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THE PRIMARY PRODUCTIVITY OF LAWNS IN A TEMPERATE ENVIRONMENT

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SUMMARY

(1) The annual net primary productivity of two lawns was studied. One lawn was not fertilized or irrigated and was infrequently cut; the other was fertilized, irrigated and cut weekly.

(2) The closely managed lawn had a lower species richness than the less managed lawn.

(3) The annual net primary productivity was very similar for both lawns, 1650 g m^{-2} (6400 Kcal m^{-2}) and equivalent to that of other managed grasses such as maize and wheat.

(4) Clearly, temperate lawns are very productive despite their deceptively short stature.

INTRODUCTION

The productivity of temperate and tropical grasslands (Ovington, Heitkamp & Lawrence 1963; Kucera, Dahlman & Koelling 1967; Van Hook 1971; Singh & Yadava 1974; Coupland 1975; Murphy 1975) and rangelands (Romney 1960; Pearson 1965; Vickery 1972; Coleman *et al.* 1976) has been widely studied, but the primary production of managed grasslands has rarely been studied (Herte *et al.* 1971; Ovington, Heitkamp & Lawrence 1963; Pasternak 1974; Falk 1976). In their study of lawns (Herte, Kobriger & Stearns 1971) did not adequately measure stubble and root weight so their estimates appear low. In the study by Falk (1976) stubble and root weights were included and estimates of net primary productivity that exceeded those for other perennial grasslands in the temperate zone were obtained. The present study was designed to verify the magnitude of the net primary productivity of lawns relative to other grasslands and to investigate the effects differing maintenance regimes have on productivity.

METHODS

The study sites were located at the Smithsonian Institution, Chesapeake Bay Center for Environmental Studies (latitude 30°53′N, longitude 76°33′W) near Washington, D.C. Total precipitation at the site during the 1-yr period November 1975–October 1976, was 117·8 cm with a peak during August. Total visible light insolation (400–700 nm) was $1{\cdot}1 \times 10^6$ Kcal m^{-2} (Klein & Goldberg 1976; Goldberg pers. comm.) for the same 12-month period. The climate and soil have been described by Correll (1971–1976) and are typical of the mid-Atlantic coastal plain of the eastern United States.

Two lawns were selected for study. Site A (0·7 ha) was a 10-yr-old lawn which had received minimum maintenance. This lawn had never been irrigated or fertilized. It was mown on average, every 2 weeks during the growing season.

Site B (0·2 ha) was a well maintained turf which was fertilized at a rate of 550 kg ha^{-1} (5–10–5), and limed at a rate of 1000 kg ha^{-1} (calcium carbonate 53·5%, magnesium carbonate 42%) once each spring. The site was mowed weekly and irrigated several times each summer. The previous spring, a large percentage of the site had been newly seeded.

Both lawns were clipped to a height of 5 cm by rotary mowers. After each mowing, the clippings were collected from fifteen areas, each of 0·25 m^2 using a portable vacuum cleaner. The clippings were weighed immediately and a subsample sorted into three categories: living material, dead material, and miscellaneous material (tree leaves, twigs, etc.). These samples were oven dried at 90 °C for 24 h and weighed.

Random core samples (5·2 cm diameter and 7·6 cm deep) were taken at 2-month intervals immediately after mowing. The stubble was cut and separated as above. Roots were washed from the soil, using the technique described by Williams & Baker (1957), dried at 90 °C for 24 h and weighed.

Net primary production was calculated using the following formula (Milner & Hughes 1968):

$$NP = \sum_{i=1}^{n} B_i(A) + B\max_{(s)}\,\theta_s + B\max_{(r)}\,\theta_r + H \qquad (1)$$

$B_i(A)$ = standing crop at the ith sampling period (all live aerial plant parts above 5 cm), $B\max_{(s)}$ = maximum standing crop of live stubble, θ_s = stubble turnover rate, $B\max_{(r)}$ = maximum standing crop of roots, θ_r = root turnover rate, and H = loss due to herbivory. Turnover rate (θ) was calculated from the ratio of annual growth to total stubble (or root) mass (Dahlman & Kucera 1965). Gross production was calculated from the following equation (Woodwell & Whittaker 1968):

$$GP = NP + R \qquad (2)$$

NP = net primary production and R = respiration.

Calorific values were determined for the generalized vegetation of each study site rather than by species, five samples per site were run. A Parr semi-micro oxygen bomb calorimeter was used following the instructions provided by the Parr company and the suggestions of Paine (1971).

A vegetational analysis was conducted once for each site during July 1976. A releve method (Mueller-Dumbois & Ellenberg 1974) was used to determine quadrat size and a modified point frequency frame (Mueller-Dumbois & Ellenberg 1974), used to quantitatively measure cover.

RESULTS

Sites A and B differed with respect to their floristic makeup as shown in Table 1. The younger, more managed site B was less diverse. The dominant grass in both sites was *Festuca arundinacea*. This species tolerates the cool season/warm season grass transition zone conditions that exist in Maryland better than either true cool season grasses like *Poa pratensis* or warm season grasses like *Cynodon dactylon*. Nearly 90% of Lawn B's cover was of preferred turf grass species, compared to less than 70% of the less managed Lawn A.

TABLE 1. The species present on the study sites

Site A Species	% Cover	Site B Species	% Cover
Festuca arundinacea (Schreb.)	37·03	*Festuca arundinacea*	68·75
Digitaria ischaemum (Schreb.)	11·25	*Trifolium repens*	9·38
Poa pratensis (L.)	10·94	*Poa pratensis*	6·25
bare ground	9·53	*Digitaria ischaemum*	4·38
Dactylis glomerata (L.)	7·50	*Plantago major*	2·50
Cynodon dactylon (L.)	5·31	bare ground	1·88
Trifolium repens (L.)	4·84	*Dactylis glomerata*	1·88
Taraxacum officinale (Weber)	2·34	*Duchesnea indica*	1·88
Digitaria sanguinalis (L.)	2·19	*Lolium perenne*	1·25
Lolium perenne (L.)	1·56	*Juncus tenuis*	0·62
Erigeron canadensis (L.)	1·56	*Muhlenbergia* spp.	0·62
Plantago major (L.)	1·41	*Taraxacum officinale*	0·62
Poa compressa (L.)	0·94		
Holcus lanatus (L.)	0·63		
Festuca ovina (L.)	0·63		
Plantago rugelii (Dcne.)	0·47		
Oxalis stricta (L.)	0·31		
Agropyron repens (L.)	0·31		
Juncus tenuis (Willd.)	0·31		
Bryophytes	0·31		
Duchesnea indica (Andr.)	0·16		
Muhlenbergia spp.	0·16		
Ambrosia artemisiifolia (L.)	0·16		
Scleranthus annuus (L.)	0·16		

Vegetational caloric content analysis showed a mean value for living grass and forbs from Site A of 4212·9 cal g^{-1} (s_x = 52·4) and 4196·4 cal g^{-1} (s_x = 18·9) for Site B. Dead plant material at Site A was 4052·2 cal g^{-1} (s_x = 133·1) and 4063·0 cal g^{-1} (s_x = 33·9) at Site B. Caloric values for underground plant material for Sites A and B differed significantly ($P < 0·05$) being 3551·1 cal g^{-1} (s_x = 529·0) and 3953·4 cal g^{-1} (s_x = 120·5) respectively.

As shown in Fig. 1, the two sites differed in occurrence of peak live standing crop, Site A

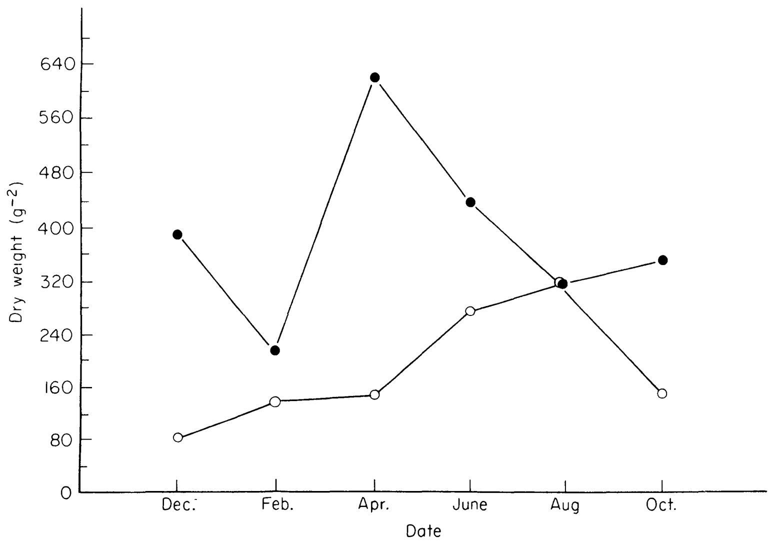

FIG. 1. Above-ground dry weight of live material for study sites A (○) and B (●) from December to October.

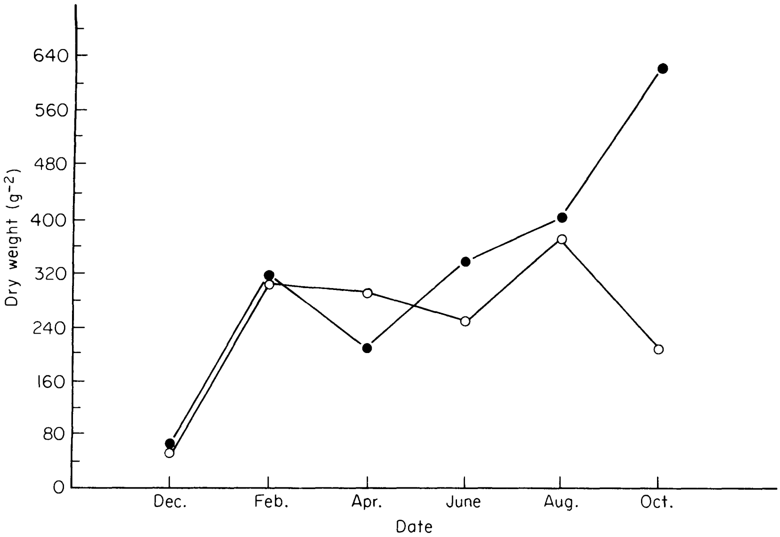

FIG. 2. Above-ground dry weight standing and fallen (clippings) dead material for study sites A (○) and B (●) from December to October.

in August and Site B in April. Total above-ground live standing crop was 1089·8 g^{-2} for Site A (s_x = 42·6) and 2398·2 g^{-2} for Site B (s_x = 124·1), ($P < 0{\cdot}05$). Standing and fallen dead (clippings) represented a major portion of the *in situ* above-ground biomass at all times of the year (Fig. 2), with maxima occurring in late summer. Total fallen dead for Site A was 1514·7 g^{-2}, 1957·5 g^{-2} for Site B. Turnover rate for the stubble portion of the lawns was approximately once every year and a half ($\theta_s = 0{\cdot}60$ for Site A, $\theta_s = 0{\cdot}65$ for Site B).

Figure 3 shows changes in below-ground standing crop. Below-ground biomass was calculated to be 1172·5 g^{-2} (s_x = 432·3) for Site A and 951·2 g^{-2} (s_x = 289·1) for

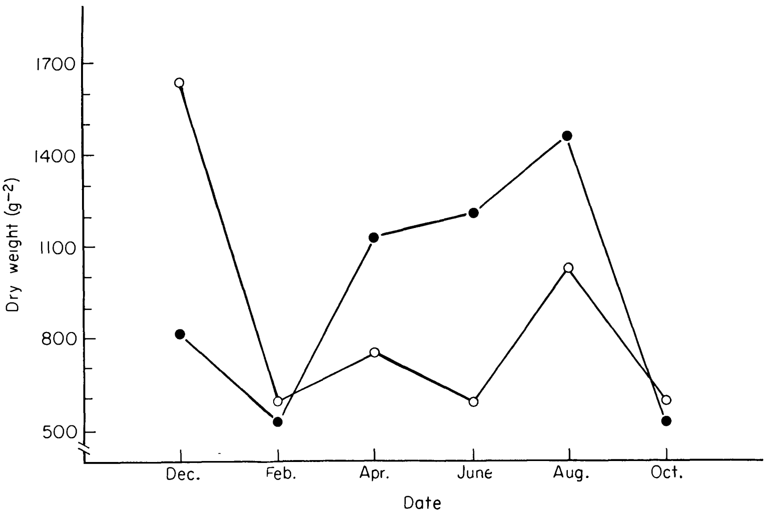

FIG. 3. Below-ground dry weight material for study sites A (○) and B (●) from December to October.

Site B. Turnover rates were comparable to stubble turnover rates of once every year and a half (Site A $\theta_r = 0{\cdot}67$, Site B $\theta_r = 0{\cdot}65$).

Losses due to invertebrate herbivory were inevitable, and an annual estimate of 124·4 Kcal m^{-2} was used (Falk 1976). Total annual net primary productivity was calculated as 1669·2 g m^{-2} ($s_x = 433{\cdot}5$) for Site A and 1649·3 g m^{-2} ($s_x = 424{\cdot}2$) for Site B, a non-significant difference. This represents 6380·0 Kcal m^{-2} yr^{-1} for Site A and 6814·2 Kcal m^{-2} yr^{-1} for Site B. Assuming an average daily respiration rate of 33% of gross production for the entire year (Gaastra 1963; Army & Greer 1967; Loomis, Williams & Duncan 1965), annual respiration for Site A was 3145·1 Kcal m^{-2} and gross production 9571·2 Kcal m^{-2}. Annual respiration at Site B was calculated at 3407·1 Kcal m^{-2}, and gross production 10 221·3 Kcal m^{-2}.

Given a measured incident radiation in the photosynthetically active wavelengths of $1{\cdot}1 \times 10^6$ Kcal m^{-2} yr^{-1}, the photosynthetic efficiency of Lawn A was 0·85% and of Lawn B 0·98%.

DISCUSSION

More intensive management led to lower species diversity and higher above-ground production. Total net primary productivity, however, was equal between sites. Although age might be given as one explanation for the difference in diversity between sites, much of Site B having been recently cleared and seeded, newly seeded turfs frequently contain larger numbers of broad-leaved weeds than established turf (Engel & Ilnicki 1969). More likely, better maintenance of Site B resulted in a denser, nearly closed canopy of perennial grasses which led to the exclusion of weedy species such as *Digitaria ischaemum*, *Taraxacum officinale*, *Plantago major*, *P. rugelii* and *Erigeron canadensis*. The spring peak in above-ground production for Site B (Fig. 1) can be attributed to a high percentage of cool season species (i.e. *Festuca arundinacea*, *Poa pratensis*) and the impact of spring fertilization. Site A exhibits a peak in the summer, probably due to warm season grasses and summer annuals (i.e. *Digitaria ischaemum*, *Cynodon dactylon*, *Taraxacum officinale*). Except for the deviation in October 1976, the two sites displayed little difference in the quantity of standing and fallen dead material (Fig. 2).

Figure 3, which compares underground biomass of Sites A and B over a year, follows a typical pattern of buildup of reserves in the spring and in the autumn, with a levelling off in the summer and a steady decline through the winter; minima usually occur in early spring (Dahlman & Kucera 1965; Garwood 1967; Laird 1930). The very high values for below-ground standing crops in December of 1975 and the very low values in October of 1976, may be related to the extremely mild autumn and winter of 1975 and the very early severe winter in the eastern United States in 1976. The first hard frost in 1975 was in December, in 1976 in October.

Although differential management plays an important role in determining species diversity, it appears to have little impact upon total productivity, 1670 g m^{-2} for Site A compared to 1650 g m^{-2} for Site B. The addition of fertilizer and lime to Site B probably accounts for its greater shoot productivity. The difference between sites in above-ground productivity was counter-balanced by differences in below-ground productivity in the opposite direction.

By comparison to the roughly 1650 g m^{-2} production for the two Maryland lawns, a California lawn produced 1050 g m^{-2} (Falk 1976). The only other published estimate of lawn productivity (Herte, Kobriger & Stearns 1971), reported about 250 g m^{-2}. This study only measured clippings which resulted in gross underestimates of both above- and below-ground net primary productivity.

Logically, it might be assumed that since lawns are frequently mowed at a set height, estimates of new growth could be made by weighing clippings after each mowing. This assumes all growth is vertical. A study by Madison (1971) indicated that mowing turf at 5 cm removes only about 3% of the total production. Most growth in well-adapted turf grass species is in a mat 5 cm above and below the soil surface. In the California study, 77% of the productivity was found in this 10 cm zone. In this study, of the order of 20% of the production was removed by clipping.

The result for the Wisconsin site becomes comparable to those from California and Maryland lawns if it is assumed that clipping removes 20% of total production when the adjusted net production becomes 1250 g m^{-2}. The range for lawn net primary production in the temperate zone is about 1000–1700 g m^{-2} yr. In comparison, net annual primary production in temperate grasslands has been measured in the range 100 g m^{-2} to 1500 g m^{-2} (Leith 1975). Temperately grown maize has been measured to yield 1066 g m^{-2} (Ovington, Heitkampt & Lawrence 1963) and wheat of Eros variety 1537 g m^{-2} yr (Pasternak 1974). Tropical grasslands produce in the range of 200–2000 g m^{-2} (Leith 1975). Estimates for pastureland fall within the estimates for grasslands, depending upon latitude (Romney 1960; Coleman *et al.* 1976).

Clearly, temperate lawns are, despite their deceivingly short stature, extremely productive grasslands, with only tropical grasslands and other intensively managed temperate grasslands comparable. At temperate latitudes, lawns surpass prairies, coniferous forests, pine plantations and approach deciduous forests in annual net primary production (Leith 1975; Olson 1975). Clipping, like grazing, has a stimulating effect upon grass (Falk 1976). Turfgrass morphology also plays a role. Turf species like *Poa pratensis* have been selected for thick heavy crowns close to the soil with extensive rhizomatous growth which forms a highly productive mat of numerous, short, rapid-growing plants. *Festuca arundinacea* is basically a bunch grass, but tends to form a vigorous mat under constant close mowing. Mowing also selects against sexual reproduction in turfgrass, hence, virtually all energy is directed into vegetative growth. In addition, lawn mowing reduces much of the aerial growth into finely cut-up pieces which can quickly be acted upon by organisms of decay. In most terrestrial systems, nutrients become concentrated in the standing biota, and consequently become unavailable for new plant growth. Mowing creates a mechanism whereby nutrients are efficiently and rapidly recycled into the system when clippings are not removed. Consequently, the combination of clipping, turf grass morphology and abundance of available nutrients help to explain the high productivity of lawns relative to other temperate zone grasslands.

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