specialty bears some relationship to the navy's varied problems. Then it is suggested that the National Research Council be requested to help select three or four representative men in each specialty who can be appointed with appropriate rank in a naval research reserve. It is proposed to have these reserve officers become acquainted with the navy by inviting them to make short cruises with various units of the fleet. It might also be found desirable to call some of them, at times, to active duty at the Naval Research Laboratory at Bellevue.

It would probably work out that in certain localities there would be a number of research reserve officers who could be brought together as a local body with contact with some local naval activity and that special naval problems could be assigned to such a local group.

The central office of the research organization in the department should maintain contacts with the local groups or individuals, and encourage reports covering scientific developments that might be of interest in any way to the navy. The classifying, correlating and applying of the information received would require considerable talent in the central office, but the results would well justify all the efforts expended.

We have been discussing a senior class of research men, but assistants will also be required who might well be inducted into this reserve during their postgraduate period, and as they become more experienced in their later civilian work be advanced to the senior class.

It is believed that the navy would materially benefit by establishing a certain number of navy research fellowships at representative technical schools. It would be proposed to have the research students holding these fellowships carry out their researches on problems assigned by the navy. It would be desirable to establish these naval fellowships at universities where senior research reserve officers are attached. The student research man would then be able to carry out his assigned work under the guidance and direction of one or more experienced research men who would also be directly interested in the naval problem. The navy would thus obtain important data and information, and at the same time would be providing for the training of research men and providing these men with some idea of navy atmosphere. These research students, after completing their fellowship and obtaining their doctor's degree, would be commissioned in the research reserve.

Individual naval officers, or a naval activity, could profitably be assigned to keep in touch with each university or school where one or more fellowships were maintained so as to afford direct personal naval contact with the work undertaken.

It is possible that the navy might find it desirable to assign, at times, naval officers to university laboratories to work, either independently or in conjunction with members of a research reserve, on special problems. All the large industrial companies have learned by experience that every cent they have spent on research has been returned to them many times over in improvement to their product. It is certain that every cent the navy may spend in fostering this proposed naval research reserve will be the most profitable expenditure made in its efforts to be ready for emergencies.

I am presenting this as an individual naval officer's views. The subject seems to me to be of great importance, and I feel that some such plan as outlined should be actively developed at once. This will require the active support of scientific societies and organizations, as well as that of naval officers.

C. S. McDowell

U. S. Navy

SOME NEW FUNDAMENTALS IN PLANT BIOLOGY, AGRICULTURE AND THE FOOD PROBLEM

The discovery that plants obey a logarithmic law of increase under the action of growth factors was announced by Eilhard Alfred Mitscherlich (Koenigsberg) in 1909. During the twenty years that have now intervened numerous investigators have tested this law both by laboratory experiments and by extensive field experiment and observation in various quarters of the globe. The earlier doubts and criticisms have been swept aside by an immense mass and variety of confirmatory data, and although the voice of skepticism has not been wholly silenced, it may be stated that the opposition has become practically negligible.[1]

It is not too much to characterize the work of Mitscherlich as by far the most important contribution that has been made to agricultural science since Liebig discovered the rôle played by mineral plant

[1] The historical development of the Mitscherlich laws of plant growth is traced mainly in the files of the *Landwirtschaftliche-Jahrbuecher*, the *Landwirtschaftliche-Versuchsstationen* and the *Zeitschrift fuer Pflanzenernaehrung und Duengung*. Readers desiring a condensed view of these laws and their experimental foundations may consult Mitscherlich's "Die Bestimmung des Duengerbedurfnisses des Bodens" (Paul Parey, Berlin). The same logarthmic law of growth was independently discovered by Spillman several years after Mitscherlich. Spillman's book "The Law of Diminishing Returns" (World Book Co., Yonkers, N. Y.) also contains a fair—although now somewhat obsolete—summary of the earlier stages of the development of these laws and the controversies they aroused. A short monograph dealing with the present-day scientific, social and economic implications of Mitscherlich's epochal discovery is in preparation by the writer.

food in the nutrition of vegetable organisms. But Liebig left an unfinished work which none of his immediate followers was able to complete; Mitscherlich has now put the capstone on the structure whose foundations were laid by Liebig and has given to agriculture new fundamental laws of vitalizing clarity. The gift has not been to agriculture alone; the biologist and especially the plant physiologist, the geneticist, the sociologist and the politico-economist may find in it new problems and new view-points of transcendent interest and importance.

The Mitscherlich laws are two in number but they really fuse into one which is mathematically represented by the equation $\frac{dy}{dx} = (A - y) \cdot c$, in which y is the increment of yield due to an increment x of a growth factor that has been placed at the disposal of the plant, A is the maximum yield which this growth factor is capable of producing when its amount is increased to the point where additional amounts thereof are without further effect and c is a constant which is characteristic of the growth factor. When integrated and transformed this equation becomes

$$\log\ (A - y) = \log\ A - c.x.$$

Mitscherlich and those who have followed in his footsteps have sufficiently proved that this equation applies to the yield of any plant growing under the influence of a given growth factor, and appropriate forms of the equation have been derived that represent the action of two or more growth factors in combination. It has also been sufficiently proved that every growth factor has a definite and invariable effect factor or constant, *c;* or, as worded by Mitscherlich: "Within every growth factor there resides a perfectly definite effect factor that is the same under all circumstances whether of soil, of climate, or of cultural conditions; it is even independent of the nature of the plant itself."[2]

This "effect law" of growth factors is the Magna Charta of a new agriculture by which the ancient art of the tiller of the soil may be given the dignity of a real, mathematically regulable science. There is here no room to show how the growing of crops is thus lifted out of the empiricism that has enshrouded agriculture from the beginning; this brief note must be limited to a bald summary of the most important new concepts derived from Mitscherlich's epochal work.

(*a*) *The ultimate limit to the effect of a growth factor.* If in the equation $\log\ (A - y) = \log\ A - c.x$ we put $A = 100$ (*i.e.,* 100 per cent. of a maximum crop), if we give x successively increased numerical values, as 1, 2, 3, etc., and insert the known effect factor c pertaining to a given growth factor, we can calculate the *percentage* values assumed by y as x is indefinitely increased. It will be found that the curves of the values of y asymptotically approach a fixed line, so that when $A = y = 100$ further increments of x do not produce further increases in yield. In other words, a point is reached where x is exerting its maximum effect. This point is determined by the magnitude of the effect factor c, which is an invariable constant. For the three most important mineral plant foods: nitrogen, phosphoric acid and potash, c is respectively 0.122, 0.60 and 0.93. By means of these factors (the mean values of which have been determined by extensive experiment) and the equation $\log\ (A - y) = \log\ A - c.x$ we find that in the limit the effective amounts of the growth factors nitrogen, phosphoric acid and potash are, respectively, about 25, 5 and 3.5 quintals per hectare of land surface.

One of the necessary consequences of the law of the effect of growth factors is that plant growth depends equally on the action of all growth factors. Thus, though a hectare of soil may be supplied with twenty-five quintals of nitrogen maximum growth will not be attained by the plants unless the soil contains the stated amounts of phosphoric acid and potash, as well as maximum amounts of all other growth factors.

(*b*) *The ultimate limit to plant growth.* Because twenty-five quintals of soil nitrogen is the maximum amount of this growth factor which can have any effect in stimulating plant growth in one growth cycle on one hectare of land surface, it necessarily follows that the amount of dry vegetable matter produced in one growth cycle on one hectare can in no case exceed that amount determined by the percentage content of nitrogen found in the dry tissues of the mature plant. Thus, if the percentage of nitrogen in the tissues of the dry plant is 1 per cent., then, if the crop were able to use all the soil nitrogen placed at its disposal, the yield of dry plant substance could in no case exceed that amount of which 25 is 1 per cent., which is 2,500 quintals per hectare.

However, the plants can not resorb all the twenty-five quintals of nitrogen, although these twenty-five

[2] Now that experimental proof of the validity of the Mitscherlich law of effect factors has been abundantly forthcoming it may be seen that the constancy of their effect is a necessary consequence or deduction from two other great natural principles: the old law of diminishing yields from land and the law of the constancy of genotypes. According to the first of these principles the increment of yield from crop plants always diminishes even though steadily increasing increments of the factors of growth are supplied; according to the second principle vegetable organisms make definite and reproducible responses to given combinations of growth factors, *i.e.,* vegetation experiments with a given strain are capable of exact replication. The existence of definite effect factors residing in growth factors is therefore a categorical necessity, and the action of these effect factors must come under a law of diminishing response.

quintals must nevertheless be present in the soil if maximum growth is to be attained. When we examine the yield curve we see that as x increases lineally, y increases asymptotically. The rate of increase conforms to a remarkable rule discovered by Baule, who has proposed to consider as one unit of a growth factor that amount of it which will produce half of the maximum yield (A). Two Baule units will produce, not 100 per cent. of the maximum crop, but only 75 per cent.; three Baule units will produce 87.5 per cent. of the maximum crop, four units 93.25 per cent., etc. The increment of yield produced by the (n+1)th unit is therefore always equal to half of the increment of yield produced by the nth unit; and naturally the consumption of the growth factor by the plant decreases *pari passu* with the decrease in the increment of yield. When this relation is evaluated mathematically from the experimental data we find about 3.6 quintals as the maximum amount of nitrogen which any species of plant can resorb from one hectare of land in one growth cycle. If the tissues of the plant in question contain an average of 1 per cent. of nitrogen the total yield of dry substance can by no possibility exceed 360 quintals per hectare (32, 120 pounds per acre).

Here we have an impassable barrier to extension of the growth power of vegetable organisms. The law of the effect of growth factors has been found to hold for all species of plants which trustworthy investigators have subjected to experiment; it has been found to hold with varieties not in existence when the law was discovered, and it will presumably hold for all new varieties created by the plant breeders or by natural processes of evolution. Why the maximum growth power of plants should thus turn out to be so distinctly a function of the unit area of land surface, and why this function should be basically the same for any and all species of plants are biological mysteries, the unraveling of which may be left to the plant physiologists, the geneticists, the experimental evolutionists, or whoever may best accomplish it.

(*c*) *The varying "calorific duty" of vegetable nitrogen.* The ultimate crop-yielding ability of a plant species is thus inversely proportional to its percentage nitrogen content; *e.g.,* some of the common legumes whose percentage content of nitrogen exceeds 2 per cent. in the dry substance produce far less dry matter per hectare than the sugar-cane, whose percentage of nitrogen is less than 0.1 per cent. Though all plants react by equal *percentages* of yield increase to equal increments of nitrogen applied to the soil, yet these increments of yield may be and are widely different in absolute amounts, and it is thus evident that the nitrogen energized by one species of plant may be more active physiologically in compelling the photosynthesis of non-proteinous matter—cellulose, carbohydrates, fats, etc., than the same amount of nitrogen taken up by another species; the photosynthetic power of a vegetable organism being inversely proportional to its nitrogen content (photosynthetic power being in effect synonymous with growth power) we are entitled to speak of the "calorific duty" of nitrogen as a differential genotypic character of plant species.

Because no plant may resorb more than 3.6 quintals of soil nitrogen per hectare of land surface, what a given species of crop plant does with its allotment of nitrogen becomes a matter of high importance both now and especially in the practical plant genetics of the future, when plant breeders will be faced with the necessity of creating new strains capable of producing more and more food calories per unit area of cultivatable land. In the interest of a constantly increasing population on the earth it devolves on the geneticists and plant breeders to discover whether and how the calorific duty of the nitrogen of food plants may be enlarged.

(*d*) *The concepts: perultra plant, perultimate yield.* The same increment of a growth factor (*e.g.,* nitrogen) always produces the same *percentage* increase in yield, no matter what the species of plant may be. But while the percentage yield increases are thus always identical the ultimate maximum crop (A) on which this percentage is calculated may be and is different for different species. However, in no case can the maximum yield (A) exceed the amount determined by the quotient of 3.6 divided by the percentage nitrogen content of the crop.

We can express this in another way that will perhaps be more immediately intelligible to those who are interested chiefly in the social and politico-economic aspects of the new agriculture. The soil nitrogen resorbed by crop plants is mostly transformed into protein (protoplasm); chemists determine the amount of protein contained in vegetable substances by multiplying their nitrogen contents by an appropriate factor, usually 6.25. If all the 3.6 quintals of nitrogen that may be resorbed by a crop growing on one hectare of land is transformed into protein, then the maximum amount of protein that can be produced on one hectare in one growth cycle is $3.6 \times 6.25 = 22.5$ quintals, equivalent in American units in round figures to 2,000 pounds per acre. A crop plant the genotypic growth power of which is equal to the production of 2,000 pounds of protein per acre has attained the uttermost of ability to energize inorganic nitrogen. Such a plant may be called a *perultra* plant because it has arrived at the *ne plus ultra* of growth efficiency; it is then giving a *perultimate* yield which that plant can not exceed under any of the ordinary circumstances now affecting the growth of plants. Corn (maize) is a plant which is known to have attained this limit in certain varieties. The total amount of nitrogen contained in a corn crop which has yielded at the rate of 225 bushels to the acre corresponds to about 2,000 pounds of protein. If the law of the effect of growth factors is a valid law of nature (as it has all the appearance of being) nobody need ever expect to produce a greater corn crop than this; per contra, the man who produces less is missing something of his privilege. On the other hand there are species of plants, as rye for example, the highest recorded yield of which is far beneath that which corresponds to the perultimate yield of protein; such plants may be called *subultra* plants, their organisms not having the metabolic energy required for reaching the perultra limit.

(*e*) *The concepts: perfertile soil, pressure of satiation.* The plant physiological difference between perultra and subultra plants lies in the different resistances which they offer to the growth-promoting stimulus of the same given amounts of growth factors. In a *perfertile soil* (*i.e.,* a soil which contains all growth factors in maximum amounts) 25 quintals of nitrogen will produce a maximum crop of either corn or rye, but corn, being in some varieties a perultra plant, will resorb more of this nitrogen than the subultra rye; and this disproportion in resorption will persist as the amount of soil nitrogen is reduced below 25 quintals. At *any* content of soil nitrogen rye offers more resistance to the nutritive action of this growth factor; or, otherwise expressed, in soils that are less than perfertile it requires a greater concentration of soil nitrogen to force rye to nourish itself so that it will take up as much nitrogen as corn. To express this idea with technical conciseness we say that plants differ in their "satiation pressures" in respect of growth factors. Perultra plants always have the minimum satiation pressure, which in the case of nitrogen is represented numerically by the ratio of the maximum effective amount of soil nitrogen to the amount resorbed under the influence of this maximum amount, that is to say, by the expression $\frac{25}{3.6} = 7$. "It takes the whole power of the 25 quintals to drive the 3.6 quintals into the perultra organism"; the smaller the external pressure of the growth factor the smaller the amount of it which is resorbed. In the limit perultra plants always have the lowest satiation pressure, which means that the satiation pressures of subultra plants are always greater than 7, being the greater the more the subultra plant lacks of metabolic energy required to attain the perultra limit.

(*f*) *The goal of crop-plant breeding.* In the existence of perultra plants and the apparent possibility of converting subultra into perultra species there lies a circumstance of vast significance, and a golden opportunity for creative work in practical genetics and plant breeding. Heretofore plant breeders (creators of new strains) have been working in ignorance of the wide margin within which they may seek to create new varieties of high and higher yielding power. The law of the effect of growth factors draws back the veil and discloses the distant goal which the plant breeder may yet reach in the service of humanity. The law declares that nature permits and even invites the plant breeder to take subultra species and breed them up to the perultra limit. By accident rather than design this has been done in a few cases, as with corn and the sugar-cane, although the great majority of growers both of corn and sugar-cane are still cultivating inferior subultra strains of these two crop plants. The most solid achievement (though also an accident) in the life work of the late Luther Burbank was the creation of a strain of potato that is now achieving yields corresponding to about 80 per cent. of the calculated perultimate limit, which is about 1,330 bushels per acre. Perhaps the most interesting example of a subultra plant that is being lifted out of the subultra class by intelligent and persistent breeding is afforded by the sugar beet; since the year 1900 the genotypic growth power of this crop plant has been enlarged 250 per cent., and if the beet breeders maintain for another dozen years the same rate of progress as they have marked in the past six years they will have definitely graduated the sugar beet into the perultra class. How many of the existing species of subultra crop plants are capable of being thus evolved under the hand of man remains to be seen, but their number is surely not a few.

(*g*) *The limit ratio of population to area of cultivatable land.* The human organism must consume a certain daily minimum amount of protein. We now know the maximum amount of protein that can ever be (directly) produced on an acre of arable land; if we know the minimum amount of protein that will suffice to sustain an average person we can determine the maximum number of persons that can be directly nourished on the produce of one acre. If we know the number of acres available for growing crops in a given region we can calculate with an assurance of finality the limit density of population in that region for the case that only perultra plants are grown and that the *known* means of causing these efficient organisms to give perultimate yields are put into effect. The law of the effect of growth factors thus opens the way to a definitive clarification of the

Malthusian problem, in so far as this problem depends on the ability of the soil to produce food. How this great new law of nature bears on the question of when the earth will become saturated with population is more extensively discussed by the writer in another place.

(*h*) *A theory of the perultimate limit to plant growth.* The existence of a common perultimate limit to the effect of growth factors and to the growth power of all plants is a circumstance striking enough to warrant an attempt to picture the underlying reason. At the present time explanation can be little more than surmise and hypothesis, but certain facts are known which furnish hints.

One likely hypothesis is suggested by the work of Stoklasa, who has apparently found that the growth power of plants is increased (*i.e.,* their pressures of satiation lowered) by exposing them to radiations from low grade Joachimsthal ores. These radioactive materials evidently create a field of force or of influence about the growing plants which acts to intensify their vital activities. But Stoklasa's field may very well be regarded as a secondary or supplemental field superposed on an original primary field of the same general kind; this primary field may be supposed to be due to a particular category of radiations which reach the earth from outer space, or they may come from the interior of the earth itself. The facts of plant growth indicate that this primary field has a certain finite intensity and thus does not supply energy or stimulus beyond a certain limit, this limit determining the perultimate limit to the amount of active protoplasm which may be formed or activated in a unit of space, or, as we may now say, in a unit field of influence. When, however, the primary field is reinforced by congruent radiations, as appears to be the case in Stoklasa's experiments, the total strength of the field is increased and the original perultimate limit on growth power is correspondingly displaced.

So much for the suppositive prime factor in the limitation on plant growth; the mechanism of the action of this prime factor remains to be accounted for. Certain hints in this direction are found in the work of the Java sugar-cane breeders whose spectacular achievements have so greatly upset the contemporary sugar trade. When a superior new variety of sugar-cane is created by cross-breeding it is found that the individual cells of the more vigorous variety are larger than corresponding cells of the less vigorous strains from which the newcomer was derived (Bremer). This will explain the existence of differences in the satiation pressures of varieties of the same species which differ in growth powers, for obviously at equal osmotic pressures a certain number of large cells may contain a greater aggregate quantity of dissolved substances than the same number of small cells of the same kind, *i.e.,* the former are able to draw more extensively than the latter on a given supply of soil nutrients without increasing the normal concentration of their cell liquids. Satiation pressure is, therefore, to some extent at least, an inverse function of cell size. The same relative lowering of the satiation pressures of the more productive new varieties would also occur if the size of the cells remained the same but their number increased relatively to the number of cells in the less productive; or increases in both number and size of cells might occur simultaneously.

The Java cane breeders have also noted that valuable new varieties are obtained from combinations which result in certain definite changes in the number of the chromosomes of the new variety. Growth power of varieties within a species is therefore also a function or an accompaniment of a particular sort of chromosome complex.

From these materials we may construct the following tentative hypothesis to account for the creation of more vigorously growing new varieties: The crossing of two different strains (particularly if the species is originally highly bastardized, like the sugar-cane) results in a certain new combination of chromosomes. There are reasons for supposing that chromosomes are intimately concerned in vital processes, and they may be supposed to constitute or to characterize a system which "tunes in" more or less accurately with the primary field or fields of influence which we have already supposed to supply the governing stimulus to plant growth. If the tuning in is perfect, then the size of the cells or their number, or both size and number, are adjusted to conform to the perultimate limit on growth, and the new variety is perultra. If the tuning in is imperfect, the full strength of the field can not be utilized and the new variety is subultra.

O. W. WILLCOX

RIDGEWOOD, NEW JERSEY

SCIENTIFIC EVENTS

A BIOLOGICAL STUDY OF NERITIC WATERS IN THE GULF OF MAINE

OVER a period of more than ten years oceanological investigations have been carried on in the Gulf of Maine and adjacent waters by Dr. H. B. Bigelow and the combined results have been published in three comprehensive monographs. These excellent reports cover very well the adult fish fauna of the gulf and the general biological and physical conditions in the offshore waters.