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MODEL STUDIES ON ACTUAL AND POTENTIAL HERBAGE PRODUCTION IN ARID REGIONS

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SUMMARY

Simulation models and techniques are being developed that enable the practical application of research in crop science, plant physiology, soil science and agrometeorology for the solution of primary production problems in arid and semi-arid regions. Procedures are being evaluated by means of experiments with natural vegetation and crops in the northern Negev.

Evaluated models are available for :

— the growth and water use of crops with water and nutrients non-limiting,

— the growth and water use of natural grassland vegetation and grain crops with nutrients non-limiting and water limiting,

— storage, leaching and evaporation of rainwater in or from soils, fully or partly covered with vegetation.

Simulation models are being evaluated for :

— the nitrogen uptake and translocation in annual grass species,

— the nitrogen supply, leaching and recycling on grazed pastures.

Sample techniques for the determination of crop growth and standing vegetation were developed; the tritium dilution technique for determining the dry matter intake by sheep was thoroughly evaluated and improved; and sample methods to determine plant species parameters that govern their water use efficiency and their competitive ability were applied.

Recently, considerable attention has been given to methods of assessment of leguminous species.

AIMS

Insight into the processes that govern crop growth has been improved during the last 15 years to such an extent that it is now possible to make a reasonable assessment of the production capabilities of arable crops and pastures under varying circumstances, especially those found in the developed countries, where large production per unit surface is achieved or at least aimed at. This knowledge has not been widely applied under more marginal conditions, as for example in those arid regions with erratic rainfall on average of 250 mm (winter) to 500 mm (summer) per year.

Recognising the growing problems in these arid regions, where animal husbandry is the main system of production, in 1970 the Dutch Minister for International Development contacted some research workers in the Netherlands and Israel. He requested them to adapt existing methods and to develop new ones to assess how herbage production in arid regions is dependent on weather, soil conditions and kind of plant cover.

The actual plan was based on work in progress on the simulation of potential production and transpiration of crop surfaces and of transport processes of water, solutes and heat in the soil; and on the nitrogen behaviour in the soil on the one hand, and the experience with primary production of natural animal pastures and their exploitation by sheep in the northern Negev on the other.

The emphasis on marginal conditions made it necessary to develop models of the water balance of the soil and to relate plant growth to water uptake. The effect of limiting nutrients involved a special study of the soil nitrogen balance and the development of models to quantify the influence of the nitrogen supply on the growth of annual species.

For the validation of the models in the field it was necessary to develop practical and applicable methods to characterise physiological plant properties that are of ecological importance, methods of

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growth estimation and determination, and methods to determine the herbage intake of grazing animals.

Although the experimental area was an arid zone with winter rains, the models and techniques had to be applicable to regions with summer rains, and hence considerable attention was paid to crop growth in summer, necessarily under (sprinkler) irrigated conditions. The aim was to restrict the input data on weather, soil and plant species to such an extent that after two years of study in a new region, reasonable estimates could be made of the level and yearly fluctuations of the primary herbage production of dry matter and protein. The emphasis being on primary production, the study of the interface with the animal was restricted to the recycling of nitrogen and the influence of grazing on production and water use during the growth of the crop. This restriction in the first phase of the project was considered justified because primary production aspects are so often neglected.

RESULTS

The so-called "basic crop simulator" for the evaluation of potential production and transpiration was further developed in Wageningen. In Israel it was evaluated in particular against the growth of Rhodes grass, one of the highest-yielding grass species available in the arid regions. Relatively little adaptation was necessary to simulate the closed crop growth and transpiration. Special emphasis was given to regrowth after cutting at various intervals and root growth and decay as a necessary sink for photosynthesis products.

The program has progressed to such a stage that it may be used with confidence to predict the yield potential of grasses in arid regions under optimal conditions, which may range up to 300 kg dry matter/ha/day. Where irrigation and fertilisation are practised, the results are used as a yardstick for actual achievement and for determination of causes of yield constraints. It is not visualized that within the arid regions, large potential yields are a justified goal, but within the whole grazing and marketing system there may be scope for fattening stations where large yields per unit area are desirable, and irrigation and fertilisation are practiced. The program is being extended also to simulate the potential yield of alfalfa.

In addition, the same program forms the basis for determining the water use efficiency of plants as dependent on the weather. This water use efficiency is used in simulation programs that establish the growth of natural vegetation and crops growing under rainfed conditions, but sufficiently supplied with nutrients. The yield under these conditions is highly dependent on the amount of rainfall and its distribution, the physical properties of the soil, and the weather during the different stages of growth. The actual yield may vary two-to three-fold in spite of the same rainfall, because of the varying fraction of water that is dissipated through the plant and contributes as such to the production.

Both practice and theory confirm that the potential growth rate of annual grassland species is as high as that of cultivated species during periods in which water and nutrients happen to be available, and therefore yield potential as such does not demand the introduction of so-called improved species, especially since the natural annual species start to form ripe seeds within a month after germination, which may safeguard the following year's crop.

It appears that under good nutritional conditions in the Negev, yields of 6,000 kg/ha dry matter may be obtained with a rainfall of only 250 mm during the winter season.

Simulated results in the Sahelian regions (c.f. Penning de Vries' paper, this seminar) provide a less promising picture because the water use efficiency of plants is much lower in regions with summer rainfall, more water is lost by soil evaporation, and sandy soils retain less water than the deep lœssian soils of the Negev. At least these latter soils retain all the water within a possible rooting zone of 2 meters, so that there is no deep drainage and water can only dissipate by evaporation from the top soil and by transpiration. Neutron probe measurements of soil water content throughout the season have shown that water loss occurs at practically the same rate under good and bad nutritional conditions. The production in the latter case may, however, be several times lower because of the poor water use efficiency of starved vegetation.

Because of the high storage capacity of the soil, small germination densities do not lead to water loss by drainage but only to delayed water use and growth. It is speculated that low germination densities on shallow, sandy Sahelian soils with an annual vegetation may lead to deep drainage of water, less growth, larger grazing pressure in summer and less seed for the next year, and thus on to disastrous ends. However, it must be said that the problem of seed dispersal and germination has been elusive up to now. Especially in years with low rainfall, several germination flushes occur and a considerable fraction of the water may be lost by evaporation. It appears then that the yield is considerably improved by soil heterogeneity, which stimulates local run on/run off. Heterogeneity is in general yield-improving, although frustrating during experimentation.

A good nitrogen status of the soil is most easily obtained by means of nitrogen fertilizer; since anaerobic conditions seldom occur, the nitrate only disappears from the soil through the plant, that is, if the soil is deep enough to prevent leaching. Nitrate not taken up this year because of a lack of water remains for the next, but this is little comfort in situations when nitrogen fertilizers in whatever form are likely to be far too expensive. The natural supply of nitrogen for grass vegetation is through rain and free-living, nitrogen-fixing bacteria, which seem to contribute in total about 12 kg N per ha per year. The recycling of N through urine is negligible because of volatization; and that through faeces is small because of volatization, irreversible drying and the absence of an active soil fauna.

The erratically occurring natural leguminous species were rhizobium infested, contained relatively large amounts of N, and could comprise up to 50 per cent of the plant cover. The Australian experience with sown legume grass mixtures is restricted to arid regions with relatively larger amounts of rainfall. However, the practice penetrates to regions with lower rainfall, interestingly enough through the introduction of species out of the Sahelian zone (e.g. *Stylosanthus fructicosa* from the Sudanian 350 mm rainfall zone).

A serious problem is that leguminous species suffer from competition with grasses that are the beneficiaries of the better nitrogen status of the soil created by the legumes themselves. Techniques of quantifying competitive interference of naturally occurring species were successfully applied in the Negev pastures, and methods are being further developed to evaluate the combining ability of species. Legumes are perhaps the only practical means of improving the nitrogen status of natural pastures in the Sahelian zone, and in any program on the improvement of primary production, considerable effort should be put into this area.

Programs for the simulation of the nitrogen balance of the soil that consider the details of microbiological processes are being developed in Wageningen. In Israel, methods have been developed that are based on a yearly accounting.

A combination of this latter model, a model on the uptake and redistribution of nitrogen in annual grass species, and the model on water use under limited rainfall forms the basis for a program of crop growth under conditions where both water and nitrogen may be limited during the season. This model is still in the developing, speculative phase.

CONCLUDING REMARKS

A most promising way to develop new grazing systems and to modify existing ways of life seems to lie in systems analysis followed by a model synthesis that covers the whole field of primary production, grazing, animal production, herd management and marketing. Our experience with but a small part of the problem shows that only thorough attempts in which scientific analyses and field experimentation are closely linked can lead to truthworthy results, and that quick results, however attractive on first sight, may be very costly in the long run.

This birds' eye view refers to the joint effort of a group of research workers, each of whom contributed in his own field of interest. Without mentioning everyone, there are in Wageningen Th. Alberta, H. Lof, S. Sibma, (IBS), H. van Keulen, F.W.T. Penning de Vries, J. Goudriaan and C.T. de Wit (Agr. Un.); and in Israel, E. Dayan, A. Dovrat, Y. Harpaz, N. Tadmor (+) (Hebrew University), R. Benjamin and N. Seligman (Volcani Institute). Their reports will be made available and summarized in the course of 1975.