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PHYTOMETRIC CHARACTERIZATIONS OF PLANT CULTURES IN MATHEMATICAL AND PHYSICAL MODELS OF SOIL PROTECTION FROM DEFLATION

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In the recent decade we notice the mathematization of agricultural sciences. The infiltration of mathematical methods directly into agricultural production at all its stages (drafting, planning, administration) is, in our opinion, determined first of all by the transition to industrial methods of agricultural production and by the transformation of agricultural sciences from descriptive into sciences basing on quantitative regularities. This in turn causes the increase of interest in numerical descriptions of plant and plant cultures, and primarily in the numerical characterizations of their physical properties.

In the second half of 20th century in all countries we observe a rapid growth of the scale and a change of the character of the active influence of man on the surrounding environment. In agriculture this process finds expression in the introduction of intensive cultivation methods, which unavoidably led to dynamic changes in the system soil — near to soil layer of air. In some cases these changes caused negative results following from the consumption attitude of the farmer to nature. In many countries (like in the USA, Canada, USSR, India, and others) the problem of protecting soil from damage became perticularly acute.

The so far undertaken attempts at fighting the soil deflation on the basis of purely empirical approach did not give the expected results. At the same time investigations were carried out on the protection of soil through ceasing to cultivate soil by overturning furrows (i.e. by leaving stubble fields), through the planting of plant stripes, through introducing stripe cultivation (i.e. a successive occurence of fields with high-stem plants and cultivable fields), through the chemical strengthening of soil aggregates. Often the empirical approach led to a situation where the application of some protective measures caused the exclusion of areas of productive soils from the direct agricultural production. In agricultural practice there appeared a new technology of cultivating plants on soils endangered with deflation. This technology is called the soil protection technology. Up to the present times the technology is based only on experimental data, and that is why it is far from optimal.

In order to optimize this technological process and to bring down to minimum the qualitative and quantitative losses at its application, the task of creating a physical and a mathematical models of soil deflation and of the anti-deflation measures was set up. As I mentioned above, the main medium in the anti-deflation measures were plants and their after-harvest remains. That is why there appeared the necessity to determine new, not investigated earier, phytometric parameters of plants and plant cultures.

Mathematical models of the above mentioned type have been worked out in the USSR. I will not describe them in detail, since they have been published. As an instance I can mention a mathematical model describing the mutual interrelationships of air stream close to the ground and the permeable plant layer of limited dimentions, i.e. when we consider a certain stripe of field, and not a whole field. In these relationships I would like to point out two coeffiecients C_f and S. These physical characteristics of plant cultures should be determined in natural field experiments, or, if possible, in model investigations. The value C_f is the coefficient of aerodynamic resistance of plant culture. The value S is the specific surface of the contact of plant culture with air stream flowing round this plant culture. The value S is at present the object of interest of specialists dealing with the problems of photosynthesis in relation to obtaining programmed crop yields, and of selectioners in relation to obtaining the optimim plant architecture. However, there are few good methods, and even less good apparati, for rapid experimental determination of S in field and laboratory conditions. Moreover their measuring accuracy is low, of the order of 25%.

The problems involved in an accurate quantitative description of the plant culture architecture are determined by the high variability of parameters even within one species, and the more so in multi-species plant cultures. That is why it seems that even the application of methods of mathematical statistics will not allow for precise description of all the actual features of the object.

What is interesting in the problem in question is not the phytometric characterization of a single plant but the phytometic characterization of plant culture, obtained through the phytometry of single plant, which is called model. As an instance I will discuss the routine of choosing such a model plant from a plant culture. I would like to stress that in the choice of the routine we tried to avoid damaging the investigated plant culture as much as possible. First of all we assumed that at all the complexity of the architecture and the variability in the build-up of the chosen plants, it is possible to utilize the approach and methods of the optics of dim media and bodies for plant cultures. This assumtion seems to be justified by the fact that every plant culture is subject to the laws of probability. On the basis of methodological considerations a phytometric and quantitative description of plant culture should be made in four stages: the particular parts of plant, whole plant, a single-species group, plant culture. In this way every subsequent stage will include the preceding one, but is not simple a combination of elements of the preceding stage, it has its own specific relationships.

The routine discussed concerned the process of phytometry. The first stage of the routine comprised: the determination of the number of sample fields, the size of one sample field, the calculation of the total number of plants in each field with the measuring of the value of diameter d at a certain height h different for different varieties of plants, the calculation of the mean value of the diameter for each variety. Then, with the help of special tables, the diameter of the main stem of model plant is found, the number of model plants for each variety that are to be subjected to further observation is calculated, for every sample field plants are chosen whose mean diameters of the main stems at a certain height are approximately equal to that of the model plant.

The second stage requires phytometric measurements for model plants only: the height, diameter, height of stems to the beginning of foliage, the calculation from these measurements the coefficient of shape of the stem, the surface area of the stem, the specific surface of the stem up to foliage. According to these data parameters for the mean model plants from model plants are calculated, mean model plants are chosen from the point of their parameters being approximately equal with the parameters of the mean model plants, the coefficient of shape is calculated for the stem of the mean model plant, and the specific surface of stems of all plants to their foliage is calculated.

The third stage requires the determination of the model branch from the branches of the model plant, separately for the branches of the levels I, II and III, and the radius at the beginning of the branch and the length of the branch are measured. The parameters of this branch are calculated and a model branch of mean values of the radius and length is determined. Then the surface of the model branch is calculated. The remaining operations are analogous to those of the two preceding stages.

The fourth stage requires the determination of the value of surface of all leaves on the model branch of each level, the summary surface of leaves of the whole model plant, and finally the total model surface of foliage.

If the calculation of the surface of stems is a not very labour consuming operation, the calculation of the surface of foliage particularly for cultures of such plants as for instance charlock is so difficult that without a certain mechanization and automation of the process it is almost impossible. As is proved by our experiment the regularity of the diameters of stems is relatively high, and, moreover, with an error not higher than 8—12% the value of stem surfaces correlates with their diameters. That is why it is possible to compile appropriate tables for every species of plants included in the plant cultures under discussion.

The determination of the surface of leaves can be carried out with one of the five methods:

1) the method of drawing,
2) the method of comparisons,
3) the method of calculations,
4) the wight method,
5. the method of automatic planimetring.

The enumerated methods are described in detail in mnographs concerning phytometry.

I would like to present a worked out in our country method of automatized decyphering of the complex interferograms for the calculation of the surface of leaves of complex shapes. For the automatic determination of the surface area of the investigated objects usually micropfytimeters with electronic scanning equipment and electromechanical systems are used. Both types of systems ensure the accuracy of the measurement of contours of surface of the order of 10%. In our method the scanning element is the stream of electrones of TV camera. This allows, first, to increase three times the speed of the co-ordinates of contours, and, second, it is easy to introduce preliminary information into a computer, where its processing takes place. In order to diminish the amount of information input to the computer, two levels of lightness are determined:

level of blackness — 0,

level of whitness — 1.

This allows for the obtaining of the measurement accuracy of the leaves contours of the order of 3.5—4%. The measurement method (for natural objects) consists in

— the object is projected on to the screen of TV camera in such a way that the picture of the object covers m lines vertically and n columns horizontally,

— every point in time is doubled by a tension impuls, the amplitude of which is in proportion to the amplitude of light signal, which is the function of lightning in a given point,

— the impulses are introduced into a system realizing their computation during the transition of one frame of TV picture; full description of the co-ordinates of the object is made during the transition of n frames,

— the impulses are formed so that they are appropriate for their introduction into a computer.

The apparatus realization of this method can be done in different ways. The measuring of the surface of leaves with the help of a lamp giving 120 levels of blackness and whiteness, and the calculation of 254 points from each line will ensure the accuracy of the determination of the co-ordinates of contours of the order of 3.5—4%.

Another parameter of plant culture the knowledge of which is necessary for the numerical realization of the mathematical measure is the coefficient of the aerodynamic resistance of plant culture C_f. The C_f coefficient can be determined in field measurements, and, with a known approximation, on models in laboratory aerodynamic tunnels. In both cases simple direct measurements of C_f are impossible. The value of C_f is calculated from the following relation

$$C_r = \frac{2\,\Delta H}{\rho\,\overline{W}_o^{2}}$$

where H is the drop of pressure of air stream at its passage through a plant environment of the density ρ at a mean speed $\overline{W}$.

The task of the experimentator is the determination of the full pressure at the entrance into the plant culture

$$P_{n1} = \int_{y_o}^{y_k} P_{n1y} dy$$

and at the exit from it

$$P_{n2} = \int_{y_o}^{y_k} P_{n2y} dy$$

There are three difficulties. First — the intersection behind the plant culture, i.e. the intersection in which occurs the joining of the separated turbulent air streams should be properly methodically chosen. Second — in field conditions the wind stream pulsates, and its speed changes differently in different points. Third — measurement of the distribution of full pressures $P_n(y)$ before and behind the plant culture should be carried out simultaneously. Only if the above difficulties are dealt with properly from the point of methodology it is possible to increase the accuracy of the measurement of C_f. We should also stress the point that for plant cultures C_f is a function of the absolute value of speed in ranges determined by the physical properties of single plants forming the culture, by the density of the plants, by the number and the degree of development of the surface of leaves.

$$C_f = C_f\,(W, S).$$

We have worked out theoretically the possibility of determining the value of the aerodynamic resistance with the avoidance of the enumerated difficulties. The following physical model of plant culture is considered: air stream moving through a plant obstacle is heterogenous, but at an adequately long distance behind it there occurs the unifying of the turbulent streams as a result of the influence of the field surface.

In this way, if in the second intersection we find a certain parameter determining the energy state of the stream and connect it with functional dependencies to the size and density of the plant cover and to the roughness state of the field surface there is the possibility of measuring this parameter in only one intersection and only at a certain distance from the second intersection along the stream. We proved theoretically the existence of such a parameter and we have determined it. It is the so called layer of losses of air stream impulses, described by a relation of the type

$$\sigma^{**} = \int_0^y \frac{v}{v_\infty}\left(1 - \frac{v}{v_\infty}\right) dy$$

where v_∞ — the speed of wind at the height of 10—12 m,
v — the speed of stream in the intersections in the direction Y.

The relation between the coefficient of resistance of plant culture C_f and the layer of losses of impulses has the form

$$Cf = 2\left(\frac{v_h}{v_y}\right)^{3,2}\left(\frac{v_y}{v_\infty}\right)^{0.2}\frac{\sigma^{**}}{C}$$

here
v_h — the speed at the height h of plant culture in the intersection 2,
v_y — mean speed in the measured intersection in the direction y,
v_∞ – speed of wind at the height of 10—12 m,
C — the geometrical parameter of the plant culture.

In this way it is possible to determine the value C_f at the restriction to the measurement of the profile of wind speed in one intersection behind the plant culture. Correlation between the layer of losses of impulses and the construction properties of various plant cultures can be presented in the form of diagram. Such a diagram can be composed of results of field measurements.

The presented method shows also a sufficient accuracy of the applicability of measurements of the resistance coefficient made for model plant cultures in aerodynamic tunnels for natural objects. I hope that my report will attract the attention of specialists dealing with the physical properties of plants in the direction of working out apparati and methods for the determination of the resistance coefficient of plant cultures. At present the architecture of plant cultures is being widely utilized not only for the purposes of soil protection from deflation, but also for the storing of snow in fields and for the protection of irrigated areas from being covered with sand in regions of frequent sand and silt storms.

Methods of calculating such protective systems are already worked out, but they can be utilized only in the case when the physical parameters I mentioned in my report are known.

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