Introduction. What is the relationship between production of agricultural and non-agricultural vegetation?

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INTRODUCTION

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This publication reports the results of a workshop held at the Institute of Mediterranean Agronomy of Zaragoza, Spain in the Winter of 1984. The workshop was co-sponsored by the Institute and the International Association for Ecology (INTECOL). Its purpose was to examine the relationship between production of natural vegetation and agricultural crops. Two questions were addressed by the participants. First, can the rate of net primary production of agricultural ecosystems be predicted from the rate of net primary production of mature, natural vegetation growing on the same site? And second, since agricultural production is a variable depending upon the levels of inputs, if one subtracts the costs of inputs to production and the costs resulting from increasing the production (from erosion, etc.) will the remainder equal, be less than, or more than the natural production rate? The motivation for asking these questions was to determine if rural planners can establish base lines of expected production levels for a region which could be used as goals or as design criteria for planning. Such criteria could be applied in the post graduate course on Rural Planning and the Environment taught at the Institute of Mediterranean Agronomy each year.

DEFINITIONS

Organic production is an important property of ecosystems and has a variety of definitions. For example, the fixation of carbon through the process of photosynthesis and the subsequent construction of organic molecules containing carbon and other elements provide the fundamental basis for all other production factors. This production quantity is called the *Gross Primary Production* when it refers to all the vegetation at a site composed of a variety of plant parts, and often plant species, interacting together in space and time. The plant tissues utilize some of the gross primary production for their metabolism. When these metabolic costs are subtracted from the gross primary production, the remainder is that available for growth and storage processes in the plant and is called the *Net Primary Production or NPP.*

Agriculturalists are especially interested in the net primary production that is stored in plant parts of the plant species important to humans. The production of these parts (for example, grain or tubers), is termed *Yield.*

Vegetation is one component of an ecosystem. Net primary production provides the energy and materials required for other ecosystem components and also is stored as organic matter within the ecosystem. However, not all net primary production is used or stored. Sometimes organic material is exported to other systems. This is true for yield sent to markets and for organic matter leached into ground water or lost to rivers. Exported organic material from an ecosystem is termed *Net Ecosystem Production.* Net ecosystem production links the ecosystem of interest to other ecosystems in the landscape.

PATTERNS OF ORGANIC PRODUCTION

Organic production may be viewed in the context of a hierarchy of agroecological systems. In this workshop systems from the leaf to the earth were considered. It is the leaf system where light energy is converted to chemical energy through the process of photosynthesis which forms the basis of organic production. At the global level the markets, world transport systems, and political systems also influence food production and distribution Between the leaf and the globe are a variety of nested systems such as the crop plant system, the field agroecosystem, the farm system, and regional systems, all of which should be considered in production studies.

Each system level behaves according to general system principles (discussed in the summary by Margalef, and by Miller, 1978; Odum, 1983), as well as to those principles appropriate to it specifically. One general feature of these systems involves their input-output relationships. Production is a system output which results from sunlight, water, nutrients and, for agricultural systems, a large array of cultural, social, economic, and political factors which control what and how much is produced at any given place and time. Mismanagement of these inputs can disturb the system, make it less resilient, and create additional outputs of soil, water, organic material, and pollutants. Correction of mismanagement requires additional inputs which ultimately are paid from the increased yield. The linkage between production outputs and inputs are frequently not clear in agroecology and provide a special challenge for research.

Thinking within this concept of a nested set of agroecological systems, we can visualize a hypothetical scale of net primary production values which ranges from zero to some maximum. The maximum possible net primary production is set by the rate of carbon fixation under non-limiting conditions. On the assumption that leaves absorb 80 % of incident light, chlorophyll uses the light with an efficiency of 20 %, and 40 % of the fixed carbon is used by the plant in metabolism, the maximum rate of net primary production might be about 40 g m^{-2}. day. This maximum daily rate multiplied by 365 days estimates a maximum annual rate of 14,600 g m^{-2}.yr, or 146 mt ha^{-1}.yr.

This number is purely hypothetical and there are other possible estimates.① The location of the actual rate of production on the scale depends on the environmental and managerial inputs and the plant species. For example, Lieth (1975) estimated that the mean global rate of net primary production of natural vegetation is 700 g m^{-2}.yr, or 7 mt ha^{-1} and the maximum rate is about 40 mt ha^{-1}. yr.

In this report H. Lieth and P. Buringh will present further information to show that rates of production are variables which depend on the system inputs. Lieth shows that where inputs were relatively predictable, as for climate and soils, the spectra of production rates are equally predictable. In contrast, Buringh emphasizes that agricultural production is variable depending upon changes in the inputs. In many studies of global production (for example, Lieth & Whittaker, 1975) the levels of production are reported as the mean rates and as ranges of rates within biogeographic regions of the earth. In this report Ryszkowski compares rates of production of forest, grassland and cropland in the North temperate regions in a different way by presenting frequency distributions of production. These distributions illustrate the patterns of variation and suggest that the rate for the three types of production systems are similar within this region. In contrast, if we examine the frequency distribution of above-ground net primary production on a global scale (Figure 1) we find a complex pattern, which can probably be resolved into two distributions, one representing forests with a mode at about 8 mt ha^{-1}. yr^{-1} and the other non-forests with a production rate about 2 mt ha^{-1}. yr^{-1}. A distribution calculated for total net primary production shows a similar pattern but less clearly because of many fewer records.

① For example, Margalef would prefer that I state that there is a maximum concentration of active chlorophyll due to autoabsorbtion of about 400 mg m^{-3}; under these conditions chlorophyll fixes about 3.5 g c per chlorophyll per hour. Production would then be 158 g C per day or 5000 g C.m^{-2}. yr or 100 metric tons organic matter ha^{-1} yr.

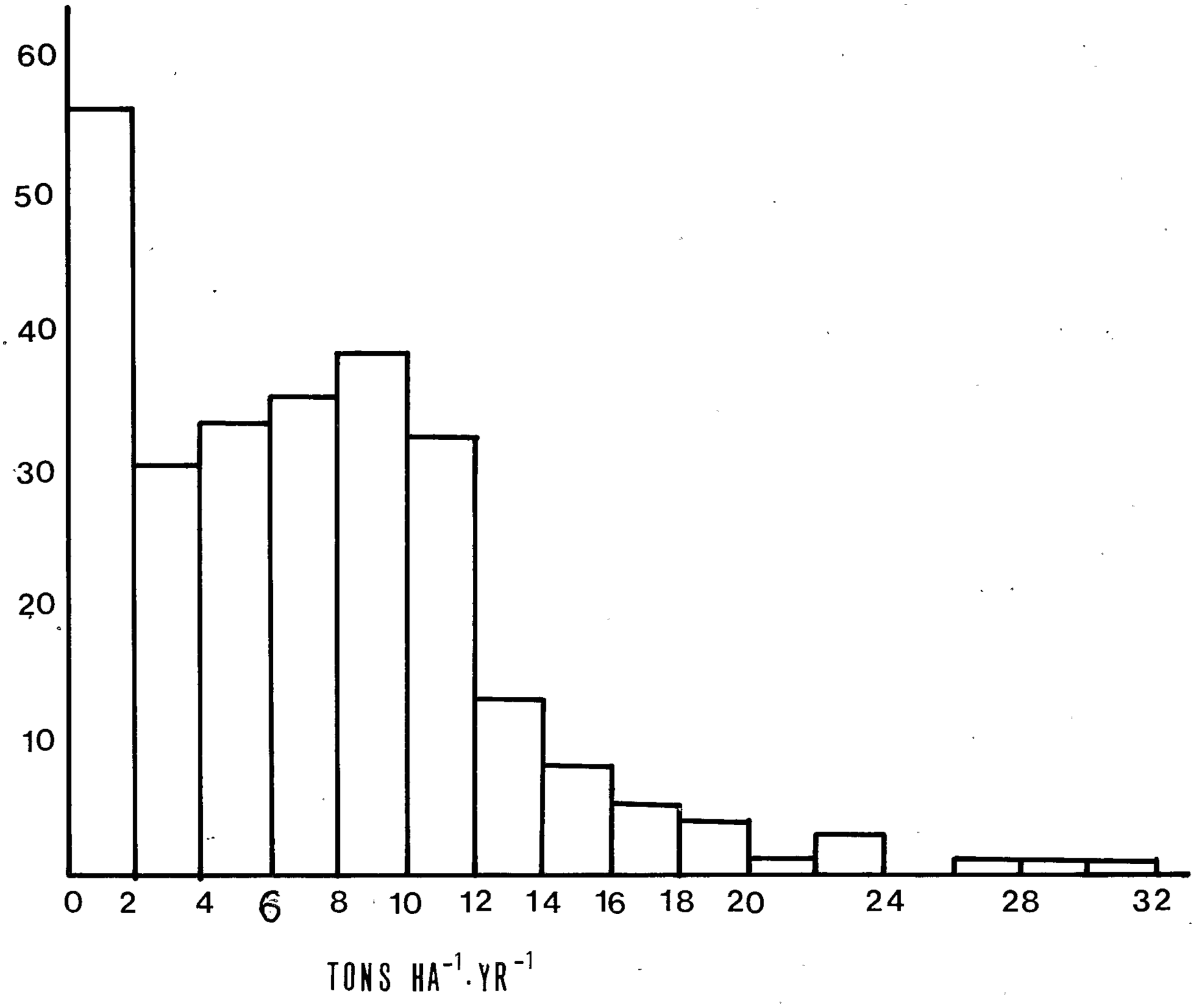

Figure 1. Frequency distribution of net primary above-ground production of natural vegetation, in tons per hectare per year. The distribution is based on 264 cases representing tundra, desert, grassland, and forests from Rodin & Bazilevitch (1965), Singh et al. *(1980), and Cannell (1982).*

These two observations suggest to me a way to resolve our first question. On a global scale production appears to be regulated by climate. Low temperatures or lack of water prevent development of forest vegetation. Where forests can grow their production rates are higher for a variety of reasons, including their ability to place the leaves over a broader vertical space, their ability to create more moderate climatic conditions, and their capacity to store essential nutrients. Thus, the division of production into biogeographic regions is reasonable. Within a region other factors, such as soil fertility, create different conditions for production so that the range of rates is wide, as Ryszkowski has shown, but the modal rates are similar for different kinds of vegetation unless conditions are extreme. The key factors, once the vegetation has displayed an optimum quantity of chlorophyll to absorb most of the incident light, is probably the number of days in which the temperature and water are not limiting to photosynthesis.

It is interesting to note that the actual rates of net primary production of vegetation fall well below the hypothetical maximum rate suggested above. Very few examples even begin to approach the maximum. I suspect that this is partly because primary production operates within an ecosystem as Melillo emphasizes in his discussion. The production of the vegetation provides energy and materials to every other organism within the system and these flows are seldom measured directly. Consumption of leaves, stems and roots and loss of plant parts from the plant during growth should be included in the production figures. Of course, in some of the estimates this correction has been made, but not commonly. If this is the explanation then one-half to three-fourths of the potential production could be going to maintain system processes during the production period.

Turning to agricultural production Ryszkowski's comparison, supported by other workshop reports, suggests that modern agriculture (what Buringh has called the specialized mode of production where the crop is managed in a modern way with inputs of fertilizer, biocides, and full mechanization) has rates of net primary production equal to that of the natural vegetation. Note that net primary agricultural production is higher than yield since it includes non-harvested plant parts and growth of non-crop plants in the crop field. Wh re agriculture operates under shifting or low traditional modes of production the rates will be much lower than the natural rate. Where special manipulation of the environment is possible (as in a glass house or under irrigation) the rates of agricultural production may exceed the natural rates. Clearly then agricultural production can slide up and down the scale depending upon the inputs man can provide. And thus the observation derived by comparative research that modern agricultural production rates and rates for natural vegetation are similar is not terribly helpful. Rather, we need to understand the relationships between the inputs to the vegetation and the output of production so that we can understand the efficiency of the process in any kind of ecosystem.

In the natural vegetation the inputs are supplied by the environment and by coevolution of plants, animals and microorganisms. These systems are constantly changing and consequently the production output varies but frequently remains within fairly narrow limits year after year for a site. In agricultural systems inputs come from outside the crop system and must be paid for ultimately from the yield (or export) from the crop system. While an agricultural production system can be subsidized (so that inputs exceed outputs) in order to produce a useful product, this is possible over the long term only when man can mine non-renewable sources of energy and materials (such as fossil fuel and rock phosphate). Thus, the evaluation of the relation of inputs to agricultural production involves both economic and ecological considerations within the context of a hierarchy of systems which provide, control or receive the products of agriculture.

Hart in his report presents a description of this hierarchy of agricultural organization. As one mov from crop field to the world markets the role of the social-economic factors become larger and the environmental-biological factors become smaller. Yet we need to be able to visualize the entire hierarchy at one time in both its biological and social terms in order to understand and manage it. This is especially true when the process of production changes the biological-environmental-social quality of the system. Changes (such as soil erosion, accumulation of toxic chemicals and depopulation of villages) produce costs. These costs must ultimately be paid from agricultural production or be subsidized by the industrial sector of society or the quality of life and the capacity to sustain agricultural production is diminished.

Pimentel and Cox describe the nature of these subsidies and the consequences of mismanagement but as yet we do not have adequate hierarchical models to examine the costs of inputs and benefits of outputs in energy, currency and material terms. Pimentel and Han and Golley show how energy analysis can be used to describe performance at the farm system level but even here controls from other levels in the hierarchy were not included.

Thus, it is clear that we do not have adequate understanding of systems to answer our second question. The field ecosystem (Ryszkowski), the crop or forest vegetation (van Keulen and de Wit, and Melillo) and the leaf or plant system (Tenhunen and associates) are well enough understood so that we can make models to predict behavior and can advance mechanistic explanations for observed deviations from predicted. We do not have similar robust models or explanations at the higher orders of scale. Indeed, to develop these models requires a combination of ecologists, biologists, economists and social scientists and these sciences seldom interact and funding agencies prevent their interaction in even advanced countries.

In my view, these reports have provided us the following conclusions:

1) production is a variable controlled by intrinsic physiological factors, the species, the environment, and management inputs;
2) within a region the distribution of values of net primary production of forest, grassland and modern managed crop vegetation are similar;

3) for development of adequate mechanistic explanation of agricultural production levels, we require understanding of the production process and its control at all levels of a system hierarchy from the leaf to global market and social-political systems;

4) with analyses of all system levels it will be possible to understand how higher level systems control lower level systems and it also will be possible to develop mechanistic explanations, including models of the production process from the global level to the plant leaf;

5) to realize further improvement of crop production it is desirable to increase research at higher system levels so that the quality of explanation is the same through the agroecological hierarchy.

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