the plants whose growth is confined to the rainy season naturally wither quickly in a blazing sun. The only other plant which behaved at all like the grasses was *Alternanthera Achyrantha* R. Br., growing in a garden. This withered in February, 1924, from 10 a.m. to 4 p.m., but was fresh in the evenings and mornings, and although subject to temporary wilting was therefore much more resistant than the associated grasses which wilted permanently at the same period. The plate on p. 673 shows a photograph of this plant (Photos 5 and 6).

Another phenomenon, however, which was very common is the protective position taken up by the plants against excessive insolation and exaggerated transpiration. This protective device of the leaves was shown notably by Leguminosae, but also by a large number of other plants. Amongst the Leguminosae were regularly observed: *Elephantorrhiza Burchellii** Benth., *Cassia obovata** Collad., *Rhynchosia confusa*.* Burt-Davy, *Indigofera cryptantha** Benth, *Acacia horrida** Willd. Amongst other plants, *Commelina Livingstonei** C.B.Cl., *C. africana** Linn., *Hermbsstaedtia elegans* Moq., *Limeum viscorum*, Fenzl., *L. africanum*, *Giesekia pharnaceoides*, Linn., *Oxalis convexula*.* *Tribulus terrestris** Linn., one of the *Euphorbiaceae*, *Grewia cana** Sond., *Hermannia brachypetala** Harv., occasionally also *Hermannia Wooddii*.* *Salvia rugosa* Tunb., *Aptosimum elongatum* Engl., *Sesamum capense** Barm., *Geigeria obtusifolia*, and sometimes certain Compositae with small leaves.

The asterisked species showed typical leaf movements; the remainder only indistinct movements.

Amongst plants which were regularly observed, but in which no leaf movement at all could be detected, may be mentioned: all *Liliaceae*, *Iridaceae* and *Amaryllidaceae*; *Oxygonum alatum*,

which has very few leaves; an *Amaranthus* species and *Aerva leucura* Moq., which grow in the rainy season; *Cleome rubella*, Burch. (rainy season), *Vahlia capensis** Thunb. (the whole year), *Monsonia biflora* D.C. (rainy season), *Polygala* (very small leaves), a species of *Rhus* with vertical leaves, *Zisyrphus zeyheriana*, Sond. (winter resistant), all *Malvaceae* (rainy season only), *Bergia decumbens* Planch. (very small leaves), many *Convolvulaceae* (some confined to the rainy season and some flourishing all the year through, but then thickly covered with hairs; *Bouchea pinnatifida** Schauer (whole year), *Stachys spathulata* Burch. (whole year, snowy hairs), *Solanum supinum** Duval (October to March), various *Sutera* with very small leaves, *Walafrida densiflora* Rolfe (small leaves), *Oldenlandia stricta* K. Schum (small leaves); all *Cucurbitaceae* (rainy season); a species of *Wahlenbergia* (rainy season, small leaves), *Vernonia Kraussii* Sch. Bip. (young forms densely hairy, leaves pressed towards stem), *Felicia fascicularis*, D.C. (very small leaves), *Nidorella resedaefolia*, D.C., various species of *Helichrysum* (woolly hairs in spring), *Epaltes gariepina*, Steetz (vertical leaves), *Geigeria passerinoides* Harv. (very small leaves), *Schkuhria bonariensis* H. and A. (very small leaves), *Gazania longifolia* (white hairs on the under side of leaves).

The asterisked species seem to have neither a morphological adaptation nor protective position to explain the fact that they do not wilt. They always appear fresh green, even in the driest soil and hottest sunshine.

The movements of the leaves are of course different in the various plant families, and only in the case of the Leguminosae can they be regarded as uniform. The various types of movement may be briefly indicated as follows:—

Commelina.—Observed species fold their leaves to a greater or less degree during the hot period of the day, but the leaf margins seldom touch one another. *C. africana* folds sooner and more extensively than *C. Livingstonei*.

Giesekia pharnaceoides.—In the young stage the leaves show a typical rolling into ball form. This position was only noticed during drought just before rain in January, 1923. The red underside of the leaves was then exposed to the sun but the surface was very much reduced by the rolling. After the rains the plant unrolled, the red colour disappeared, and the leaves remained open until the plant finally died down. In 1924 the plant only came up after the rains and the drought position of its leaves was therefore never visible.

Oxalis convexula.—Forms a blunt pyramid during the hottest time of day by folding of its three leaf-portions. A special night position was not observed. The pyramidal position was only observed in 1923, since in 1924 the plant only appeared after the rains. An intermediate position, however, which apparently precedes the pyramid form and in which the leaf parts are placed vertically, was noted both in 1923 and 1924.

Tribulus terrestris.—In the hot period of day folds its leaves along the midrib, which is held more or less vertically; illustrated in Photos 7 and 8.

Grewia cana.—The leaves are open and horizontal in the mornings and evenings. During the hotter period of the day they are

folded along the midrib or held more or less vertically. The changes are only noticeable on young leaves. In times of great drought the leaves are cast off.

Hermannia brachypetala.—In the early morning and at night the leaves are spread out horizontally. According to drought and temperature, the leaves, during the course of the day, tilt up at a variable angle, the vertical position being assumed under extreme conditions. Young leaves react more readily than old ones, and may also fold. Frequently the young leaves are vertical while old leaves are inclined at an angle of 50 degrees to the soil, or even completely spread out. *Hermannia woodii* behaves in similar fashion. Photos 9 and 10 shows the two positions of *H. brachypetala*.

Salvia rugosa.—In this case the behaviour is due to water translocation rather than to active movement. In time of drought the lower leaves droop and their water is transferred to the younger upper turgescient leaves. During the night the older leaves regain more water through the roots and in the early morning they are again spread out.

Sesamum capense.—This only shows leaf movement in the young state. In the morning, or after rain, the leaves are spread horizontally, but during the day at times of drought they either drop down or rise up so as to strike a sharp angle with the stem.

Leguminosae.—The movements of this group have often been described already (Literature: Benecke and Jost, 1923, pp. 369-371), but since the climatic conditions of Bechuanaland are different to those under which Indian and American observations have been made, it is of interest to record a few local observations. In some cases (Haberlandt, 1910, p. 111) the folding of leaves of Leguminosae has even been regarded as due to high rainfall, but in Bechuanaland such an explanation is naturally out of the question.

The movement shown by *Rhynchosia confusa* is relatively simple. In the early morning, and at night, the three leaf-portions are spread out, but with increasing temperature and drought they strike a steadily increasing angle to the soil, and in extreme cases incline together as a pyramid. This type of movement was observed in January and October, 1923, and during the first two months of 1924 (Photos 11 and 12). The movements of *Cassia* are more varied. Apart from the infrequent horizontal position, all transitional stages up to the completely closed leaf are found, according to the severity of drought (Photos 13, 14, 15). From September, 1923, to February, 1924, the completely closed position was the rule for *Cassia*, except after rains. After March it was rare. The movements may be considered to be of hygronastic rather than photonastic nature, since in 1923 *Cassia* retained its leaves open, even in the strongest sunlight, so long as the soil was sufficiently moist; and only closed them as the soil dried out. Apart from leaf movements of the day-time, *Cassia* also shows a characteristic night position; closes its leaves completely in the dark and only reopens after sunrise (Photo 15). In bright moonlight, however, the leaves do not close completely, and partial closing occurs under a dark sky before rains or before a thunderstorm even if the sky is not dark. The leaf position is then much the same as under drought and strong light, but is more uniformly adopted. The diurnal course of leaf movement during a period of drought is interesting. The "profile position" of night changes, from sunrise to about 7.30 a.m., over into the fully open position; but the leaves

only retain this position for a few minutes before the closing again commences, the closed position of day-time being then completed in about two hours' time. Before sunset the leaves again open in a short space of twenty minutes, and after sunset again close in about three minutes. Some of these movements were so rapid that for some months photographing was impossible, and good pictures were only obtained when the daily closing was delayed by subsequent rains.

Elephantorrhiza Burchellii behaves in much the same way. In time of drought the leaves close before 8 a.m. and are completely shut by 10 a.m. The leaves of various individual plants then behave differently. Some content themselves with the closed position; others take up a meridian position over noon, the single leaves approaching so closely that the west-east dimensions are only 2 cm. as against 25 cm. for the south-north. Towards evening the leaves again open, and then quickly after sunset pass over into the usual completely closed night position. A meridian position was never observed at night (Photos 16, 17, and 18).

With *Elephantorrhiza* the leaf stalks as well as the leaf segments are capable of movement. During extreme drought complete opening of the leaves was rarely observed; and in the evening the day position may pass directly over into the night position without intermediate opening, although the converse was never noted in the morning.

Indigofera crypthantha may also be specially mentioned, because in taking up the night position its leaves move towards the under side, although complete closing in this direction has never been observed. In the early morning the leaf is outspread, but the leaflets soon begin to approach one another towards either the upper or under side, often folding in the process. Only the youngest leaves have been observed to close completely; for the rest the angle of inclination ranged from a minimum of 30 degrees upwards.

The daily leaf movements described here depend primarily upon the prevailing degree of drought and generally run parallel with the wilting behaviour of the grasses. At a period when the grasses wilt in the early morning, plants such as *Elephantorrhiza* close their leaves at an early hour. The night positions of both *Cassia* and *Elephantorrhiza*, however, are of a photonastic nature. The closing movements of the Leguminosae during day-time on the other hand, and probably also the movements of other plants, are of an hydronastic nature. If the soil is sufficiently moist and the air not too dry, no movements occur. They are in any case protective devices against excessive transpiration (*cf.* companion paper of transpiration).

DETERMINATION OF SUCTION FORCE AND OSMOTIC DATA.

In determining suction force and osmotic values of selected Bechuanaland (Armoedsvlakte) plants, the methods and terminology of Ursprung were adopted (1916, pp. 525-539; 1920, pp. 193-216; 1923, pp. 338-343), as since cited in "Pflanzenphysiologie" by W. Benecke and L. Jost, Vol. I, pp. 57-58, 1924. Since these methods are not yet recorded in the generality of textbooks, they may be described here. In all there are three.

Method I.—1916, p. 530. As Ursprung expresses it:—"The suction force of a living cell is the resultant of all the forces operating on the inflow and outflow of water. As regards inflow, must be

considered the osmotic suction of the contents, together with all external distorting strains tending to increase the cell volume. As regards outflow, must be considered the tension of the elastic wall and all external pressures tending to decrease the cell volume. The central pressure may be neglected, and disregarding external forces the suction force of the cell may be taken as the suction force of its contents minus the wall pressure. The first method of measurement consists in determining the resultant by estimating the components. The suction force of the contents may be obtained from their osmotic value at constant cell volume, and the tables of Morse, or Berkeley and Hartley. This osmotic value may be measured by observing incipient plasmolysis with cane sugar, noting the cell volume in the normal state and at the point of plasmolysing. The wall pressure at normal pressure may be reckoned from the wall pressure under water saturation, when it is the same as the osmotic value (since equilibrium prevails), and the wall pressure at incipient plasmolysis when it is zero."

In personal investigations spherical, cylindrical, or prismatic cells were always used. The thickness of the cell, i.e. the dimension in the direction of the microscope axis, was measured by means of a micrometer screw, the observed value being multiplied by the refractive index of the liquid used or the liquid introduced between lens and coverglass to obviate multiplication. The transverse section of the cell was drawn with the Abbe apparatus and measured with a Conradi planimeter. Normal cell volume was determined in paraffinum liquidum. The observational fluid was changed as required, by immersing the sections in fresh liquid in small flasks, since this allowed better rinsing of the section than can be accomplished by irrigating the slide, although it has the disadvantage that often the particular cell is lost and cannot be found again in spite of marking or counting. For plasmolysis, cane sugar was used, the corresponding osmotic values being obtained from Ursprung's tables (1916, p. 253; 1923, p. 368); or for higher values from a table Professor Ursprung calculated for me. The wall pressure was calculated on Ursprung's assumption that increase of volume and wall pressure are proportional in the various fluids used.

A practical example will make the application of the method clear:—

Eragrostis superba, 2nd January, 1923, 6 a.m. Incipient plasmolysis noted in preliminary experiment at 0.6 molar cane sugar. Palisade cells cut under liquid paraffin, observed and drawn. Area found to be 57, thickness 6.6, and hence volume 376.2, expressed in arbitrary units depending upon the magnification. Measured in distilled water (with water immersion of lens to avoid use of refractive indices), thickness unchanged, area 82, and cell volume 662.2. Section now measured in 0.6 molar cane sugar solution; thickness unchanged, area 50.0, cell volume 330.0. Osmotic value at incipient plasmolysis equivalent to 0.6 molar cane sugar; in water is therefore $0.6 : x = 662 : 330$, i.e. 0.299 mol.; in liquid paraffin $0.6 : x = 376.2 : 330$, i.e. 0.526 mol. Taking the wall pressure in water as 0.299 mol., the volume at incipient plasmolysis as unity, and reckoning on percentage basis, the wall pressure in liquid paraffin becomes $0.299 : x = 100 : 13$, i.e. 0.04 mol. cane sugar. Neglecting external pressures, the suction force is therefore 0.52 minus 0.04, i.e. 0.48 mol. cane sugar, or 13.66 atmospheres.

This method was used for the first 50 determinations carried out, but it offers considerable practical difficulties in volume measurement and, on the advice of Professor Ursprung, it was therefore abandoned.

Method II.—In its place was substituted the second method (1916, p. 537) in which the treatment with water falls away, and the relationship between wall pressure and cell volume is disregarded. Instead of the volume itself, change of volume is noted, and a sugar concentration found in which the cell does not alter. The section is cut as in the preceding method and the cell measured in liquid paraffin by micrometer screw, Abbe drawing apparatus, and Conradi planimeter. By the method of trial and error two concentrations of cane sugar are then ascertained, one of which effects slight increase in cell volume and the other slight decrease. Greater accuracy is obtained by taking further sugar solutions of intermediate concentration, fresh sections being of course necessary for each observation. Calculation is then made directly from the final sugar solution in which no appreciable volume change occurred. Comparison of this method with the preceding one showed substantially the same values for both. Since in the first method the sections have to be in the water and cane sugar solutions for two hours to ensure constant volume before measurement, the second method is much preferable when several observations have to be made daily. It was therefore used in all subsequent determinations on grasses.

Method III.—A letter was subsequently received from Professor Ursprung in which a third method was described as giving good results so long as values are only required for purposes of general orientation. In this the general principle is the same as in the second method, but instead of considering a single cell, a piece of tissue, or cell complex, is measured. It has the advantage that it can be used directly in the field, although in the present investigations, determinations were actually executed in the laboratory owing to the ease with which the required plants could be secured in the immediate vicinity. A brief description is of interest, although the method has now been published (1923, pp. 338-343). A fair number of sections is cut under liquid paraffin and measured with the aid of an ocular micrometer graduated against a standard stage micrometer. Suitable single sections are then transferred to various cane-sugar solutions of known concentration and the volume change of each noted. A series of sections is thus obtained in which the volume is greater, and another series in which it is less, than in liquid paraffin. By then utilizing intermediate concentrations of sugar, the point at which no volume change occurs is readily determined. Since the method is only for orientation purposes the test solutions of cane sugar were made up at intervals of 0.05 molar, instead of the 0.02 molar used in the two previous methods. The process is of special value when the plant-physiological investigations are of a geographical character, and a large number of determinations have to be carried out on the spot. Without this method it would not have been possible to make all the observations recorded in this article, and special acknowledgment is therefore made to Professor Ursprung for his private communication in advance of publication.

This third method was chiefly used to estimate suction force in material other than grass leaves, and in fruits and roots. For finer determinations, especially for small changes such as the increase in suction force from bundles to palisade cells, it cannot be used, since it

only gives the average value of a cell complex. In such cases recourse has to be taken to the previous method. In the following pages reference is sometimes made to work published before Ursprung, but wherever possible earlier data are expressed in his later terminology.

The Plant Material.—All the plants investigated were obtained in the vicinity of the Armoedsvlakte laboratory buildings, so that no damage occurred during transport in liquid paraffin. The main data concerned grasses, and *Eragrostis superba* was taken as comparative standard, regular weekly observations being conducted upon it right throughout the vegetative periods from December, 1922, until January, 1924. For *Tragus racemosus* weekly observations were also made until June, 1923, but during 1923-24 this grass was so scarce that the more resistant *Themeda triandra* was substituted as second standard. On *Antheophora pubescens* and *Digitaria eriantha* determinations were carried out at intervals of three to four weeks until the end of 1923, at which time no green leaves of these species could be obtained. At irregular intervals, but sufficiently frequent to allow of construction of annual curves, *Cynodon dactylon*, Pers., *Panicum helopus*, Trin., and *Sporobolus fimbriatus*, Nees., were examined. Occasional determinations were also made upon *Eragrostis lehmanniana*, Nees., *Aristida uniplumis*, Licht., *Chloris petraea*, Thunb., and *Tragus koelerioides*, Hsch.

With the exception of *Cynodon dactylon* and a few sections of *Digitaria eriantha*, determinations were carried out upon transverse sections of leaves. With *Cynodon*, haulms were used, since the leaf was found very difficult to cut. For most of the Gramineae, roots, sectioned in the absorption zone, were investigated at the same time as leaves throughout the summer 1923-24.

Of other plants, leaf sections were investigated of the following:—

- COMMELINACEAE : *Commelina africana* Linn., and *C. Livingstonei* V.B.Cl.
 LILIACEAE : *Anthericum spec.*, *Urginea rigidifolia*, *Scilla spec.*
 IRIDACEAE : *Morea spec.*, *Gladiolus nova spec.*
 AMARANTACEAE : *Hermbstaedtia elegans*, Moq., *Aerva leucura*, Moq., *Alternanthera Achyrantha* R.Br.
 PHYTOLACCACEAE : *Limeum viscosum* Fenzl. and *L. africanum*, *Giesekia pharnaceoides* Linn.
 PORTULACACEAE : *Portulaca spec.*
 AIZOACEAE : *Mesembryanthemum Lesliei* U.E.Br., *Mesembryanthemum unidens* Harv., *Mesembryanthemum spec.*
 CRUCIFERAE : *Sisymbrium spec.*
 CAPPARIDACEAE : *Cleome rubella* Burch.
 SAXIFRAGACEAE : *Vahlia capensis* Thunb.
 LEGUMINOSAE : *Elephantorrhiza Burchellii* Benth., *Cassia obovata* Collad., *Listia heterophylla* E. Mey., *Tephrosia capensis* Pers., *Rhynchosia confusa* Burt-Davy, *Acacia horrida* Willd.
 OXALIDACEAE : *Oxalis convexula*.
 EUPHORBACEAE : *Euphorbia sanguinea* Höchst., *Phyllanthus maderaspatensis* Linn.
 ANACARDIACEAE : *Rhus spec.*

- RHAMNACEAE : *Zisypheus zeyheriana* Sond.
 TILIACEAE : *Grewia cana* Sond.
 MALVACEAE : *Hibiscus trionum* Linn., *Hibiscus atromarginatus* E. & Z.
 STERCULIACEAE : *Hermannia filipes* Harv., *H. brachypetala* Harv.,
H. coccocarpa K. Schum., *H. linnaeoides*,
H. spec. Nat. Herb. 2765, *Melania Rehmanni* Szysz.
 MYRTACEAE : *Eucalyptus spec.*
 CONVULVULACEAE : *Ipomaea spec.*
 VERBENACEAE : *Bouchea pinnatifida* Schauer.
 LABIATAE : *Salvia rugosa* Thunb., *Stachys spathulata*
 Burch., *Acrotome inflata* Benth.
 SOLANACEAE : *Solanum supinum* Dunal.
 SCROPHULARIACEAE : *Aptosimum depressum* Burch., *Sutera aurantiaca*
 Hiern., *Sutera atropurpurea* Hiern., *Sutera caerulea* Hiern., *Walafrida densiflora*
 Rolfe.
 PEDALIACEAE : *Sesamum capense* Burm.
 RUBIACEAE : *Oldenlandia stricta* K. Schum.
 CUCURBITACEAE : *Citrullus vulgaris* Schrad., *Cucumis myriocarpus*
 Naud., *Cucumis heptodactylus* Naud.
 COMPOSITAE : *Vernonia Kraussii* Sch., Bip., *Pentzia cana*,
Felicia fascicularis D.E., *Gazania longifolia*, *Lactuca spec.*, *Dicoma capensis* Less.,
Nidorella resedaefolia D.C., *Geigeria obtusifolia* and *passerinoidea* Harv., *Nolletia ciliaris* Steetz, *Helichrysum agyrosphaericum* C., and *H. caespititium* Sond.

The bulb of *Gladiolus* and the fruit of *Cucumis* were also investigated.

In selecting the various plants for investigation the period of growth was the deciding factor. As already mentioned in describing the veld, a large number of plants appear only in the rainy season and complete their vegetative and reproductive life within a few weeks, while others grow all the year round except for two winter months.

Results.—A glance at the Tables 2-8 given in the appendix on pp. 645-62 shows that, both for suction force and osmotic value, the values are subject to wide fluctuations for one and the same species. With *Eragrostis superba*, for instance, the suction force varies from 1 to 52 atmospheres. It is further evident that in the early part of 1923 the morning figures are not unduly high, the average value being approximately 15 atmospheres. Since the grasses were always fresh at the time of sampling this may be looked upon as the "normal value".

Comparison of the data of 1923 with those of 1924 shows that suction force and osmotic values of the latter are far higher than the former. A general survey of all the tables makes it clear that the various grasses investigated have very similar values at the same time of the year.

Diurnal and Annual Curves.—The diurnal values were obtained by making a first determination early in the morning, generally between 5 a.m. and 8 a.m.; a second between noon and 2 p.m.; and a third in the evening after sunset, between 6 p.m. and 9.30 p.m. If

the three values are compared for the same grass, it is apparent that in the dry months and on clear days the figures differ very markedly. The morning value, for instance, of the suction force in the beginning of 1923 (Table 4) is often only half that at noon. The evening value is generally similar to the morning value, although occasionally it may be much higher. At times of rain, however, especially in February and March, 1923, and then again in November, the three figures do not differ much, and it may even happen that the morning value exceeds the noon value. It is also noticeable that in February and March, 1923, the figures are considerably below the so-called "normal values." There is no doubt that the reduced values are directly due to the rain. At this period the soil was approximately half saturated, and since it has little capacity for retaining moisture (*vide* p. 12) the plant readily absorbs so much water that its cells approach saturation point. Complete saturation probably never occurs naturally with land plants, and indeed Pfeffer (1897, p. 129) indicates a lower limit equivalent to 0.1 molar potassium nitrate, or 0.15 molar cane sugar (uncorr.).

A feature of special interest in the present determinations is the fact that the low values are only reached eight to twelve hours after the rainfall. In view of the short distance between the shallow grass roots and the relatively low leaves, this time seems unduly long, and the transport of water into grass leaves is therefore regarded as very slow. In this same connexion the observations on suction force of leaves covered with dew (No. 27, Table 3) are interesting. If examined between 5 a.m. and 6 a.m., immediately after dew fall, they showed values much below the usual morning average. Apparently the leaves absorbed the dew directly, without the water making the usual detour by the roots. It is surprising, however, that such direct absorption does not take place during rainfall. The explanation is probably that the rainfall is too violent (p. 620) and that the leaves do not retain the drops, whereas the light dew droplets can be readily held by the numerous papilli of the leaf surface. The slow transport of water is doubtless responsible for the fact that the noon values are usually lower than the morning values, especially since the rains generally fall during the night. In November, 1923, the figures for suction force are not so specifically decreased by rain (Tables 2 and 4), since all values in the season 1923-24 were higher than in the preceding season, and the effect of rain was rather to bring to normal.

The lower extremes in the recorded data seldom prevailed for long, and the evening values often exceed the noon values of the same day, although a few days later big differences between morning and noon values may again appear. It is quite obvious that grass leaves can lose very large amounts of water by transpiration. The very high noon values are not shown by normal fresh-looking leaves, but only by leaves which are folded, rolled, or wilted, and they can therefore not be called "normal." It is recorded in the literature (Meier, 1916, Ursprung, and Blum, 1916, p. 106) that plants display a higher suction force, or at any rate a higher osmotic value, towards noon, but the difference rarely exceeds 0.1 molar cane sugar; whereas in the determinations recorded for Armoedsvlakte the differences can reach 0.5 molar. One might perhaps be inclined to assume that under the influence of the dry climate a flora has developed in which the normal suction force can vary over a wide range, but if this were so

other plants should also show the same phenomenon, and even grasses might be expected to go a step further and increase their suction force to such an extent that no wilting occurred at all.

How, then, is the suction force really increased? Is it by simple loss of water or by production of osmotically active material, such as sugar by carbon assimilation or by hydrolysis of preformed starch, or is it by absorption of salts from the soil? This last factor obviously does not come into practical account since it involves simultaneous absorption of water having the reverse effect, and hence the former factors need only be considered. Since adequate water is a condition of carbon assimilation, it is highly improbable that lively assimilation takes place during wilting, and indeed the experiments of Iljin have shown that during withering soluble organic matter actually disappears. Details of similar experiments at Armoedsvlakte need not be discussed at this juncture, but it should be mentioned that the dry matter determined in leaves at noon may be 25 per cent. to 60 per cent. higher than the dry matter determined on similar leaves in the early morning, while at the same time the proportion of sugar remains below 2 per cent. The discrepancy between these figures shows that the osmotic value and suction force is not due to the active production of soluble organic material, but only to passive loss of water. This loss is the direct consequence of excessive transpiration from the leaves and slow water transport from the roots, the latter being further restricted by the small amount of available moisture in the soil. The factors which increase suction force are therefore only passive and external. This fact is also brought out by the determinations (1-50) made by Ursprung's original method, in which the wall pressure of the cells is calculated. In the very period of drought the wall pressure is in many cases exceptionally low, and the whole leaf would doubtless collapse much sooner if it were not for the supporting sclerenchymatous tissue. With an active increase of suction force and osmotic pressure of cell contents the wall pressure should be great.

If the question of devices to guard against this passive increase in suction force be raised, the answer can only be that none are apparent. If the grasses had a higher normal suction force or osmotic value from the beginning, then wilting should not occur so rapidly, firstly, because, on physical grounds, less water would be evaporated as a consequence of reduced vapour tension and, secondly, because a high normal suction force would transport even the scanty soil moisture more rapidly into the leaves.

In regard to *annual variations*, the behaviour throughout the year (Table 4) is self-evident after the preceding discussion. In the rainy season very low values prevail, which rise with the drier months and reach a maximum in times of hottest drought. Towards the end of 1923 (Curve 1-4) high values occur even in the morning, at a time when several of the grasses were in a state of permanent wilting. The figures for May and July, 1923, merit special notice, since the three daily values are then much the same in spite of the continuous dry weather. They are only moderately high and scarcely vary throughout a period of two months. This means that from the time of ripening until the time of dying down, the suction force and osmotic value of the grasses are not changed by loss of water, a fact which is in accordance with the observed very low transpiration and consequent adequacy of the scanty soil moisture.

For the sake of rapid graphic survey of the main facts, the values for *Eragrostis superba*, and for the other grasses grouped together, are plotted in the form of charts, upon which the rainfall is also shown. To avoid complicating the curves too much, only morning and noon figures are used (Charts 1-6, pp. 667-668).

Absolute Values.—As already mentioned, the suction force and osmotic pressure of the cells of different grass leaves are very much alike when determined at the same time of day in the same period of the season. Expressed in absolute units, the highest value reached was 59 atmospheres. About this figure was shown by *Antheophora pubescens*, *Cynodon dactylon*, and *Digitaria veriantha* (Tables 2, 7, 10), although the "normal values" on fresh leaves of these grasses do not differ much from those of other grasses. In regard to the differences between the seasons of 1923 and 1924, it is not legitimate to conclude that the "normal values" were higher in the latter than in the former, since at the end of 1923 and beginning of 1924 the prevailing drought occasioned unduly high values. Indeed, at this time the grasses were at times so poor in water that their dry matter reached the extraordinarily high figure of 70 per cent., and this certainly indicates an abnormal state. It therefore follows that the osmotic value of 0.6-0.7 molar cane sugar, and suction force of 14-17 atmospheres, determined for the Bechuanaland grasses in the so-called "normal" state, is really low in relation to the dry climate, and that the "average" figure for any given period in a series of seasons would be considerably higher. Comparative data for other arid climates are not available, since grasses have rarely been investigated, but Fitting has indicated in a private communication that he also obtained a surprisingly low osmotic value in a grass at Biskra, an observation which may account for the fact that grasses are so scarce around Biskra and only represented by dwarf forms. If it were not for the occasional years of greater rainfall the grasses of Bechuanaland would probably also disappear in time, to make way for other plants better adapted to the drought.

Grass Roots.—At the commencement of these investigations it was considered that the wilting of grasses would only occur at a definite osmotic value and suction force, but this is apparently not the case, though high values may be found both on rolled and on withered leaves. The deciding factor is now known to be *the difference in values between leaves and roots*. If this is greater than 0.2 molar cane sugar, the leaves wilt, assuming, of course, that in practice the values for leaf are generally greater than for root. Only when the root itself is harmed by the drought, do the leaves wilt at a lower difference of suction force.

In this connexion it is interesting to recall the main views expressed in the literature concerning the significance of the osmotic values in the two organs. Fitting (1910, s. 223), considering the earlier data which had been obtained almost exclusively on leaves, supposed that the osmotic value of the roots must always be higher than, or at least the same as, that of the leaves, since otherwise the roots would give up their water to the aerial portions of the plant, dry cut, and wither. Ursprung, basing his views upon data derived by his new method, comes to exactly the opposite conclusion, and holds that a gradual increase in osmotic value and suction force is shown from the zone of absorption of the roots, through the stalk and stem, up to the leaf. (1919, pp. 577-599.) Passing over details such as the leap

at the endodermis (1921), it is just this upward graduation in suction force which enables the plant to supply the leaves with the necessary water.

The investigations recorded in the present paper support the views of Ursprung, although the actual gradient observed may often be very small. Indeed, in the early morning, or on rainy days, practically no difference could be detected between leaf and root, but this is doubtless due to the limitations of the method used for the roots (third orientation method described earlier). After a continued hot, dry spell, however, the difference was readily demonstrable.

The diurnal variation in osmotic value in the absorption zone of the roots is similar to that already described for leaves, except that the fluctuations are smaller. The highest value on bright days is always at noon, and never only reached in the evening, as often the case with leaves. It is indeed this fact, that the suction force of the roots does not exactly follow the suction force of the leaves, which accounts for wilting if the discrepancy is wide enough. This may not, of course, hold for all soils, since a lively transpiration in a moist soil could theoretically cause as great a difference in suction force as the wilting gradient of 0.2 molar cane sugar for Armoedsvlakte soil, without causing withering. So long as abundant water is present in the soil, a good root system with even a small suction force may well supply the leaves with sufficient water to prevent wilting. Indeed the observed difference of 0.2 molar sucrose, between leaf and root, which effected wilting in the present investigations, is no greater than that observed by Ursprung and Blum (1919) between root and leaf of *Hedera helix*, and by Ursprung and Hayoz (1923) between individual cells of a single leaf.

In general the transpiring leaf takes up water from the root, but since the root at the same time absorbs from the soil, the concentration of root cell sap, and the suction force, need suffer no immediate change. So long as the root system absorbs in unit time the same amount of water as is lost by the leaf system in unit time, equilibrium is maintained and the osmotic relationships may remain substantially the same. If the leaves transpire water faster than the roots absorb it, constitutional water is lost by the leaf, the osmotic value of its cells rises, and its suction force is increased. Despite this, however, it may not be able to abstract sufficient water from the roots, and two courses are then open. It may actively increase its suction force still further by hydrolysing preformed starch, or it may suffer passive increase of suction force by further evaporation of water: water which it cannot replace if the soil moisture is insufficient, and the loss of which will therefore lead to wilting. From the experimental data alone, in which only suction force is measured, it is impossible to decide whether only one process takes place or whether both play a part. In any case, a dehydration of the roots by the leaves, and great difficulty in replacement of water by the soil, occurs. During the hot day the rate of transpiration of the plant exceeds the resources of a dry Armoedsvlakte soil, so that the water of constitution of the leaf is not replaced until the evening, when transpiration ceases. Under conditions of "temporary wilting" the root then secures sufficient water overnight for restoration of its normal suction force; indeed secures water more rapidly than it can be transported, since its suction force then decreases faster than that of the leaf, and attains a normal value sooner.

This explanation of the water relationships between root and leaf is the simplest one, but in practice it hardly covers all the facts, and there is good reason to believe that there is some sort of periodicity in the water transport of the plant in nature. There is evidence that after about 4 p.m.-5 p.m. more water is absorbed by the roots, or at least is transported to the leaves, than at noon or in the early afternoon. Limitations of apparatus prevented the clearing up of this point at the time of the original observations, but further experiments are contemplated at a later date.

The difference of suction force between root and leaf in the Bechuanaland grasses in the normal or un wilted state never exceeded 0.1 molar sucrose. If it increased to 0.2, or higher, withering commenced and passive increase of suction force continued. From the observations made it cannot be stated whether a passive increase occurs in roots or not. It is possible that for some time the initial increase of suction force is an active process, i.e. that hydrolysis of preformed starch takes place, with subsequent resynthesis. On the other hand, the fact that in times of extreme drought (before January rains of 1923) the roots are flaccid and without hairs suggests a passive process. The roots, however, are much more resistant to wilting and lose their water of constitution more slowly. The fact that the root more rapidly decreases to its normal value for suction force is doubtless due to the fact that it is nearer the source of water.

In regard to the annual variations in the root, they follow that of the leaves so closely that further discussion is unnecessary.

Osmotic Values of Plants other than Grasses.—As already mentioned in the introduction, the plants of Armoedsvlakte, other than grasses, may be divided into two main groups: those which are found all the year round and those which are limited to the rainy season. Physiologically these two groups are definitely characterized by difference in suction force and osmotic values. A glance at Table 11 shows that members of the first group all have the high values which might be expected. In the rainy season (March, 1924), both suction force and osmotic value of course decrease, but not so markedly as in the case of grasses (*cf.* February-March, 1923). This group stands in contrast to the grasses, since its members were never observed to wither. On the other hand, the second group, the life of which is confined to the rainy season, shows a small osmotic value and a low suction force (Table 11), and during periods of drought following rain its members are unable to raise this beyond very narrow limits; and therefore dry out in a few days. The highest figure shown by these plants is only about 0.5 molar sucrose, equivalent to about 14 atmospheres. This higher limit represents the lower limit to which the more durable plants come down during the rainy season. Table 11 shows the behaviour so clearly that only the more interesting details need be mentioned. Some succulents, a *Mesembryanthemum* and a *Portulaca*, are noteworthy for their exceptionally low osmotic values (*cf.* Cannon, 1917), and this is in harmony with the American observations that succulents in general cannot thrive in an excessively dry habitat. Fitting (1910, p. 216) found the same for *Opuntia* in the Biskra oasis, but also records other succulents (p. 237) which show very much higher osmotic values under the same environmental conditions. At Armoedsvlakte an occasional succulent of this type may also be found, and in April,

1924, another species of *Mesembryanthemum* was observed, which showed a suction force much higher than that of any other succulent investigated at the same period.

For *Elephantorrhiza Burchellii* several diurnal observations were carried out (Table 9). The noon value was generally higher than the morning or evening value, but the difference was not nearly so marked as with grasses; did not exceed 0.2 molar sucrose, and was probably due to an active process. The reason for this supposition is the fact that *Elephantorrhiza* ceases transpiration entirely in time of drought (*cf.* transpiration), so that it is hardly possible to regard variations of osmotic values as due to passive loss of water. It may also be stated that the durable plants of Armoedsvlakte have, in contrast to the grasses of the same habitat, a high suction force and osmotic value, both of which are much decreased by rain. The figures are not so high as those recorded by Fitting (1910) for real desert plants. The differences may be partly due to the fact that the direct plasmolytic method used by him gives higher results than the modified Ursprung method utilized in this Armoedsvlakte work, but they must in part also be due to the differences in climate and soil between the areas studied, and to the difference in protective devices (hairs, giant roots, leaf structures) of the various botanical species.

The highest figures were obtained with *Gazania longifolia* and *Rhynchosia confusa*, the leaves of which showed osmotic equivalence with 1.4 molar sucrose. Not far below this comes a group with values 1.0-1.2, including *Cassia obovata*, *Vernonia Kraussii*, *Salvia rugosa*, *Stachys spathulata*, *Oldenlandia stricta*, and *Hermannia brachy-petala*. Two spring plants, a species of *Gladiolus* and of *Morea*, gave similar values. All the other plants of the group lasting all the year round, and most of the other spring plants in the normal state, showed figures equivalent to about 0.9 molar sucrose. It is interesting that *Vahlia capensis* and *Bouchea pinnatifida* are also in the same category, although they do not show any special morphological protective devices against drought.

Annuals, and all the plants limited to the rainy season of summer, have low values. This corresponds to the observation of Fitting that plants of an arid region, which have the opportunity of growing in the vicinity of water, show lower osmotic values. In his case the plants were annuals growing in erosion valleys; in the case of Armoedsvlakte were annuals of the rainy season.

SUMMARY.

A description of the meteorological, tellurical, and edaphic features of a typical farm in the semi-arid region of Bechuanaland is given, and the osmotic behaviour of the local flora recorded. The differences between suction force of grasses and of plants other than grasses are recorded in relation to soil moisture, atmospheric humidity, rainfall, and insolation. The phenomenon of wilting is explained upon the basis of the osmotic gradient between root and leaf, withering commencing in most grasses, under the conditions of soil and climate investigated, when the difference exceeds 0.2 molar sucrose. The local grasses display no morphological mechanism for protection against drought and show enormous variations in osmotic values. The other plants which survive throughout the year display

various protective devices of an anatomical and physiological nature, and are characterized by high suction force. Those for which the life-cycle is confined to the brief rainy season of summer show low values incapable of much variation.

Quantitative protocols are compared with figures on European plants and with the very scanty data available for arid regions in other parts of the world.

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APPENDIX.

EXPLANATION OF TABLES 1-10.

- (1) In all tables of grass leaves the biggest palisade cells in the wreath (Kranz), near the midrib, were measured in a section parallel to the small side of the leaf. In Nos. 1 to 50, Method I was used; in all higher numbers, Method II.
- (2) The root-values were obtained from transverse sections through the absorptive part. Here, not single cells, but a strip of tissue was measured. The average value of the absorptive tissue of the roots is therefore obtained.
- (3) The same method was adopted to get the values of all plants other than grasses. A transverse strip through the palisade cells was measured.
- (4) In the case of *Mesembryanthemum Iesliei*, sections were cut through the chlorophyll-bearing tissue. In the case of fruits or bulbs, the sections were cut from the interior.
- (5) The values of palisade cells away from the midrib do not differ much from those near the midrib (about 3 atm.), so that these values on grasses can be directly compared with those of other plants.
- (6) In the last columns of the tables the osmotic value is given, and is the value corresponding to the normal volume of cell or tissue (volume in paraffinum liquidum). In determination 1 to 50, this value was calculated by Method I. In all other determinations it is the value in which no change of volume of cell or tissue occurred (Method II or III).
- (7) Compared with Fitting's values, those recorded in the tables must be regarded as lower, as his values are found by the direct plasmolytic method.
- (8) As it was not the object of this investigation to show minute differences in tissues, but to characterize for plant geographical purposes the flora of Bechuanaland by its suction force, concentrations of cane sugar differing by 0.05 mol. were taken, except in the first fifty determinations, in which the intervals were 0.02 mol.
- (9) Until the Assmann's psychrometer became available, meteorological data of the laboratory were accepted. From September, 1923, the psychrometer was employed over the plants in the open veld. The moisture readings in the open veld were always lower than those shown by the dry and wet bulb thermometers at the meteorological station, probably on account of the wind. In the tables the relative humidity given between January and August, 1923, is therefore somewhat high.
- (10) When in the "Remarks" column nothing to the contrary is stated, determinations are to be taken as made during bright sunshine.

TABLE I.

Table on Relationship of Soil Moisture and Wilting of the Grass.

Date.	Soil Moisture in per Cent.	Rain in Inches.	Maximum Temp. (Mean) in ° C.	Minimum Temp. (Mean) in ° C.	Veld.
7. 2. 1923	2.82	—	—	—	Some old haulms of various grasses getting green. Few fresh green grass leaves of <i>Eragrostis</i> , <i>Sporobolus</i> , <i>Digitaria</i> , <i>Cynodon</i> , <i>Fingerhuthia</i> , <i>Themeda</i> .
31. 8. 1923	2.05	—	24.7	4.41	
3. 9. 1923	2.11	—	29.3	6.49	<i>Eragrostis</i> with rolled leaves. <i>Themeda</i> leaves folded.
12. 9. 1923	1.33	—	26.4	5.14	Haulms no longer green. <i>Themeda</i> dying down.
18. 9. 1923	1.02	—	26.3	8.3	Much less green grass than in the beginning of the month.
25. 9. 1923	1.95	—	29.7	7.7	Much less green grass than in the beginning of the month.
4. 10. 1923	3.08	—	31.2	11.3	Taken after two dull days.
11. 10. 1923	1.01	—	30.6	11.1	<i>Digitaria</i> withered. <i>Themeda</i> almost without green leaves. <i>Eragrostis superba</i> and <i>lehmanniana</i> folded and rolled. <i>Eragrostis superba</i> showing red leaves. <i>Sporobolus</i> with few green leaves. <i>Fingerhuthia</i> dry. <i>Cynodon</i> fresh.

TABLE I—(continued).

Table on Relationship of Soil Moisture and Wilting of the Grasses.

Date.	Soil Moisture in per Cent.	Rain in Inches.	Maximum Temp. (Mean) in ° C.	Minimum Temp. (Mean) in ° C.	Veld.
18.10.1923	0.42	—	33.3	16.1	Grasses drying out.
24.10.1923	1.20	—	34.1	13.5	Grasses drying out.
29.10.1923	Soil gets	moist before the	rain falls.		
1.11.1923	7.07	0.576	28.9	12.6	4.11.1923.—Grasses with haulms coming up. <i>Tragus</i> appears. <i>Antheophora</i> and <i>Eragrostis</i> with few haulms. <i>Eragrostis</i> with green leaves.
8.11.1923	3.70	—	33.6	14.4	10.11.1923.— <i>Antheophora</i> with few haulms and more green leaves, folded at noon. <i>Eragrostis superba</i> with more open green leaves. <i>Schmidtia</i> flowering. All grasses with green leaves coming up at the margin of the tufts.
14.11.1923	9.48	2.141	29.4	14.7	Old haulms of <i>Aristida uniplumis</i> green up to the spike. Grasses more luxuriant with rapid growth of haulms.
21.11.1923	12.39	1.38	28.9	15.7	Young shoots of <i>Tragus</i> , <i>Brachiaria Marlothii</i> . All grasses excellent.
29.11.1923	3.46	—	32.3	12.4	Veld in fine condition. Haulms growing rapidly.
5.12.1923	2.50	—	33.2	15.1	1.12.1923.—Old haulms of <i>Aristida</i> still green, but only to the penultimate node.
12.12.1923	1.95	0.137	33.2	15.2	5.12.1923.—First sign of grass wilting shortly after noon. Veld eaten down by locusts. Only <i>Themeda</i> not touched. Old haulms of <i>Aristida</i> no longer green after 14th December.
Whole week	very dry	until 19th	December.		
19.12.1923	3.95	0.165	33.5	15.7	No grass on account of locusts. Even <i>Themeda</i> scarce.
27.12.1923	5.09	0.76	33.5	16.0	Young leaves of different grasses coming up.
3. 1.1924	3.36	0.23	33.4	16.2	No <i>Digitaria</i> , <i>Antheophora</i> , or <i>Tragus</i> .
10. 1.1924	4.07	0.22	35.8	20.2	Veld dry.
17. 1.1924	2.23	—	33.7	15.7	Young leaves and haulms coming up; no <i>Digitaria</i> .
24. 1.1924	3.85	0.33	32.6	17.1	Young leaves and haulms coming up; no <i>Digitaria</i> . Rain in the beginning of the week.
30. 1.1924	5.50	0.685	31.2	15.8	4.2.1924.—Grasses drooping, folded and rolled.
8.2.1924	1.32	0.276	30.1	18.1	8.2.1924.—Young leaves and haulms of <i>Antheophora</i> , <i>Sporobolus</i> , <i>Aristida uniplumis</i> ; <i>Cymbopogon plurinodis</i> with green leaves. No <i>Digitaria</i> . <i>Eragrostis superba</i> with few green leaves.
15. 2.1924	3.15	—	27.2	11.9	11.2.1924.—Veld dying down. Young haulms dying from the top. Veld permanently wilted from 11th to 28th February.
21. 2.1924	0.40	0.046	30.1	13.9	Only <i>Cymbopogon excavatus</i> green with haulms. No <i>Antheophora</i> and <i>Digitaria</i> , except at the boundary of B Camp and in permanent fallow, where haulms are 1 foot high.
29. 2.1924	0.86	0.090	33.6	14.3	The same.
7. 3.1924	5.97	2.490	28.8	17.0	Grasses coming up, including <i>Antheophora</i> and <i>Digitaria</i> . Haulms of 1-2 feet in height are flowering.
14. 3.1924	5.03	0.615	26.2	15.2	Good veld, but short haulms. Creepers coming up.
21. 3.1924	9.00	1.012	27.4	16.7	" " " " "
28. 3.1924	8.79	0.630	27.4	15.5	" " " " "
4. 4.1924	5.12	0.225	20.0	10.0	Haulms growing higher. <i>Aristida congesta</i> coming up and spreading.
11. 4.1924	2.92	—	22.0	9.5	Veld drying out again. Growth stopping. Creepers dying. <i>Aristida congesta</i> dominating.
17. 4.1924	1.97	0.005	30.2	9.1	Veld drying out again. Creepers dead. <i>Aristida congesta</i> dominating.
25. 4.1924	7.32	0.877	19.8	11.3	Veld recovered, but apex of leaves open dry. <i>Eragrostis superba</i> with red leaves. <i>Aristida congesta</i> dominating.
2. 5.1924	4.82	—	22.7	11.9	Most haulms yellowish. No ripe seeds, except on <i>Aristida congesta</i> .
9. 5.1924	2.51	—	26.1	5.7	Veld dying down because of frost and lack of rain.
16. 5.1924	1.45	—	26.8	6.7	Veld dying, in spite of rain. Some green leaves of <i>Digitaria</i> , <i>Themeda</i> , <i>Eragrostis superba</i> . <i>Aristida congesta</i> dry.
23. 5.1924	10.0	1.194	18.1	4.8	Veld dead, with exception of <i>Themeda</i> , which shows a few young green leaves.
17. 6.1924	4.27	0.05	22.0	2.8	

TABLE II.
Suction Force and Osmotic Value.—*Digitaria eriantha*—Leaves: *Palisades near Midrib.*

No.	Date.	Remarks.	Temperature in °C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.			
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.	
12	11. 1. 1923	Rain till 12 p.m.....	23°	55 %		16.1			0.37		
12	1. 1. 1923	No more rain.....	Morning, 22° Evening, 31°	68 % 17 %	13.6		12.37	0.48			0.44
22	12. 2. 1923	In the night heavy rain.....	Morning, 22° Noon, 30°	70 % 42 %	3.4	6.7	17.4	0.13	0.24		0.59
40	20. 3. 1923	During morning cloudy.....	Morning, 24° Noon, 32°	58 % 22 %	16.3	16.3	21.1	0.56	0.56		0.69
49	11. 4. 1923	Morning cloudy; rain in the afternoon	Morning, 20° Noon, 26°	37 % 16 %	17.0	18.1	8.7	0.58	0.61		0.32
64	7. 5. 1923	Bright sunshine.....	Morning, 11.5° Noon, 21.5°	78 % 16 %	21.4	21.4		0.7	0.7		
75	1. 6. 1923	Last green leaves; sunny.....	20°	15 %		21.4			0.7		
83	23. 8. 1923		27°	20 %	34.6			1.0			
85	29. 8. 1923	Sunny.....	Morning, 15° Noon, 24°	67 % 49 %	29.7	29.7	29.7	0.9	0.9		0.9
86	4. 9. 1923	Grass rolled and withered.....	Morning, 21° Noon, 28°	17 % 0 %	39.8	37.6		1.1	1.0		
96	18. 9. 1923	Afternoon no sun; wind.....	Morning, 14.5° Noon, 23.7° Evening, 19.4°	68 % 31 % 29 %	45.4	48.4	45.4	1.2	1.25		1.2
102	28. 9. 1923		Morning, 23° Noon, 33° Evening, 25°	44 % 19 % 26 %	45.4	51.6	45.4	1.2	1.3		1.2
106	9.10. 1923	Leaves, especially at noon and in the evening, withered and rolled	Morning, 17° Noon, 25° Evening, 29°	23 % 9 % 9 %	51.6	58.4	58.4	1.3	1.4		1.4
122	13.11. 1923	After 2.15 in. of rain.....	Morning, 19° Noon, 27° Evening, 24°	84 % 54 % 65 %	17.7	17.7	14.3	0.6	0.6		0.5

TABLE II—(continued).
Suction Force and Osmotic Value.—*Digitaria eriantha*—*Roots*: *Absorptive Zone*.

No.	Date.	Remarks.	Temperature in °C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
83	29. 8. 1923		Morning, 15° Noon, 24°	67 % 49 %	29.7	29.7	29.7	0.9	0.9	0.9
86	4. 9. 1923	Roots dry.....	Morning, 21° Noon, 28°	17 % 0 %	34.6	34.6		1.0	1.0	
96	13. 9. 1923		Morning, 14.5° Noon, 23.7° Evening, 19.4°	68 % 31 % 29 %	39.8	48.4	48.4	1.1	1.25	1.25
102	28. 9. 1923		Morning, 23° Noon, 33° Evening, 25°	44 % 19 % 26 %	45.4	51.6	45.4	1.2	1.3	1.2
106	9. 10. 1923		Morning, 17° Noon, 36° Evening, 29°	23 % 9 % 9 %	42.5	39.8	34.6	1.15	1.1	1.0
122	13. 11. 1923	After 2.135 in. of rain.....	Morning, 19° Noon, 27° Evening, 24°	84 % 54 % 65 %	11.1	14.3	14.3	0.4	0.5	0.5

TABLE III.
Suction Force and Osmotic Value.—Themedra trianda—Leaves: *Palisades near Midrib.*

No.	Date.	Remarks.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.			
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.	
	23. 8. 1923	Fresh leaves.....	27°	C.ca. 20 %		37.6				1.0	
82	28. 8. 1923	Fresh leaves.....	25°	C.ca. 3 %		29.7				0.9	
95	17. 9. 1923	No sun at noon.....	Morning, 18.5° Noon, 23.0° Evening, 16.2°	16 % 23 % 24 %	25.5	25.5	21.5	0.8	0.8	0.7	0.7
101	25. 9. 1923	Leaves folded; at noon hard.....	Morning, 18.8° Noon, 35.0° Evening, 24.5°	18 % 8 % 11 %	29.7	34.6	34.6	0.9	1.0	1.0	1.0
105	8. 10. 1923	Leaves folded; at noon dry.....	Morning, 23° Noon, 31° Evening, 26°	18 % 14 % 18 %	29.7	39.8	34.6	0.9	1.1	1.0	1.0
110	15. 10. 1923	Leaves folded; dry.....	Morning, 24° Noon, 32°	31 % 15 %	45.4	51.6	39.8	1.2	1.3	1.1	1.1
116	25. 10. 1923	Leaves folded; dry.....	Morning, 22° Noon, 30°	25 % C.c. 10 %	39.8	51.6		1.1	1.3		
	26. 10. 1923		C.c. 25°	C.c. 15 %			45.4				1.2
118	31. 10. 1923	Rain; leaves open.....	16°	80-90 %	34.6	29.7	25.5	1.0	0.9	0.8	0.8
128	7. 12. 1923	Leaves folded.....	Morning, 21° Noon, 31°	60 % 23 %	45.4	51.6		1.2	1.3		
146	10. 1. 1924	After rain fresh leaves open.....	31°	C.c. 27 %		29.7	29.7		0.9	0.9	0.9
	11. 1. 1924	After rain fresh leaves open.....	23°	51 %	25.3			0.8			

TABLE III—(continued).
Suction Force and Osmotic Value.—Themedra trianda—Roots: *Absorptive Zone.*

No.	Date.	Remarks.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.			
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.	
79	28. 8. 1923		25°	C.c. 3 %		29.7			0.9		
95	17. 9. 1923		Morning, 18.5° Noon, 23.0° Evening, 16.2°	16 % 23 % 24 %	21.4	21.4	21.4	0.7	0.7	0.7	0.7
101	25. 9. 1923		Morning, 18.8° Noon, 35.0° Evening, 24.0°	18 % 8 % 11 %	25.5	25.5	25.5	0.8	0.8	0.8	0.8
105	8. 10. 1923		Morning, 29° Noon, 31° Evening, 26°	18 % 14 % 18 %	27.6	29.7	29.7	0.85	0.9	0.9	0.9
110	15. 10. 1923	Roots not turgescnt.....	Morning, 24° Noon, 32°	31 % 15 %	34.6	39.8	39.8	1.0	1.1	1.1	1.1
116	25. 10. 1923	Roots not turgescnt.....	Morning, 29° Noon, 30°	25 % C.c. 10 %	45.4	45.4		1.2	1.2		
	26. 10. 1923		C.c. 25°	C.c. 15 %			39.8				1.1
118	31. 10. 1923	Rain, leaves open.....	16°	80-90 %	29.7	17.7	14.3	0.9	0.6	0.5	0.5
128	7. 12. 1923	Roots not turgescnt.....	Morning, 21° Noon, 31°	60 % 23 %	34.6	39.8		1.0	1.0		
146	10. 1. 1924	After rain.....	31°	C.c. 27 %		21.4	25.5		0.7	0.8	0.8
	11. 1. 1924	After rain.....	23°	51 %	25.3			0.8			

TABLE IV.
Suction Force and Osmotic Value—Eragrostis superba—Roots: Absorptive Zone.

No.	Date.	Remarks.	Temperature in °C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
84	30. 8. 1923....		Morning, 15° Noon, 25°	61 % C.c. 40 %	14.3	21.4		0.5	0.7	
85	8. 9. 1923....		Morning, 16.5° Noon, 24.0°	67 % C.c. 3 %	21.4	25.5	25.5	0.7	0.8	0.8
89	11. 9. 1923....		Morning, 17.5° Noon, 22.0°	52 % C.c. 30 %	17.7	21.5	21.5	0.6	0.7	0.7
94	17. 9. 1923....		Morning, 18.5° Noon, 23.0° Evening, 16.2°	16 % 23 % 24 %	14.3	17.7	21.5	0.5	0.6	0.7
99	24. 9. 1923....		Morning, 22.4° Noon, 31.0° Evening, 27.6°	19 % 11 % 13 %	17.7	21.5	21.5	0.6	0.7	0.7
103	2. 10. 1923....		Morning, 24° Noon, 31°	35 % C.c. 10 %	21.5	29.7		0.7	0.9	
104	8. 10. 1923....		Morning, 23° Noon, 31° Evening, 26°	16 % 14 % 18 %	21.5	25.5	29.7	0.7	0.8	0.9
109	15. 10. 1923....		Morning, 24° Noon, 32° Evening, 27°	31 % 15 % 20 %	34.6	39.8	39.8	1.0	1.1	1.1
115	23. 10. 1923....		Morning, 24° Noon, 32°	20 % 12 %	34.6	39.8		1.0	1.1	
	24. 10. 1923....		26°	18 %			39.8			1.1
117	29. 10. 1923....		Morning, 21.5° Noon, 30.0° Evening, 26.0°	57 % 29 % 38 %	39.8	45.4	39.8	1.1	1.2	1.1
119	1. 11. 1923....	After rain.....	Morning, 15.5° Noon, 20.0° Evening, 25.0°	90 % 34 % 31 %	21.5	21.5	25.6	0.7	0.7	0.8

TABLE IV—(continued).
Suction Force and Osmotic Value.—Eragrostis superba—Roots: Absorptive Zone—(continued).

No.	Date.	Remarks.	Temperature in °C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
120	5.11.1923....		Noon, 35° Evening, 32°	10 % 13 %	34.6	34.6	34.6		1.0	1.0
	6.11.1923....		25°	16 %	29.7			0.9		
121	12.11.1923....	Rain before midday and in the afternoon	Morning, 29° Noon, 25° Evening, 17°	28 % 74 % 91 %	17.7	17.7	12.6	0.6	0.6	0.45
124	19.11.1923....	After rain.....	Morning, 24° Noon, 27° Evening, 21°	73 % 73 % 75 %	11.1	14.3	14.3	0.4	0.5	0.5
126	26.11.1923....		Noon, 31° Evening, 25°	25 % 27 %	14.3	14.3	21.5		0.5	0.7
	27.11.1923....		18°	41 %	17.7			0.6		
127	3.12.1923....		Morning, 27° Noon, 33° Evening, 33°	36 % 11 % 8 %	25.5	25.5	25.5	0.8	0.8	0.8
129	10.12.1923....		Noon, 32° Evening, 31°	13 % 15 %	39.8	39.8	39.8		0.95	1.1
	11.12.1923....		18°	25 %	34.6			1.0		
132	18.12.1923....		Morning, 25° Noon, 36°	61 % C. 25 %	29.7	25.5	32.1	0.9	0.8	0.95
133	28.12.1923....		Morning, 21° Noon, 33°	42 % C. 10 %	34.6	42.5	45.4	1.0	1.15	1.2
144	3. 1.1924....	First determination before sunrise.....	Morning, 28° Noon, 39°	14 % 5 %	29.7	34.6	32.1	0.9	1.0	0.95
145	9. 1.1924....	After rain.....	Morning, 24° Noon, 36°	59 % C. 16 %	17.7	14.3	14.3	0.6	0.5	0.5

TABLE IV—(continued).
Suction Force and Osmotic Value of Eragrostis superba—Leaves: Patisade-cells near Midrib.

No.	Date.	Remarks.	Temperature in °C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
5	2. 1.1923....	Leaves spread morning before 6 a.m.; rolled at 8 a.m.; spread in the evening before rain	Morning, 26° Noon, 36°	52 % C. 14 %	13.3	18.4	8.1	0.48	0.62	0.3
7	5. 1.1923....	Leaves folded after 8 a.m.; rolled at noon; spread in the evening	Morning, 26° Noon, 33°	46 % C. 20 %	13.9	21.5	15.6	0.49	0.7	0.54
8	8. 1.1923....	After rain in night.....	Morning, 22° Noon, 34°	68 % C. c. 20 %	6.9	29.2	17.0	0.26	0.80	0.58
13	12. 1.1923....	Rain fell noon, 11th January.....	22°	68 %	8.1			0.3		
19	5. 2.1923....	After heavy rain.....	Morning, 23° Noon, 33°	62 % C. c. 22 %		9.0	8.4		0.33	0.31
25	6. 2.1923....	After heavy rain.....	23°	62 %	5.3			0.2		
26	16. 2.1923....	After heavy rain.....	Morning, 20° Noon, 27°	90 % C. c. 40 %	8.4	1.0	9.0	0.31	0.04	0.33
27	26. 2.1923....	Morning plant covered with dew; bright sunshine during day	Morning, 22.5° Noon, 29°	87 % C. c. 33 %	2.9	5.3	1.3	0.11	0.22	0.05
30	8. 3.1923....		Morning, 25° Noon, 31°	57 % C. c. 30 %		14.6	15.3		0.51	0.53
36	9. 3.1923....		25°	38 %	13.0			0.46		
37	14. 3.1923....		31°	C. c. 20 %		14.6			0.51	
43	19. 3.1923....	Leaves full of dew in the morning.....	Morning, 16° Noon, 31°	80 % C. c. 20 %	20.3	22.2	14.6	0.67	0.72	0.51
45	26. 3.1923....	Leaves full of dew in the morning.....	Morning, 20° Noon, 29°	66 % 16-20 %	13.6	32.1	12.7	0.48	0.95	0.45
47	3. 4.1923....	Rolled leaves.....	Morning, 18.5° Noon, 28.0°	61 % C. c. 15 %	30.7	33.1	30.2	0.92	0.97	0.91
53	10. 4.1923....	After heavy rain in the morning.....	Morning, 18.5° Noon, 28.5°	64 % C. c. 20 %	17.4	20.3	13.3	0.59	0.67	0.47
	19. 4.1923....	After heavy rain in the morning.....	Morning, 15.5° Noon, 22.5°	76 % C. 40 %	22.6	22.6	17.7	0.73	0.73	0.6

TABLE IV—(continued).
Suction Force and Osmotic Value of Eragrostis superba—Leaves: Palisade-cells near Midrib—(continued).

No.	Date.	Remarks.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
57	26. 4. 1923....	Whole afternoon strong wind.....	Morning, 17° Noon, 22°	72 % C. c. 40 %	23.4	23.4	25.5	0.75	0.75	0.80
	27. 4. 1923....		15°	71 %	23.4			0.75		
62	4. 5. 1923....	After rain.....	14°	95 %	21.5			0.7		
67	11. 5. 1923....		14°	70 %	21.5			0.7		
70	21. 5. 1923....		14°	70 %	20.7			0.68		
72	29. 5. 1923....	Difficult to get green leaves.....	Morning, 11° Noon, 22°	41 % C. c. 2 %	21.5	21.5		0.7	0.7	
84	30. 8. 1923....	Morning, spread; rolled at noon.....	Morning, 13° Noon, 21°	61 % C. c. 40 %	21.5	29.7		0.7	0.9	
85	3. 9. 1923....	Rolled at noon; fresh in the evening..	Morning, 16.5° Noon, 24.0°	67 % C. c. 3 %	21.5	34.6	25.5	0.7	1.0	0.8
89	11. 9. 1923....	In the morning covered with dew; rolled at noon; open in the evening	Morning, 17.5° Noon, 22.0°	52 % C. c. 30 %	16.0	25.5	21.5	0.55	0.8	0.7
94	17. 9. 1923....	No sun.....	Morning, 18.5° Noon, 23.0° Evening, 16.2°	16 % 23 % 24 %	17.7	17.7	17.7	0.6	0.6	0.6
99	24. 9. 1923....		Morning, 22.4° Noon, 31.0° Evening, 27.6°	19 % 11 % 13 %	17.7	25.5	21.5	0.6	0.8	0.7
103	2. 10. 1923....	Leaves in the morning already partly rolled; completely rolled at noon	Morning, 24° Noon, 31°	35 % C. c. 10 %	25.5	39.8		0.8	1.1	
104	8. 10. 1923....	Leaves half rolled in the morning; rolled and grey-green at noon and evening	Morning, 23° Noon, 31° Evening, 26°	16 % 14 % 18 %	20.7	34.6	34.6	0.9	1.0	1.0
109	15. 10. 1923....		Morning, 24° Noon, 32° Evening, 27°	31 % 15 % 20 %	34.6	45.4	45.4	1.0	1.2	1.2
115	23. 10. 1923....		Morning, 24° Noon, 32°	20 % 12 %	34.6	45.4		1.0	1.2	

TABLE IV—(continued).
Suction Force and Osmotic Value of *Eragrostis superba*.—Leaves.

No.	Date.	Remarks.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
115	24.10.1923....		26°	18 %			45.4			1.2
117	29.10.1923....	Small hailstorm before.....	Morning, 21.5° Noon, 30.0° Evening, 26.0°	57 % 29 % 38 %	39.8	45.4	45.4	1.1	1.2	1.2
119	1.11.1923....	After rain.....	Morning, 15.5° Noon, 26.0° Evening, 25.0°	90 % 34 % 31 %	21.5	17.8	21.5	0.7	0.6	0.7
120	5.11.1923.... 6.11.1923....	(Morning.)	Morning, 25° Noon, 35° Evening, 32°	16 % 10 % 13 %	32.1	34.6	39.8	0.95	1.0	1.1
121	12.11.1923....	Rain before midday and in the afternoon	Morning, 22° Noon, 22° Evening, 17°	28 % 74 % 91 %	37.2	31.6	14.3	1.05	1.0	0.5
124	19.11.1923....	After rain.....	Morning, 24° Noon, 22° Evening, 21°	73 % 73 % 75 %	14.3	16.0	14.3	0.5	0.55	0.5
126	26.11.1923....		Noon, 31° Evening, 25°	25 % 27 %		21.5	25.5		0.7	0.8
127	27.11.1923....		18°	41 %	17.7			0.6		
129	3.12.1923....	Leaves rolled at noon.....	Morning, 27° Noon, 33° Evening, 33°	36 % 11 % 8 %	25.5	39.8	25.5	0.8	1.1	0.8
129	10.12.1923	Leaves rolled and withered at noon....	Noon, 32° Evening, 31°	13 % 15 %		51.6	39.8		1.3	1.1
132	11.12.1923....	Leaves open.....	18°	25 %	34.6			1.0		
132	18.12.1923....	Leaves in the morning partly, at noon and evening completely, rolled	Morning, 22° Noon, 36°	61 % C.25 %	42.5	45.2	45.2	1.15	1.2	1.2
133	28.12.1923....	Morning and evening (late) leaves open ; noon rolled	Morning, 21° Noon, 33°	42 % C.c.10 %	37.2	51.6	51.6	1.05	1.3	1.3
144	3. 1.1924....	Before sunrise leaves open ; afterwards rolled	Morning, 28° Noon, 39°	14 % 5 %	29.7	51.6	51.6	0.9	1.3	1.3
145	9. 1.1924....	After rain ; beautiful roots ; leaves open	Morning, 24° Noon, 3°	59 % C.c.16 %	17.7	17.7	21.5	0.6	0.6	0.7

TABLE V.
Suction Force and Osmotic Value of Different Grasses.—Leaves: Palisade-cells near Midrib; Roots: Absorptive Zone.

No.	Date.	Name of Plant, and Remarks.	Temperature in °C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
17	27. 1. 1923.	<i>Panicum Helopus</i> ; after long rain.	20°	90 %	11.1			0.40		
29	27. 2. 1923.	Moist atmosphere between rains.	Morning, 21.8° Noon, 25.0°	87 % 63 %	9.0	10.2	9.0	0.33	0.37	0.33
34	13. 3. 1923.	Dying down in spite of previous rain; plant at noon withered	Morning, 21.5° Noon, 29.5°	68 % C. ca. 25 %	9.9	27.1	13.3	0.36	0.85	0.46
55	23. 4. 1923.	Showing new shoots.	Morning, 8° Noon, 20°	75 % C. c. 5 %	25.5	25.5	22.7	0.8	0.8	0.73
80	28. 8. 1923.	<i>Aristida uniplumis</i>	25°	30 %	34.6			1.0		
	12. 9. 1923.	Leaves rolled.	28°	29 %		39.8			1.1	
	13. 12. 1923.	Leaves open.	31°	20 %	34.6			1.0		
		Roots.	31°	20 %	34.6			1.0		
80	28. 8. 1923.	<i>Eragrostis lehmanniana</i> ; leaves open; leaf	25°	30 %	21.4			0.7		
		Roots.	25°	30 %	21.4			0.7		
79	23. 8. 1923.	<i>Tragus koelerioides</i>	27°	20 %	32.1			0.95		
79	23. 8. 1923.	<i>Sporobolus imbricatus</i>	27°	20 %	25.5			0.8		

TABLE VI.
Suction Force and Osmotic Value.—*Tragus racemosus*: *Leaves*: *Palisade-cells near Midrib.*

No.	Date.	General Remarks.	Temperature in °C.	Air Moisture	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.			
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.	
6	3. 1. 1923	Leaves curled; grey-green.....	30°	19 %			39.8				1.1
	4. 1. 1923	Leaves fresh in the morning; curled at noon	Morning, 26.0° Noon, 37.5°	37 % 7 %	17.7	50.3		0.6	1.28		
9	8. 1. 1923	After week's rain; strong sun in the afternoon	Morning, 22° Noon, 34°	68 % C.c. 13 %	13.3	9.5	21.1	0.47	0.35		0.69
14	15. 1. 1923	After 1.35 in. of rain; cloudy.....	Morning, 16.5° Noon, 23.0°	90 % 48 %	16.3	11.1	10.1	0.56	0.4		0.37
19	6. 2. 1923	After rains.....	Noon, 31.5°	21 %		11.7	11.4		0.42		0.41
	7. 2. 1923	After rains.....	24°	63 %	10.1			0.37			
26	23. 2. 1923	After rain; no rain in the afternoon..	Morning, 21° Noon, 25°	79 % 54 %	7.8	6.9	10.7	0.29	0.26		0.39
31	9. 3. 1923	At 6.30 p.m. plant covered with rain-drops	Morning, 25.0° Noon, 31.5°	38 % 31 %	13.4	24.6	15.6	0.62	0.78		0.54
35	16. 3. 1923		Noon, 30°	25 %		18.8	19.6		0.63		0.65
	17. 3. 1923		21.5°	71 %	16.3			0.56			
42	23. 3. 1923	At 7.25 p.m. plant moist.....	Morning, 20.5° Noon, 20.0°	79 % 33 %	26.3	25.9	14.3	0.82	0.81		0.5
44	28. 3. 1923		Morning, 22.0° Noon, 28.5°	54 % 25 %	29.8	25.9	23.4	0.89	0.81		0.75
46	9. 4. 1923		27°	25 %		39.8	20.3		1.1		0.67
	10. 4. 1923		19°	60 %	27.3			0.84			
52	18. 4. 1923		24.5°	41 %		35.4			1.0		
	19. 4. 1923	Rain in the morning after determination	Morning, 16° Noon, 22°	90 % 50 %	22.6		17.7	0.73			0.6

TABLE VI—(continued).
Suction Force and Osmotic Value.—*Tragus racemosus*: *Leaves*—(continued).

No.	Date.	General Remarks.	Temperature in °C.	Air Moisture.	Suction Force in Atmospheres			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
56	25. 4. 1923		Morning, 14.0° Noon, 23.5°	74 % 19 %	23.4	23.4	23.4	0.75	0.75	0.75
63	4. 5. 1923		22°	35 %	21.4				0.7	
66	9. 5. 1923	Bright sunshine.....	13.5°	64 %	21.4			0.7		
69	18. 5. 1923		Morning, 11.5° Noon, 18.5°	60 % 21 %	20.2	20.2		0.68	0.68	
71	29. 5. 1923		Morning, 11° Noon, 22°	41 % 5 %	21.4		21.4	0.7		0.7
125	21. 11. 1923	Leaves.....	Morning, 20.0° Noon, 26.5°	83 % 43 %	21.4	21.4	17.7	0.7	0.7	0.6
		Roots.....	Morning, 20.0° Noon, 26.5°	83 % 43 %	14.3	14.3	17.7	0.5	0.5	0.6

TABLE VII.
Suction Force and Osmotic Value.—*Anthephora pubescens.*—*Leaves: Palisade-cells near midrib of Leaves.*

No.	Date.	Remarks.	Temperature In °C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
15	18.1.1923	After rain.....	Morning, 19.5° Noon, 22.5°	98 %	6.1	3.7		0.23	0.14	
21	9.2.1923	Small shower of rain the day before; afternoon cloudy; strong wind	Morning, 22.5° Noon, 29.5°	83 % C.c.40 %	5.2	14.6	17.7	0.2	0.5	0.6
28	27.2.1923	Moist atmosphere; rain at noon....	Morning, 21.8° Noon, 25.0°	87 %	4.2	3.7	4.7	0.16	0.14	0.18
33	13.3.1923	Rain the night before.....	Morning, 21.5° Noon, 29.5°	68 % 25 %	8.4	10.2	12.6	0.31	0.37	0.45
51	16.4.1923	At noon drooping.....	Morning, 16.5° Noon, 27.0°	67 % 18 %	34.6	48.5	34.6	1.0	1.25	1.0
60	30.4.1923		Morning, 14.0° Noon, 26.0°	60 % 50 %	34.6	34.6	34.6	1.0	1.0	1.0
74	30.5.1923		Noon, 19.0°	C.c. 2 %		21.40			0.7	
90	12.9.1923	Leaves very soft.....	Morning, 17.8° Noon, 28.2° Evening, 20.8°	48 % 29 % 31 %	37.2	45.4	45.4	1.05	1.2	1.2
100	25.9.1923		Morning, 12.8° Noon, 34.7° Evening, 24.5°	23 % 8 % 11 %	39.8	39.8	39.8	1.1	1.1	1.1
114	20.10.1923	Plant drying out.....	Morning, 22.0° Noon, 34.0° Evening, 25.8°	11 % 10 % 17 %	51.6	58.4	51.6	1.3	1.4	1.3
121	6.11.1923	Overcast; plant drying.....	Noon, 32° Evening, 32°	10 % 11		51.6	51.6		1.3	1.3
	7.11.1923		Morning, 22.0°	25 %	45.4			1.2		

TABLE VII—(continued).

Suction Force and Osmotic Value.—*Anthephora pubescens*—Leaves: Palisade-cells near midrib of Leaves—(continued).

No.	Date.	Remarks.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
130	13.12.1923	Drooping in the morning; dry at noon and evening	Morning, 20.0° Noon, 31.0° Evening, 28.0°	59 % 20 % 20 %	51.6	45.4	45.4	1.3	1.2	1.2
ABSORPTIVE ZONE OF ROOTS.										
90	12.9.1923		Morning, 17.8° Noon, 28.2° Evening, 20.8°	48 % 20 % 31 %	29.7	40.6	40.6	0.9	1.1	1.1
100	25.9.1923		Morning, 12.8° Noon, 34.7° Evening, 24.5°	23 % 8 % 11 %	34.6	39.8	34.6	1.0	1.1	1.0
114	20.10.1923	Roots, with some root-hairs; but dry	Morning, 23.0° Noon, 24.0° Evening, 25.8°	11 % 10 % 17 %	51.6	58.4	51.6	1.3	1.4	1.3
121	6.11.1923	Roots dry.....	Noon, 32.0° Evening, 32.0°	10 % 11 %		51.6	51.6		1.3	1.3
	7.11.1923		Morning, 22.0°	25 %	39.8			1.1		
130	13.12.1923		Morning, 20.0° Noon, 31.0° Evening, 28.0°	59 % 20 % 20 %	39.8	39.8	39.8	1.1	1.1	1.1

TABLE VIII.
Suction Force and Osmotic Value of Chloris petraea. — Leaves: Palisade-cells near midrib.

No.	Date.	Remarks.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
17	27. 1. 1923	After rain; plant from farm Dryharts...	20°	90 %	2.9			0.11		
18	30. 1. 1923	After rain; soil completely soaked....	31°	14 %		7.5			0.28	
24	14. 2. 1923	Strong rain in the night.....	Morning, 22° Noon, 26°	80 % 59 %	11.1	5.2	6.1	0.4	0.2	0.23
38	19. 3. 1923		Morning, 16° Noon, 31°	80 % C.c. 20 %	9.0	14.9	15.2	0.33	0.52	0.53
54	20. 4. 1923		15.5°	80 %	17.7			0.6		
68	17. 5. 1923		20.0°	C. 2 %		19.9			0.66	

TABLE IX.
Suction Force and Osmotic Value.—*Elephantorrhiza Burchellii*—*Letœes*: *Palisade-cells in the midst.*

No.	Date.	General Remarks.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
4	28. 12. 1922		Morning, 25° Noon, 33°	54 % C. 29 %	23.0	23.0	20.3	0.74	0.74	0.67
10	9. 1. 1923	After rain.....	Morning, 23° Noon, 27°	69 % C. 45 %	22.2	15.9	13.3	0.72	0.55	0.47
20	8. 2. 1923		Morning, 25.5° Noon, 31.0°	60 % C. 35 %	25.5	39.8	42.5	0.8	1.10	1.15
32	12. 3. 1923		Morning, 23° Noon, 29°	51 % C. 30 %	19.6	24.2	28.7	0.65	0.77	0.88
41	22. 3. 1923	After rain.....	Morning, 17.0° Noon, 27.5°	90 % C. 36 %	15.6	29.8	21.1	0.54	0.89	0.74
49	13. 4. 1923	After rain.....	Morning, 16° Noon, 22°	90 % C. 45 %	34.1	42.0		0.99	1.14	
61	3. 5. 1923	After rain.....	13.6°	90 %	28.7			0.875		
70	23. 5. 1923		Morning, 18.5° Noon, 25.0°	28 % C. 5 %	28.7	28.7		0.875	0.875	
73	30. 5. 1923		Morning, 10° Noon, 20°	54 % C. 5 %	28.7		28.7	0.875		0.875
98	21. 9. 1923		18°	20 %	34.6			1.0		
108	12. 10. 1923		34°	9 %		58.4			1.4	
135	22. 12. 1923		21°	64 %	45.4				1.2	
148	4. 4. 1924		13°	79 %	17.7				0.6	

TABLE X.
Suction Force and Osmotic Value.—Cynodon dactylon—Palisade-cells near Midrib: Leaves.

No.	Date.	Remarks.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.		
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.
11	11.1.1923	After rain; rain continues in the morning	Morning, 16.5° Noon, 23.0°	90 % 51 %	12.0	4.2	14.9	0.43	0.16	0.52
23	13.2.1923		Morning, 23.0° Noon, 30.0°	72 % 39 %	11.7	10.4	13.3	0.42	0.38	0.47
39	20.3.1923	During morning, cloudy.....	Morning, 24.0° Noon, 32.0°	58 % C.c. 2.1 %	7.8	13.3	15.0	0.29	0.47	0.54
48	11.4.1923	Cloudy during morning; small shower, afternoon	Morning, 20.0° Noon, 26.0°	37 % 17 %	10.1	17.4	12.3	0.37	0.59	0.44
05	8.5.1923		Morning, 12.5° Noon, 25.0°	68 % C.c. 4 %	20.5	21.4	21.4	0.67	0.7	0.7
111	16.10.1923	Plant very dry; folded at noon.....	Morning, 20.5° Noon, 34.2°	C.c. 20 % 1 %	45.4	58.4		1.2	1.4	
123	14.11.1923	Rainy period.....	Morning, 19.0° Noon, 26.0° Evening, 22.0°	8 % 42 % 33 %	17.7	19.6		0.6	0.65	
SUCTION FORCE OF ABSORPTIVE PARTS OF ROOTS AT THE RHIZOME.										
111	16.10.1923		Morning, 20.5° Noon, 34.2°	20 % C.c. 1 %	39.8	39.8		1.1	1.1	
123	14.11.1923		Morning, 19.0° Noon, 26.0°	80 % 42 %	14.3	14.3		0.5	0.5	

TABLE XI.
Suction Force and Osmotic Value of Different Plants on Armoedsulakte.

No.	Date.	Name.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mod. Cane Sugar.			Time of Growth.
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.	
149	21.10.1924	<i>Commelina africana</i>	35·5°	1 %		32·1			0·95		Whole year.
148	28. 3.1924	<i>Commelina africana</i>	18·4°	66 %	17·7			0·6			Whole year.
148	28. 3.1924	<i>Commelina Livingsstonei</i>	13·4°	66 %	21·4			0·7			Whole year.
148	28. 3.1924	<i>Sida spec.</i>	18·4°	66 %	8·1			0·3			Rainy season.
148	3. 4.1924	<i>Anthericum spec. I.</i>	13·5°	74 %	17·7			0·6			Rainy season.
149	21.10.1924	<i>Anthericum spec. II.</i>	35·5°	1 %		17·7			0·6		Spring.
139	31.12.1923	<i>Uryinea rigidifolia</i>	30·5°	56 %	29·7			0·9			Leaves the whole year round.
86	10. 9.1923	<i>Gladiolus edulis</i>	28·0°	c. 2 %		39·8			1·1		Spring and autumn.
113	18.10.1923	<i>Gladiolus edulis</i> , bulb.....	31·0°	14 %		58·4			1·4		
92	12. 9.1923	<i>Morea spec.</i>	28·2°	29 %		34·6			1·0		Spring.
151	22.10.1924	<i>Aloe spec.</i>	35·0°	5-10 %		21·4			0·7		Leaves the whole year round.
150	22.10.1924	<i>Nerine fiberosa</i>	35·0°	5-10 %		27·5			0·85		Spring.
149	21.10.1924	<i>Albica spec.</i> , fleshy leaves.....	36·0°	1 %		25·5			0·8		Spring.
148	29. 3.1924	<i>Hemistachia elegans</i>	25·5°	9 %		21·4			0·7		Whole year.
153	24.10.1924	<i>Hemistachia elegans</i>	25·0°	33 %	29·7			0·9			Whole year.
148	28. 3.1924	<i>Geseria pharmacoides</i>	22·0°	22 %		9·5			0·35		Rainy season.
148	28. 3.1924	<i>Limeum viscosum</i>	22·0°	22 %		8·1			0·3		Rainy season.
148	3. 4.1924	<i>Portulaca succulent</i>	27·0°	7 %		4·7			0·18		Rainy season.
148	5. 4.1924	<i>Meembryanthemum spec.</i>	28·5°	1 %		21·4			0·7		Whole year.

TABLE XI—(continued).
Suction Force and Osmotic Value of Different Plants on Armoedsvlakte—(continued).

No.	Date.	Name.	Temperature in ° C.	Air Moisture.	Suction Force in Atmospheres.			Osmotic Value in Mol. Cane Sugar.			Time of Growth.
					Morning.	Noon.	Evening.	Morning.	Noon.	Evening.	
148	5. 4. 1924	<i>Mesembryanthemum unidens</i> , . . .	28·5°	1 %		9·5			0·35		Whole year.
140	31. 12. 1923	<i>Mesembryanthemum unidens</i> , . . .	36·5°	19 %		14·3			0·5		Whole year.
151	22. 10. 1924	<i>M. semibryanthemum Leskei</i> , . . .	35·0°	5 %		18·4			0·62		
148	3. 4. 1924	<i>Sisymbrium spec.</i> ,	27·0°	7 %		14·3			0·5		Rainy season.
148	2. 4. 1924	<i>Cleome rubella</i> ,	13·0°	79 %		11·1			0·4		Rainy season.
151	22. 10. 1924	<i>Crassula spec.</i> ,	35·0°	10 %		25·5			0·8		Whole year; town lands.
78	25. 8. 1923	<i>Valhnia capensis</i> ,	15·0°	20 %		21·4			0·7		Whole year.
98	21. 9. 1923	<i>Valhnia capensis</i> ,	23·0°	15 %		29·7			0·9		Whole year.
148	28. 3. 1924	<i>Tephrosia capensis</i> ,	20·5°	54 %		20·7			0·68		Whole year.
112	16. 10. 1923	<i>Crassia obovata</i> ,	23·5°	12·5 %		45·4			1·2		Whole year.
135	22. 12. 1923	<i>Crassia obovata</i> ,	21·0°	64 %		29·7			0·9		Whole year.
148	2. 4. 1924	<i>Crassia obovata</i> ,	13·0°	79 %		17·7			0·6		Whole year.
148	3. 4. 1924	<i>Melolobium canalicum</i> ,	13·5°	74 %		5·2			0·2		Flats; autumn; rainy season.
139	31. 12. 1923	<i>Acacia horrida</i> , shaded,	21·0°	56 %		29·7			0·9		Whole year.
139	31. 12. 1923	<i>Rhynchosia confusa</i> ,	21·0°	56 %		58·4			1·4		Whole year.
149	21. 10. 1924	<i>Rhynchosia confusa</i> ,	36·0°	1 %		32·1			0·95		Whole year.
98	21. 9. 1923	<i>Leslia heterophylla</i> ,	23·0°	15 %		17·7			0·6		Spring.
148	28. 3. 1924	<i>Oxalis convezida</i> ,	20·5°	54 %		14·3			0·5		Scarce during drought at end of 1923; from February to winter, 1924, abundant.

148	4. 4. 1924	<i>Phyllanthus maderaspatensis</i> ...	13.0°	79 %	14.9				0.52		After rain has fallen; but also present during drought.
97	19. 9. 1923	<i>Euphorbia sanguinea</i>	26.5°	10 %	17.8				0.6		Whole year.
108	12. 10. 1923	<i>Rhus spec.</i>	34.0°	9 %		43.2				1.15	Whole year.
148	2. 4. 1924	<i>Zisophus Zeyheriana</i>	12.5°	84 %	21.5				0.7		October-winter.
150	22. 10. 1924	<i>Zisophus Zeyheriana</i>	35.0°	10 %		29.7			0.9		October-winter.
10	21. 1. 1923	<i>Grewia cana</i> , after rain.....	Morn., 25.0° Noon, 35.0°	25 % 18 %	6.5	16.7	13.0	0.24	0.57	0.46	Whole year, with the exception of extreme drought, October, 1923, without leaves.
139	31. 12. 1923	<i>Grewia cana</i>	21.0°	56 %	39.8			1.1			Whole year, with the exception of extreme drought, October, 1923, without leaves.
148	4. 4. 1924	<i>Grewia cana</i>	13.0°	79 %	17.7			0.6			Whole year, with the exception of extreme drought, October, 1923, without leaves.
148	28. 3. 1924	<i>Hibiscus tritanum</i>	21.5°	24 %		8.1			0.3		Rainy season.
148	29. 3. 1924	<i>Hibiscus atromarginatus</i>	12.6°	77 %	7.2			0.27			Rainy season.
78	24. 8. 1923	<i>Hermannia brachypetala</i>	15.0°	46 %	14.3			0.5			Very young leaves; whole year.
87	6. 9. 1923	<i>Hermannia brachypetala</i>	23.5°	5 %		35.4			1.0		Whole year.
134	24. 12. 1923	<i>Hermannia brachypetala</i>	29.5°	16 %	34.6			1.0			Whole year.
148	4. 4. 1924	<i>Hermannia coccocarpa</i>	13.0°	79 %	11.1			0.4			Rainy season.
148	2. 4. 1924	<i>Hermannia filipes</i>	12.5°	84 %	9.6			0.35			Rainy season.
148	29. 3. 1924	<i>Hermannia linnacoides</i>	26.0°	C.C. 30 %		8.1			0.3		Rainy season; very poorly the other time.
153	24. 10. 1924	<i>Hermannia linnacoides</i>	Morn., 21.0° Noon, 32.0°	60 % c. 20 %	23.4	23.4		0.75	0.75		Rainy season; very poorly the other time.
148	28. 3. 1924	<i>Hermannia spec.</i>	20.5°	54 %	8.1			0.3			Rainy season.
148	3. 4. 1924	<i>Melhavia Rehmanni</i>	13.5°	74 %	25.5			0.8			Whole year.
78	25. 8. 1923	<i>Eucalyptus spec.</i>	15.0°	20 %	17.7			0.6			Whole year.

TABLE XI—(continued).
Suction Force and Osmotic Value of Different Plants on Armadsetate—(continued).

No.	Date.	Name.	Temperature in °C.	Air Moisture.	Suction Force in Atmospheres.		Osmotic Value in Mol. Cane Sugar.		Time of Growth.
					Morning.	Evening.	Morning.	Evening.	
149	21. 10. 1924	<i>Conrotacius ornatius</i>	36.5°	1%		27.5		0.85	Whole year.
137	24. 12. 1923	<i>Boehia pinnat. fida</i>	29.5°	16%	32.1		0.95		Whole year.
149	21. 10. 1924	<i>Boehia pinnatifida</i>	36.0°	1%	29.7			0.9	Whole year.
148	3. 4. 1924	<i>Aerolome infida</i>	13.5°	74%	9.5		0.35		Rainy season.
77	23. 8. 1923	<i>Stachys spathulata</i>	27.0°	20%	29.7		0.9		Whole year.
92	12. 9. 1923	<i>Stachys spathulata</i>	Morn., 8.5° Noon, 28.2°	42% 29%		34.6		1.0	Whole year.
108	12. 10. 1923	<i>Stachys spathulata</i>	34.0°	9%		39.8		1.1	Whole year.
143	2. 1. 1924	<i>Stachys spathulata</i>	27.0°	33%	34.6		1.0		Whole year.
147	11. 1. 1924	<i>Stachys spathulata</i>	23.0°	51%	21.4		0.7		Decumination after rain.
148	5. 4. 1924	<i>Stachys spathulata</i>	28.5°	1%	21.4			0.7	Whole year.
77	23. 8. 1923	<i>Salsola rugosa</i>	27.0°	20%	29.7			0.9	Whole year.
93	12. 9. 1923	<i>Salsola rugosa</i>	28.0°	29%	39.8			1.1	Whole year.
136	24. 12. 1923	<i>Salsola rugosa</i>	29.5°	16%	19.6		0.65		Whole year.
142	31. 12. 1923	<i>Solanum supinum, leaf</i>	30.5°	19%		39.8		1.1	November to end of March.
		<i>Solanum supinum, fruit</i>	30.5°	19%		37.2		1.05	
98	21. 9. 1923	<i>Aposinum depressum</i>	18.0°	20%	21.4		0.7		Whole year.
88	11. 9. 1923	<i>Sutera atropurpurea</i>	22.0°	C. c. 2%		34.6		1.0	Whole year.
148	3. 4. 1924	<i>Sutera atropurpurea</i>	27.0°	C. c. 7%		14.3		0.5	Whole year.
148	3. 4. 1924	<i>Sutera coriacea</i>	13.5°	74%	11.1		0.4		Rainy season.
148	29. 3. 1924	<i>Nesamum capense</i>	12.0°	77%	8.1		0.3		Rainy season.

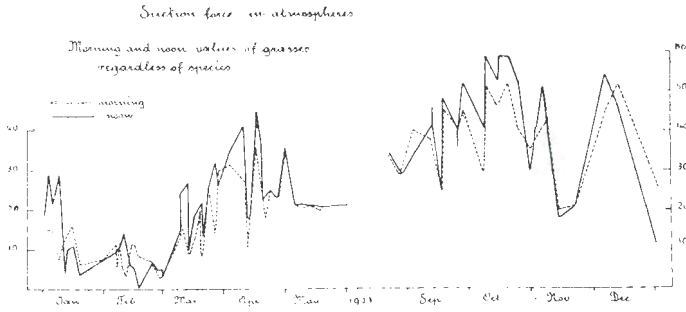


CHART 1.—Suction force of grasses regardless of species. Morning and noon values. Note the low values in time of rain, the high values in time of drought.

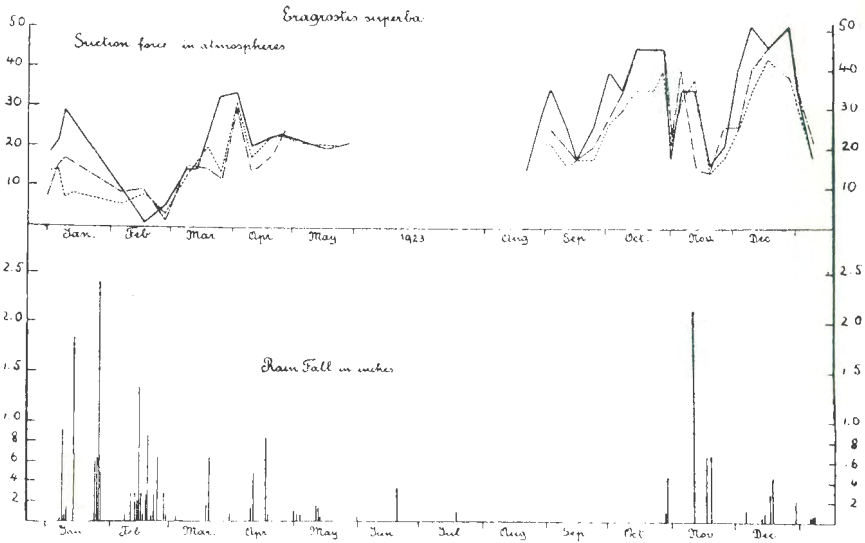


CHART 2.—Suction force of *Eragrostis superba* in atmospheres.

Morning
 Noon
 Evening

} Value.

CHART 3.—Rainfall during 1923 (in inches). The curve should be compared with curves 1, 2, 4, 5, and 6.

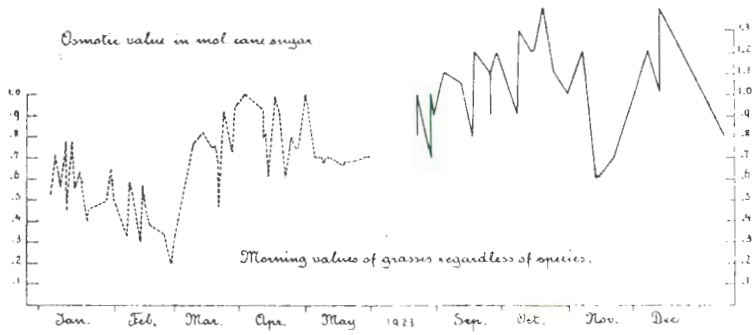


CHART 4.—Osmotic values of grasses regardless of species. Morning values. Note the low values during rainy, the high values during drought periods.

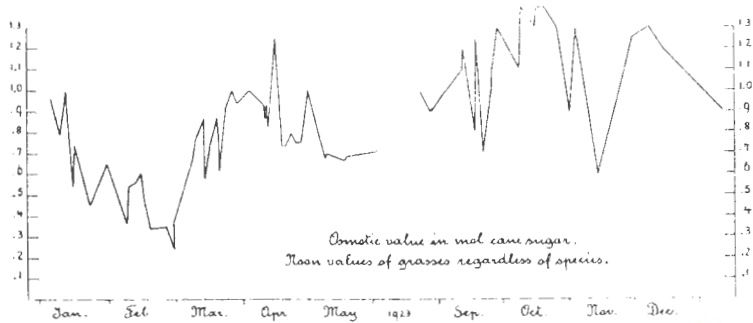


CHART 5.—Osmotic values of grasses regardless of species. Noon values. Note the low values during rainy periods, the high values during drought. In time of temporary wilting (January, 1923) morning and noon value differ much more than in extreme drought (end 1923).

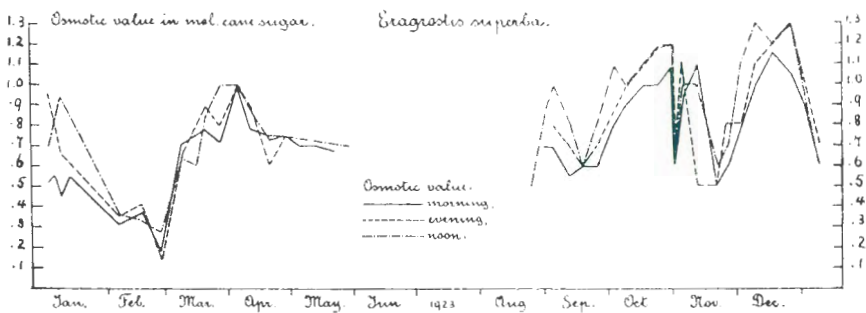


CHART 6.—Osmotic values of *Eragrostis superba*. Note the higher values at the end of 1923 compared with values of beginning of 1923. Highest values during drought, lowest during rainy periods.

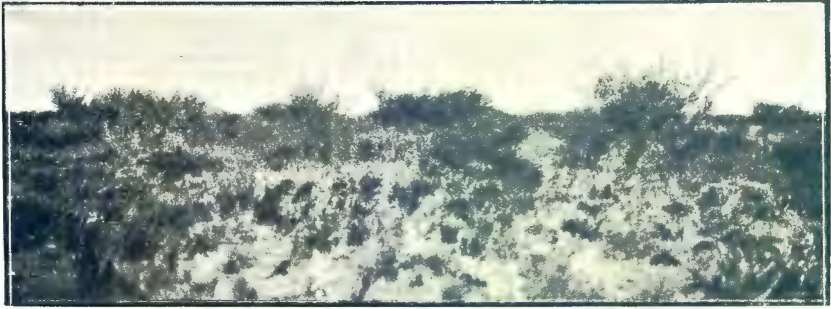


PHOTO 1.—Grass veld with *Grewia cana* at Armoedsvlakte; *Elephantorrhiza* in front, October, 1924.



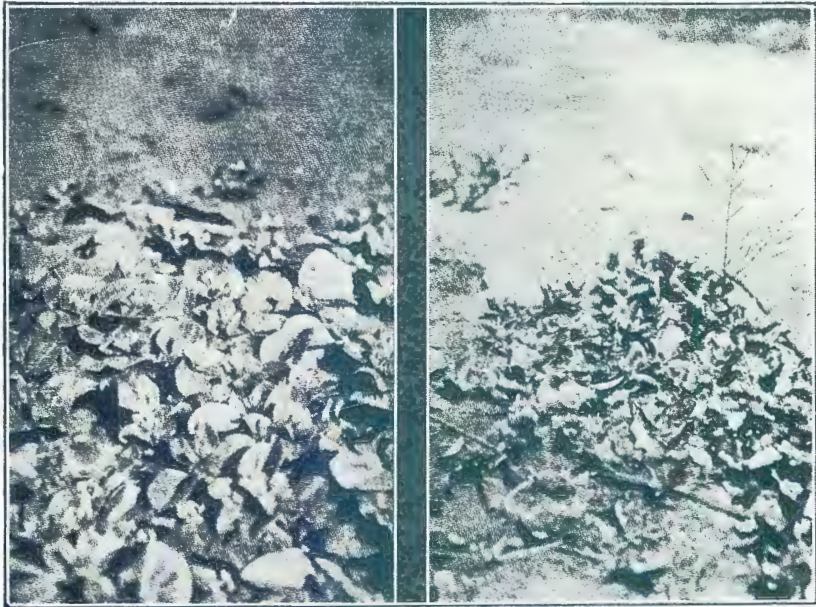
PHOTO 2. Grass veld with *Grewia cana* at Armoedsvlakte, March, 1924.



PHOTO 3.—Grass-veld at Armoedsvlakte with *Tarchonanthus camphoratus*, May, 1924



PHOTO 4.—Roots of *Eragrostis superla*,
with removable spongy tissue.



A.
PHOTO 5—*Alternanthera achyrantha*
in the early morning.

B.
PHOTO 6.—*Alternanthera achyrantha*
at noon.

Both photos are taken on the same day in February, 1924, of the same individual.

A from above.

B from the side.



A

PHOTO 7.—*Tribulus terrestris*, in the early morning, fresh, spread.



B.

PHOTO 8.—*Tribulus terrestris* at noon, folded and vertical.

In both instances exactly the same part of the plant was photographed: in A from above, in B from the side. Taken 28th February, 1924.



PHOTO 9.—*Hermannia brachypetala* in moist weather, leaves spread, taken 5th March, 1924: taken from above.



PHOTO 10.—*Hermannia brachypetala* in drought position, taken in December, 1923; taken from the side.



PHOTO 11.—*Rhynchosia confusa* in moist weather position; taken from above; taken 15th February, 1924.



PHOTO 12.—*Rhynchosia confusa* in drought position taken from the side, December, 1923.



PHOTO 13.—*Cassia obovata*, early morning position; open leaves taken from above, 10th March, 1924.



PHOTO 14.—*Cassia obovata*, drought position; completely closed leaves taken from the side, 20th March, 1924, 2.30 p.m.



PHOTO 15.—*Cassia obovata*, night position ;
taken with magnesium light from the
side, April, 1921.



PHOTO 16.—*Elephantorrhiza Burchellii*
in early morning position, 15th
February, 1924.

PHOTO 17.—*Elephantorrhiza Burchellii*
in drought position at noon ; note
“meridian-position,” December,
1923.



PHOTO 18.—*Elephantorrhiza Burchellii* in night position, April, 1924.

Physiological Plant Studies I.

[*Henrici*