Grazing, stocking, and production efficiencies in grazing research

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Abstract

The term *harvest efficiency* has been used with increasing frequency to describe results of intensive grazing management. A concept of harvest efficiency for grazed systems, i.e., a *grazing efficiency* concept compatible with the dynamics of herbage growth and disappearance is needed. This paper (1) describes variables and objectives needed in constructing a concept of grazing efficiency, (2) offers a formal definition of the term, (3) defines 2 other efficiencies related to grazing efficiency, and (4) discusses the interpretation and use of grazing efficiency and the other efficiencies in grazing research. More effective application of the efficiency concepts will require improved methods of measuring or modeling herbage growth and disappearance.

Key Words: grazing systems, grazing management, harvest efficiency, herbage dynamics, standing crop

In recent years, several authors (Stuth et al. 1981, Heitschmidt et al. 1982, Heitschmidt 1984, Walker 1984, Heitschmidt et al. 1987) have used the terms *harvest efficiency* or *defoliation efficiency* to evaluate and describe results of grazing trials. During this time, the explicit and implicit definition of *harvest efficiency* has both evolved and varied, leaving a need for an improved conceptualization and definition of harvest efficiency for grazed systems, i.e., a grazing efficiency. This paper (1) briefly describes the variables and objectives needed in constructing a concept of grazing efficiency, (2) offers a formal definition of the term, (3) defines 2 other efficiencies related to grazing efficiency, and (4) discusses the interpretation and use of grazing efficiency and the other efficiencies in grazing research.

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Constructing a Concept of Grazing Efficiency

Certainly some of the variation in the definition of grazing efficiency has resulted from efforts to construct a concept to fit available data, rather than obtaining data to fit an appropriate concept. The latter procedure is preferred and Figure 1 shows the 3 rate variables which add to or substract from standing crop (SC), and are important in defining grazing efficiency. The standing crop is dynamic, with both new herbage being added and existing herbage disappearing at most times.

A sound concept of grazing efficiency should be based on rigorous definitions of the variables shown in Figure 1 and able to deal with the changes indicated. Hodgson (1979) observed that the definition would preferably be developed in terms of new growth, rather than net herbage accumulation, even though the measurement of new growth is seldom attempted. Values of grazing efficiency should range from 0–100%. A grazing efficiency of 100% need not represent ideal management in any sense, but it should indicate that 100% of the existing herbage (in the SC compartment at time t_0) and the amount growing over some period of time $t-t_0$ has been grazed during the time $t-t_0$.

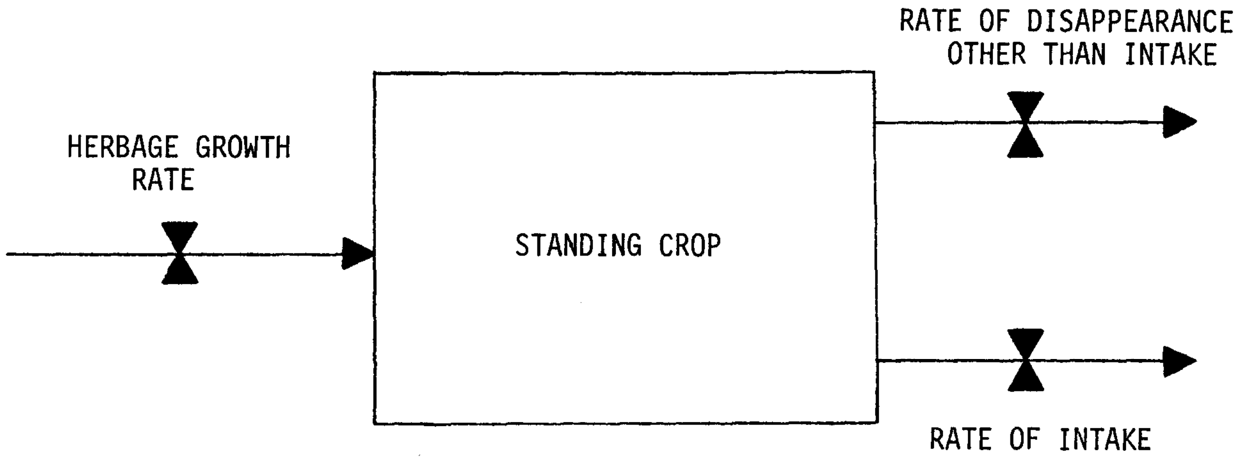

Fig. 1. *A model of dynamics of herbage growth and disappearance, with standing crop and rate variables important in formulating a concept of grazing efficiency. Rate of disappearance = rate of intake + rate of disappearance other than intake.*

A mathematical formulation of grazing efficiency which meets these criteria is

Equation 1

$$\text{grazing efficiency (during time } t\text{-}t_0) = \frac{\text{total intake}_{(t-t_0)}}{A \times [\text{cumulative herbage growth}_{(t-t_0)} + SC_{t_0}]} \times 100\%,$$

where the grazing efficiency (%) is calculated over a discrete period of time t-t_0, total intake $_{(t-t_0)}$ is the herbage intake during t-t_0 of animals whose grazing efficiency is being calculated, cumulative herbage growth (CHG) (Scarnecchia and Kothmann 1986) is the amount of new herbage growth per unit area during t-t_0, SC_{t_0} is the standing crop (kg herbage per unit area) in the SC compartment (Fig. 1) at time t_0, and A is the area of land grazed.

As can be seen in Figure 1, grazing efficiency may also be calculated as:

Equation 2

$$\text{grazing efficiency (during time } t\text{-}t_0) = \frac{\text{total intake}_{(t-t_0)}}{A \times [\text{cumulative herbage disappearance}_{(t-t_0)} + SC_t]} \times 100\%,$$

where cumulative herbage disappearance (CHD) (Scarnecchia and Kothmann 1986) is the amount of herbage per unit area leaving the standing crop during time t-t_0, including the amount of livestock intake and grazing by other herbivores.

The grazing efficiency calculated in equations 1 and 2 can refer to the efficiency of grazing of livestock alone and/or other herbivores. Whatever intake is described in the numerators, Equations 1 or 2 will calculate the grazing efficiency for the appropriate animal or animals. In range livestock research, the grazing efficiency of livestock, calculated using the total herbage intake of livestock alone will most often be of interest. In any case, all intake contributes to cumulative herbage disappearance in Equation 2.

The approach shown in Equations 1 and 2 has distinct conceptual advantages over other recently published approaches. It differs from the method of Stuth et al. (1981) in which the denominator in Equation 1 is replaced by a cumulative herbage disappearance (Scarnecchia and Kothmann 1986) excluding intake, in that (1) grazing efficiency cannot be greater than 100%, and (2) grazing efficiency represents the efficiency of harvest of both the standing crop at the beginning of grazing and the cumulative herbage growth during grazing.

Stocking Level and Grazing Efficiency

The methods of Stuth et al. (1981) and Heitschmidt et al. (1987) use stocking level (animal-unit-days(AUD)/ha) in the calculation of grazing efficiency. There are some sound conceptual reasons not to do these without a direct, independent estimate of intake per animal-unit stocked. For example, Heitschmidt et al. (1987) estimated intake from the calculation [AUD/ha]* [kg/AUD], where [AUD/ha] is the stocking level and [kg/AUD] is a standardized intake/AUD conversion of 11.8 kg/AUD (Society for Range Management 1974). In that example, not only is the animal-unit being inappropriately used as a unit of intake (Scarnecchia 1985, Scarnecchia and Gaskins 1987), but without an independent estimate of intake, the calculated grazing efficiency becomes a direct and exclusive function of stocking level; i.e., double the stocking level, double the efficiency. Grazing efficiency should not be exclusively a function of animal numbers, animal-units, or stocking level, but should be sensitive to changes in total intake and cumulative herbage growth in Equation 1.

Parallel Concepts

Animal-unit-days may be properly used in calculating a relationship which is here termed *stocking efficiency*. The relationship of animal demand over a period of time t-t_0 to both the standing crop at the beginning of grazing and the cumulative herbage growth during that time may be expressed as

Equation 3

$$\text{stocking efficiency (during time } t\text{-}t_0) = \frac{\text{total animal demand}_{(t-t_0)}}{A \times [\text{cumulative herbage growth}_{(t-t_0)} + SC_{t_0}]},$$

where total animal demand is expressed in AUD. Like grazing efficiency, stocking efficiency is defined over a period of time, but whereas grazing efficiency is an intake/supply relationship, stocking efficiency is a demand/supply relationship. Stocking efficiency is not a unitless percentage as is grazing efficiency and has units of AUD/kg. Also stocking efficiency does not have mathematical limits on its value, although in real systems its value is limited by realistic levels of animal demand and herbage. Analogous to grazing efficiency, stocking efficiency can also be described by the equation

Equation 4

$$\text{stocking efficiency (during time } t\text{-}t_0) = \frac{\text{total animal demand}_{(t-t_0)}}{A \times [\text{cumulative herbage disappearance}_{(t-t_0)} + SC_t]}.$$

Also analogous to grazing efficiency, stocking efficiency may be calculated for any animal or animals whose units of demand may be modeled and summed for the numerators of Equations 3 and 4.

It may be considered a special variation of cumulative grazing pressure or grazing pressure index (Scarnecchnia and Kothmann 1982) one calculated using initial or final standing crops and cumulative herbage growth or disappearance, respectively.

Another parallel concept is derived by replacing the numerator of Equations 3 or 4 by a unit of animal production, so that

Equation 5

$$\text{production efficiency (during time } t\text{-}t_0) = \frac{\text{animal production (appropriate units)}_{(t-t_0)}}{A \times [\text{cumulative herbage growth}_{(t-t_0)} + SC_t]}.$$

Any appropriate unit (kg body weight, kg milk, kg wool, etc.) will serve in describing animal production, and the resulting efficiency describes the amount of animal production relative to both the standing crop at the beginning of grazing and the herbage growth during grazing. A production efficiency is described in (units of animal production/units of herbage), and is a production/supply relationship parallel to stocking efficiency. There are no mathematical limits on its value; it may be negative if animal production is negative. Analogous to both other efficiencies, it may be alternatively defined as

Equation 6

$$\text{production efficiency (during time } t\text{-}t_0) = \frac{\text{animal production(appropriate units)}_{(t-t_0)}}{A \times [\text{cumulative herbage disappearance}_{(t-t_0)} + SC_t]}.$$

Like the other efficiencies, production efficiency may be calculated for any animal or animals whose units of production may be measured or modeled *and* summed for the numerators of Equations 5 and 6.

Interpretation and Use and Grazing, Stocking and Production Efficiencies

The 3 efficiencies (Equations 1-6) would usually be calculated on an herbage dry matter basis, but if advantageous for specific objectives, they may also be calculated on a wet basis. The 3 efficiencies may be calculated for animals grazing different forages, animals grazing at different stocking densities, different kinds or classes of animals grazing the same forages, or any of the many comparisons possible in case studies of livestock grazing (Scarnecchia 1988). If periods of grazing are 1 or 2 days, and rates of herbage growth and non-intake disappearance are slow, they may be assumed to be insignificant, and pre-harvest and post-harvest clipping, along with a direct independent estimate of intake may give reasonably accurate calculations of grazing efficiency. If herbage growth or non-intake disappearance is rapid, or if $t\text{-}t_0$ exceeds a few days, accurate estimates of either CHG or CHD will be needed so that values of harvest efficiency and the other efficiencies are not overwhelmed by propagated error. Clean, simple methods of estimating CHG and CHD await development. Most existing methods are of questionable accuracy and are time consuming (Davies 1981). Empirically based simulation methods may be the best prospects.

Grazing efficiency or the other 2 efficiencies should not be maximized independent of other considerations. As defined in this paper, they are derived variables relating intake, animal demand, and animal production, respectively, to a dynamic description of aboveground herbage. They should be used along with appropriately chosen stocking variables and herbage characteristics to scientifically describe and fine-tune grazing to meet the objectives of management.

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