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ANNUAL REPORT OF THE DIRECTOR OF THE DEPARTMENT OF BOTANICAL RESEARCH

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DEPARTMENT OF BOTANICAL RESEARCH.*

D. T. MacDougal, Director.

Most of the problems under consideration are mentioned in the following paragraphs, which also indicate methods of procedure, describe progress, and summarize the more important results.

The study of the available facts and accepted conclusions concerning photosynthesis, perhaps the most important single process in the organic world, eliminates the theory of Baeyer from the possible explanations. The experimental research on this subject is planned on the conception that its initial stage is much more complex than a simple condensation of formaldehyde to sugar.

The cacti have been selected for the study of the carbohydrate economy of plants, and no evidence has so far been uncovered indicative of special formative substances. These and other plants may get into a state of starvation for sugar, although having an ample supply of starch on hand which can not be hydrolyzed at temperatures inhibiting enzymatic action or when the shoot is in a desiccated condition.

The lower limit at which certain cacti may begin to grow has been found to vary from 10° to 25° C. in the same plant, and the upper limit at which growth ceases from 26° to 43° C. in a single plant. Temperature coefficients of 2 or more for every rise of 10° C. were found between 10° and 30° or 35° C. Maxima of 49° C. for growth were encountered. Endurance of temperatures of 52° and 53° C. were noted. All temperatures were those of the plant-body instead of the air, as ordinarily taken.

The precision auxograph has now been perfected to a point where it will record a change of 0.0004 inch in length or thickness. It has been made in a form suitable for recording growth or shrinkage of plants, imbibition swellings, or the swelling of colloids of interest in connection with growth.

Eriogonum nudum exhibits a course of growth in which the maximum is in daylight, and the rate is largely determined by the balance between absorption and water-loss, no recognizable inhibiting effect by light being found.

The screens of special glass have now been developed to a point where they can be manufactured in 16 cm. squares in quantity.

Imbibition is defined as the distensive force in the earlier stage of growth of the cell, and it plays an important but diminishing part as vacuoles are formed and the protoplast enlarges. Osmosis increases in importance with the development of the cell. Most plant-cells have a greater capacity for water when slightly alkaline, unlike gelatine, which swells most in acidified solutions. In consequence of this fact acidity checks or retards growth.

*Situated at Tucson, Arizona.

The capacity of shoots of cacti for water increases up to maturity at an age of a year or more, with the dry weight, then decreases. Disks cut from the joints of young platyopuntias increase in thickness about 23 per cent in water and in alkali, but only 16.4 per cent in acid, while samples from plants a year old swelled 40 per cent in water, 52 per cent in alkali, and 36.6 per cent in acid.

A search for a mixture of colloids that would exhibit imbibition similar to those of the plant disclosed that gelatine with a smaller quantity of agar makes such a mass. Gelatine swells most in acid, and agar in distilled water. The mixture shows greatest swelling in alkali, and simulates the plant as to general composition and behavior.

The rate of transpiration, movements, etc., is influenced by the capacity of the plant for imbibition. The water-holding capacity of tissues of cacti is less at night than in the daytime, although the stomata are open at night and closed during the day.

The relative parts which might be played by imbibition and turgor in the growth of pollen-tubes in cane sugar and acids and alkalies were studied. The colloids in these cells are of a kind which swells more in acid than in alkali in very low concentrations.

The ratio of precipitation to evaporation is found to be the factor which limits the areas of forest, grasslands, and desert, and a new subdivision of the vegetational areas of the United States has been worked out, and with this a new method of determination of the domination of different growth-forms has been devised and put into use.

Flattened bodies of plants like those of the platyopuntias in a meridional position receive more heat in the course of a day at Tucson than those in an east-and-west position, and attain temperatures of 53° C. (124° F.) or more. Transpiration, dry weight, etc., correspond to the exposure.

The roots of different plants show varied relations to oxygen, which is correlated with soil-penetration and habit. Similar differences as to temperature at which growth proceeds have been measured. The forms taken by root-systems of plants may be greatly affected by change in environmental conditions.

The roots of the swamp willow (*Salix* sp.) grow for extended periods in atmospheres devoid of oxygen.

For study in connection with the physical characters of their habitats, 300 determinations have been made of the concentration of the saps of plants in mountain and desert habitats. The sap of parasites is generally of a higher concentration than that of the host, though not always or necessarily so, as suggested by MacDougal in 1910.

A map of the vegetational areas of the United States, based on behavior and anatomy of growth-forms, has been brought to the publication stage.

Beetles (Leptinotarsæ) introduced at Tucson show gradual morphological changes which do not seem to be reversible, and which react as

Mendelian recessives when crossed back with the original stock. Some physiological changes react as dominants in crosses. Some of the 20 mutants previously observed have recurred. Accumulating evidence tends to show that the mutability is not a hybridization splitting.

Wide divergences were found in the progenies of single species of *Oenothera* from widely separated localities and some striking aberrants or mutants were found.

The taxonomic investigation of the Cactaceæ has been carried to a point where it has been possible to prepare the first of the volumes dealing with the Pereskieæ and Opuntiæ, in which it is proposed to give a comprehensive treatment of the family.

Some extensive regions in South America inhabited by cacti remaining unexplored, Dr. N. L. Britton, one of the associates engaged in the research, has undertaken the expense and execution of the field-work.

The Salton Sea has come down to a stage where the level is oscillating, with a final reduction of 40 inches in depth annually. The total solid matter in solution amounted to 1.6 per cent on June 10, 1916. The increased salinity has been followed by a modification of the activities of organisms supposedly active in the precipitation of calcium, but that element is still being shown in a proportion not consistent with mechanical concentration.

The revegetation of an island has been followed from a stage in which it was inhabited by but two individuals in 1908 to 1916, when the census showed 470 individuals, representing 10 species.

Variations in climate affecting vegetation in the preceding geological periods are attributed chiefly to the frequency and distribution of cyclonic storms. Solar and terrestrial data for each day of seven years have been computed in this connection.

The study of the Mohave River, the chief streamway of the Mohave Desert, leads to the conclusion that this river has been of the truncated type during the greater part of its history, and that its waters cut across the barrier and flowed into Death Valley for a very brief period only. This evidence is of great value in making out the evolutionary history of the vegetation of this ancient desert.

Precipitation being limited in desert regions, the underflow becomes of the greatest importance to vegetation. It is shown that artesian conditions do not require a bowl-shaped basin, but that buried streamways in trough-like valleys may have layers of impervious clays and of sand and gravel in which water collects under such head that it may rise to the surface or above it when tapped. Some generalizations of practical value in putting down deep wells are reached.

Wind erosion in the Painted Desert and the torrential flow of a desert river when its channels have been progressively cleared are included in the surface phenomena of arid regions which are being kept under systematic observation.

PHOTOSYNTHESIS, IMBIBITION, AND GROWTH.

Studies in Photosynthesis, by H. A. Spoehr.

The Baeyer theory of photosynthesis which for almost half a century has dominated investigation in this field is being made the subject of critical experimental study. The basis of this theory is the condensation of formaldehyde in aqueous solution by means of alkalies, as discovered by Buterlow in 1861. No consideration has ever been given to the question whether this reaction actually takes place under conditions such as exist in the chlorophyllous leaf. Accordingly a series of tests was undertaken to determine whether formose is formed from formaldehyde in weak alkaline or in neutral solution and at ordinary temperatures, and whether the reaction is influenced by sunlight. Pure 3 per cent solutions of formaldehyde (free from methyl alcohol and formic acid) were used, with the salts in N/10 concentration, in glass flasks. These were exposed directly to the sunlight for 5 months, and the amount of sugar formed determined every month. Not a trace of sugar was formed by $CaCO_3$, $3MgCO_3.Mg(OH)_2.3H_2O$., K_2CO_3, $KHCO_3$, KOH, colloidal Fe $(OH)_3$, in the dark or the sunlight. $ZnCO_3$ formed a trace in the light, but none in the dark. Light does increase the sugar formation with the stronger alkali hydroxides. Pure neutral formaldehyde solutions in glass and quartz vessels formed no sugar at all in the sunlight. Even then, if formaldehyde were formed as the first reduction product of carbon dioxide, which has previously been shown to be highly improbable, it would seem that this second step in the photosynthetic process must proceed in a different manner than is supposed by this theory. The whole process is, no doubt, of a nature much more highly complex, involving the operation of unknown enzymes in cooperation with the chloroplasts.

The Carbohydrate Economy of Cacti, by H. A. Spoehr.

The phenomenon of metabolism presents such a complex and multiplicity of molecular disintegrations and reconstructions that a comparative study of plants of different physiological behavior is of the greatest importance in order to gain a clear and comprehensive conception of this activity. The higher plants exhibit differences not so much as to the course and nature of their metabolism, but rather as to the accumulation of substances formed either as by-products or as intermediate steps in the complete katabolism. These differences are often the result of structural or environic conditions. For the purpose of studying these relations the cacti offer very interesting material, both on account of their structural peculiarities and the rather extreme climatic conditions under which they live. Certain of the characteristics of the metabolism of these plants have already been thoroughly studied by Dr. H. M. Richards. However, our knowledge of the essential features of the earlier stages of the metabolic activity of cacti is still very incomplete. In studying the various vital processes of these plants, it is possible to deal with the visible products, and these products afford certain proof of and insight into the metabolic activity, although the exact nature and causes of these changes may be still undetermined.

The carbohydrates predominate in the general food economy of the cacti. It was necessary to develop accurate methods to determine various groups of sugars of different physiological significance. *Opuntia blakeana* and *O. discata* have been most generally used, and analyses, together with determinations of the rate of respiration, have been carried out under a variety of experimental and natural conditions. A growing young joint seems to affect the food-supply of the mother joint but very slightly, apparently becoming autonomous in this respect very early in its development. The rate of respiration, as well as of photosynthesis, is naturally much higher in the growing than in the mature joint. There is no evidence of the existence of special formative and respiratory substances, and in regard to food-content young and mature joints exhibit the same or parallel reactions to changes in environic conditions, *e. g.*, temperature or water-supply. The nature of food consumption is shown in a series of starvation experiments; these, when compared with the results from normal material, indicate that although ordinarily the metabolic functions make submaximal demands on the food-supply, during times of intense heat and drought the plant is in a state of privation in regard to certain sugars. It remains to be determined whether this labile equilibrium of starch $\rightleftarrows$ monosaccharide is purely a temperature effect or is here related also to the water-content of the plant.

The function of the slimes, which are of pentosan nature, is still quite obscure. It is certain, however, that the pentoses are not to be regarded as inert components, but are drawn into the complex of metabolic activity quite as actively as the hexoses. In this work very helpful assistance has been rendered by Mr. J. M. McGee.

Temperature and Growth, by D. T. MacDougal.

The lower limit at which growth may begin, the degree at which it proceeds most rapidly and continuously with regard to the stage of development of the organ measured, the point at which a higher rate may be maintained for a short period, and the upper limit of temperature have been the subject of many observations. Some attention has also been paid to the acceleration ensuing from definite rise in temperature with reference to the van't Hof law of chemical action.

Growth includes a number of separate processes, each of which goes on at a rate modified by the temperature by the amount of material brought into the chemical reactions and by the concentration of the products of the reactions. The rate and amount of expansion of a growing organ depends upon osmosis and imbibition, which are modified in a manner not closely conformable to the van't Hof law. A statement of definite temperatures for any of the critical points will lack final value unless given as the resultant of a formula expressive of the intensity of the contributory factors. Attention has been paid to the upper and lower limiting temperatures of growth. It might be possible in either case to find some theoretical point where one of the processes would be stopped absolutely with all of the other contributory factors at an optimal intensity. It does not follow, however, that growth will begin when a rising temperature passes the lower limit, or that it will carry on to the upper limit.

Extensive tests and measurements of about 40 growing shoots of *Opuntia* in their native habitats showed that the temperature of the body at which enlargement might begin ranged from 10° to 25° C. Growth ceased under varying conditions at temperatures ranging from 26° to 43° C.

The rates of growth of an etiolated shoot of *Opuntia* during a month in a dark room is illustrated by the following excerpts from the notes:

Varying rates of 1.2, 1.2, 1.15, 0.85, and 1.15 daily at 16 to 18° C.
Increasing rate of 2.9, 3, 3, 3, 3.2, and 3.44 mm. daily at 26° C.
Increased rate of 3.6, 6.7, and 9.6 mm. daily at 30° C.
Increased rates of 11.4, 11.4, 8.4, 9.2, and 11.4 mm. daily at 31.5° to 32° C.
Decreased rate of 5.3 to 5.7 mm. daily at 18° to 19° C.
Increasing rate of 8.4 to 16.8 mm. daily at 39° C.
Decreasing rate of 5.4 to 9 mm. at 39° to 40° C.
Increased rate of 13.2 mm. at 35° C.
Increased rates of 16.8 to 19.2 mm. daily at steady temperature of 38° C.
Decreased rate of 13.2 mm. daily while temperature rose from 38° to 45° C.
Cessation of growth at 45° C.
Resumption of growth at 46° C.
Increased rate of 25 mm. daily during the first hour at 46° C.
Decreased rate of 20 mm. daily for 4 hours at 46° C.
Increased rate of 20.4 mm. daily during an hour at 45° C.
Decreased rate of 18.5 mm. daily during hour temperature was raised to 48.5° C.
Cessation of growth at 48.5° C.
Resumption of growth at rate of 19.2 mm. daily at temperatures of 48° and 46° C.
Growth of 15 mm. daily as temperature rose to 47.5° C.
Cessation of growth at 49° C. with air-temperature 40° C.
Resumption of growth after 20 minutes at 49° C., but soon stopped.
Temperature of plant 52° C. for half an hour; air 43° C.
Resumption of growth at 49° C. with air at 41° C. at rate of 9.6 mm. daily.
Similar results with many plants at high temperatures were obtained.

The above records show a gradual progression of the rate as the development of the shoot proceeded. The comparison of the rate at any point, as for example, at 16° to 18° C., is made with the next observed rate at 25° or 26° C. to obtain the temperature coefficient. The advanced stage of development when the temperature again returns to 16° to 18° C. would be responsible for a rate higher than the preceding one at that temperature. The average rate at 16° to 18° C. was first found to be 1.5 mm. daily and that at 26° C. was 3.1 mm. daily, giving a coefficient of 2 for the rise of 10° C. Inspection of other results gave higher values. A point is reached below 35° C. where a maximum rate is obtained which is not maintained. When a plant is placed under constant exposure to any temperature in their range, a decreasing high rate is exhibited. When this has run its course, a new rise in temperature is followed by a new maximum, from which the plant slows down. This stepping up and sliding back appears to prevail practically to the upper limit of growth.

The observations reach the high limit of 49° C. for the growth of the higher plants. A new limit of endurance of 52° C. for growing plants was also observed. Growth after such exposure was resumed at the high limit of 49° C. as before.

The discovery of these upper limits of endurance and growth of developing organs are probably conditioned on the use of new methods of taking temperature rather than upon any specialization of the protoplasm of the cacti. It has been assumed that the temperature of growing organs approximated that of the air in nearly all studies which have hitherto been made on this subject. A. M. Smith secured body temperatures of the giant bamboo (*Dendrocalamus giganteus*) as much as 6° C. above that of the air in his work on the growth of that plant in Ceylon in 1906, and the use of such temperatures made possible some advanced generalizations. The differences between the temperature of the air and of the growing shoots of cacti are as much as 8° or 9° C. at times. Thermometers of the "clinical" type with thin bulbs were used. The thin bulbs were fixed in the tissues of joints from which new shoots were arising, and in growing shoots similar to those being measured.

A Precision Auxograph, by D. T. MacDougal.

The changes in volume of growing organs and the measurement of the swelling of colloids similar to those concerned in the process have made necessary the designing of recording apparatus applicable to both kinds of material. The essential part of such an apparatus consists of a delicately balanced compound lever, carrying a tracing-pen on one free end and having an arrangement by which the movement to be measured may be applied at various intervals on the other free arm. Magnifications of 10 to 50 are secured in this manner. A clock-driven cylinder of the standard used in thermographs, barographs, etc., carries the recording sheet, which has been specially designed. The ruled space on these sheets is 8 cm., divided into millimeters, numbered on the "fives" and shaded on the "tens." The paper is of a quality to take a tracing from a fine pen-point, making it possible to divide the millimeters and to read actual changes in size of 0.01 mm. or 0.0004 inch. The lever set is supported on a rack-and-pinion column with a vertical movement of 10 cm. and the clock may be adjusted at any height on a fixed vertical column by a sleeved arm and set-screw. A dozen of these instruments have been constructed and used in getting the accompanying results on growth.

Growth of Eriogonum in relation to Light, Temperature, and Transpiration, by Francis E. Lloyd.

It was mentioned in a previous report (Carnegie Institution Year Book for 1912, p. 61), that in *Eriogonum nudum* the transpiration-rates and growth stand in reverse relation to each other, the magnitudes of water-loss being sufficient to produce a checking of growth or even shrinkage of volume of the growing parts. It was inferred that this checking of growth was the direct result of net water-loss, and not of supposed inhibiting effect of light upon growth, a doctrine which has been passively accepted for many years. During the present season opportunity has presented itself for a more careful study of the behavior of the plant in question, which, on account of its long, slender, naked internodes, supplies a peculiarly good object for investigation. This was carried on by methods of field auxanometry, the apparatus being so arranged that the growing portion under observation could be inclosed within a chamber in such manner that humidity, both quality and quantity of light, and, to a large extent, temperature also, could be controlled.

The average rates of growth during the daylight periods were found to be usually greater and only occasionally less than in the periods of darkness, depending upon the state of the growing part, temperature, humidity, or the amount of water available for that part.

The daily march of growth is as follows: During the early daylight hours until about 8 there is usually a slight rise in growth-rate. After that hour the rate falls to a low value, or, much more frequently, there ensues an actual shrinkage. This is the period during which the loss of water by transpiration is rapidly increasing, reaching its maximum at about noon. Coincidentally with the checking of transpiration, the growth-rates rapidly increase in value, the maximum rate being attained by 1 or 2 p. m., and thereafter maintained, with fluctuations, until 6 p. m., when the rates fall to the night values. The afternoon rates are great enough to more than make up for the negative behavior of the morning, except, as above stated, under unusual conditions.

That light can not be held to account for the retardation of growth during the morning hours as above indicated has been shown to be an untenable view, since it was found possible experimentally to alter the rates both positively and negatively quite independently of the constancy, increase, or decrease of illumination, even when this has been increased with respect to the growing part by insolation from three directions. There seems, indeed, to be no maximum insolation normally occurring in the field at this locality which can cause any cessation or inhibition of growth when conditions obtain which insure water-supply to the growing part. Thus, when a cessation of growth is apparent, it may be checked, and high rates instituted, by the removal of leaves (which divert the water-supply), by increasing the vapor-tension in the vicinity of the growing part, or by merely increasing the temperature when the volume of the growing part is small (as when the internode under observation is young). These positive changes may occur coincidentally with increase of illumination from the blue or red portions of the spectrum to full insolation.

It thus appears that the dominant factor in the mechanism of growth is the water-balance of the growing part, a conclusion in accord with studies of A. M. Smith, Lock, W. L. Balls, and Blaauw, thus substantiating (contrary to the widely diffused belief) the view earlier pronounced by MacDougal that light under normal conditions does not inhibit growth.

Glass Screens for testing the Influence of Light upon Growth and Development, by D. T. MacDougal.

Glasses for the purpose of screening organisms from various parts of the solar spectrum have been fixed upon by cooperation with Dr. H. P. Gage, of the Corning Glass Works. The manufacture of this material was at first confined to the molding of bell-jars. Not all of the desired ones could be treated in this manner, and during the present year the effort was made to blow cylinders which could be flattened and annealed into sheets. This process has also proved unsatisfactory and has been discontinued. The method finally fixed upon is that of stamping out small sheets 6.5 by 6.5 inches (about 16 cm. square). Some glasses in this form have already been secured and others are in course of manufacture.

The Distensive Forces in Growth, by D. T. MacDougal.

The embryonic cells of the growing regions of plants, to the activities of which the external measurable features of growth are due, are compressed globular masses of colloids of varying composition and dispersion, including both nitrogenous gels and mucilaginous material of the pentosans and hexoses. The outermost layer of each protoplast is the seat of specialized activities and is of greater density than the remainder of the unit. Not all solutes or suspensions pass through it with equal facility. The kinetic theory of osmosis, by which a pressure is set up inside this membrane by the impact of the molecules which can not pass through it, will be adequate for the purpose of the present discussion without reference to its inadequacies in some respects.

The greater part of the mass of the protoplast is at first a fairly homogeneous mass mechanically, with the exception of the large nucleus. No distinct "cavities" or large hiatuses in the gelatinous matter are to be seen. The only forces which might cause the cell to enlarge in this condition would be the swelling of imbibition and the osmotic action of the colloids. Definite information on this latter action in the plant-cell is not available, but it is safe to assume that the molecular aggregates of the colloids would act much in the same manner as single molecules or smaller associations of them.

The presence of hexoses and various salts soon results in the accumulation of water in places in the mass and these irregular vacuoles become the seat of a much greater osmotic pressure than that displayed by the colloids. The protoplast soon attains a stage in which it presents the mechanical features of a sac of denser material with irregular lighter strands and sheets of cytoplasmic gel separating clearer spaces or vacuoles, the nucleus somewhat diminished in size and variously held in the lighter cytoplasm. The cavities or vacuoles undoubtedly contain colloidal material which in its high state of dispersion carries its capacity for swelling with hydration.

The picture of the cell as thus described includes the principal features by which it and thousands of its fellows expand and thus give rise to the enlargements measurable as growth and to the shrinkages or diminution of volume which have hitherto received but little attention. The state of distension or turgidity of the cell has been chiefly attributed to osmotic pressure and it has been customary to assume that the expansive force of growth was practically identical with its action. The use of isotonic solutions in the measurement of turgor is based on this assumption, and the acceptance of the freezing-point of the sap as a measure of the pressure of the cell rests on the same conception.

It is clear, however, that imbibition or hydration of the colloids in addition to their osmotic pressure is also a force to be reckoned in such determinations. Interpretations of the action of external agencies, such as temperature on growth, must take into account not only the effect exerted upon respiration, enzymatic action, and other reductions and oxidations, but also the effect of concentration and the state of the membrane in osmosis. In addition, the colloids (including those of the cell-wall, the lining layer, the cytoplasmic sheets, and the nucleus) are undergoing changes in mass as well as in imbibition or hydration capacity. The hydration phenomena are not those of a single gel, nor is the resultant a mechanical one, for the admixture of two or more colloids produces a substance which, as seen in the case of gelatine and agar, may swell in a manner not to be predicted, in the present state of theories as to the structure of colloids.

A varying amount of water is lost at all times by transpiration from the growing parts of plants and may exceed the supply to such an extent that a stoppage of growth or an actual shortening may ensue; how far this is accompanied by a slackening or cessation of adsorption of new material in protoplastic colloids can not be said at present. Marked variations in volume of the plant, however, are caused by such excessive water-loss.

The expansion or enlargement feature of growth is therefore a complex process, the principal energy for which comes from imbibition and osmotic pressure of colloids in the earlier stages of the cell. Osmosis plays a larger part in the later stages of distension. The tissues and embryonic regions of the plants tested in the experimental work at the Desert Laboratory swell more in weak alkaline solutions than in acid or neutral solutions. Studies of the daily course of growth show that it is most rapid at the time when the acidity of the sap is at a minimum or when a neutral or alkaline condition has been reached. High acidity with decrease of imbibition and excessive water-loss may check or stop growth with consequent shortening of growing organs.

The Effect of Age, Acids, and Alkalies upon Imbibition by Growing Regions and Tissues of Plants, by D. T. MacDougal.

The capacity of a developing organ for taking up water by osmosis and imbibition is a feature which plays a very important part in growth. Mature organs generally have a greater capacity than those in an embryonic condition. The possibility of making measurements of material at various ages and under different conditions was one of the important advantages of using the cacti in studies on growth.

Clean disks 12 mm. across were cut from the flattened joints of *Opuntia*. Three of these were arranged in a triangle in the bottom of a Stender dish and a triangle of thin sheet-glass arranged to rest its apices on the three disks. The vertical swinging arm of an auxograph was now adjusted to a shallow socket in the center of the glass triangle, while the pen was set at zero on the recording sheet. Water or a solution being poured into the dish, the course of the swelling was traced on a sheet ruled to millimeters.

That the amount of imbibition depended on the presence of certain recognizable substances, not on the mechanism of the living cell, was demonstrated by the fact that dried disks gave proportionate differences equivalent to those of living material.

The average thickness of disks varied from 4 or 5 mm. in the case of young joints to 18 or 20 mm. in mature ones. The apical parts of joints showed greater capacity for absorption than the basal ones in the proportion of 21 or 22 to 16 or 17 per cent. Comparative tests were finally based on disks taken from apical regions. The capacity for absorbing water was seen to increase up to maturity (about 1 year old) then to decrease, as illustrated by the following set of tests with *Opuntia blakeana*, made May 17 to 29, 1916:

	Young.	Mature.	Old.
	p. ct.	*p. ct.*	*p. ct.*
Swelling (distilled water)	24.3	50	41.3
Dry weight	16.03	24	25.95
Total sugar	44.91	38.04	35.27
Fiber	4.65	9.13	11.51

The amount of imbibition is seen to be not a continuous function of any one substance or group of substances. This would harmonize with the results of swelling mixtures of gelatine and agar described in the next paragraph.

The phenomena of proportionate swelling of gelatine in water, acids, alkalies, and salt solutions have been mistakenly used hitherto in attempts at explanation of the mechanism of growth. It has been demonstrated by repeated tests that the tracts of the growing cells studied as well as maturing or mature tissues do not swell more in acid than in distilled water or alkali, as will be illustrated by the following results:

Swelling of disks of Opuntia.

	Distilled water.	Sodium hydrate N/100.	Hydrochloric acid N/100.
	p. ct.	*p. ct.*	*p. ct.*
Young	23.6	22.9	16.4
Mature	40	52.1	36.6

It is conclusively established that both young and old tissues take up more water when neutral or alkaline. Acidity, therefore, in addition to retarding enzymatic action and respiration, indubitably operates to retard growth by its effects on imbibition by plant tissues.

The Swelling of Colloidal Mixture in Water, Acids, and Alkalies, by D. T. MacDougal.

It being demonstrated that growing masses of embryonic cells in plants and tracts of mature tissue do not show their greatest capacity for the imbibition of water in acidified but in alkaline solutions, it was sought to find what substance or mixture of substances would behave in a similar manner. The first inquiry was made with agar, which is a pentose presumably having some qualities identical with those of the mucilages of the plant. Dried cylinders and sheets of this material were first subjected to the tests, being placed under the auxograph after the manner in which disks of living material were treated, as described in a previous paragraph. The results compared with the swelling of gelatine were as follows:

	Sodium hydrate N/100.	Hydrochloric acid N/100.	Water.
	p. ct.	*p. ct.*	*p. ct.*
Swelling of agar..........	124.4	113	197
Swelling of gelatine.......	250	382	83

As the plant did not show water-relations which might be interpreted as a mechanical resultant of the separate action of gelatine or agar, it was next proposed to test the reactions of a mixture in which these substances would be blended. The first test-mass was one which consisted of about 3 parts of agar and 2 parts of gelatine; both were soaked and melted separately; then the gelatine was poured into the hot agar, which was kept near the boiling-point of water for a half hour. The mass was then poured onto a glass slab for cooling. Two days later it was stripped off as a fairly clear and transparent sheet slightly clouded, the average thickness of which was 0.2 mm. Strips about 5 by 7 mm. were placed under the apices of sheet-glass triangles in glass dishes after the manner in which plant sections had been tested, and auxographs were arranged to record the action of acids, alkalies, and distilled water.

The first trial, made on July 21, gave the following final relative thickness of the strips as compared with the original: Distilled water 850 per cent; nitric acid (N/100) 725 per cent; hydrochloric acid (N/100) 750 per cent; sodium hydrate (N/100) 950 per cent. These results were obtained while some enlargement was still in progress, but which would not in the end disturb the relations given. A second test on the following day at temperatures of 61° to 65° F. gave the following: Distilled water 675 per cent; hydrochloric acid 625 per cent; nitric acid 687.5 per cent; sodium hydrate 750 per cent. These results were taken to be of such importance that a series of mixtures of agar with 20, 50, and 80 per cent of gelatine by dry weight were made up. The mixtures were poured into molds on glass plates and dried sheets from 0.1 mm. to 0.6 mm. thick were obtained. The first series of measurements given below includes the results of tests under varied conditions not only of thickness of the samples, but also of temperature, length of period of swelling, tension of instruments, etc. Each set of three measurements of the swelling in the three liquids is therefore to be considered separately.

The outstanding fact that a mixture consisting mostly of gelatine to which a small proportion of agar has been added shows its greatest swelling in alkaline solutions is the most important feature of these results. The mixture in question is available as a physical analogue which has already been found useful in the study of growth and swelling of plants. Mixtures consisting half or more of gelatine give acid swellings of second rank and expand least in water. Mixtures containing more than half of agar swell most in water, with the effects of weak acids and alkalies fairly equivalent.

Swelling of agar-gelatine mixtures.

Gelatine 80, agar 20 parts.			Gelatine 50, agar 50 parts.			Gelatine 20, agar 80 parts.		
Sodium hydrate N/100	Hydrochloric acid N/100	Distilled water.	Sodium hydrate N/100	Hydrochloric acid N/100	Distilled water.	Sodium hydrate N/100	Hydrochloric acid N/100	Distilled water.
p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
800	700	425	788	788	692	600	400	1,150
875	775	...	500	333	1,133	600	600	1,450
600	900	...	600	350	525	600	700	1,200
850	650	558	675	225	.....			
600	600	275						

The results described constitute a gratifying success in the search for a colloidal mixture which would exhibit the swelling reactions of plant-cells. The variations in imbibition exhibited by these mixtures are of a kind and range displayed by the plant, and it seems probable that the addition of a hexose albumen and of minute quantities of salts would make a still more accurate analogue of the plant. Both agar and gelatine are colloids of the emulsoid type believed to be composed of two aqueous phases differing from each other only in the relative concentration of the organic compound in the water. The behavior of agar-gelatine mixtures is therefore of much interest in connection with prevalent theories of the structure of gels of this type, as well as with relation to the nature and behavior of the plant colloids.

Causes of Variations in the Transpiring Power of Cacti, by Edith B. Shreve.

During the assembly of the data secured from the investigation of the transpiration of cacti, which has been under way for the past two years, it became evident that further experimentation was advisable. Measurements of transpiration, of water-intake by the roots, of water-absorbing capacity of the tissues, of relative acidity of the tissues, and of stomatal movement have now been made under various controlled environmental conditions. These experiments have shown the existence of a constant interrelation between transpiring power and water-holding capacity of tissues, water-content of the aerial parts of the plant, and also degree of openness of the stomata. Likewise there appeared an interrelation between the water-intake by the roots and the water-holding capacity of the tissues and also the water-content of the plant. The following conclusions may now be drawn:

(1) The transpiring power is greatly influenced by light intensity, air-temperature, water-content of tissues, and available soil moisture; these factors clearly exert their influence indirectly through their action upon some internal process.

(2) Variations in the rate of water-intake by the roots exist and are evidently independent of variations in transpiration. Variations in water-intake at the roots are due, on the one hand, to variations in soil-retentivity, and on the other to variations within the plant itself. The latter may be further subdivided into variations in absolute transpiration-rate and in water-absorbing power of the tissues. The variations in soil retentivity may be reduced to zero, for experimental purposes, by the use of water-cultures or supersaturated soil, and then the absolute water-intake divided by the absolute transpiration for the same period gives quantities whose variations may be traced neither to soil retentivity nor to transpiration changes. This quantity, A/T, is given the name "secondary absorbing power." It was found to vary in a direction which is always opposite to the variations in T/E for the same period, that is, T/E is greater by night and A/T by day.

(3) The water-holding capacity of cylinders cut from internal tissue is less at night than during the day. It parallels the behavior of A/T under all the several environmental conditions which were used in the experiments.

(4) Stomata are, in general, shut during the day and open at night. Some evidence appeared that a decrease in T/E preceded the closing of the guard-cells.

(5) The above conclusions suggest the theory that the variations in transpiring power and in secondary absorbing power are due to variations in the water-holding capacity of internal tissue. In the case of the transpiring power, the changes in water-holding capacity act indirectly by causing the closure of the stomata and directly by resisting the evaporative power of the air.

(6) The source of the energy for this resistance to the evaporative power of the air may be traced to the imbibitional forces of colloidal gels and the cellulose walls, and hence to surface-tension forces.

(7) The effects exerted by light intensity and air temperature, especially when their duration is considered, indicate that the variations in water-holding capacity of tissue are due, at least in part, to chemical changes brought about by the metabolic processes. Under "typical" conditions, a high water-holding capacity is accompanied by a low acidity, and *vice versa*. However, certain exceptions, occurring

under controlled conditions, prove that the relation is not so simple as the influence of mere changes in H-ion concentration. The regular accumulation and disappearance of many substances within the plant must be considered not only in the light of their individual influence on the water-holding capacity, but in that of their combined effect.

(8) In former experiments the author has found well-defined autonomic movements in cacti which could be traced to changes in the water-content of the plant. These changes in water-content are of such a nature that the difference between absorption and transpiration is positive for the day and negative for the night. The discovery of corresponding variations in the water-holding capacity of internal tissue traces the causes of the autonomic movements one step further.

(9) As desiccation progresses a cactus loses less and less water by transpiration until a point is reached where the total loss for 24 hours is almost zero. There is a small loss occurring during the daylight hours which is frequently entirely replaced by a gain at night. Only about one-tenth of this gain can be accounted for by hygroscopicity of the spines.

(10) The water-absorbing capacity of internal tissue from plants which have been without water for 6 months is about 5 times as great as of tissue from plants which have had sufficient water. This is true only if the absorbing capacity be based upon wet weight.

(11) The interpretation of paragraphs (9) and (10) seems to be as follows: As the plant loses water during a drought period the total mass has an increasing hold upon its water, until a balance is reached where the vapor pressures within and without the plant are nearly equal, even a gain at night taking place when the relative humidity is higher than during the preceding day. The increased absorbing capacity of the tissue would tend also to increase the pull of the roots on the soil-water, and thus perhaps change the amount of available soil-water, even though the water-content of the soil is not raised.

(12) By the above, the ability of the cactus to withstand long periods of drought is traced to its power to hold water within its tissue against the evaporative force of the air.

Experimental evidence is now being sought for the theory mentioned above, *i. e.*, that the same internal agencies influence both the transpiring capacity and the water-absorbing capacity of cacti. Joints have been taken from plants at various times of the day and night and simultaneous measurements made of their evaporating capacity and water-holding capacity. The experiments thus far show promising results, but the work has not progressed far enough to permit of the statement of a definite law. Experiments are also under way for the investigation of the relation of evaporation-rate and water-absorbing rate in non-living colloidal gels.

The Behavior of Protoplasm as a Colloidal Complex: Factors affecting the Growth of Protoplasm, by Francis E. Lloyd.

It has already been shown that the protoplast in many kinds of pollen contains no sap-vacuoles of optically demonstrable size. The evidence offered indicates that the water taken up when the pollen is placed in contact with it is solely imbibed, and that the earlier growth-period of the pollen-tube results in chief part from imbibition pressure and not from turgor. That osmotic pressure during this period is absent or negligible in quantity (as compared with imbibition pressure, optical evidence aside) is inferred from the fact that growth may take place against a surrounding medium of very high concentration (50 per cent cane sugar), and the protoplasm may even burst, preventing, by rupturing the sustaining cellulose wall, the normal attainment of size which might otherwise be possible.

Proceeding from the above inference, it has been sought to determine quantitatively what the imbibition pressure of growing pollen protoplasts might be, as well as the effect of the presence of electrolytes upon growth-rates. Pollen of *Lathyrus* was found most useful.

In distilled water the pollen may either burst very soon without measurable growth or it may produce short tubes, in exceptional instances only reaching a maximum length of about 100 microns in 2 hours. At or before this length of tube is attained it bursts at the apex and the protoplast gushes forth. A portion may be retained and live for some hours. In 10 per cent cane sugar the matter is little better, giving a maximum length of 100 microns in 40 minutes, with bursting at or before this time. A maximum growth-rate of 200 microns an hour and total growth of 640 microns were attained in 20 per cent cane sugar. At higher concentrations both growth-rate and total growth were less, but were not totally inhibited even in a concentration of 50 per cent. In 30 per cent the rate was about one-half that in 20 per cent and in 40 per cent less than 0.1 (0.07). It thus appeared that an outward pressure of the protoplast upon the cell-wall in excess of a certain quantum can not be used for effective growth. To speak more specifically, and so far as we can see at the moment, the rate at which the protoplast can build the cell-wall of the pollen-tube is a limiting factor. The total range of pressures which allow growth at a greater or lesser rate is, however, wide, as indicated by the above-mentioned cane-sugar concentrations which permit growth.

When the pollen-tubes have attained a length of 80 microns more or less, vacuolization sets in, and we may no longer attribute to imbibition pressure the chief or, at length, even the greater rôle. Until this inversion of rôle has taken place, however, the rates of growth of the pollen-tubes may be regarded as a critical index of the effects of swelling or shrinking of the protoplasm by electrolytes upon growth-rates, since it has already been shown (Carnegie Institution Year Book for 1915, p. 66) that certain electrolytes can cause marked swelling of the protoplasm, as of such emulsion colloids as gelatine. It must be noted, however, that indirect effects may conceivably occur, such as changes induced in the structure of the cell-wall, and these must not be overlooked.

Acids (hydrochloric, nitric, acetic, citric), in concentrations within the range N/200 to N/51200 inclusive were found in no case to increase the growth-rate when combined with 20 per cent cane sugar. At the lower concentrations the rates were approximate or equal to the control. At the higher (N/200 to N/1600), growth was less and less, and bursting took place most quickly in the highest concentrations. When, however, acid (acetic) is combined with cane sugar in a concentration of 40 per cent, in which, in the absence of acid, growth occurs only slightly, the maximum growth (four times that of the control) occurred in the concentration N/6400 of the acid component. It seems clear that the acid increased the imbibition pressure of the living colloids sufficiently to enable them to overcome the contrary effect of the cane sugar—a form of antagonism not hitherto recognized. Concentration below N/6400 produced less growth, while those above caused bursting.

Of the alkalies, the effect of sodium hydrate has been studied. In combination with 20 per cent cane sugar, the rate of growth is greater at the concentrations N/800 to N/1600 than in the control and than in other concentrations. In the higher concentrations bursting occurs. That growth takes place in concentrations of alkali lower than acid may be due to the probably already present acid of the protoplast or to the possibility that the alkali acts merely on the outer protoplasmic membrane or on the cell-wall. Similar concentrations in water cause bursting, and the ready penetration of sodium hydrate has been shown to occur by means of neutral red. The result obtained, therefore, can hardly be referred to effects on the membrane alone, though it has been found, especially in the case of *Lupinus* pollen, that certain concentrations cause, in the absence of increase of growth of the protoplast, an excessive deposition of cellulose, especially within the apex of the tube. It is also evident that the failure of acids to cause increased growth in the presence of 20 per cent cane sugar is not due to poisonous effects, since the tubes remain alive, and since, at higher concentrations of sugar, growth actually takes place in excess of that in the control.

In addition to the excessive deposition of cellulose the shape of the pollen-tube may be affected. In general, the tube tends to become bulbous, or even spherical, under conditions which increase the imbibition of the contained protoplast.

The investigation of a typical salt (potassium nitrate) in similar combination with cane sugar gave no increased swelling and no increased growth-rates.

From the above it is seen that the behavior of protoplasm as a hydrophile emulsion colloid, as previously shown (Carnegie Institution Year Book for 1915, p. 66), may express itself in terms of normal activity. We have here demonstrated, on material from which turgor as a factor in growth is excluded, that the analogy between the behavior of hydrophile emulsion colloids (such as gelatine) and protoplasm in living condition in fact obtains, and that this behavior can express itself directly in alterations in growth-rate. It must, however, be noted that the concentrations are very low as compared with those which produce measurable alterations in the imbibition capacity of non-living emulsion colloids. Protoplasm is, however, a complex of such colloids whose imbibition capacities are probably different among themselves, and are at all events at present unknown.

ECOLOGY AND PHYTOGEOGRAPHY.

The Rôle of Climatic Factors in determining the Distribution of Vegetation in the United States, by Burton E. Livingston and Forrest Shreve.

A joint study of the distribution of climatic conditions and the distribution of vegetation has been in progress for eight years. The aim has been to secure a basis upon which to enter into an examination of the correlations between the distribution of climatic factors and of plants, and to ascertain some of the climatic controls which are operative in limiting distributions of vegetation and of individual species. Prior to the present year the progress of this work has consisted in the collection and elaboration of data by both of the authors. New modes of expression of climatic data, as related to plants, have been devised, and are described in the Year Book for 1915. A new subdivision of vegetational areas for the United States has been worked out, as described on another page, and some new methods of charting the relative dominance of different growth-forms of plants have also been worked out in connection with this study.

During the present year the assembling of climatic and vegetational data has been completed, the correlations which formed the object of the work have been made, and the material has been brought to an advanced stage of readiness for publication.

Some 38 climatological features have been elaborated, chiefly from the published observations of the United States Weather Bureau, using from 134 stations in some cases to over 1,000 stations in others. The number of features worked out for each of the major climatic factors is as follows: Temperature, 12; precipitation, 7; evaporation, 4; moisture ratios (ratio of precipitation to evaporation), 5; vapor-pressure, 2; humidity, 3; wind, 1; sunshine, 1; moisture-temperature indices (the moisture ratio times a temperature datum), 3.

One of the most carefully elaborated of the climatic features is the length of the frostless season, which has been determined for 1,200 stations, ranging in their conditions from the expectancy of frost on any day in the year to the invariable absence of it. The annual means have been secured for each of the major climatic factors and the annual extremes for some of them, but in the great majority of cases the climatic conditions have been determined for the growing season only. This results in bringing into comparison the conditions of a very short period in the northern parts of the United States and the conditions of a long period in the southern States. Inasmuch as the activities of vegetation are chiefly controlled by the conditions of the growing season, the distribution of the climatic conditions of the year as a whole are, therefore, of relatively small significance in an investigation of this character.

Considerable attention has been given to the elaboration of moisture ratios, owing to the significance of the relation which exists in all parts of the country between the precipitation and the rate of evaporation. The importance of this ratio has not only been demonstrated in experimental work by both of the authors, but has been shown by Transeau to be of importance in connection with distributional work. Moisture ratios have been worked out for all of the evaporation data which it is now possible to secure for the United States, and for the year as well as the growing season.

Summations of temperature have been made by four methods, the best of which is based upon Lehenbauer's work on the relation of temperature to the growth of corn. This "physiological summation" is one in which the different degrees of temperature are given weight in proportion to their influence upon growth. The older methods of summation provide for the addition of all temperatures to form a single total, without regard to the very different physiological effects of the lower and higher temperatures which are added.

The temperature and moisture factors have, in general, been given independent treatment, but an effort has been made in the moisture-temperature indices to obtain a composite expression of the moisture and temperature conditions of the various sections of the United States.

Three series of vegetational data have been secured for correlation with the climatic conditions: (*a*) the distribution of distinctive types of vegetation, or formations; (*b*) the cumulative occurrence of selected growth-forms, or anatomically similar plants; (*c*) the distribution of selected individual species. Under the first heading nine leading types of vegetation have been used: four areas of evergreen needle-leaved (coniferous) forest, deciduous forest, grassland, the transition region between the last two, and two types of desert. Under the second heading several maps have been made which show the cumulative occurrence of all species of a given growth-form, or of the commonest ones. These maps show, for example, in what part of the eastern United States there may be found the largest number of species of deciduous trees, how this abundance shades off in all directions, and what are the outermost limits of this group of trees. In another case the range of buffalo grass is shown so as to indicate the region in which it is a dominant element in the vegetation, the region in which it is frequent, the region in which it is rare, and the limit beyond which it is not known to occur. Under the third heading have been secured the geographical ranges of a number of trees, shrubs, grasses, and other plants, selected to represent the different types of distribution common in the United States—or, in the case of certain aquatics, selected because of their independence of the moisture factors in distribution.

A total of 115 distributional areas were worked out under these three headings and drawn on large-scale maps. Overlays were made from these maps, and used in connection with climatological maps drawn to the same scale and bearing the readings of all the stations. Of the 38 climatological maps, 31 were used in this manner, and the maximum and minimum values of each factor were secured for each of the vegetational areas, making a total of 3,565 sets of values. This operation has yielded, in brief, a set of 31 climatic values for each of the 115 vegetational areas. For each type of vegetation or for each individual species it is possible to state the maximum and minimum values of each temperature, moisture, humidity, or other factor characterizing that area.

The data secured in this manner serve to show, for example, the highest and the lowest minimum temperatures recorded at any of the stations in the grassland, or Great Plains, area; or to show the highest and lowest rates of evaporation that have been found to occur in the range of the sage-brush. These maximum and minimum values are, in short, the particular intensities which seem to limit the occurrence of the particular vegetation or plant under consideration, in so far as such a geographical correlation may be taken in lieu of experimental evidence. The maximum and minimum values will be presented in tabular form, and the total range of conditions within the distributional areas will be shown in graphic form, so that it will be possible to use either of our sets of basic data in extending this somewhat preliminary investigation with respect to other climatic features and other plants or vegetational areas.

Our results have also served to indicate which of the climatic features are the most critical in determining particular cases of distribution. This phase of the investigation has been prosecuted by a comparison of the climatic and vegetational maps themselves, and by a search for the coincidence of isoclimatic lines with distributional limits. In this manner the moisture ratios have been found to show a close relation to the distribution of the leading plant formations of the United States. While certain of the temperature features appear to be critical in limiting the ranges of some of the individual species, the controls which limit the great areas of forest, grassland, and desert appear to be best expressed in the ratio of precipitation to evaporation.

A Map of the Vegetation of the United States from a Purely Vegetational Standpoint, by Forrest Shreve.

A map showing the principal vegetational areas of the United States has been in preparation for several years in connection with the work on correlation of vegetation and climate which is described elsewhere. Repeated revisions of the map have been made whenever further materials were secured regarding it, and the latest of these has been prepared for publication.

The aim of this map has been to distinguish the various types of vegetation in the United States solely upon the basis of the collective physiological behavior and anatomical character of the dominant plants concerned. No weight whatever has been given to floristic relationships nor to any of the climatic, physiographic, and geological factors which are known to influence the distribution of vegetation. This departure from the method by which former maps of the plant life of the United States have been made has necessitated the use of original sources of information throughout its preparation. The importance of using purely vegetational data has resided in the fact that the primary purpose of the map was to serve as a foundation for correlations of the distribution of vegetation and the distribution of climatic conditions.

The chief criterion by which the plant formations of the United States have been distinguished is the character of the growth-forms comprised in these formations. The differentiation of growth-forms among plants is largely an expression of their adjustment to a particular set of water-relations. The form, structure, and foliar organs of every plant betray its water requirements, while no such visible criteria indicate its temperature requirements. It is therefore impossible at the present time to characterize large units of vegetation without neglecting the temperature requirements of the plants, an extended knowledge of which awaits further experimental work. It has been impossible in the preparation of this map to escape these limitations.

It has been found necessary, as a result of personal exploration, to subdivide the desert portion of the United States. The regions in the Great Basin and southern California are characterized almost solely by microphyllous shrubs, while the deserts of Arizona, New Mexico, and western Texas abound in succulent and semi-succulent plants. The coastal portions of California and of Texas are to be regarded as semi-desert areas, differing widely from the continental areas just mentioned. There is also a well-marked transition area between the succulent deserts of Arizona, New Mexico, and Texas and the western edge of the grassland. All of these subdivisions of the desert are biologically distinct and merit separation in vegetational work as much as do the deciduous and the evergreen forests of the eastern States.

The Effect of Position upon the Temperature and Dry Weight of Joints of Opuntia, by J. M. McGee.

The flattened joints of the platyopuntias were held in a vertical position, either edgewise or lengthwise. Terminal mature joints of *Opuntia blakeana* were chosen to test the relation of the position with respect to sun, to the body-temperature, and dry weight. The separated joints were held apex downward by impalement upon the bulb of a thermometer, which in turn was fastened with wooden clamps in such manner that the two surfaces of the joint faced north and south and it was said to be in an "equatorial" position. The second lot faced east and west, one such double set being exposed during March, a second during June, and a third during the latter half of July. The chief results may be summarized as follows:

(1) Joints of *Opuntia blakeana* in any position show temperatures above the air-temperature while exposed to solar radiation.

(*a*) The temperatures of joints in an equatorial position rise steadily till 12 m., then more slowly till 2 p. m. when the maximum is reached. After 2 p. m. the temperatures steadily decline, becoming the same as that of the air soon after sunset and then falling slightly below the air-temperature and remaining so during the night.

(*b*) The temperatures of the joints in a meridional position rise sharply after sunrise, reaching a maximum about 11 a. m. They then slowly drop until 12^h 30^m p. m., when they begin to rise again, reaching the second and highest maximum point about 4 p. m., after which they fall, at first slowly and then more abruptly, till sunset. After sunset the temperatures slowly fall below the air-temperature, as in the case of the other joints.

(*c*) Computation of the area inclosed by each curve, using the 10-degree line as a base, shows that on March 9, 1916, the number of hour-degree units inclosed by the air-temperature curve was 134.6; by the curve of the joints in an equatorial position 211.5 hour-degree units; and by the curve of the joints in a meridional position 230.8 hour-degree units. Hence it will be seen that the temperature of the joints in a north-and-south position exceeds that in an east-and-west position by 19.3 hour-degree units and the air-temperature by 96.2 hour-degree units and that in these joints the temperature effects would be accentuated. Similar computations show that on June 2, 1916, the number of hour-degree units inclosed by the air temperature curve was 273.0; by the curve of the equatorial joints 328.8 hour-degree units; and by the curve of the meridional joints 376.9 hour-degree units. The meridional joints exceed the equatorial joints by

48.1 hour-degree units of exposure, and the air-temperature by 103.9 hour-degree units.

(*d*) From the data just given, it will be seen that from sunrise to sunset the number of hour-degree units inclosed by the temperature curve for a June day is very much greater than the number for a March day, and that the increase is greater in the case of the meridional joints than in that of the equatorial joints. The numbers of hour-degree units inclosed by the curves of the meridional joints for March 9 and for June 2, 1916, differ by 146.1 hour-degree units; the numbers inclosed by the curves of the equatorial joints differ by 117.3 hour-degree units; and the numbers inclosed by the cuves of the air-temperatures differ by 138.4 hour-degree units.

(*e*) The loss of weight from February 28, 1916, to April 5, 1916, of joints in a meridional position was 18.59 per cent, the loss of weight of joints in an equatorial position was 16.30 per cent, and that of shaded joints was 5.79 per cent, whereas the loss of weight from May 15 to June 28, 1916, of joints in a meridional position was 24.70 per cent, that of joints in an equatorial position was 26.23 per cent, and that of shaded joints was 23.32 per cent. The dry weight of joints similar to those used in these observations was 16.15 per cent on March 8, 1916, and had increased to 17.70 per cent on April 5, an increase of 1.55 per cent; whereas the dry weight of joints on May 17 was 29.37 per cent and had increased to 36.38 per cent on July 10, 1916, an increase of 5.01 per cent.

(*f*) The maximum temperatures reached by joints growing under natural conditions were found to be 53.0° C. on July 24, and 55.0° C. on July 25, 1916. These temperatures are higher by several degrees than those reported by Askenasy or Ursprung for succulent plants such as *Opuntia*, and it is interesting to note that Pfeffer states that "Prolonged exposure to a temperature of from 45° C. to 46° C. kills most Phanerogams" (Pfeffer's *Plant Physiology*, vol. 11, p. 226).

On the Relation between the Rate of Root-Growth and the Oxygen of the Soil, by W. A. Cannon.

It is now known that the perennials of the Tucson region associated in the same habitat, or growing under apparently similar conditions, may be subject to an environment which in many particulars is unlike. This follows from possible differences in root-habits. Thus, the cacti have roots lying within a few centimeters of the surface of the soil, while *Prosopis*, for example, forms roots which may reach to comparatively great depths. Among the environmental differences to which such widely different root-types are exposed are those of soil-moisture, soil-temperature, and aeration.

A study of the response of the leading types of root-systems to the environmental factors of the soil has been made with the object of estimating their influence as determinants of the root-system types themselves. It is believed that such unlike root development is not directly due to differences in the soils or variation in the soil-moisture as the various root-types may be developed in soils that are uniform and suitably moist throughout. It is concluded, however, that the widely different root-types are in the main the direct response of the roots to temperature, and to a less degree perhaps to the variation in the composition of the soil-atmosphere which is associated with differences in depth. To test the latter hypothesis, experiments have been carried out on the roots of *Opuntia* and *Prosopis*, in which they were exposed, at known soil-temperatures, to atmospheres of known but different composition. The atmospheres used were composed of pure carbon dioxide, or of carbon dioxide to which atmospheric air had been added in known amounts.

The experiments showed that the composition of the soil-atmosphere, as well as the length of the exposure, were alike important. Exposure of both *Prosopis* and *Opuntia* for a period of 15 minutes to pure carbon dioxide did not alter the growth-rate as observed hourly. An exposure of the roots of both species to pure carbon dioxide to periods over 30 minutes, however, inhibited growth during the time of the exposure. Exposures were made up to 3 hours. Growth of the roots was renewed soonest after the shortest exposures, sooner in *Prosopis* than in *Opuntia*, and sooner in both species at high than at low soil-temperatures. In general, a longer time was required to bring about cessation of growth in the atmospheres with an admixture of air than in oxygen-free atmospheres, and recovery was soonest in atmospheres most rich in oxygen. Also, the roots of *Prosopis* recovered their usual growth-rate sooner than did those of *Opuntia*. It would appear, therefore, from the experiments, that the response of the roots of *Opuntia* to a diminished oxygen-supply of the soil is such as would tend to prevent deep penetration, and thus to support the effects of the relatively high temperature characteristic of the upper soil-layers in bringing about the formation of a superficial type of root-system. On the other hand, the reaction of the roots of *Prosopis* to a diminished oxygen-supply in the soil-atmosphere indicates that poor aeration, or a comparatively small proportion of oxygen in the soil, does not operate as a factor limiting the penetration of the roots of the species.

Rate of Root-Growth of Covillea tridentata in relation to the Temperature of the Soil, by W. A. Cannon.

It has already been shown (Carnegie Institution Year Book for 1914, p. 93), that there appears to be a causal relation between the depth of root penetration in *Prosopis velutina*, *Fouquieria spendens*, and *Opuntia versicolor* and the response of the roots of these species (as shown by the rate of growth) to the temperature of the soil. It will be suggested in this place that similar relation is probably to be found in *Covillea tridentata,* the depth of penetration of the roots of which is fairly intermediate between that of the roots of *Prosopis* and of the other two species mentioned.

The roots of *Prosopis* have a comparatively rapid growth-rate and those of *Opuntia* a comparatively slow growth-rate at relatively low soil-temperatures. For example, at soil-temperatures ranging between 12° and 19° C., in 72 hours the root of a young *Prosopis* increased 22.5 mm. in length, while a root of a young *Opuntia* grew only 6 mm. under the same conditions. Relatively low soil-temperatures, therefore, do not constitute a factor limiting root-penetration in *Prosopis,* while they do in *Opuntia.* A study of the reaction of the roots of *Covillea* to soil-temperatures shows that the root-temperature relation in this form is unlike that in either of the other species mentioned.

The rate of growth of the roots of *Covillea tridentata* is relatively slow at all soil-temperatures, particularly at those that are comparatively low. Thus, at soil-temperatures between 15° and 20° C., the average rate of root-growth in young plants is about 0.12 mm. hourly; between 20° and 25° C. it is about 0.16 mm. an hour; between 25° and 30° C., the hourly rate is about 0.31, and between 30° and 35° C. it is approximately 1.6 mm. It appears, therefore, that at parallel soil-temperatures the growth-rate of the roots of *Covillea* is intermediate between that of the roots of *Prosopis* on the one hand and of *Opuntia* on the other. It is therefore probable that in the case of *Covillea,* low soil-temperatures do constitute a factor which limits the penetration of the roots.

Root-Growth of Introduced Desert Plants at Carmel, by W. A. Cannon.

Species native to the daya region of Algeria, the Mohave Desert of California, and the vicinity of the Desert Laboratory in southern Arizona have been growing in the experimental plots at the Coastal Laboratory from one to five years for the purpose of placing under observation the effects of the cool, equable climate of Carmel on their growth, especially on the growth and development of the roots. The plants studied in this connection consisted of *Opuntia basilaris* and *O. ramosissima* from the Mohave, *O. versicolor* and *Prosopis velutina* from Tucson, and *Pistacia atlantica* from Algeria.

The three regions from which the species came may be characterized as warm temperate with rain in winter only (Mohave and Algeria), or rain both in winter and in summer (Tucson). Such climatic conditions are to be contrasted with the fairly humid climate of Carmel, with relatively little difference in air-temperature between summer and winter and with rains in winter only. In the regions with winter rains the growing-season is in late winter or early spring, when the soil is relatively cold, but at Tucson it is in midsummer as well. In the latter region, in fact, the season of most active root-growth is in summer, when the soil is relatively warm as well as moist. Whether any species characteristic of either of these regions will grow in the other regions depends largely, therefore, on the temperature of the soil at the time it is suitably moist, since an appropriate soil-temperature is a condition indispensable to an effective rate of growth of roots.

The following summary gives the maximum and minimum temperatures of the soil at the Coastal Laboratory for the summer in 1916 and for the depths indicated:

Depths.	June.		July.		August.	
	Max.	Min.	Max.	Min.	Max.	Min.
	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*
60 cm.	16.6	14.7	18.6	17.5	18.3	17.7
30 cm.	17.2	15	18.6	17.5	20	17.2
15 cm.	27.7	15	28.6	19.4	27.7	18.3

It should be said that at the depth of 30 and 60 cm. the soil in midsummer at Carmel is moist, but at the least depth it is air-dry at that time; at all depths, owing to the sandy nature of the soil, it is well aerated.

The types of root-systems represented by the species referred to are the specialized superficial type of the cacti and the deeply penetrating type of *Prosopis* and *Pistacia.* Under natural conditions the roots of the cacti, for the most part, lie within 5 to 10 cm. of the surface of the soil and extend away from the central axis as far as 1 to 3 meters or more.

Growing in the soil of the garden at the Coastal Laboratory the Opuntias, from whatever region, tend to form generalized root-systems. Specimens which had been over two years at Carmel had formed root-systems which may be described as constituting a tuft of approximately equal length, none of which exceeded 25 cm. These took a downward as well as an outward course in their growth. However, most of the roots were confined to the uppermost 15 cm. of soil, or that stratum where, as the accompanying table indicates, the soil temperature is the highest.

The specimens of *Pistacia,* five years from the seed, had shoots about 25 cm. in length. The root-system was dominated by a tap-root which was traced down over 105 cm. There were deeply penetrating laterals also, and within 15 cm. of the surface of the soil many short, fibrous rootlets had been formed.

The *Prosopis* observed were seedlings one year old. The seed was sown in September. In the following May the roots were seen to have penetrated to a depth of about 80 cm., and in the following August a depth of 1 meter was attained. The shoots were approximately 6.5 cm. in length a year after the seed was sown.

The results observed in the outdoor cultures, therefore, confirm the results of laboratory experimentation. Numerous tests have indicated that the roots of cacti from the Tucson region and from the Mohave grow comparatively slowly at soil temperatures below 20° C. The factor limiting root-penetration in these forms at the Coastal Laboratory, consequently, is the relatively low soil-temperature that obtains at that place. On the other hand, it has been seen in many experiments that the roots of *Prosopis* have an effective rate of growth at temperatures under 20° C., although the optimum, as in the case of the cacti, is much above this. The soil-temperature at depths thus far studied is well above the minimum for root-growth of *Prosopis*. We find, accordingly, that the roots of this species penetrate the soil at Carmel relatively deeply.

From the observed behavior of the roots of *Pistacia* at Carmel it is concluded that the temperature reponse of the roots of the species is similar to that of the roots of *Prosopis*. Thus, it is because the roots of *Pistacia* have a fairly active growth-rate at relatively low soil-temperatures that in their proper habitat they penetrate to the soil horizon carrying moisture throughout the year. The characteristic temperature reaction of the roots of *Pistacia*, therefore, constitutes a vitally important adjustment of the species to its difficult environment.

Relation of Soil Aeration to Plant-Growth, by B. E. Livingston and E. E. Free.

In this report for 1915 announcement was made of experiments on the amount of oxygen necessary for the roots of *Coleus* growing in soil.[1] These experiments have been continued with an improved and simplified technique and tests have been made also of heliotrope (*Heliotropium peruvianum*), oleander (*Nerium oleander*), and swamp willow (*Salix* sp.). Heliotrope is found to resemble *Coleus* in requiring the maintenance of a certain oxygen-content in the air of the soil. The roots of oleander also require oxygen, but appear to need much less of it than do the roots of *Coleus* and heliotrope. Also the injury produced by entire deprivation from oxygen is much less quickly developed. The roots of the swamp willow appear to be unaffected by oxygen deprivation. Plants grown in soil the atmosphere of which contained no oxygen showed normal behavior and growth over periods as long as 10 weeks. It appears that plants of different species may differ widely as to the oxygen required by their roots. Together with the work of Cannon, reported in preceding paragraphs of this report, this indicates that soil aeration is probably a much more important ecological factor than has been suspected.

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[1]Carnegie Inst. Wash. Year Book for 1915. pp. 60–61.

Osmotic Concentration of the Tissue Fluids of Desert Plants, by J. Arthur Harris.

The studies on the relationship between the physico-chemical properties of the sap of desert plants and their local distribution, carried out in the vicinity of the Desert Laboratory and briefly mentioned in a preceding report (Carnegie Inst. Wash. Year Book for 1915, p. 81), have recently been published (Physiological Researches, vol. 11, pp. 1–50, 1916). These studies were made in the period of winter vegetative activity in 1914. During the summer of 1916 Dr. Harris, assisted by Mr. William G. Leamon, devoted the months of July and August to the investigation of the sap properties of the annuals and perennials active during the summer. A series of about 300 determinations of osmotic concentration was made, based upon collections from habitats ranging from Mount Lemmon, in the Santa Catalina Mountains, phytogeographically studied by Shreve (Carnegie Inst. Wash. Pub. No. 217), to the Desert Laboratory domain and immediate vicinity, where a large part of the field physiological investigations published from this Laboratory have been carried out. In view of the differences already demonstrated in the osmotic concentration of the sap of plant species of different habitats, a comparison of the vegetations from selected points in such a gradient as that from the driest mesa and the most highly developed salt spots of the desert floor to the densely forested slopes of the higher Santa Catalinas has many obvious points of interest, both physiological and phytogeographic.

For comparison with these studies on the southwestern deserts, a series of determinations have been made from other similar as well as highly dissimilar environments. Papers on the coastal deserts of Jamaica and on the rain forests of the Blue Mountains of Jamaica, concerning which a publication has already appeared,[1] will be ready shortly. Extensive observations on the vegetation of subtropical Florida and on the mesophytic environments of the Station for Experimental Evolution, in collaboration with which three studies are being made, are also under way.

Osmotic Properties of Tissue Fluids of Parasitic Plants, by J. Arthur Harris.

In an early publication from the Laboratory appearing in the Institution series (MacDougal and Cannon, Carnegie Inst. Wash. Pub. 129) the suggestion was made (as the result of experimental studies) that a necessary condition of artificial parasitism is a higher osmotic concentration of the fluids of the plant species used as parasite. Harris and Lawrence have carried out an extensive investigation of the problem on Loranthaceous parasites in the Jamaican rain forests, and in a paper now in press have shown that in the case of plants growing under these conditions the parasite is generally but not

[1] Shreve, A Montane Rain Forest, Carnegie Inst. Wash. Pub. 199.

invariably characterized by a higher osmotic concentration of its fluids. They also show that on theoretical grounds higher osmotic pressure of the tissue fluids is not a necessary prerequisite of successful parasitism in the case of a species living under natural conditions.

A substantial beginning has also been made by Messrs. Harris, Lawrence, and Leamon in the study of the sap properties of desert Loranthaceæ.

GENETICS AND TAXONOMY.

Experimental Evolution in a Desert Habitat, by W. L. Tower.

The rebuilding operations begun in 1915 did not, as feared, produce loss in or interruption of any experiments in progress at Tucson. The mortality in hibernation was the lowest it has ever been, while the progress of the cultures during the breeding season has been highly satisfactory.

Unexpected uniformity of the physical environment in the different cages and of the progress of the cultures is given by the new arrangements, so that the entire series can now be started and come to the close of the first summer generation, all at the same time, thus facilitating the task of checking, recording, and arranging for the next generation. In past years different cultures varied from one to four weeks in their emergence from hibernation and in maturity, a fact which greatly complicated the work.

EXPERIMENTAL EQUIPMENT AT TUCSON.

The rebuilding of the entire plant, begun in 1915, was continued this year. A food-cage absolutely proof against contamination and of a capacity large enough to supply all the food needed has been erected, and as a result we had the novel experience of having a surplus of food throughout the year. The grading about the entire establishment has been completed and the top finished by a layer of 4 to 6 inches of fine crushed-stone screenings. Improved instrument shelters of substantial construction have also been erected. These improvements greatly reduce the cost of maintenance and also of operation. The time consumed in irrigation, food production, and control has been decreased to about one-fourth the expenditure in 1914, while the effectiveness of the plant is greatly increased.

INTRODUCED SPECIES OF LEPTINOTARSA.

The largest and longest-continued culture of any pure type are those of *Leptinotarsa decemlineata,* which came from stocks of known composition and reactions living in the mesophytic conditions at Chicago. Successive introductions into the Tucson conditions from the same Chicago stock all show the same progress and changes. These cultures which have been introduced at Tucson are in their fourth, tenth, twelfth, and eighteenth generations, and all show the same uniform progressive change in their water-retaining capacity during hibernation. In no instance has it been possible to reverse this change by returning the stocks from Tucson to Chicago. Accompanying this change are behavior changes, especially to desiccation, and in rates of reaction to stimuli changes not observed in their early stages and only seen after considerable alteration had taken place. In that there is a wide range in any culture of these behavior changes it seems probable that the alteration is a gradual one, but this must be checked by close observation of future introductions.

Morphological changes in pattern, color, and size continue as noted in previous reports, and most notable are the reductions of portions of the elytral pattern and of the ventral surface. These changes are genetic, as shown by test crossings with the basic stocks, and behave as Mendelian recessives and have not regressed to the original condition by living at Chicago for two to four generations.

These alterations are of the order observed in ecological varieties in nature or in varietal states under domestication. The genetic behavior is also the same, due to "losses," thus giving "recessives" in crosses with the normal. This, while true of the morphological changes, is the opposite in the observed physiological alterations, *i. e.*, water-relation, altered behavior, which are "dominants."

MUTATING STEM STOCKS.

Two chief series of these are now carried at Tucson—one C. H. 156.8, a synthetic product of three species, *L. decemlineata, oblongata, multitæniata;* the other, C. H. 15.7, a compound of *L. decemlineata* and *multitæniata*. The manner of production has been recorded in preceding reports.

In the past year the stem stocks which were not subjected to experiment continued to breed true with little variability. In the C. H. 156.8 series only slight mutations have been produced thus far, and they are all in the elytral pattern and are of an order unknown in the parent species.

The mutating lines of the C. H. 15.7 series continued their behavior in this respect during the year. The mutants in this series are of two types: (1) recombinations of characters from the original parents, and (2) alterations of these. Of the first no new types were discovered during the year and apparently the possible array has been exhibited. More than 20 of these recombination types have been observed and are being tested out in the laboratory at Chicago. Two or three years more will be required for completion.

One interesting fact was demonstrated in the year, namely, that some of the mutants mutated, either regressively, towards the stem stock, but not thereto, and also progressively away from the stem form, the two kinds being about equal in frequency. As far as tested, these secondary mutations are stable and homozygous.

The point of most interest in this series in the year is the increasing evidence that mutability is not a hybrid splitting. Crosses of mutating and non-mutating lines show that in F_1 mutation is a recessive, segregating in F_2 with normal non-mutating as the dominant. The results of F_2, F_3, and F_4 in this series will, it is hoped, throw much light upon the mutation phenomena in these cultures.

ECOLOGICAL ADJUSTMENTS.

As the result of accompanying changed ecological or environmental conditions in the cultures at Tucson, necessary adjustments of the cultures to the new habitat were made or the culture failed. These reactions are, in our experience, of brief duration, occupying one or two or at most ten generations, and are final; that is, the newly introduced form either can or can not adjust itself to the desert habitat, a decision made in the shortest possible time. Thus far, only savannah and mesophytic habitat species have survived at Tucson, while all rain-forest, monsoon-forest, and moist-habitat types in general have failed. In these the limiting factor is water-loss, but the critical stage varies with the species, *i. e.*, *L. panamensis* egg and first larval stages; *L. undecimlineata* in hibernation; *L. diversa* in pupation and in hibernation; *L. signalicollis* in hibernation.

In species that do meet the change adjustment has been a graduated, continuous, though often a rapid, reaction, and not a jump to the full accommodation. In the earlier generations only a few pass the critical stage, and these often with difficulty; but the descendants of those that do pass through show increasing adjustment to the new conditions until in some of our older cultures, now in F_{16} to F_{18}, the adjustment is complete as far as discoverable.

Thus far I can discover no evidence that this result is the product of an environmental selection of pure lines, and therefore a selection result; but it is due, as far as I can discover, to accidental positions or circumstances such that the surviving members, while intensely acted upon, did not receive the action of the environmental force to the extent that would eliminate them. Many accidents of time, of position, and of environmental and ontogenetic progression would give opportunity for exactly this effect.

The most conclusive and impressive experience which comes from these cultures is that accommodation or adaptation is environmentally directed and limited, and not produced internally in the organism. The "adaptation" is therefore in certain ways molded by and fitted to the environment, and not offered to the environment for selection by internal and orthogenetic forces.

EVOLUTIONARY MOVEMENTS.

Of the many activities of evolutionary import in these cultures at Tucson, which duplicate as nearly as possible conditions of evolution in nature, the chief and impressive result is that of a gradual continuous change in the population in the direction forced by the habitat, resulting in alterations, with habitudinal adjustment or adaptation. These changes in function and structure, some additions, others losses, produce gradually altered aspects and behavior of the population, are genetic and not somatic, and not reversible, as far as experience goes.

Mutations also occur as the product of complex hybrid constitution, of sharp incident external forces, and there may well be other methods of origin of many mutant types, which may and do become progenitors of specific isolated groups. Populations, apparently, do not change suddenly, but rather by slow accommodation to changed conditions.

Transmission or Recurrence of Environic Effects in Phytolacca, by Francis E. Lloyd.

The progeny (F_1) resulting from seeds developed by abnormal green fruits of the "Tucson plant No. 1," which were reported upon while they were still young last year, have now come to maturity, and have produced inflorescences. These, though arrested by the climatic conditions, developed far enough during the present season to show that they are quite normal. The condition under examination, therefore, appears not to be inherited.

Plants (of lot No. 131) originating at Carmel, and normal as to structure of floral parts, were grown in Tucson and there produced abnormal inflorescences (see Year Book, 1915). An individual known to have behaved thus in 1915 was returned to its original habitat at Carmel in December 1915. It was grown under glass and produced three shoots. One of these bore normal flowers and accompanying structures, while the other two bore abnormal inflorescences.

It is recalled that this abnormal condition was first shown by the "Tucson plant No. 1," grown in Tucson in 1913 by Dr. MacDougal. The coincident occurrence of insect galls on this plant in 1914 suggested the possibility of insect origin in explanation of all the abnormalities observed. A shoot of this plant, protected against the approach of insects during 1915 by a suitable screen, continued to produce abnormal inflorescenses, but no galls. The two phenomena appear, therefore, to be of separate origin, while the possible inheritability of the abnormality appears to be negatived.

Experimental Cultures of Oenothera, by R. R. Gates.

The seeds for all experiments were counted and then placed in phials in water under a bell-jar and the air exhausted. In this way much air was removed from the seed-coats, but this method was not entirely satisfactory, since many of the seeds continued to float.

The seeds were then germinated between blotters at constant temperature by Miss Anne M. Lutz in the United States seed laboratory at Berkeley, California. In this way the percentage of germination was obtained in all cases. It varied all the way from 0 to 100 per cent. The seedlings were then planted in flats and the ungerminated seeds examined for embryos. The results show that, except in a few cases, no conclusions can be drawn from a knowledge of the percentage of germination and the number of empty seeds. There are also certain sources of error. For example, the seeds sometimes vary in size so enormously that it is difficult to determine whether the smallest should be counted as seeds.

Among the plants grown this year were wild species from California, North Dakota, Nova Scotia, and elsewhere, whose characters and variability were studied. A form belonging to *Oenothera hookeri* was represented by 11 cultures, each from a capsule of seeds from a different individual, collected in 1915 from the large population of oenotheras at Lake Merced, near San Francisco. The percentage of germination in these 11 cultures varied from 19.5 per cent to 100 per cent, and the percentage of empty or nearly empty seeds from 54.6 per cent to 0. The culture (No. 64) in which all seeds germinated contained originally 66 seedlings, but of these only 26 survived until they were planted out in May. The remainder died during the interval from January to May, when they were kept in a greenhouse without artificial heat. When the rosettes of the survivors developed, 20 were found to be of the ordinary broad-leafed type and 6 were very narrow, linear-leafed dwarfs. The original seeds were nearly all large and plump. It is probable that those which died contained at least as many dwarfs as the survivors, and some of the dwarfs at least must therefore have come from large, plump seeds.

The main results of these *Oe. hookeri* cultures were as follows: 9 of the 11 families were relatively uniform, while 2 produced markedly aberrant mutant types. One of the latter families was mentioned above; the other (No. 63) contained 63 plants, representing 4 rather well-marked types. Type (1) was the normal broad-leafed rosette (37 plants); type (2) the linear-leafed dwarf found also in culture No. 64 (5 plants); type (3) narrow-leafed and clearly marked (13 plants); type (4) rather narrow-leafed, paler green, smaller and more compact rosettes, these shading into the broad-leafed condition (8 plants). The appearance of these strikingly aberrant types, many of which have since come into bloom, in *Oe. hookeri*, was all the more unexpected, as my previous cultures of this species had proved very uniform. Some of the remaining families contained plants, all of the broad-leafed type above mentioned, although they numbered hundreds of individuals. This shows that individuals which were externally alike may breed true or may produce a large percentage of aberrants. The remaining families, although by no means uniform in all their characters, were in some cases constantly different from each other in such features as depth of green in the foliage and predominatingly red or green midribs. These experiments throw an interesting light on the amount of diversity which may be found by growing the offspring of different individuals of a species occupying the same locality.

Another experiment yielding results of considerable interest is a series of F_3 families from *Oe. rubricalyx* × *biennis* and the reciprocal. They are for the most part essentially uniform in foliage and pigmentation, having the red buds of *rubricalyx* and foliage intermediate in character but nearer the *rubricalyx* parent. The inheritance of the difference in flower-size, between *rubricalyx* having large flowers (petals about 40 mm. in length) and *biennis* having small flowers (petals about 20 mm. in length), is very striking. There is (1) segregation in flower-size between different individuals. In the majority the length of petals is near 25, 30, or 35 mm.; but in certain plants they are as small as in *biennis* or (more rarely) as large as in *rubricalyx*. Occasionally they far overstep the size of the smaller parent and plants have been found whose petals were all as small as 10 to 12 mm. in length. In addition to this type of segregation there is often (2) striking segregation of flower-size in the same plant. For example, the average length of petals in 9 flowers blooming on the main stem during a period of 8 days was respectively 30, 20.75, 17.75, 31, 15.25, 15, 19.25, 28.5, and 31 mm. Furthermore (3) in some cases there is striking segregation, if such it may be called, in the length of petals of the same flower. In rare cases the longest petals of a flower may be twice the length of the shortest. In one extreme case the lengths were respectively 18, 20, 15, and 12 mm. Usually, however, the difference in length of the petals of a flower is less. When it is large it is frequently accompanied by irregularities in the shape or in the color development of certain petals. It is rather surprising to find somatic segregation occurring on such a large scale.

One other result which may be mentioned is the F_1 hydrid *Oe. hewettii* × *rubricalyx*. *Oe. hewettii* is a relative of *Oe. hookeri* described by Cockerell from Colorado. The parent strain used in the cross had red stems and green buds, while *Oe. rubricalyx* has red buds and more green stems. There are many other differences, such as width of leaf and character of pubescence. The F_1 hybrid is essentially intermediate in all its characters but two, the red buds of *rubricalyx* and the heavy pubescence of *hewettii* being dominant.

Relationships and Distribution of the Cactaceæ, by N. L. Britton and J. N. Rose.

The taxonomic investigation of the cactus family (by Dr. J. N. Rose and Dr. N. L. Britton) has proceeded uninterruptedly during the year and much progress has been made. The work has been mostly in the greenhouses, museums, and herbaria at New York and Washington, in the preparation of manuscript and of illustrations for the monograph. Dr. Britton carried out field investigations on the Isle of Pines and in northern Cuba during the early part of the year, and Dr. Rose intends to visit the northern coast of Venezuela in the autumn.

The first volume of the monograph will include descriptions and illustrations of the two tribes Pereskieæ and Opuntieæ. It is expected that the second volume, the Cereæ, will include descriptions and illustrations of the two subtribes Cereanæ and Hylocereanæ; the third is designed to include the three subtribes, Echinocereanæ, Echinocactanæ, and Cactanæ, while the fourth will probably comprise the three subtribes Coryphanthanæ, Epiphyllanæ, and Rhipsalidanæ. Manuscript and illustrations for all the volumes are largely prepared.

If expeditions to Venezuela and to Paraguay, southern Brazil, and northern Argentina are successfully carried out, the only extensive cactus region little known to us will be that of Ecuador.

Improvement of Guayule, the Desert Rubber Plant, by W. B. MacCallum.

Much of the interest in the desert rubber plant, *Parthenium argentatum,* has centered at the Desert Laboratory since the publication by the Institution of Professor F. E. Lloyd's book on this wild plant. The volume in question,[1] Guayule: A Rubber Plant of the Chihuahuan Desert, embodies the results of an organized attempt to bring under cultivation a hitherto feral desert plant, together with an extensive ecological study of the same under normal and cultural conditions. Careful consideration is given to the question of rate of growth and reproduction of the guayule in its native habitat, and a large body of pertinent data is given. The various conditions of climate, soil, vegetational environment, and parasitism affecting the plant are presented in this connection. The life-history, habit, and anatomical and histological structure of the wild and cultivated forms are minutely described and compared, in order to secure exact knowledge concerning the relation between growth and the rate of rubber secretion.

The wild shrubs are collected in great quantities in Mexico and the rubber, which grades much lower than Para, is extracted by such simple processes as to make it a very profitable operation. The task of developing methods of cultivation has now been successfully accomplished by Dr. W. B. MacCallum and in making a genetic analysis of the plant he has established the fact that it includes a large number of elementary species which do not readily interbreed.

The company under whose auspices the experiments in cultivation were carried out has purchased 7,000 acres near Tucson, and guayule is now being established on this land. This effort is notable in that it is a successful attempt to bring a wild plant under profitable cultivation, and that it is the only rubber-producing plant within the borders of the United States.

[1]Carnegie Inst. Wash. Pub. No. 139, VIII+213 pp., 46 pls., 20 figs.

EREMOGRAPHY.

The First Stage in the Recession of Salton Sea, by D. T. MacDougal.

The studies on the recession phenomena of the Salton Sea have been carried on continuously since 1906. About half of the original depth of 84 feet has been lost by the balance of evaporation and seepage over inflow and underflow. The rate of fall of the level of the water has been reduced from over 50 inches yearly to less than 40. The loss from January to April was less than the amount received from rains and from overflow of irrigation systems during the winter of 1915–16, so that the lake has now altered from a constantly falling level to an oscillating level. This and the fact that the emerging beaches are now occupied by halophytic or salt plants only are used as criteria to mark the end of the first stage of the recession.

The reduction of the total body of water from an original total of about 3 or 4 cubic miles to half that amount has been accompanied by a concentration of salts dissolved from about 0.33 per cent to 1.6 per cent. The variations in the principal constituents during the last three years are given below:

	1912	1913	1914	1915	1916
Solids	.....	.....	1,179.6	1,377.4	1,647.2
Water occlusion	.....	.....	36.2	42.2	47.5
Calcium	.....	.....	22.22	25.27	29.85
Potassium	.....	.....	4.01	5.2	5.71
Magnesium	.....	.....	19.03	22.63	27.17
Chlorine	.....	.....	559.66	650.95	787.64
Sulphuric (SO_4)	.....	.....	148.10	174.47	207.89
CO_2 total	12.09	11.28	10.68	11.92	11.40

The concentration of calcium was checked during the first few years of the recession of the lake by reason of the fact that it was being deposited as travertine as a result of the activity of a group of organisms, and it is now showing a higher concentration, the water having become too salty for the algæ and bacteria earlier concerned in this action.

The larger islands have become joined with the mainland, but Cormorant Island, originally freed from all seed-plants, is still separated by a mile of salt water from the northeastern shore. Its reoccupation by plants has proceeded as shown in the table herewith (the census for 1916 was taken in May).

Revegetation of Cormorant Island.

Pioneer species.	No. of individuals.		
	1908	1912	1916
Atriplex lentformis	..	5	35
Baccharis glutinosa	1	2	..
Crypanthe barbigera	..	..	1
Distichlis spicata	..	..	1
Erigeron canadensis	..	..	2
Heliotropium curassavicum	..	2	15
Lactuca asper	..	..	2
Pluchea sericea	1	2	4
Rumex berlandieri	..	..	1
Sesuvium sessile	..	2	5
Spirostachys occidentalis	..	20	404
Total, 2 species	2	..	..
Total, 6 species	..	33	..
Total, 10 species	..	..	470

The total number of species now occupying the island is probably as great as when it was a desert hill. It is to be noted that 460 of the 470 individuals on the island are salt plants, and that one of the pioneers, *Baccharis*, has already been lost.

Composition of Salton Sea Water, June 10, 1916, by A. E. Vinson.

The annual sample of the water of Salton Sea was taken June 10, 1916, over deep water off Salton Station. The results of the analysis are given in the following table:

Composition of Salton Sea Water, June 10, 1916 (in parts per 100,000).

Total solids (at 110° C.)	1,647.2	Carbonic, CO_2 (total)	11.40
Water of occlusion and hydration	47.5	Bicarbonic, HCO_3 (volumetric)	16.10
Sodium	528.9	Silicic, SiO_4	1.21
Potassium	5.71	Phosphoric PO_4	doubtful trace
Calcium	29.85	Boric acid	trace
Magnesium	27.17	Oxygen consumed	0.170
Aluminum	.034	Nitric	None
Iron	.060	Nitrous	Trace

From June 8, 1915, until June 10, 1916, the total solids in the Salton water have increased from 1,337.4 parts per 100,000 to 1,647.2 parts per 100,000, equivalent to a concentration of 19.6 per cent. This is the greatest annual concentration noted, except the concentration from June 8, 1909, till May 22, 1910, which was 21 per cent. Aside from the concentration of the solids collectively, there is little requiring discussion at this place. Mention, however, should be made of phosphoric acid. In the early annual analyses of the series weighable amounts of yellow precipitate were obtained. For several years the phosphoric-acid test remained positive, the test being made by scratching the sides of the beaker with a stirring-rod, but at this time no unmistakable reaction can be obtained from 3 liters of water. Phosphoric acid, therefore, has been reported as a doubtful trace.

Climatic Investigations, by Ellsworth Huntington.

During the past year two important steps have been taken in the study of climatic changes. In the first place, the work begun in 1903 by the Pumpelly expedition to Transcaspia and described in publications Nos. 26[1] and 73[2], together with later investigations in the western hemisphere, as described in Publication No. 192[3], has now been summed up in a volume entitled "Civilization and Climate." This not only gives a résumé of the entire problem of climatic changes during historic times, but adds hitherto unpublished data derived from last year's work in the Mohave region. It also considers the effect of various conditions of climate and weather upon human energy.

[1]Pumpelly, R., Ellsworth Huntington, et al. Explorations in Turkestan, with an account of the Basin of Eastern Persia and Sistan. Expedition of 1903. Carnegie Inst. Wash. Pub. No. 126.

[2]Pumpelly, R., Ellsworth Huntington, et al. Explorations in Turkestan, Expedition of 1904. Carnegie Inst. Wash. Pub. No. 73.

[3]Huntington, Ellsworth. et al. The Climatic Factor, as illustrated in Arid America. Carnegie Inst. Wash. Pub. No. 192.

During the past few years the daily work of some 15,000 students and factory operatives has been tabulated. The results lead to the conclusion that human energy is more closely dependent upon climate than has hitherto been supposed. It also appears that to-day civilization and climatic energy bear a surprisingly intimate relation. Furthermore, the final analysis of the evidence obtained last year in the Mohave Desert leads more strongly than ever to the conclusion that the climate of the past has been extremely variable and that the variation has consisted essentially of changes in the distribution and number of cyclonic storms. Thus there is reason to think that in the past civilization and climatic energy were as closely associated as now.

The second important step in the study of climate during the past year arose in part from the work in the Mohave Desert during 1915 and in part from the suggestive writings of M. A. Veeder. In the Mohave work the wonderful series of salt lakes and dry basins from Owens Lake to Death Valley emphasized the conclusion set forth in Publication 192, that changes of climate not only are more important and more rapid than has hitherto been supposed, but that there is no break between small variations visible within a single lifetime and the great variations of the glacial period. In other words, there seems to be growing evidence that a study of present climatic variations furnishes the key to those of the past.

The other conclusion from the lakes of the Mohave Desert was that variations in the strength of the wind have been one of the most important factors in producing climatic changes. As far back as 1888 Veeder suggested that changes in electrical activity of the sun from day to day, as evidenced in the variations of sun-spots, give rise to variations in barometric pressure and thus in winds and rains. This hypothesis in connection with the huge beaches which seem to have been formed in former times by the action of phenomenally strong winds around Owens Lake, for example, led Dr. Huntington to undertake a mathematical analysis of the relation between sun-spots and barometric pressure. Instead of using the actual sun-spot numbers, as has been the almost universal custom, the change in spottedness for each day was computed. A new method was likewise employed to compute the barometric pressure. The problem was to determine the strength of the wind-producing forces. Therefore, instead of using extremes or averages, as is commonly the case, an actual count was made of the number of isobars crossing every fifth degree of latitude and every tenth degree of longitude.

Both the solar and terrestrial data have been computed for each day for seven years. The two sets of figures have been compared by a method of correlation coefficients. Since the day and month are the units instead of the month and year as in most investigations, a period of seven years gives results of comparatively high accuracy. There appears to be an unmistakable relation between changes in the solar and terrestrial atmospheres. The probability of this conclusion is increased by the fact that when the terrestrial area includes not merely the United States, but also the Atlantic Ocean and Europe, the evidence of a relationship becomes much stronger.

Inasmuch as the terrestrial response follows the solar phenomena with a delay of no more than a day or two, the actuating cause can scarcely be heat. It would require far more than a day for a change in solar heat to warm the earth's surface and thereby warm the atmosphere enough to cause pronounced barometric rearrangements. Accordingly there seems ground for believing that Veeder's hitherto neglected hypothesis may be correct. According to that hypothesis cyclonic storms and other periodic barometric variations of the earth's atmosphere are not due to heat alone, but are the coordinate effects of solar heat plus solar electricity. Whether electricity or some other form of energy is the dominating cause is not yet evident, but it seems highly probable that some great factor has thus far escaped attention. If this view is correct it will demand an important reorganization of our theories of meteorology and of climatic changes throughout historical and geological times. The matter is so complex that it requires investigation on a scale far larger than has thus far been possible.

An Ancient Lake Basin on the Mohave River, by E. E. Free.

The Mohave River rises in the San Bernardino Mountain Range, on the southern border of the Mohave Desert, and flows northeastward across this desert to the "sink" of Soda Lake, where its waters now suffer final evaporation. In an earlier period the river was more vigorous and flowed through Soda Lake northward to a junction with the Amargosa River and thence to Death Valley.[1] A recent examination of Soda Lake and of the divide which marks its northern limit has confirmed these conclusions, but indicates that the amount of the overflow discharged by the river into Death Valley was surprisingly small.

The Soda Lake basin is really double, containing not only Soda Lake proper, but also Silver Lake, 10 miles to the north. Both of these "lakes" are playas of usual character. The drainage line beween them is still open and at times of extreme flood Silver Lake is still reached by the waters of the Mohave. Just north of the Silver Lake playa is the divide which now truncates the river. It is a narrow ridge of rock in place and is apparently quite ancient geologically, being far earlier than the period of greater river activity which we are considering. The lowest point of this divide is 32 feet above the present surface of the Silver Lake playa, and that this lowest point determined the overflow of a lake which formerly covered both Soda Lake and Silver Lake is proved by a well-marked beach terrace surrounding the basin at this same elevation. There is also one lower terrace which is

[1]See Huntington, Carnegie Inst. Wash. Year Book for 1915, p. 26.

distinctly marked, and there are doubtful signs of several intermediate and lower ones. Doubtless these were produced by temporary pauses in the recession of the lake.

The channel of the ancient overflow over the Silver Lake divide is clearly marked in the alluvium north of the divide, but is small. In places it is less than 20 feet wide and only 8 to 12 feet deep. Since it is cut in poorly consolidated alluvium and since its grade is ample for extensive alluvial cutting, it is impossible to escape the conclusion that the overflow out of the ancient lake was both small and transient. This is confirmed by the entire absence, so far as discovered, of any sign of stream erosion of the rock portion of the divide. No signs of any alternative overflow channel were discovered, in spite of careful search, and the topography renders it improbable that any such channel exists.

The ancient lake was the sole discharge-point of the ancient Mohave River, and the lake-level must have served as a gage of the river's volume. The fact that the overflow from this lake was so small and transient serves to confirm the conclusions, for which much other evidence is accumulating, that the geologically recent period of lake and river expansion in the North American deserts was neither so humid nor so long-continued as has usually been imagined. It is probable that during most of its existence the Mohave River has not differed greatly from its present character. A period during which it was similar to rivers of the humid regions is not to be thought of. All evidence, however, indicates the reality of the minor climatic pulsations, the existence and importance of which has been emphasized by Huntington.

Underground Structure and Artesian Water in the Desert Valleys of the Great Basin, by E. E. Free.

An incident of the investigations of desert geology and topography during the last ten years has been the accumulation of several hundred records of wells bored in the desert alluvium in search of water or for other practical purposes. Among these are the records of 15 deep holes (500 to 1,200 feet) and over 50 shallower ones which were drilled under my direction. Consideration of this accumulated data, as well as of the physiographic processes now observed to be active on the present surface of the deserts, has led to some generalizations regarding the structure of the underground portions of the desert alluvium, which generalizations are of interest especially in connection with the occurrence of artesian waters in the desert valleys. Such artesian waters have been found in several valleys and under circumstances which indicate considerable differences from the conditions existing in the older artesian areas.

It is necessary to recall the geographic character of the Great Basin as composed of a series of long mountain ranges separated by long and comparatively narrow valleys. These trough-like valleys have been filled deeply with alluvial débris from the erosion of the bordering mountains, and it is from these alluvial deposits that nearly all of the underground waters of the region have been obtained. There being no outward drainage and very few through-flowing streams, the filling of the valleys has been done entirely by local storm-waters and by the small streams of the mountain slopes. By erosion at higher levels and deposition at lower, this process is gradually lowering the mountains and filling the valleys.

The occurrence of artesian and other underground waters in the accumulations of alluvium which fill the valley troughs appears to depend entirely on the existence of buried stream-channels. The streams which descend the mountain slopes and which have brought about the alluvial filling are extremely variable both in volume and in position. As they vary from flood to dryness, and as they migrate back and forth over the slope which they are building, they leave alternate and variable deposits of gravel, sand, and clay. Where a stream is stationary long enough to form a channel this channel will be marked by a line of sand and gravel, and when the stream moves on, floods or other streams may cover the sand-streak of this abandoned channel with finer material, even with clay. In this way there are built into the mass of alluvium many such abandoned stream-channels, all leading from the mountain-slope toward the center of the basin. Since these buried channels are of sandy and gravelly material, they are easily pervious to water. Many come to be sealed above and below by clay or by the desert hardpan called caliche. The dish-shaped or bowl-shaped contour of the valleys gives such buried channels a considerable difference of elevation between the lower end at the basin center and the upper end toward the rock wall. Usually this upper end merges into the talus of gravel and boulders which borders the mountain. It is obvious that this structure may result in artesian conditions. Water which falls as rain on the mountains flows freely through the bordering talus of coarse material and enters the upper ends of the buried channels, which offer it easy passage down the slope. Further down this slope the intercalated clay or caliche beds confine the water of the channels and an artesian pressure is developed.

It is possible to make three deductions of practical value: First, artesian water is to be expected only where this bowl-shaped structure of the alluvial fill occurs. Second, artesian water will not occur necessarily in well-marked strata or at definite depths as it does in rock artesian areas, but may occur at different depths and pressures in adjoining wells, depending upon which of the buried channels may have been penetrated; it is possible even to have entirely dry wells and productive wells side by side. Third, if a valley be divided into concentric zones outward from the center, artesian conditions will be most likely to occur in the intermediate zones. The outer zones will not have sufficient clay or caliche seals to confine successfully the water of the channels. The inner zones will be so far from the mountains that most of the sand-streaks of the buried channels will have pinched out or been choked with clay so that they no longer serve as water conduits.

It must not be imagined that the requirement of bowl-shaped structure in the alluvial beds necessitates that the valley be an inclosed basin without outward drainage. It is true that the necessary structure and the typical artesian conditions are best exhibited in such undrained basins, but the same structure and sufficiently favorable conditions may occur also in open valleys, provided there is enough breadth and depth of alluvial fill to produce the proper contour of the underground beds. The important criterion of artesian occurrence is not inclosure of the drainage, but the slope of the valley and the breadth and flatness of the alluvial fill. In valleys which are steep or narrow the materials of the alluvial deposits are poorly sorted. All of the beds contain much coarse material and are permeable to water both horizontally and vertically. Broad valleys and slopes gentle enough to permit standing or slow-moving water are essential to the collection and deposition of clay, and the deposition of clay layers is essential to the sealing of the buried channels and the production of artesian conditions.

From the considerations outlined in the discussion one can formulate the first necessary condition for the occurrence of artesian water in the desert valleys, namely, the existence of a deep alluvial fill the superposed layers of which have the structure of a shallow bowl, flat or nearly so toward the center. Breaks in the rock wall of this bowl, allowing the escape of surface drainage, are not important, provided the stated condition is satisfied. Since the water, as in all artesian areas, must be provided by rainfall on higher land, this forms another necessary condition. In the desert valleys this means the existence around the valley of fairly high mountains, on which the fall of rain and snow will be considerable and from which the water can drain into the talus slopes and enter the buried channels. These two are the only conditions necessary for artesian occurrence.

If these criteria be applied to the valleys of the Great Basin it is obvious at once that many valleys are too narrow or too steep to have the necessary bowl-shaped structure of the underground beds. Many others have insufficient drainage areas or have watersheds of such low altitude that precipitation upon them is inconsiderable. There are, however, many desert valleys in which the necessary conditions appear to be satisfied. In several of these artesian waters have already been discovered; for instance, in the Salton Basin, California, and in the Carson Sink, the Las Vegas Valley, and Railroad Valley, Nevada. Doubtless water will be discovered in others of the valleys when it is intelligently sought for, and in connection with this search it is possible that the considerations outlined above may prove of practical value as well as of scientific interest.

The Surface of the Painted Desert, by Godfrey Sykes.

A brief reconnaissance has been made in the so-called Painted Desert in Northeastern Arizona, supplementing cursory examinations of the same region made 25 years ago. Superficially there are some points of resemblance between this drainage area and that of the Santa Cruz which render a simultaneous examination of the two desirable. Both consist in the main of broad, open valleys, containing typical desert rivers running from southeast to northwest; both areas are comparatively arid and both are flanked by mountain ranges or high plateaus. The resemblance almost ceases here, however, since, owing to the general sandy and porous nature of the soil in the Painted Desert, eolian influences are far more potent in effecting topographical change than they are in the Santa Cruz Valley, and vegetation is much more scanty and its existence more precarious.

The region is comparatively unexplored scientifically, and should prove a most interesting one for the botanist, zoologist, and eremographer, from the fact that it consists in large part of a series of platforms or terraces, extending parallel with the Little Colorado River and isolated from each other by fairly well-defined cliffs or ramparts, each possessing very distinctive features in soil and topography.

Erosion in the Santa Cruz Valley, by Godfrey Sykes.

During the past season the work of collecting data concerning the physiography of the Santa Cruz drainage area has been carried on. As a type of intermittent desert river the Santa Cruz affords many features of the greatest interest. It has also undoubtedly served as a channel for human intercourse from the earliest times, and since the advent of the Spaniard in the Southwest its importance as such has been very great. At present it is undergoing somewhat extensive changes in the vicinity of Tucson, for it is in effect cutting through the rim of a playa-like basin or bolson, in a temporary effort to render its gradient more even. This effort has far-reaching effects upon vegetation, water-supply, and kindred matters, and is therefore of considerable scientific interest. The examination of the valley in its entirety has been hampered, however, by the chaotic conditions across the Mexican border, as, although rising in Arizona, the river makes a greater detour through the Mexican State of Sonora before assuming its main course towards the northwest.

EQUIPMENT.

The development of facilities for control of temperatures has included the construction of a glass compartment 12 by 20 feet, with an attached work-room, at the Coastal Laboratory. An attached work-room shelters the switchboards and current controls. Darkened chambers for similar purposes have also been equipped in the main building at the Coastal Laboratory and at the Desert Laboratory. These features have already demonstrated their usefulness.

The principal instrumental additions include a set of 12 auxographs designed by the Director for the purpose of recording variations in volume accompanying growth, and for measuring the swelling of colloids.

A food-cage 30 by 60 feet, inclosed with wire netting, has been constructed for growing solanums, to serve as food for the beetles used in Professor Tower's experimental work in evolution. Other changes in the equipment have consisted principally in minor replacements and repairs and minor improvements in machines and apparatus already on hand.

FIELD WORK.

The practical radius of action in the study and connotation of natural conditions has now been extended 60 to 100 miles by improvement in motor transportation. In addition to frequent excursions to such distances, some detached field parties have been sent out during the year. One party, accompanied by Dr. W. T. Hornaday, of the New York Zoological Park, traversed the region southwest of Tucson to the Ajo Mountains and north to Casa Grande in October 1915. A second party went northward through Arizona to the Grand Canyon, eastward to the Painted Desert of the Little Colorado, and southward by two different regions. A westward line was carried across the drainage of the Colorado River, the Mohave Desert, and the Coast Range to Carmel. The region between Tucson and the summit of the Santa Catalina Mountains is covered frequently. Workers at the Desert Laboratory easily visit the points of interest in an area of about 5,000 square miles, and material from this area is readily procurable for experimental purposes.

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