Forage production under suboptimal conditions: an overview of drought problems in Mediterranean-type ecosystems

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Summary

This paper reviews the current state of forage production studies in dry environments, with special attention to semi-arid (man-made oak savannas or "dehesas") and arid Mediterranean-type ecosystems in Spain. Forage production in dry environments is usually affected by non-climatic constraints and is linked to important characteristics of ecosystem functioning and management. Past studies are grouped into 1) classification of agrosystems, 2) water constraints and links between forage production and other ecosystem characteristics 3) soil constraints, and 4) implications for ecosystem management. Agrosystems have been classified on the basis of a number of variables such as floristic composition, vegetation physiognomy and production. Water supply in these habitats is conditioned by the high variability of seasonal rainfall, topography, and the effect of tree shadows. It influences various ecological properties such as diversity and persistence. Soil constraints are related to nutrient content, nutrient uptake by plants and salinity. Management is aimed at optimizing the usually low productivity of these regions. The possibilities are planned extensive grazing, fertilization, introduction of species and ecotypes, planting forage shrubs, growing forage grain plants and alternating annual cycles of arable crops and pastures. The most promising studies of forage production in dry regions are related to the Sustainable Biosphere Initiative, and in turn biodiversity and sustainability. Techniques such as remote sensing are fostering these studies.

Keywords: management, extensive grazing, semi-arid and arid regions, forage production, ecosystems.

Introduction

Plant production can be defined as the increase of dry material per unit of area and per unit of time. It is the result of the interaction of various factors: species genetics and phenology, environment (soil, climate), and management. Production is also an important generating factor of community, ecosystem and landscape patterns. The limiting factors of plant production have long been recognized in scientific literature. In turn, the main environmental constraints of primary productivity on a large-scale basis are precipitation and temperature (Whittaker & Likens, 1973), i.e., biologically available energy. The effect of drought on primary production has been considered on different scales, from the analysis of clipped biomass in the field up to remote sensing studies of satellite imagery (Tucker & Sellers, 1986). Besides climate, other constraints can be distinguished on a smaller scale, e.g., soil characteristics, chiefly nutrient availability, and topographic features (topography controls run-off and groundwater flow regimes and consequently, water availability).

The present paper is an overview of rangeland production in dry areas under a Mediterranean climate. Climatic constraints usually affect primary production together with overlapping phenomena. Past studies of plant production in arid and semi-arid areas can be grouped into four areas. The first group of studies is aimed at providing a **typology of agrosystems**. Agrosystem classification has been based upon variables such as climate, bioclimate, soil, vegetation physiognomy, plant communities (floristic composition, phytosociology), biomass/forage production ratio, carrying capacity, management, etc., or a combination of some of them (González Bernáldez & Pineda, 1980; Robles & Passera, 1994. The second group (Section 2 of this paper) refers to **water constraints** under Mediterranean climate conditions and its effects on plant communities. We will review the factors that conditions water availability, provide some production values and describe the relationships between production and other ecosystem characteristics such as diversity or persistence. The third group deals with studies of **soil constraints** in dry environments, such as the effect of nutrient availability, nutrient uptake by plants and soil salinity on primary production. Section 3 discusses some of the results of these studies. The fourth group embraces studies related to implications for **ecosystem management** such as cattle migration patterns, effects of extensive grazing, fertilization, and soil and vegetation conservation. These issues are considered in more detail in Section 4.

Most of the semi-arid and arid ecosystems in western Europe are on the Iberian Peninsula, which consequently receives special attention here. The semi-arid environments are man-made oak savannas called "dehesas". The arid, subdesertic environments of Europe spread through south-eastern Spain and some parts of Greece, Cyprus, and Corsica. Finally, Section 5 considers some ideas about future research trends in plant production under drought conditions.

Water constraints in Mediterranean ecosystems and its effects on plant communities

Water is the main factor limiting plant growth under Mediterranean climatic conditions. Relations between drought duration and production, plant distribution, phenology and morphology have been well established (Mooney, 1981; Miller, 1982).

Factors affecting water supply

The factors that affect water supply in Mediterranean pastures are 1) a highly variable seasonal rainfall that changes from one year to the next, 2) inter-annual precipitation fluctuations, 3) topography, 4) the effect of tree shadows, and 5) soil water retention. These ecosystems are characterized by the coincidence of the warmest and driest seasons and, consequently, a long period of low production. Exceptions occur, however, on a local scale e.g., groundwater seepages that feed some lowlands. This provides a spatial change of the highest production areas throughout the annual climatic fluctuation; lowlands are usually the most productive habitats in the climatically driest season. The aerial biomass:below-ground biomass ratio has been found to increase as the relative position on the topographic gradient decreases from the top of the hills towards the valley (Fernández, 1987).

The effect of tree shadows on pasture water availability deserves an special comment. The tree overstorey affects the rainwater distribution, soil infiltration and moisture retention, and decreases temperature, wind speed and albedo. It allows for a more efficient use of water by the vegetation and, consequently, increases production and nutrient conservation (Montoya, 1983). Joffre & Rambal (1988) studied the soil water improvement by trees in oak-woodland rangelands sites of southern Spain by means of neutron probes, and found that the soil storage capacity amounted to 215 to 266 mm under trees and 137 to 172 mm in open areas. Trees induced changes in soil properties and thus in soil water flow. Olea *et al.* (1989) found that soil depth and water capacity are the main factors affecting pasture production in these areas.

Production values

In semi-arid regions, with an average precipitation of 400-600 mm, the overall pasture production is moderate in both quantity and quality. Esselink *et al.* (1991) reported production values of 2000 to 2750 kg ha^{-1} year^{-1} at three representative locations of south-western Spain, while Olea *et al.* (1989) reported an average value of 1440 kg ha^{-1} year^{-1}, with 10.3% of crude protein and 55.2% of digestible dry matter. According to Olea *et al.* (1989) autumn precipitation affects total production more than annual and spring precipitation. There is a production peak in the spring (April-June) that ranges between 1300 and 2000 kg ha^{-1}. A rainy autumn encourages therophyte species, mainly legumes, allowing high production if the temperature is sufficiently warm (autumn production with standard precipitation is 550 kg ha^{-1}. Winter production ranges from 50 to 300 kg ha^{-1}. Production is highly variable in the different pasture types and in different years, although trees stabilize intra-annual and interannual production since they provide oak nuts, twigs and branches used as forage (Cañellas *et al.*, 1991). Forage production is affected by topography. The lowest levels are in the upper parts of the hills (usually less than 500 kg ha^{-1}) and the highest in the valleys e.g. 2400 kg ha^{-1} in *Agrostis castellana* communities.

In the arid, subdesert regions of south-eastern Spain, mean annual precipitation ranges from 250 to 400 mm, although it is very irregularly distributed throughout the seasons. Autumn and spring are the rainiest seasons, and summers are very dry and hot. Most production is in spring, when rain and high temperatures coincide. Another production peak is in autumn, while winter and summer are troughs. Robles *et al.* (1991) reported forage production values that ranged between 160 and 1400 kg ha^{-1} $year^{-1}$ for shrub species, and between 70 and 500 kg ha^{-1} $year^{-1}$ for herbaceous species. Le Houérou & Hoste (1977) reviewed data from eight countries of the Mediterranean Basin and concluded that annual dry matter production with 300 mm annual rainfall was about 1200 kg ha^{-1}, of which only about 400 kg ha^{-1} was consumed by various animals.

Links to other ecosystem properties

Pasture vegetation in dry Mediterranean environments may be described as dynamic ecosystems in which plant composition and cover respond to cycles of drought and rain, continous disturbance by grazing and recurrent disturbance by fire. In the driest years, plant composition changes and the size and density of most plant populations are reduced. In mountain pastures of central Spain, Montalvo (1992) showed that that the main source of plant community variation (species composition, persistence, diversity) at a regional scale was related to altitude.

The length of the drought periods affects various characteristics of Mediterranean-type ecosystems. The persistence ("r" or reproductive strategies and "k" or low reproduction, persistent strategies) of pastures in the mountains of central Spain increases from the semi-arid, lower altitude areas to the more rainy, higher altitude areas, while species diversity decreases. Lowland pastures, such as the *Agrostis castellana* communities are more diverse (greater species richness and turnover) and closer to the climax than upland pastures (Miguel, 1983). Scheiner & Rey Benayas (1994) found that competition for water results in more clearly differentiated ecological units. These ecological processes and functions have to be taken into account by ecosystem management.

Effects of soil constraints

Soil constraints such as nutrient content, pH, depth, and toxicity are important limiting factors of plant production in dry environments. Habitats in Mediterranean-type ecosystems vary from those which are relatively fertile to those markedly deficient in mineral nutrients (Specht & Moll 1983). Evergreen plant communities on soils of low nutrient status have evolved both nutrient and water conservation strategies (Specht, 1987).

Esselink *et al.* (1991) distinguished two groups of semi-natural grazing lands (dehesas) in south-western Spain with soil nutrient defiency as a limiting factor of forage production. In one, N was the main limiting factor, while in the other, P was the main limiting factor. They proved the P:N ratio in living plant tissues to be a good indicator of N- or P-limited plant growth (plant growth seemed to be limited by N at a P:N ratio of 0.20 or higher). Of three other macronutrients, only Ca was low or in short supply.

Hernández *et al.* (1991), in their study of oligotrophic pasture communities of western central Spain, found that soil nutrient content (mostly K and Mg), together with pH, was related to biomass production. Production values are sometimes up to three times greater in dehesas cattle "night parks" (4000 kg ha^{-1} $year^{-1}$) than in the surrounding areas, since their faeces trigger production (Hernández, 1985). The frequent fires also cause significant non-seasonal temporal changes in nutrient availability (Rundell, 1983).

Arid and semi-arid pasture soils are generally in the slightly acid to alkaline range. Soil pH may influence nutrient absorption and plant growth. Several essential elements such as Fe, Zn, Mo, and Mn tend to become less available as pH increases from moderately acid to slightly alkaline. The availability of P ions is dependent upon soil pH. At very high pH values, the bicarbonate ion may interfere with the uptake of other ions (Leonard *et al.* 1988). Natural toxicity occurs on those areas under the influence of a saline or alkaline water table, where evapotranspiration concentrates groundwater solutes in the soil, and production decreases (González Bernáldez & Rey Benayas, 1992).

Implication for ecosystem management in Spanish Mediterranean habitats

Ecosystem management aims to optimize the use of an often poor forage production due to water and soil limitations. Water availability in arid and semi-arid regions is responsible for various spatial and temporal management patterns of agrosystems. The alternation of forage production (summer-winter, lowlands-uplands) conditions the seasonal movements of cattle within small areas (Ruiz, 1989). "Transhumancia" (seasonal cattle droving between, for example, the northern and southern halves of a large mountain range) is declining but still exists (Gómez, 1992). Forage production management in the semi-arid and arid regions of Spain is discussed in detail below. The alternatives are based upon extensive grazing management and human input to increase forage production. One of the main problems of forage production in these environments is related to sustainable management (long-term use of forage and vegetation and soil conservation).

Strategies in semi-arid environments: dehesa habitats

Dehesas ("montados" in Portugal) are man-made agroforestry systems characterized by a savanna-like physiognomy. The term also denotes the land use system in rural areas, mainly rangelands, which are occupied by scattered tree species (*Quercus rotundifolia*, *Quercus suber*, and *Quercus faginea*) with a density of 10 to 80 trees ha^{-1}. The shrubland understorey is eliminated by grazing. *Quercus* forest gaps permit light penetration and, together with cattle activity, encourage the establishment of pasture. The dehesas have been used for centuries, since they represent a multiple, sustainable exploitation system, including recurrent cereal cropping (Joffre *et al.*, 1988). Dehesas cover 6 million ha (Olea *et al.*, 1989) in the central and south-western regions of the Iberian Peninsula, on acid soils developed from granite and shale rocks, since the sedimentary rock provides better soils for crops. The dehesa water balance is different from that in open pastures or croplands and slight variations in topography result in a mosaic of herbaceous communities with different floristic composition, production, and forage qualities (see previous sections on water constraints in Mediterranean ecosystems). The complexity of this mosaic requires careful individual planning for each agrosystem.

Cattle, vegetation and human modifications are linked by complex multiple interactions. Under oak shadows, some higher latitude species as well as species with greater fertility and moisture requirements may thrive (pasture becomes dry up to 20 days later). Perennial species provide higher cover and diversity to the plant communities. Gramineous species thrive better under oaks than legume species, which are more abundant out of the shade. Some characteristic gramineous species are *Poa bulbosa, Bromus hordaceus, Gaudinia fragilis, Cynosurus echinatus, Cynodon dactylon, Anthoxanthum aristatum, Phalaris minor, Holcus lanatus, Briza maxima, Agrostis castellana, Dactylis glomerata, Lolium perenne,* and *L. multiflorum*. Some of the most important legumes are *Trifolium subterraneum, T. brachycalycinum, T. striatum, T. glomeratum, T. tomentosum, T. gemellum, T. bocconei, T. cernuum, T. suffocatum, T. hirtum, T. smyrnaeum, T. cherleri, Ornithopus compressus, Biserrula pelecinus, Medicago polymorpha, M. minima, Astragalus hamosus, Scorpiurus vermiculata*, and *Trigonella polycerata* (Martín & Pastor, 1984; Hernández, 1985).

Three main strategies are used for increasing production: 1) appropriate cattle management, 2) fertilization plus management, and 3) fertilization plus management, plus the introduction of selected species and adapted ecotypes. These different strategies imply differences in production that range between 400 and 1000 kg ha^{-1} $year^{-1}$. In the less productive areas, management is the only strategy that can be readily applied, because application of fertilizers is often not greatly succesful. Two options for dehesa management can be considered: extensive grazing over large areas or grazing cattle in selected areas of the dehesa mosaic according to their phenological state (controlled grazing). The carrying capacity of the natural pastures on the acid soils in south-western Spain ranges between 0.8 and 1.7 sheep ha^{-1} $year^{-1}$. Fertilizers are applied in areas with a higher precipitation and better soil conditions. Besides quantity, forage quality is also important, and can be achieved by P manuring of legume pastures. Species introduction can be used in recently ploughed fields, since their vegetation is dominated by annual herbs of low quality. Some species that can be introduced include subclovers such as *Trifolium subterraneum, T. brachycalycinum, T. yanninicum,* and *T. glomeratum* (Pastor *et al.*, 1980) and *Ornithopus compressus*. Yañez *et al.* (1991) found that the introduction of native ecotypes of species such as *T. glomeratum* and *O. compressus* increased forage production by up to 57%. González & Hernández (1990) pointed out that the species *Vicia sativa, V. villosa, V. monantha, V. ervilia, Lathyrus sativa*, and *Trigonella foenum-graecum* are good fodder legumes to be used in rotation with grain crops.

Ploughing in and the rotational cereal cultivation adversely affects the organic matter content of the soil and hence also the availability of nutrients, chiefly P, for plant growth. Because of this harmful effect, ploughing should be replaced by reduced tillage or conservation tillage systems. As long as the future of livestock exploitation in the dehesas is not assured, the trees should be preserved because their removal is irreversible.

Strategies in the arid regions of southeastern Spain

Sheep and goat grazing is mostly extensive. They use stubble, xerophyte pastures in shrublands and steppe-like habitats, and browse on some tree species. Boza (1993) quantified the carrying capacity at 0.3-1.3 goats ha^{-1} for the area.

In these lands, desertification may be induced (vegetation degradation, salinization, erosion, land abandonment) as a result of overgrazing (Montserrat, 1990). Consequently, the ratio of biomass production versus forage production and its implications for soil erosion and ecosystem restoration in dry environments is now an important research task (Robledo *et al.*, 1989; Robles, 1990). These authors found that extensive grazing by goats is compatible with soil conservation and vegetation regeneration.

The main strategies for forage production are 1) sowing adapted ecotypes of herbaceous species, 2) growing forage grain plants, 3) alternating annual cycles of arable crops and pastures, 4) growing forage shrubs, and 5) adequate ecosystem management for extensive grazing, which imitates ecological mechanisms. The introduction of species such as *Dactylis glomerata ssp. hispanica, Lolium rigidum, Onobrychis sativa, Medicago tribuloides, M. polymorpha, M. truncatula*, and *Sanguisorba minor* has had limited success in higher precipitation areas. Alternation of grain plants and pastures is expensive and risky.

Planting forage shrubs (*Anthyllis cytisoides, Atriplex numularia, A. halimus, Collutea arborescens, Ceratonia siliqua*, etc.) is, however, an efficient way to increase forage production in spite of the seasonal rainfall distribution. These shrubs are deeply rooted and present phenological and physiological adaptations (e.g., minimum loss of tissue water) that makes them thrive in these areas. They also have a high aerial phytomass, much of which is woody biomass. Consequently, these species are resistent to overgrazing since most of the plant tissues persist, which makes them very useful for soil conservation. These species have been selected for their characteristics of drought resistence, winter cold tolerance and adaptation to soil conditions (moisture retention, salinity). Considerable research effort has been devoted over the last few years (Range Management for Cattle Management in SE Spain Project) to characterize pastures in this arid region: species composition, (Correal *et al.*, 1992; Robles & Morales, 1992), management, evolution, carrying capacity (Boza, 1993) and nutrient quality of the different forage species (Robles, 1990).

Comments on future research trends

The Sustainable Biosphere Initiative: an Ecological Research Agenda (Lubchenco *et al.*, 1991) points out three issues of priority interest for ecological research: global change, biodiversity and sustainable ecosystems. We think that the future goals of applied studies of plant production should be linked to these topics. It is necessary to highlight the actual and/or potential effects of climate change on primary production, such as total biomass production, the allocation of this biomass (e.g., above ground or below ground), and the physiological processes involved. It has been mentioned that production is related to biodiversity at different scales; however, the processes involved and the levels at which diversity is affected have not been fully understood.

The need to combine forage production and ecosystem conservation is already triggering a number of activities as well as theoretical (modelling) and empirical studies. For instance, the E.U. is subsidizing the abandonment of agricultural lands, some of which could be managed as pasture lands for farm cattle or could be devoted to wild game for hunting. To prevent soil erosion and desertification, detailed studies of the carrying capacity of every particular ecosystem are very necessary. Techniques such as remote sensing are already providing advances in the field of primary production, particularly by mapping, temporal variation and associated phenomena (Wickland, 1991). Joffre & Lacaze (1993), for instance, estimated tree density in dehesa systems, a key parameter that reflects the functional vegetation-soil-climate equilibrium which exists for both woody and herbaceous strata. The most promising studies will be those that integrate the three "pieces of the cake" at the one time from an ecosystem perspective, such as the use of forage together with soil and biodiversity conservation and ecosystem restoration.

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