Reprinted from the *Journal of Production Agriculture*
Volume 8, no. 1, January-March 1995
677 South Segoe Rd., Madison, WI 53711 USA

Stocking Rate Affects Production and Profitability in a Rotationally Grazed Pasture System

S. L. Fales, L. D. Muller, S. A. Ford, M. O'Sullivan, R. J. Hoover, L. A. Holden, L. E. Lanyon, and D. R. Buckmaster

Research Question

Stocking rate, defined as the relationship between the number of animals and the grazing management unit used over a specified time (a grazing season, for example), is key to determining the potential for production and the profitability of a grazing system. The objective of this trial was to compare forage production and quality, milk production, and profitability on a per cow and per acre basis for three different stocking rates, using high-producing Holstein cows grazing grass pasture.

Literature Summary

Where pastures are the primary source of feed for dairy cows, research consistently has shown that stocking rate is a major factor in determining the efficiency of the system. It determines the amount of the pasture that is available per cow, the proportion of the pasture that is consumed, and also influences the quality and long-term productivity of the sward. Stocking rate is a crucial variable in New Zealand because pasture systems there are designed to maximize returns per acre. In contrast, dairy production in the USA traditionally focuses on returns per cow, and even where pastures are used, concentrates and supplemental forage are fed to maintain high levels of milk production per cow. Although grazing is increasing in the Northeast and North Central dairy states, little attention has been paid to stocking rate as a management tool, and there is virtually no current information available concerning the econommic implications of varying stocking rate with high-producing dairy cows.

Study Description

The trial was a replicated farmlet experiment, conducted in 1990 and 1991 at the Pennsylvania State University Dairy Research and Education Center in University Park.

Pasture Composition: Old pasture, consisting mainly of orchardgrass and Kentucky bluegrass.

Soil: Hagerstown silt loam.

Stocking rates: 1.0, 1.3, and 1.6 cows/acre for a 6-mo grazing season.

Grazing management: Stocking rates were achieved by adjusting paddock size for 8 cows/treatment. A total of 38 acres were used. The area for each treatment was divided into 14 paddocks for rotational grazing. In the spring, seven paddocks for each treatment were not grazed, and were set aside for silage. When regrowth from the silage area was available, all 14 paddocks were grazed.

Nitrogen fertilization: 250 lb/acre of N as ammonium nitrate in five split applications.

Full scientific article from which this summary was written begins on page 88 of this issue.

Supplementary feeding: All cows were fed grain daily at the rate of 1 lb grain dry matter (DM)/4 lb milk. Supplemental grass silage (previously harvested from pastures in the spring) was individually fed when pasture growth was limiting.

Data collected: Pasture production, quality, and use; milk production and composition.

Applied Questions

What was the effect of stocking rate on pasture production?

When pasture growth was adequate, as it was during 1990, increasing stocking rates above 1.0 cows/acre resulted in higher pasture production due to the fact that more forage was removed at the higher stocking rates, encouraging new growth. When pasture growth was slow, as it was during 1991 (a drought year), there was no effect of stocking rate on pasture production.

What was the effect of stocking rate on pasture quality?

Increasing stocking rate tended to increase the nutritional value of the forage, particularly when pasture growth was vigorous.

What was the effect of stocking rate on pasture use?

There was less pasture wasted due to trampling, fouling, and rejection as stocking rate was increased. At the low stocking rate, up to 44% of the paddock area was classified as "rejected," compared with 22% for the high stocking rate in 1990. In 1991, because pasture growth was slower, grazing pressure was higher. Therefore, more of what grew was removed, resulting in no significant treatment differences in paddock area rejected.

What was the effect of stocking rate on milk production?

No effect of stocking rate on milk production per cow occurred because grass silage (previously harvested from the pastures) was fed when pasture production was limiting for any treatment. Average production per cow for the 6 mo trial was approximately 10 000 lb of milk (3.5% fat-corrected).

What was the effect of stocking rate on profitability?

When calculated on a per acre basis, profitability increased directly with stocking rate because of the greater amount of milk produced per acre. Returns over the costs examined were approximately $481/acre greater for the high than the low stocking rate during the pasture season. When calculated on a per cow basis, however, profitability was greatest at the low stocking rate, which showed a $36/cow greater return than the high stocking rate.

How should the optimal stocking rate be determined?

The ideal stocking rate in any given grazing situation will vary with each farm and can change from one year to the next, because it depends on the relative prices of inputs and outputs, as well as on farm resources. If land is scarce compared with other resources (barn space, cows, etc.), then a higher stocking rate will be the most profitable. On the other hand, if land is relatively plentiful, rental rates are low, or the value of the land for other uses is low, then a low stocking rate will be the most profitable.

Stocking Rate Affects Production and Profitability in a Rotationally Grazed Pasture System

S. L. Fales,* L. D. Muller, S. A. Ford, M. O'Sullivan, R. J. Hoover, L. A. Holden, L. E. Lanyon, and D. R. Buckmaster

Stocking rate is a key management variable in determining productivity and profitability of grazing systems, but it has not been adequately researched in the USA with high producing dairy cows. A replicated farmlet study was conducted to investigate the potential for improving dairy profitability through increasing stocking rates without influencing milk yield per cow. The study was conducted at the Pennsylvania State University Dairy Research and Education Center in University Park, on pasture dominated by orchardgrass (*Dactylis glomerata* L.) and Kentucky bluegrass (*Poa pratensis* L.). Forty-eight high-producing Holstein cows (*Bos taurus*) were rotationally grazed at seasonal stocking rates of 1.0 (low, LSR), 1.3 (medium, MSR), and 1.6 (high, HSR) cows/acre, and were fed grain at the rate of approximately 1 lb grain DM to 4 lb milk production during a 2 yr study. Stocking rate had a positive effect on pasture nutritional quality, particularly when growth was more vigorous, and had a negative relationship with the percentage of the pasture rejected by cows. Seasonal milk yield per cow (approximately 10 000 lb) and milk composition were not affected by treatments in either year. Consequently, milk production per acre was directly related to stocking rate. An economic analysis of costs and returns indicated that profits per unit area of land increase with stocking rate—a $481/acre advantage was shown for the HSR over the LSR. In contrast, profits per cow decrease with stocking rate—the LSR showed a $36/cow advantage over the HSR. The optimal stocking rate for a given farm therefore will depend on individual farm resources (e.g., land, buildings, cows, etc.), and can be adjusted to meet the constraints of those resources without fear of significant adverse economic impact.

IN TEMPERATE GRASSLANDS worldwide, where dairy cows receive the major portion of their ration from pasture, stocking rate (defined as the number of animal units per unit land area) is the most important variable influencing milk production per cow and per acre (Leaver, 1985). The influence of stocking rate on milk production occurs primarily through its effects on herbage allowance, and thus on intake. Stocking rate affects production per acre by determining the proportion of the pasture that the cows consume. By influencing the use of pasture dry matter (DM), stocking rate also can be an important variable in determining the structure, quality, and long-term productivity of the grazed sward (Baker and Leaver, 1986).

Theoretical relationships predict a decrease in performance per cow as stocking rate increases, accompanied by an increase in output per acre until very high stocking rates are reached, at which point a rapid decline in per acre output results (Mott, 1961). These relationships have been validated in numerous studies over the years (Harris, 1990; King and Stockdale, 1980; Leaver, 1985; McMeekan and Walshe, 1963). The optimal stocking rate will depend on a number of factors, including the sward's yield potential (determined by soil, rainfall, species, and fertility) and the herd's energy requirements, which are related to the level of production. This varies considerably among herds, locations, and seasons within a location.

Although the U.S. dairy industry moved away from pasture over the past several decades, there is a growing trend towards increased pasture use, particularly in the Northeast and North Central regions (Parker et al., 1993). This is driven mainly by the goal of reducing production costs, and several studies have confirmed that adoption of intensive grazing can result in approximately $150 lower cost per cow per year (Emmick and Toomer, 1991; Tranel and Frank, 1991). Nevertheless, on most U.S. farms the emphasis remains on per cow milk production, and most herds on pasture systems continue to use supplemental concentrates and forages to maintain high levels of milk production because of the favorable price of milk compared with the cost of concentrates. This is in contrast to the situation in grassland-based countries such as New Zealand (Parker et al., 1991).

Regardless of production levels, the focus must remain

S.L. Fales, M. O'Sullivan, R.J. Hoover, L.E. Lanyon, Dep. of Agronomy; L.D. Muller, L.A. Holden, Dep. of Dairy and Animal Sci.; S.A. Ford, Dep. of Agric. Econ. and Rural Sociology; D.R. Buckmaster, Dep. of Agric. and Biological Engineering, Pennsylvania State Univ., University Park, PA 16802. Received 29 Dec. 1993. *Corresponding author (slf@psu.edu).

Published in J. Prod. Agric. 8:88–96 (1995).

Abbreviations: CP, crude protein; DHIA, dairy herd improvement association; DM, dry matter; HSR, high stocking rate; IVDMD, in vitro dry matter disappearance; LSR, low stocking rate; MSR, medium stocking rate; NDF, neutral detergent fiber; NHA, net herbage accumulation.

on profitability, and the appropriate measure of profitability is the return to the resource that is most scarce. For example, New Zealand systems are designed to maximize returns to each unit of land (Holmes and Parker, 1992) because of the relative scarcity of land and great flexibility in animal housing systems and milking parlor design. Farmland in New Zealand is priced based on the land's productivity, measured in the amount of milkfat. In the USA, however, many farmers are constrained by animal capacity, either in terms of labor, credit, or physical facilities (barn size, etc.). The limiting economic factor in these cases is the number of cows the farmer can manage. Consequently, return per cow has been the appropriate measure of profitability for these farms. Nevertheless, for many U.S. farmers who have flexibility in herd size or are considering herd expansion and have a limited land base, returns per acre of land may be the appropriate measure.

Stocking rate has not been researched adequately for high producing dairy cows in the USA. Given its fundamental importance in determining the productivity of pasture systems, there is a need to study this variable. Furthermore, an analysis of optimal stocking rates must consider the economics of the alternative systems. The objective of this experiment was to examine forage production, forage quality and use, animal performance, and profit potential of high-producing dairy cows intensively grazing grass-dominant pasture at three different stocking rates, when cows were supplemented with concentrate daily and with additional forage when pasture availability became limiting.

MATERIALS AND METHODS

A farmlet-scale experiment was conducted in 1990 and 1991 at the Pennsylvania State University Dairy Research and Education Center. Three treatments were imposed, consisting of seasonal stocking rates of 1.0 (LSR), 1.3 (MSR), and 1.6 (HSR) cows/acre for the grazing season. Eight Holstein cows were assigned to each treatment-replicate combination for a total of 48 cows for the experiment. Stocking rate differences were achieved by adjusting paddock areas to 0.57, 0.44, and 0.35 acres for the LSR, MSR, and HSR, respectively. Each treatment was replicated twice, resulting in 37 acres for the entire study. Different animal groups were used each year, and the cows were blocked by milk production, calving date, and parity, and within those blocks were randomly assigned to the experimental treatments. Cows averaged approximately 80 lb milk/d at the beginning of each grazing season and averaged 70 to 80 d in milk at the beginning of the trial each year. For 7 d prior to the start of the trial each season, cows grazed for approximately 8 h/d to adapt to the pasture. Production data from this adaptation period were not included in the study.

Grazing Management

Each of the six farmlets (three treatments × two replicates) was divided into 14 paddocks. Seven paddocks of each treatment were set aside in spring for haylage, and the remaining seven were grazed rotationally for 2 d each. Haylage was wilted to approximately 50% moisture, field chopped, and stored in upright silos. When regrowth from the silage cut was judged to be ready to graze in the summer, all 14 paddocks were grazed. Rest periods were approximately 12 d in spring and approximately 26 d thereafter. Accumulated herbage rejected during the first four grazing cycles was removed from the nonsilage ("spring") paddocks in June each year, using a flail mower.

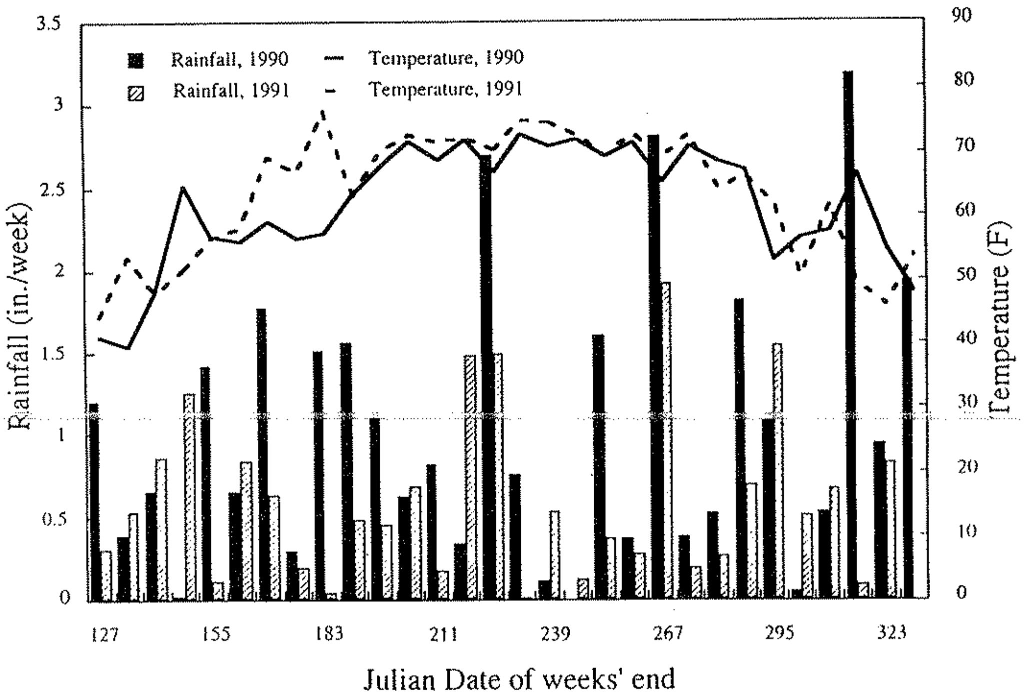

Fig. 1. Weekly precipitation and average daily temperatures for the grazing season during 1990 and 1991.

Table 1. Herbage on offer, area rejected, and quality of herbage on offer in 1990 in response to stocking rates of 1.0 (LSR), 1.3 (MSR), or 1.6 (HSR) cows/acre.

Treatment	Mean herbage on offer	Mean pasture growth rate	Fraction of area rejected	Quality of herbage on offer CP	NDF	IVDMD
	lb/acre	lb/acre/d	%	% of DM		
			Spring			
LSR	3300	48	43.6	23.6	52.9	69.4
MSR	2840	55	31.8	26.5	49.7	71.1
HSR	2580	61	21.8	27.3	49.2	71.2
SR linear†	0.01	0.01	0.01	0.02	0.02	0.01
SR quad	NS	NS	NS	NS	0.07	0.04
			Summer			
LSR	2900	36	39.3	23.2	56.7	63.8
MSR	2680	38	31.2	23.8	55.5	64.7
HSR	2440	38	22.1	24.5	54.6	65.5
SR linear	0.06	NS	0.03	NS	NS	0.09
SR quad	NS	NS	NS	NS	0.07	0.04
			Autumn			
LSR	3500	20	38.4	23.4	54.9	62.6
MSR	3120	22	30.1	25.0	53.0	63.6
HSR	2840	27	21.2	25.9	51.9	65.2
SR linear	0.04	0.01	0.02	0.06	0.09	0.04
SR quad	NS	0.02	NS	NS	NS	NS

† Significance of orthogonal polynomials in regression.

Table 2. Herbage on offer, area rejected, and quality of herbage on offer in 1991 in response to stocking rates of 1.0 (LSR), 1.3 (MSR), or 1.6 (HSR) cows/acre.

Treatment	Mean herbage on offer	Mean pasture growth rate	Fraction of area rejected	Quality of herbage on offer CP	NDF	IVDMD
	lb/acre	lb/acre/d	%	% of DM		
			Spring			
LSR	3260	40	29.2	26.7	53.4	66.9
MSR	3060	53	20.7	26.0	52.9	67.2
HSR	3060	50	18.0	27.0	52.8	67.2
SR linear†	0.07	0.06	0.02	NS	NS	NS
SR quad	NS	0.09	NS	NS	NS	NS
			Summer			
LSR	2500	11	6.1	21.5	54.6	54.0
MSR	2400	9	4.2	22.3	53.4	56.6
HSR	2280	12	5.0	22.8	50.9	57.4
SR linear	0.07	NS	NS	0.08	0.06	0.01
SR quad	NS	NS	NS	NS	NS	0.02
			Autumn			
LSR	2500	14	14.7	26.0	49.9	60.5
MSR	2540	15	13.2	26.4	50.1	61.0
HSR	2180	16	12.7	27.4	49.8	61.5
SR linear	0.01	NS	NS	NS	NS	NS
SR quad	NS	NS	NS	NS	NS	NS

† Significance of orthogonal polynomials in regression.

Pasture Composition and Nitrogen Fertilization

The pastures used in this study were typical of many in the Northeast. A botanical survey for species frequency at the beginning of the experiment indicated that the dominant species were orchardgrass (38% of species present), Kentucky bluegrass (34%), smooth bromegrass (*Bromus inermis* L.) (18%), and an assortment of herbaceous weeds. Regular applications of manure had been made for many years, and pastures contained very little clover (*Trifolium spp.*). Soil test results indicated that P, K, and pH were adequate. Ammonium nitrate, at 250 lb N/acre, was applied in five equal applications, a higher rate than normally would be used by producers, but which has been shown to result in optimum N use by orchardgrass (Donohue et al., 1973). Our objective was to ensure that N was nonlimiting for pasture growth throughout the trial.

Pasture Measurements

To estimate pasture availability and production, pre- and post-grazing paired quadrats were cut to ground level using electric shears, and herbage was dried to constant weight at 221 °F (105 °C). Immediately before cutting each quadrat, bulk height measurements were made with a rising plate meter and were regressed on the quadrat dry weights to develop a calibration equation. Fifty additional height measurements were taken and, using the calibration, paddock mass was predicted (O'Sullivan et al., 1985). Differences between pre- and post-grazing mass over grazing cycles were used to estimate net herbage accumulation (NHA) (Frame, 1981). At the same time that pre-grazing mass was estimated, additional samples were taken and dried in a forced-draft oven at 158 °F (70 °C) for determination of forage quality. Predictions of in vitro dry matter disappearance (IVDMD), crude protein (CP), and neutral detergent fiber (NDF) were made with near-infrared reflectance spectroscopy using calibration procedures outlined by Shenk and Westerhaus (1994). When appropriate, to estimate areas that were rejected because of fouling or an overabundance of forage, transects were randomly placed in each paddock. Each transect contained 100 marks at 12 in. intervals, and a trained observer recorded for each mark whether the grass immediately below it was "grazed" or "rejected." To evaluate the possible relationship between stocking rate and sward composition, tiller density was measured in early July, 1991. Five 4-in. diameter cores were taken from each nonsilage paddock, brought to the lab, and counts were made of tiller numbers for the species present (primarily Kentucky bluegrass and orchardgrass).

Supplementary Feeding

An experimental goal was to maintain comparable milk production per cow across treatments by providing grain and supplementary forage when pasture forage was inadequate. All cows were fed grain daily at the rate of approximately 1 lb of grain DM/4 lb of milk, with a minimum of 9 lb/cow daily and a maximum of 20 lb/cow daily. Cows were fed the grain individually in two equal feedings each day and the refusals were measured daily. The grain mix was corn (*Zea mays* L.)-based, with protein, vitamins, and minerals included and periodically adjusted to complement the nutrient content of the pasture. The amount fed was adjusted every 28 d based on the average milk yield during the previous 14 d. The grain ration fed in 1990 was corn based and in 1991 it contained both corn and barley (*Hordeum vulgare* L.). Supplemental protein, primarily soybean [*Glycine max* (L.) Merr.] meal, was added to make a grain ration that contained approximately 14% CP. Minerals were added to the ration to meet NRC (1989) requirements for lactating dairy cows. No buffers were included. Supplemental grass silage (previously harvested from the pastures) was individually fed if pasture availability per paddock fell below approximately 80% of that required for 1 to 2 d grazing, assuming forage needs per cow of approximately 3% of body weight (NRC, 1989). The grass silage for the 2 yr averaged approximately 15% CP, 32% acid detergent fiber, and 48% NDF. Amounts of silage fed were weighed and recorded for each cow and charged to the respective farmlets.

Animal Measurements

Milk yields were recorded at each milking. Milk samples were taken weekly at consecutive a.m. and p.m. milkings, with each milking analyzed separately for fat, protein, and somatic cell count. Weekly milk samples were analyzed for fat, total protein, and somatic cells by the Pennsylvania Dairy Herd Improvement Association (DHIA) lab, University Park, using a Foss 605B Milko-Scan (Foss Electric, Hillerod, Denmark). Cows were weighed at the beginning of the trial and at 4-wk intervals thereafter. Weights were recorded on two consecutive days, and the average of the two weights was used for analysis. Three independent observers scored cows for body condition based on a 1 to 5 scale (Wildman et al., 1982), where 1 = thin and 5 = fat at the same time that cows were weighed. The average value of the three observers was used for analysis.

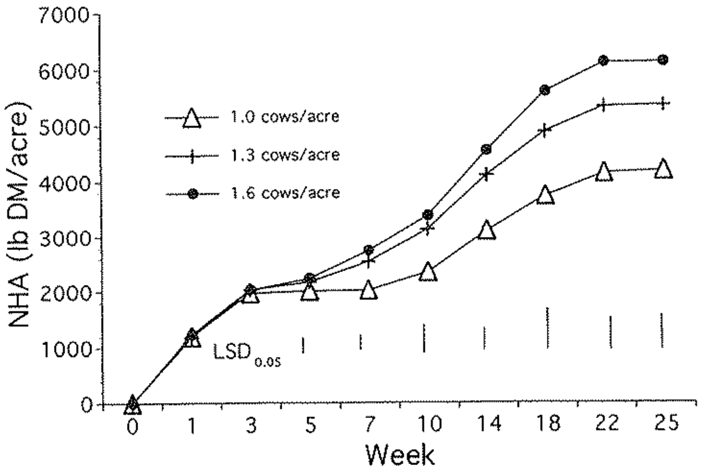

Fig. 2. Net herbage accumulation of mixed grass pastures grazed rotationally at three stocking rates durting 1990 (0 = April 23).

Statistical Analysis

For the animal data, the experimental design was a randomized complete block design (Steel and Torrie, 1980). The within-block replication was accomplished using field replicates, and there was no replicate within a block × field replicate unit. The model used for analyses was as follows:

$$Y = B + R + B^*R + SR + B^*SR + R^*SR + B^*R^*SR + W + SR^*W + B^*W + \text{error}$$

where B = blocks, R = field replicates, SR = stocking rate, and W = week. The block × replicate term was used as the error term to test the effect of block and replicate. In addition, repeated measures analyses were used (SAS, 1985). All means presented were least squares means.

Agronomically, the experimental design was a randomized complete block, with two replications of the three stocking rate farmlets. Data were analyzed for linear and quadratic responses to stocking rate using orthogonal comparisons in regression (Steel and Torrie, 1980; SAS, 1985).

Economic Analysis

Partial budgeting analysis was used to evaluate the effects of stocking rate on dairy profitability. This type of analysis includes only quantities and prices of inputs and outputs that change across treatments. Prices used in the analysis are reasonable estimates of those expected in the Pennsylvania dairy sector in the intermediate-run future. Those prices were used to reflect the relative profitabili-

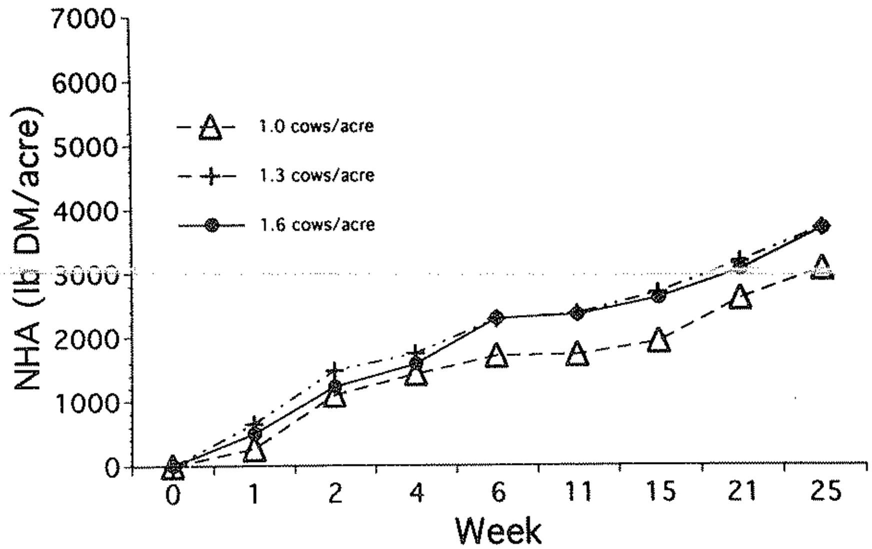

Fig. 3. Net herbage accumulation of mixed grass pastures grazed rotationally at three stocking rates during 1991 (0 = April 23).

Table 3. Effect of stocking rate on tiller density (tillers/sq ft) as assessed 1 yr after imposition of treatments (LSR, MSR, and HSR = 1.0, 1.3, and 1.6 cows/acre, respectively).

Treatment	Orchardgrass	Kentucky bluegrass	Other	Total
LSR	87	203	16	315
MSR	66	249	15	312
HSR	46	352	13	409
SR linear†	0.02	0.004	NS	0.015

† Significance of orthogonal polynomials in regression.

ty of the three stocking rates in normal weather years, rather than in the extremes in both weather and milk prices experienced during 1990 and 1991.

RESULTS AND DISCUSSION

Weather Conditions and Grazing Season

The 1990 grazing season was characterized by wetter than normal weather (Fig. 1), and grass growth was not limiting for most of the year. In 1990, grazing was initiated on 23 April and terminated on 14 October, for a total of 175 grazing days. In 1991, severe drought conditions prevailed during much of the season (Fig. 1). Grazing was initiated on 23 April and terminated on 21 October, for a grazing season of 182 d. Because of the drought in 1991 and the resulting low pasture availability, the MSR and HSR cows grazed evenings only during the month of June, which underscores the potential risk associated with higher stocking rates. Forage availability remained adequate for the LSR cows throughout the study, however. Spring grazing consisted of four 14-d cycles; summer and autumn grazing consisted of two 28-d cycles, each.

Pasture Production and Quality

For simplicity, data are presented as means across grazing cycles within each of three seasons: spring, summer, and autumn (Tables 1 and 2). Pasture growth varied with both year and stocking rate. While average daily growth rates (pounds per acre per day) tended to be directly related to stocking rate both years, the relationship was more pronounced in 1990, due to better growing conditions. In 1991, lack of moisture restricted pasture growth, thus increasing the effective grazing pressure for all stocking rates. In 1990, NHA ranged from a high of approximately 6800 lb DM/acre for the HSR to a low of 4600 lb DM/acre for the LSR (Fig. 2). In 1991, there were no stocking rate differences in NHA, and mean seasonal DM accumulation was less than 4000 lb/acre (Fig. 3). Pasture availability prior to grazing was inversely related to stocking rate both years, a result of the greater accumulation of herbage during the season at lower stocking rates. The lowest amounts of herbage available were observed for the summer cycles. Differences in growth rates and NHA due to treatment and season reflect the positive effect of higher grazing pressure on removal of old tissue and the production of new growth (Bircham and Hodgson, 1984). This concept is further supported by the results of tiller counts made during the second year of the trial (Table 3). Kentucky bluegrass tillers dominated at all stocking

Table 4. Seasonal silage production, and silage and grain use by dairy cows rotationally grazing at stocking rates of 1.0 (LSR), 1.3 (MSR), or 1.6 (HSR) cows/acre.

Treatment	Silage			Grain fed
	Harvested†		Fed	
	ton/treatment	ton/cow	ton/cow	ton/cow
		1990		
LSR	9.22	1.15	0.02	1.18
MSR	7.11	0.89	0.06	118
HSR	5.80	0.73	0.06	1.19
		1991		
LSR	9.16	1.14	0.85	1.37
MSR	6.94	0.87	0.98	135
HSR	5.62	0.70	1.03	1.35

† Silage from pasture = (Forage into silo) − (8% loss of forage in silo).

rates, and significantly increased in number with stocking rate. Orchardgrass tillers, however, declined with stocking rate. Because tiller weights were not recorded in this experiment, it is difficult to determine the exact effect of stocking rate on the relative productivity of each species in the sward. At all stocking rates, orchardgrass tillers were fewer in number than bluegrass tillers, but were larger; and orchardgrass, therefore, made a greater contribution to total pasture mass than is apparent from tiller number alone. Also, the decline in orchardgrass tillers with stocking rate probably reflects a decline in orchardgrass plants and hence a smaller contribution of orchardgrass to total sward mass, because it is unlikely that individual tiller mass would increase in response to greater grazing pressure. Further research is warranted on the effect of grazing pressure on botanical composition, structure, and productivity of multi-species indigenous pastures.

In 1990, use of pasture, as represented by estimated percentages of paddock area rejected, also showed a direct response to stocking rate (Table 1). Because it was influenced by both pasture growth rate and animal demand, the rejected proportion varied with season and year, however, with up to 44% of LSR paddock rejected during the spring. Several LSR paddocks exceeded 55% rejected at times during that period. In 1991, rejected areas were smaller due to drought and the resulting lower pasture availability and higher effective grazing pressure that year (Table 2). It should be stressed that the protocol for this study dictated that animal rotations be based on time (i.e., 2 d grazing per paddock) and not sward state (e.g., forage mass or height). Nevertheless, by accounting for differences in forage availability pre- and post-grazing for each grazing cycle, the relative efficiencies of the stocking rate treatments could be compared.

The accumulated rejected herbage was removed once in June each year in this experiment, effectively resetting all treatments to a comparable state. Many farmers typically clip pastures at this time for the same reason. Otherwise, the areas rejected during the period of rapid pasture growth in the spring will impair summer production because cows will not be inclined to graze them. Herbage rejection is an important consideration in pasture management because it reflects the efficiency of the system—herbage rejected in one cycle of rotational stocking is unlikely to be grazed during subsequent cycles and hence

Table 5. Summary of animal performance during 1990 and 1991 for Holstein cows in response to stocking rates of 1.0 (LSR), 1.3 (MSR), or 1.6 (HSR) cows/acre.

	Stocking rate									
	1990					1991				
Measurement	LSR	MSR	HSR	Mean	SE§	LSR	MSR	HSR	Mean	SE
Milk production/cow										
Milk, lb/cow/season	9 731	9 876	9 898	9 835	162	9 942	9 881	9 947	9 923	110
Milk, lb/cow/d	55.6	56.4	56.5	56.2	0.9	54.6	53.4	54.7	54.5	0.60
Milk fat, %	3.48	3.52	3.46	3.48	0.04	3.61	3.76	3.72	3.73	0.05
Milk protein, %	2.96	3.00	3.07	3.01	0.02	2.93	2.97	3.02	2.97	0.02
Milk fat, lb/cow/d	1.94	1.98	1.96	1.96	0.02	1.98	2.05	2.03	2.02	0.03
Milk protein, lb/cow/d	1.68	1.70	1.74	1.71	0.02	1.61	1.61	1.65	1.62	0.02
3.5% FCM, lb/cow/season†	9 702	10 123	9 830	9 885	190	10 121	10 293	10 302	10 238	130
Milk production/acre										
3.5% FCM, lb/acre	9 702	13 159	15 728	12 863		10 121	13 381	16 483	13 328	
Body condition changes										
Weight increase, lb/cow	72.3	108.9	113.2	98.1		168.9	148.2	147.3	154.8	
Body condition score‡	+0.31	+0.22	+0.39	+0.31		+0.25	+0.26	+0.31	+0.27	

† FCM = fat corrected milk.
‡ Increase in body condition according to visual scores on a scale of 1 to 5.
§ SE = standard error of the mean.

represents wasted DM. Therefore, where stocking rate (and hence grazing pressure) is too low, significant amounts of forage can go unharvested.

Herbage nutritional value was positively related to higher stocking rate throughout the grazing season in 1990 (Table 1), due to the more complete removal of leaf tissue at higher grazing pressures. A higher proportion of young tillers also was evident at the onset of each subsequent grazing cycle at the HSR compared with the LSR. Although a quantitative assessment of senescent tissue was not made, those areas of the LSR paddocks determined to have been grazed also appeared to have more senescent material than the grazed areas of the HSR paddocks. Response of all measured quality parameters to stocking rate was greater during periods of more rapid growth (spring and autumn vs. summer) in 1990. Average CP concentrations exceeded 20% of DM throughout both 1990 and 1991, and were similar for both years (Tables 1 and 2). In contrast to 1990, NDF generally was higher and IVDMD was lower in 1991, possibly due to the higher temperature and dry weather in 1991. Interestingly, in contrast to what was observed in 1990, quality differences due to stocking rate in 1991 were observed mainly during the summer, when CP and IVDMD were positively related and NDF concentration was negatively related to stocking rate (Table 2).

Silage, harvested from excess pastures in the spring, amounted to approximately 1.2 tons DM/acre of pasture harvested each year, and did not vary with stocking rate on a per acre basis (Table 4). Because of the differences in land area associated with the stocking rate treatments, however, approximately 60% more silage was harvested from the LSR than from the HSR paddocks, and this had a significant impact on the economics of the different systems.

Animal Response

In general, the overall milk production and composition were quite satisfactory for Holsteins of high genetic potential (Table 5). For reference, the Penn State University Holstein herd had a Dairy Herd Improvement Association (DHIA) yearly milk production average of about 20 000 lb milk/cow at the time of the study. No direct comparisons were available in the literature with high producing Holstein cows fed and managed under the experimental conditions of this study over an entire 6 mo grazing season. Somatic cell counts did not differ among stocking rate treatments either year.

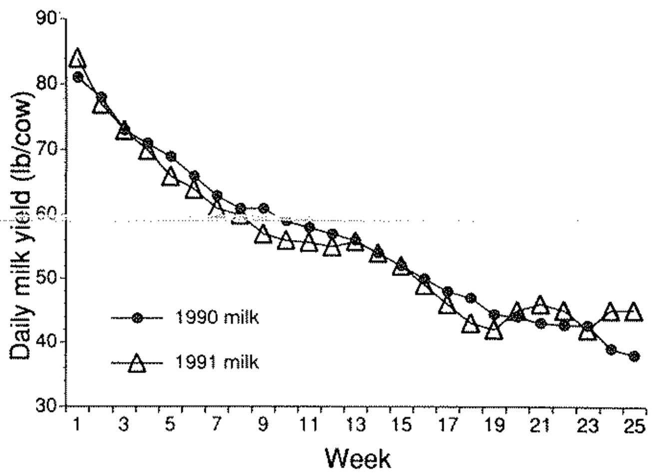

Fig. 4. Average daily milk yields of Holstein cows rotationally grazing mixed grass pasture during 1990 and 1991.

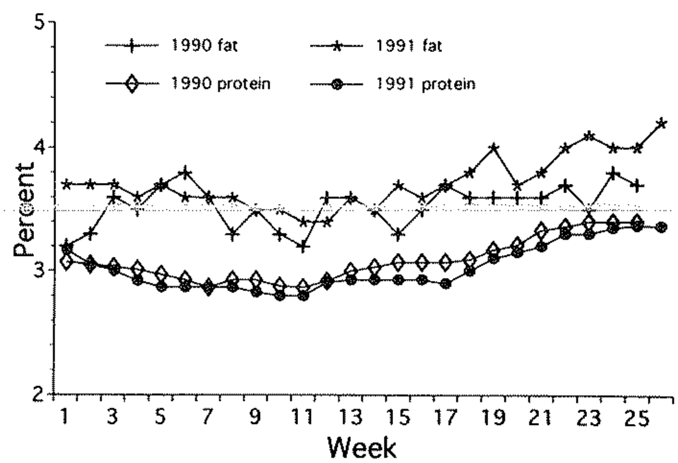

Fig. 5. Milk fat and milk protein percentage of Holstein cows rotationally grazing mixed grass pasture during 1990 and 1991.

Although no statistical comparisons can validly be made between the 2 yr, a few observations are worthy of mention. During 1991, cows tended to produce more milk with a higher milk fat percentage (Table 5). They also tended to gain more body weight. These small differences may be related to the greater amount of grass silage fed in 1991 than in 1990.

Due to favorable growth conditions during 1990, pasture supplied nearly all the forage needed by the cows that year, and most of the silage harvested in the spring remained at the end of the grazing season. Due to the drought in 1991, however, more silage was fed to the MSR and HSR cows than was harvested from their respective pastures. An average of 12 to 15 lb grain/cow daily was fed, with the amount decreasing from approximately 18 lb/d at the start of each year's trial to 10 lb/d at the end of the grazing season. Total seasonal grain consumption averaged 1.18 tons/cow in 1990 and 1.36 tons/cow in 1991 (Table 4).

Because of the management imposed (i.e., silage fed when pasture was limited), milk production per cow was similar for all stocking rates (Table 5), although the quality of the HSR paddocks was measurably higher than that of the LSR paddocks. Milk production per cow averaged about 55 lb/cow daily for both grazing seasons and no stocking rate differences were observed. Likewise, per cow milk fat percentage and yield, milk protein percentage and yield, body weight increase, and body condition changes did not vary with stocking rate (Table 5). Milk production per acre, however, was approximately 6000 lb higher for the HSR than for the LSR.

Whereas the overall trial values are of major importance, some trends in animal responses during the 6 mo grazing season are important for discussion. During the first 6 to 8 wk of the grazing season both years, all cows tended to decrease in milk yield more than is normally expected in a typical lactation (Fig. 4). This response also was observed by Hoffman et al. (1993) with high-producing Holstein cows, and corresponded to the period of highest pasture availability and quality. Furthermore, overall milk fat percentage (3.48%) tended to be lower in 1990 than the Pennsylvania DHIA average for Holsteins of 3.62% (Pennsylvania Dairyman's Association, 1992). Comparison of milk fat percentage by week across stocking rates followed rather typical patterns, with lower percentages during the early grazing season when cows were at or near peak milk production (Fig. 5). Total milk fat yield did not differ among stocking rates during either year. During both years, total milk protein tended to be lower than the Pennsylvania DHIA average of 3.16% for Holsteins. Milk protein concentration followed a normal pattern expected over a lactation period (Fig. 5), however. Cows at the three stocking rates both years gained body weight and condition over time. Average body condition scores were generally low (average of 2.7 at the end of both years), however, and the gain in condition during the trial was lower than typically desired (Fig. 6).

Economic Interpretation

The returns per cow over pasture and other feed costs during the grazing period for the six treatment-year outcomes are presented in Table 6. It should be emphasized that these returns are only the returns over costs that change with stocking rate in the study. They are not farm profits. Milk sales, adjusted for butterfat, were constant over stocking rates. Total returns for each outcome varied inversely with stocking rate, however, because of the value of the silage associated with each stocking rate. Note that the MSR and HSR ran short of silage in the drought year, 1991, and required the purchase of silage, shown in Table 6 as a negative return. This silage cost is partially offset by higher milkfat tests, however. Silage prices would be expected to be higher than those used

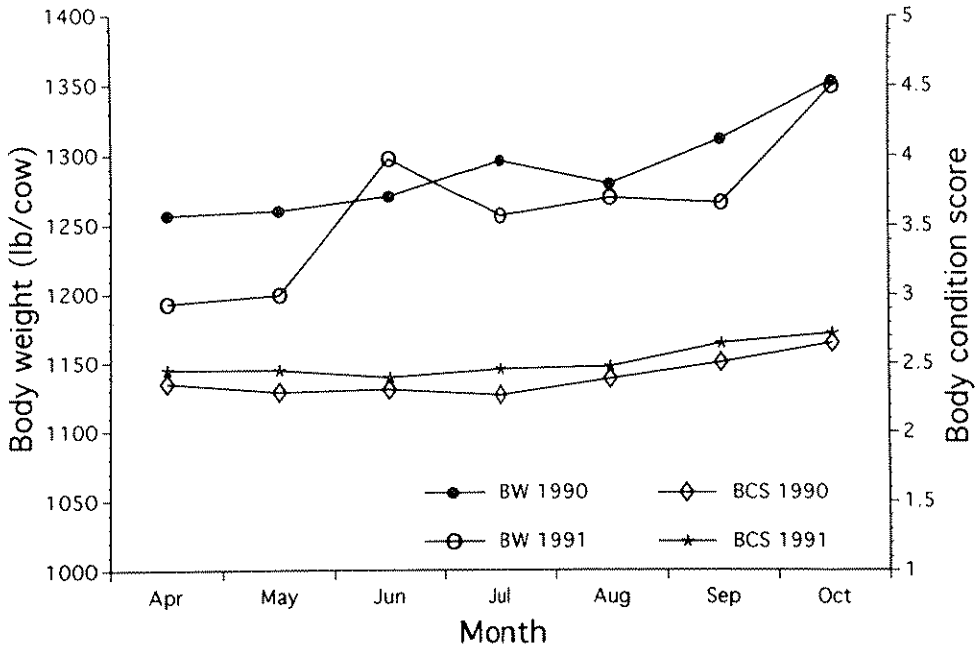

Fig. 6. Body condition scores (BCS) (scale 1 to 5) and body weight (BW) of Holstein cows rotationally grazing mixed grass pasture during 1990 and 1991.

Table 6. Grazing season costs and returns per cow for stocking rates of 1.0 (LSR), 1.3 (MSR), or 1.6 (HSR) cows/acre.

	1990			1991		
	LSR	MSR	HSR	LSR	MSR	HSR
Base milk sales, $12.50/cwt @ 3.5% BF	$1236	$1233	$1215	$1242	$1234	$1242
Butterfat payment, $0.075/point	−3	0	−2	16	19	9
Silage value at end of grazing, $40/ton	151	110	88	39	−15	−43
Total returns	1384	1343	1301	1297	1238	1208
Grain expense, $6/cwt	160	160	162	186	184	184
Land charge, $25/acre	25	19	16	25	19	16
Cow charge	121	121	121	121	121	121
Machinery cost, custom @ $46.50/acre	47	36	29	47	36	29
Fertilizer expense, $0.25/lb N	63	48	39	63	48	39
Labor cost, 3 h @$5/h	15	15	15	15	15	15
Total cost, $	431	399	382	457	423	404
Net return over costs shown	$953	$944	$919	$840	$815	$804

in this analysis in a year with widespread drought. Silage prices, however, would not be expected to appreciate significantly in the case of localized drought. Because the purpose of the economic analysis of the stocking rate issue is to evaluate a typical year, typical silage values are used to assess the economic impacts of the physical grazing and milk data of the 1990 and 1991 trials.

Ideally the economics of any particular management alternative should be evaluated as returns to the whole farm. Unfortunately, the evaluation of experimental data often precludes this approach due to the scale of the experiments. Profitability usually is evaluated at a return to a decision unit, because at the margin, farm decisions are based on returns to such individual decision units: either cows or area of land. The stocking rates in this study were evaluated as both returns per cow and returns per acre to demonstrate differences and conflicting interpretations of the results using the two methods.

The inputs were valued as shown in Table 6. Costs associated with pasture include grain fed, a charge for land, machinery operations, fertilizer, and labor associated with moving the cows between barn and pasture. Machinery operations were charged at average custom rates for one silage harvest on half of the total pasture acres, one clipping, and all fertilizer spreading (PASS, 1992). The labor charge can be thought of as part of the harvest system. Cow charges were $121/cow, based on an average annual cost for a $600 difference between purchase and cull price, ammortized over three lactations and using a 10% discount rate. Only half the annual charge was used to reflect a 6 mo grazing season. The land charge reflects the average rental value of pasture in Pennsylvania in 1992 (USDA, 1993). These costs also vary inversely with stocking rate. Additionally, they were slightly higher during the drought year because of added grain fed.

The economic comparison of the MSR and HSR compared with the LSR are presented in Table 7. When profitability is measured per cow, the LSR had an $18 and a $36 advantage over the MSR and HSR, respectively. When profits are measured as return per acre, however, the HSR shows an advantage of $481 over the LSR, and the MSR shows a $247 advantage over the LSR.

Table 7. Comparison of net returns from 1.3 cows/acre (MSR) and 1.6 cows/acre (HSR) to net returns from 1.0 cows/acre (LSR) (average of both years for same treatment).

	MSR	HSR
Advantage/cow	−$18	−$36
Advantage/acre	$247	$481
Advantage/cwt	−$0.14	−$0.28

The sensitivity of the return per cow relationships can be evaluated by adjusting costs that are allocated on a per acre basis—fertilizer, machinery, and land—to breakeven levels. These costs (associated with units of land) averaged $141/acre. If, for example, they increased by 54% ($76), then the MSR would become the most profitable. The HSR becomes most profitable when those costs are increased 110% ($155). Therefore, if land rent was valued at over $100 instead of $25 as in Table 6, the MSR would be the most profitable. A similar evaluation could be made for the high rate.

The choice of optimal stocking rate depends on relative prices of inputs and outputs and also farm resource endowments. If land is scarce, then the return per acre suggests that the HSR is the most profitable. Conversely, if land is relatively plentiful and cow capacity is limiting, the LSR is most profitable. If the rental value or the value of an alternative use of the land is relatively high (in effect an indication of its scarcity), however, the relative profitability per cow among the stocking rates will change.

The profit levels of the different stocking rate alternatives evaluated in this study are relatively comparable depending on the scarcity of land as reflected by rental rates for pasture. The implications is that stocking rate can be adjusted to meet individual farm resource constraints without fear of significant adverse economic impact, at least within the bounds evaluated in this study. An additional insight offered by this study is the importance of properly evaluating stocking rate profitability. In the absence of whole-farm analysis, stocking rate should be evaluated based on returns to the most scarce resource.

CONCLUSIONS

Results of this trial represent a snapshot, illustrating for two grazing seasons the sensitivity of pasture and animal production, and farm economics to stocking rate. From the agronomic perspective, stocking rate had a positive effect on pasture productivity, quality, and the efficiency of use—but only under conditions of good pasture growth. When plant growth was limited, these advantages of higher grazing pressure diminished, pointing to the desirability of maintaining flexibility in a grazing system. Setting the stocking rate to allow the harvesting of excess pasture as hay or silage in the spring is one way to achieve that flexibility. One aspect of HSR that was not addressed in this study is the potential effect on pasture development and long-term productivity. Our data indicate that increasing stocking rate encouraged Kentucky bluegrass and discouraged orchardgrass. Additionally, increasing stocking rate tended to enhance sward nutritional value. What are the long-term consequences of this trend, and what might the trade-offs be between higher sward quality and a restriction in management alternatives? Over time, the increased nutritional value might make possible a further reduction in concentrate feeding. From the negative standpoint, it also could be argued that a reduction in management flexibility might arise, due to the replacement of the taller-growing orchardgrass by the more prostrate bluegrass, which is less conducive to mechanical harvesting. While this might not be a serious problem where other sources of hay or silage are available, it could be an important consideration if an effort is being made to optimize the system and minimize inputs, recognizing that external sources of forage do have associated costs.

From the animal perspective, the results of this study show that by feeding concentrates and by being prepared to feed conserved forage if pasture is limiting, producers can increase the number of animals per unit area (at least within the range of stocking rates in the current trial) while maintaining satisfactory per cow performance. This is in contrast to stocking rate research results from New Zealand (e.g., McMeekan and Walshe, 1963; Holmes and Parker, 1992), where supplementary grain or forage generally is not fed and animal productivity is allowed to fall as pasture availability declines.

Our findings point to the possibility for increasing per acre profitability significantly, simply by increasing cow numbers per acre of pasture. We have observed that most of the dairy farms in the Northeast currently under some form of intensive grazing are understocked (Cunningham, 1993, unpublished data; Parker et al., 1993). While some of this can be attributed to inexperience and the resulting inability to match animal demand with expected pasture production, it also has much to do with the perception of risk minimization—it is better to waste forage in a "good" year than to be short of forage in a "bad" year. It is probable, however, that as graziers gain experience and confidence in their pastures, they will increase their stocking rates, and our data support that approach as both biologically and economically valid.

REFERENCES

Baker, A.M.C., and J.D. Leaver. 1986. Effect of stocking rate in early season on dairy cow performance and sward characteristics. Grass Forage Sci. 41:333-340.

Bircham, J.S., and J. Hodgson. 1984. The effect of change in herbage mass on herbage growth and senescence in mixed swards. Grass Forage Sci. 38:323-331.

Donohue, S.J., C.L. Rhykerd, D.A. Holt, and C.H. Noller. 1973. Influence of N fertilization and N carryover on yield and N concentration of *Dactylis glomerata* L. Agron. J. 65:671-674.

Emmick, D.L., and L.F. Toomer. 1991. The economic impact of intensive grazing management of fifteen dairy farms in New York State. p. 19-22. *In* Proc. Forage and Grassland Conference, Columbia, MO. 1-4 Apr. Am. Forage and Grassl. Council, Georgetown, TX.

Frame, J. 1981. Herbage mass. p. 39-70. *In* Sward measurement handbook. J. Hodgson et al. (ed.) Br. Grassl. Soc. Hurley, Maidenhead, Berkshire, UK.

Harris, W. 1990. Pasture as an ecosystem. p. 75-131. *In* R.M. Langer (ed.) Pastures: Their ecology and management. Oxford Univ. Press, Oxford.

Hoffman, K., L.D. Muller, S.L. Fales, and L.A. Holden. 1993. Quality evaluation and concentrate supplementation of pasture grazed rotationally by lactating cows. J. Dairy Sci. 76:2651-2663.

Holmes, C., and W.J. Parker. 1992. Stocking rate and its effects on dairy farm profitability. Dairy farming annual. Dep. of Anim. Sci., Massey Univ., NZ. p. 4-15.

King, K.R., and C.R. Stockdale. 1980. The effects of stocking rate and nitrogen fertilzier on the productivity of irrigated perennial pasture grazed by dairy cows. 2. Animal production. Aust. J. Exp. Agric. Anim. Husb. 20:537-542.

Leaver, J.D. 1985. Milk production from grazed temperate grassland. J. Dairy Res. 52:313-344.

McMeekan, C.P., and M.J. Walshe. 1963. The interrelationships of grazing method and stocking rate in the efficiency of pasture utilization by dairy cattle. J. Agric. Sci. (Camb.) 61:147-166.

Mott, G.O. 1961. Grazing pressure and the measurement of pasture production. p. 606-611. *In* C.L. Skidmore (ed.) Proc. 8th Int. Grassl. Congr., Reading, England. 11-21 July 1960. Br. Grassl. Soc., Hurley, Maidenhead, England.

National Research Council. 1989. Nutrient requirements of dairy cattle. 6th ed. Natl. Acad. Press, Washington, DC.

O'Sullivan, M., W.F. O'Keefe, and M.J. Flynn. 1985. The value of pasture height in the measurement of dry matter yield. p. 833-834. *In* T. Okubo (ed.) Proc. 15th Int. Grassl. Congr., Kyoto, Japan. 24-31 Aug. Natl. Grassl. Res. Inst., Nishi-nasumo, Tochigi-ken 329-27 Japan.

Parker, W.J., W.T. McSweeney, and L.D. Muller. 1991. A physical and financial comparison of dairy farming in Pennsylvania and New Zealand. Staff Paper no. 195. Dep. Agric. Econ. and Rural Soc. Pennsylvania State Univ., University Park, PA 16802.

Parker, W.J., L.D. Muller, S.L. Fales, and W.T. McSweeny. 1993. A survey of dairy farms in Pennsylvania using minimal or intensive pasture grazing systems. Prof. Anim. Sci. 9:77-85.

Pennsylvania Agricultural Statistics Service. 1992. Pennsylvania's 1992 machinery custom rates. PASS-110. Pennsylvania Agric. Stat. Serv. Harrisburg.

Pennsylvania Dairyman's Association. 1992. Yearbook of Pennsylvania Dairy Herd Improvement Assoc. PDA, New Cumberland, PA.

SAS Institute. 1985. SAS users guide: Statistics. Version 5 ed. SAS Inst., Cary, NC.

Shenk, J.S., and M.O. Westerhaus. 1994. The application of near infrared reflectance spectroscopy (NIRS) to forage analysis. p. 406-449. *In* G.C. Fahey (ed.) Forage quality, evaluation, and utilization. ASA, CSSA, and SSSA, Madison, WI.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics, a biometrical approach. (2nd ed.) McGraw-Hill, New York.

Tranel, L., and G. Frank. 1991. Dairy pasture economics. p. 6-7. *In* Managing the farm. Vol. 24(4). Dep. of Agric. Econ., Univ. of Wisconsin, Madison, WI 53706.

USDA. 1993. Agricultural resources - agricultural land values - situation and outlook report. AR-31. USDA-ERS, Washington, DC.

Wildman, E.E., G.M. Jones, P.E. Wagner, R.L. Bowman, H.F. Troutt, Jr., and T.N. Lesch. 1982. A dairy cow body condition scoring system and its relationship to selection production characteristics. J. Dairy Sci. 65:495.