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Modelling the growth and utilisation of kikuyu grass (*Pennisetum clandestinum*) under grazing. 2. Model validation and analysis of management practices

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Abstract

This paper presents validation results and some management applications of a Tropical Pasture Simulator. The effects of different environmental conditions, N fertilisation regimes and grazing intensities are analysed, and physiological concepts are used to aid in the interpretation of the responses obtained. The model demonstrates the importance of flexible management guidelines depending on environmental conditions. It stresses the need for an increased understanding of the processes controlling the development and senescence of the sward, since these largely influence the responses to nutrients and determine sward structure. Strategies based on morphological indicators such as number of live leaves were derived in order to develop simple and applicable pasture management guidelines at the farm level. Examples are presented with reference to kikuyu grass (*Pennisetum clandestinum*) production and utilisation in dairy systems in the highlands of Costa Rica. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The profitability and sustainability of tropical dairy grazing systems is largely based on efficient management of resources at the farm level. Of special importance is the role of grazing management, since it has multiple effects at various levels within the farming system. It plays a central role in land use, animal productivity, external resource use and the economic, social and environmental sustainability of the farming system (see Humphreys, 1991, for a review).

This paper examines the role of a grass growth and utilisation model (Herrero et al., 2000), which is a component of a whole dairy farm decision support system (Herrero et al., 1996, 1997, 1999), for resolving grazing management and pasture production issues in tropical dairy systems. The effects of different environmental conditions, N fertilisation regimes and grazing intensities are analysed, and physiological concepts are used to aid the interpretation of the responses obtained. The model demonstrates the importance of flexible management guidelines depending on environmental conditions. It stresses the need for an increased understanding of the processes controlling the development and senescence of the sward, since these largely influence the responses of pastures to available nutrients and determine sward structure.

Morphological indicators, such as number of leaves, can provide the basis for developing simple management rules at the farm level (Fulkerson and Slack, 1994; Reeves et al., 1996). Therefore, to increase the applicability of the model on the ground, another objective of this paper was to develop these indicators for kikuyu pastures in dairy systems in Costa Rica, and to study the factors affecting them.

2. Model performance and analysis of management practices

2.1. Herbage mass, responses to fertiliser and sward growth

The performance of the grass growth and utilisation model presented in a companion paper (Herrero et al., 2000) was tested in several ways using data from the Poás region, Costa Rica, and data from various authors.

The data from the Poás region consisted of herbage mass and botanical composition of rotationally grazed paddocks from four farms (Herrero, 1997). Since cows were highly supplemented with concentrates, pasture utilisation was consistently low (15–30% green dry matter [GDM]) across all farms, thus masking any management effects on pasture production. There was little variation in the pre-grazing instantaneous herbage mass between farms (5.6–6.4 t/ha), even when rest periods varied from 25 to 35 days. Nevertheless, model outcomes were within 10% (5.2–6.4 t/ha) of the observed results. When the results were expressed on a GDM basis, model outcomes were equally close to the field data (observed 3.6–5.2 t/ha vs. predicted 3.2–5.0 t/ha). Similar results were obtained when simulating the data of Whitney (1976).

The efficiency of response of kikuyu grass to N fertiliser ranged from 13 to 27 kg dry matter (DM)/kg N (Mears, 1970; Kemp, 1975; Colman and O'Neill, 1978; Soto

et al., 1980; Tainton et al., 1982; Cook and Mulder, 1984; Consentino et al., 1985). The model was tested up to N fertiliser levels of 400 kg N/ha at temperatures between 10 and 20°C and the responses obtained ranged from 11.7 to 23 kg DM/kg N, which are clearly in the range observed in the literature. The magnitude of the response was dependent on the growth stage of the pasture (see below) and on the basal soil N content. The lower the N content of the soil, the higher the response to applied fertiliser; and the higher the fertiliser application the lower the response to additional N. Both factors are qualitatively correct and the magnitude of the responses agree with the literature.

It is difficult to validate this type of model from a physiological perspective, since data for comparisons are usually scarce. However, Murtagh (1987) and Murtagh et al. (1987) did some experiments on the respiration rate of kikuyu grass, and quoted values of 11 and 15 mg/g/day for specific maintenance respiration rates at 15 and 20°C, while the model predicts rates of 10.1 and 18 mg/g/day, respectively. Another way of testing the physiological responses was to observe the magnitude of the storage fraction (W_s) relative to the total crop weight. This fraction contributed to less than 10% of the total herbage mass and declined with temperature, which confirms the results of Betteridge (1979), Ito et al. (1985), Marais and Figenschou (1990) and Reeves et al. (1996), who suggested that kikuyu had a low storage/structural carbohydrate ratio. These results suggest that the physiological relations of the C cycle in the model are accurate enough for predictive purposes.

The root sections of the model are also difficult to assess since there is no accurate data. However, Mears and Humphreys (1974) in an experiment in New South Wales, Australia, included data on root mass and above-/below-ground plant organs, and found that root mass was generally similar or higher than the above-ground herbage mass, which agrees with the model outcomes. This is due mainly to the structure of the partitioning functions, which try to optimise a balance between both above- and below-ground organs.

In general terms, estimation of pasture availability was surprisingly accurate and responded realistically to the environmental variables tested, which suggests that the structure of the Hurley models is robust and also convenient for modelling tropical pasture growth in vegetative stages.

2.2. Responses to grazing

Assessment of the responses to grazing was done by testing the grazing functions and the allometric scaling of parameter K (see Herrero et al., 2000). Simulations were run for swards with green herbage masses close to where intake begins to be limited (1200–2400 kg GDM/ha) and with proportions of leaf commonly found in the literature (0.3–0.7). Results were obtained for animals ranging from 50 to 800 kg body weight (BW) in 50-kg increments and response surfaces where constructed to present the results.

Fig. 1 shows model results for the effects of altering the proportion of green leaf in the sward on the functional response between intake and green herbage mass for animals of different body sizes. Although larger animals are able to consume the
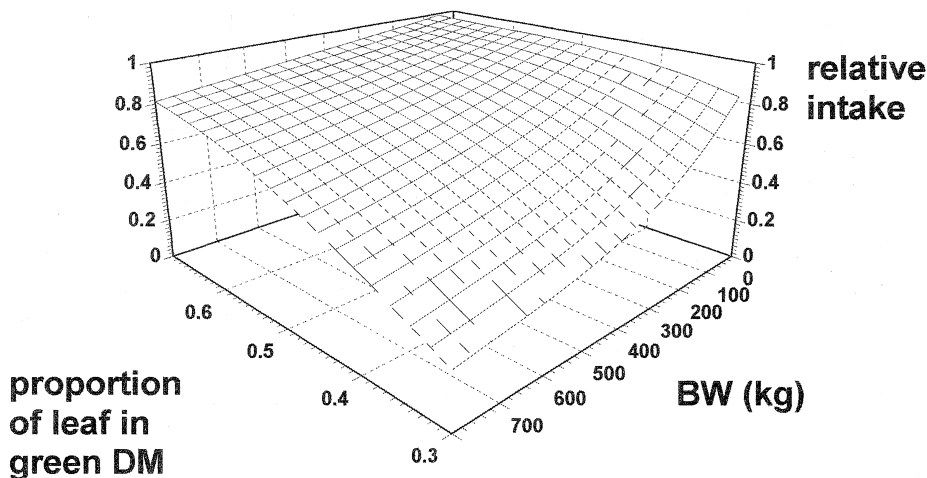
Fig. 1. Effect of changes in the morphological composition of green dry matter (DM) (at 1500 kg/ha) on the relative pasture intake of ruminants of different body weights (BWs, kg).

stem fraction to a certain limited extent (modified by the density of the lower sward horizons), their intake is more affected as the proportion of leaf (i.e. which reflects leaf area index [LAI], and therefore sward height) is reduced, which agrees with the results of Stobbs (1975) and Illius and Gordon (1987). Smaller animals have a great advantage due to their higher capacity to graze in shorter swards due to mouth size diffferences.

In swards where potential intake can be attained, intake scales allometrically to $BW^{0.75}$ (Brody, 1945; ARC, 1980; Peters, 1983; Illius and Gordon, 1987), while on short swards the allometric coefficient tends to decrease (Illius and Gordon, 1987). However, there might be partial compensation at low herbage masses due to body size differences in diet selection as animals may weight energetic costs and benefits of harvesting plant fractions (Hodgson, 1985; Illius et al., 1995), with larger animals being able to graze less selectively (Stobbs, 1975; Gordon et al., 1996). Taking the 0.75 allometric coefficient as the base level, deviations from potential intake were calculated for animals of different body sizes grazing at five green herbage masses between 1200 and 2400 kg/ha and five proportions of leaf material from 0.3 to 07. Allometric equations described by $X = A \times BW^{B}$, were fitted on the deviations from intake for each combination, and the estimated values for the B parameter were graphically represented in Fig. 2. All equations were fitted accurately ($R^2 = 0.85$–0.99), and parameters were obtained with very low coefficients of variation (cv < 10%). The A parameter always decreased (0.24–0.0008) as the B coefficient increased.

Fig. 2 demonstrates that the effects of reducing the proportion of leaf in the swards on the allometric coefficient are greater than the effects of herbage mass per se; and demonstrates why smaller animals can graze at lower herbage masses before reductions in intake occur. This gives further justification to the fact that leaf mass, which is a predictor of sward height or LAI (Penning et al., 1991; Parsons et al.,
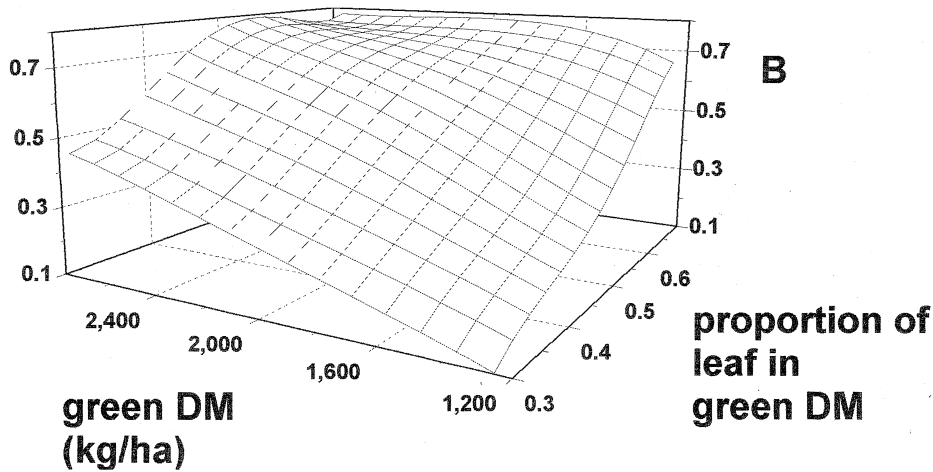
Fig. 2. Effect of green herbage dry matter (DM, kg/ha) and botanical composition on the allometric scaling coefficient (*B*) of intake of grazing ruminants.

1994) largely determines the responses of ruminants to grazing (Johnson and Parsons, 1985; Illius and Gordon, 1987; Laca et al., 1992; Flores et al., 1993; Illius et al., 1995), and also explains why studies based on total herbage mass without considering the morphological composition of the sward or attributes representing it (LAI, sward height), often fail to describe grazing processes adequately (Allden and Whittaker, 1970; Hodgson, 1986; Ungar and Noy-Meir, 1988).

The response surface in Fig. 2 is also useful to estimate at what herbage masses, intake stops being proportional to $BW^{0.75}$. Different sward characteristics produce different ways of achieving intakes proportional to $BW^{0.75}$. For example, only 1500 kg GDM/ha are required if the sward contains 0.7 of leaf material, while almost twice would be required if the sward contains only 0.4 of leaf. These results provide an explanation of why utilisation of tropical pastures in humid tropical regions, which are often low in leaf material is most of the times low, when expressed on total herbage mass basis (Humphreys, 1991), and would also provide an explanation for the wide variety of shapes on the functional responses between herbage mass and intake reported by several authors (Herrero et al., 1998). Although the results were reported down to very low allometric coefficients (< 0.36), it is quite likely that below this level the forage might be physically unavailable to grazing animals, or animals might be reluctant to graze due to the relative energetic costs of harvesting the material.

This simple function provides an advantage over other empirical relationships between sward characteristics and intake of grazing ruminants. While other relationships are fixed (see Herrero et al., 1998, for a review), have empirical coefficients, and are commonly related to total herbage mass, this equation acknowledges the effects of body size and sward morphology on the functional response in a realistic and biologically explainable way. It also links physiologically the resource capture by plants with the grazing process by maintaining the relationship with LAI.

2.3. Applications to grassland management

Several simulations were done to study the effect of temperature and irradiance on the regrowth of kikuyu grass, in order to represent kikuyu grass growing in different highland regions or latitudes. In real life, these two effects are very difficult to separate since both variables follow the same seasonal cycle. These limitations simply show the advantages of using simulation models to study independently these effects.

2.3.1. Irradiance

An analysis of solar radiation records from Wollongbar, New South Wales, Australia (latitude 28°50′ S; Murtagh, 1990) and Poás, Costa Rica (latitude 10°01′ N) fitted to the 20°C light response curve (Herrero et al., 2000), indicated that solar radiation is unlikely to be a major source of variation in photosynthesis between those latitudes, because of the small difference in their seasonal irradiance ranges and the small slope of the light response curve as it reaches its asymptotic value at saturating light levels (P_{max}) (Herrero, 1996). This would explain why Murtagh (1988) found no significant effect of total solar radiation on kikuyu grass growth rate between 12 and 30 $MJ/m^2/day$ in experiments at Wollongbar.

2.3.2. Temperature

The temperature effects on the regrowth of kikuyu grass can be observed in Fig. 3. It shows that the rest period of kikuyu grass paddocks should be different at different temperatures if high green herbage masses are required. As temperature increases, the regrowth period should decrease. These results also show that, for example, at 17 °C, the year round temperature in Poás, with rotation lengths of more than 25 days, increased senescence and respiration losses would prevent the net accumulation of
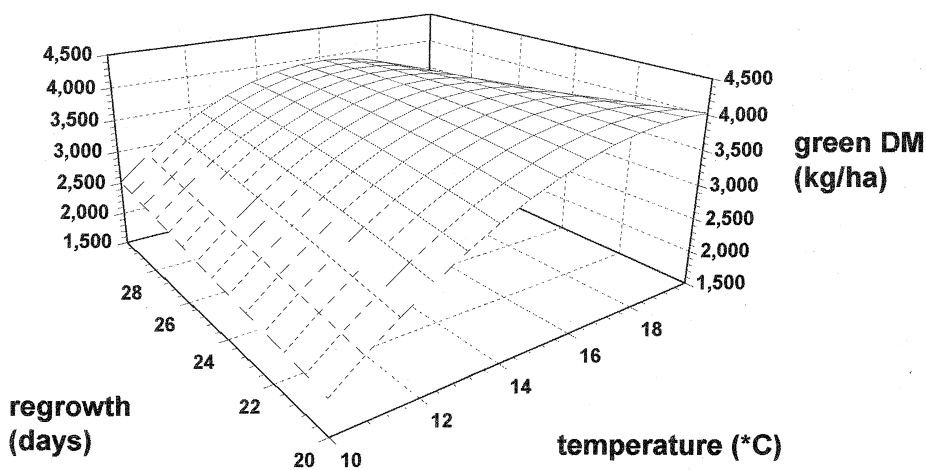

Fig. 3. Effect of temperature and regrowth period on the accumulation of green dry matter (DM) of kikuyu grass fertilised with 100 kg/N ha.

DM. This is consistent with the results of Parsons et al. (1983, 1988) on ryegrass pastures. These effects are mediated via two processes. First, temperature has a marked effect on the rate of leaf appearance of kikuyu grass. The interval required for one new leaf to be produced increases with decreasing temperatures. Second, there is a linear reduction in the asymptote single leaf photosynthesis as temperature decreases. Both processes affect canopy development and light interception and therefore retard DM accumulation. These observations point out the need for flexible management strategies depending on the seasonal or regional environmental conditions, and can largely explain latitudinal differences in the production of kikuyu grass.

2.3.3. N fertiliser use

The model was also used to study responses to N fertilisation. Fig. 4 shows the GDM accumulation of kikuyu grass at different levels of N fertiliser and rest periods. Two important characteristics can be observed. There is a strong interaction between fertiliser use and rest period. The overall effect of N fertilisation is to linearly increase the net growth of the pasture at short regrowth periods, mainly because it promotes LAI development and thus, higher canopy photosynthesis, without the onset of high losses due to increased respiration and senescence. However, as the regrowth period increases, high losses are observed, suggesting that low fertiliser levels should be associated with longer regrowth periods. This suggests that the level of N fertiliser applied plays an important role in determining the length of the rotation. It is important to observe that the contribution of N mineralisation from the soil organic matter is notable in the region under study, and relatively high grass yields can be obtained without fertiliser. This is certainly a process that deserves more attention for the development of more sustainable grassland systems. Management practices which promote a higher rate of N mineralisation would reduce the reliance
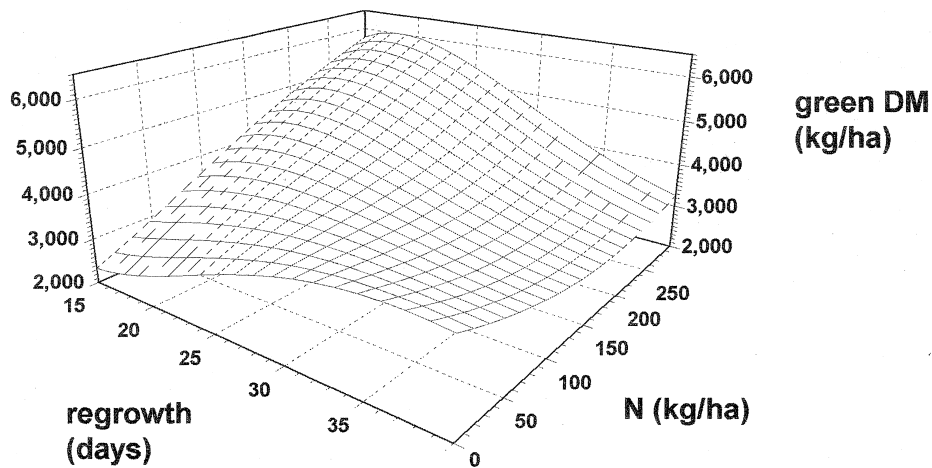

Fig. 4. Interaction between N fertilisation and regrowth period on the net accumulation of green dry matter (DM) of kikuyu grass growth at 17°C.

on high applications of inorganic N. Nevertheless, a delicate balance would exist between keeping the swards in a good state to obtain the desired levels of animal production while optimising plant growth. Another well-known option would be the use of legumes, but again, careful management and understanding of the ecophysiology of grass/legume associations is required to ensure their long-term success. These compromises need to be studied, and it is clear that mechanisms to select between alternative strategies to optimise several processes simultaneously, while considering farm characteristics and production objectives, are required.

Recent Australian studies (Reeves et al., 1996) have suggested the use of morphological indicators, leaf number in this case, to determine the optimal time to graze, rather than having rotational grazing systems based on fixed rest periods. This would be extremely convenient at farm level, since a simple variable obtained by observation could provide management guidelines without the time-consuming logistics always associated with grazing studies (e.g. quadrats, cutting, drying). These authors suggested that the most desirable stage of regrowth for kikuyu was at fout to five leaves per tiller, since after this threshold the sward started to accumulate dead material and decreased in quality. Although, since common kikuyu is always vegetative, quality changes due to stage of growth are not marked. These data were particularly interesting to simulate, since it provided more validation for the temperature responses on rate of leaf appearance and on green herbage accumulation, and would link the use of a mechanistic pasture model to derive simple management practices. The model was run for N fertiliser levels between 0 and 300 kg N/ha and at different temperatures. Results are presented in Fig. 5.

The model confirmed the results from Reeves et al. (1996), who used high fertiliser levels. However, a functional interaction between fertiliser level and optimal number of leaves was found. Without fertiliser, the number of leaves should be close to seven, while above 100 kg N/ha, the simulations suggest that to maximise
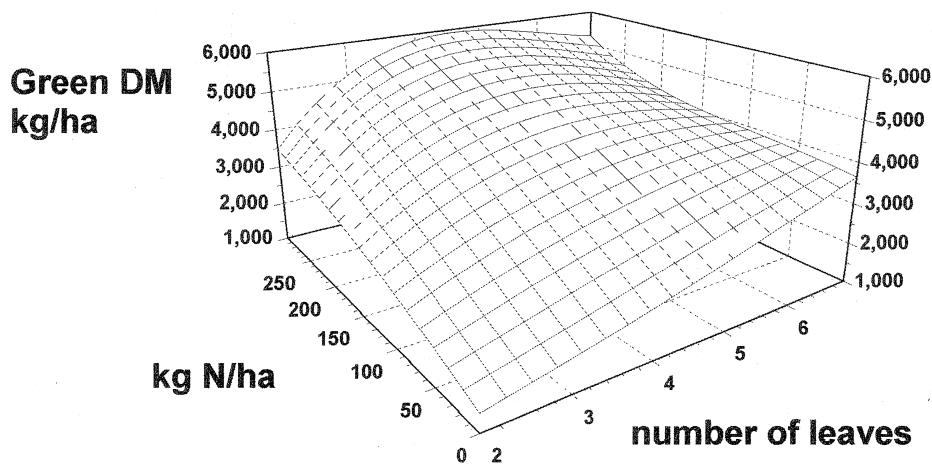

Fig. 5. The relationship between number of leaves, N fertiliser level and green dry matter (DM) accumulation for kikuyu grass grown at 17°C.

the net accumulation of GDM, kikuyu should be maintained at four to six leaves, depending on N fertiliser level. Since the effects of fertiliser are to increase the rates of leaf extension, less leaves are required to achieve the same leaf area, thus physiologically explaining why the number of leaves is reduced as fertiliser levels increase.

This response was also studied at different temperatures (Fig. 6) in simulated kikuyu swards fertilised with 150 kg N/ha. The optimal number of leaves was again between four and six, and the range was temperature dependent. Six leaves were required at higher temperatures, mainly because since specific maintenance respiration rates increase with temperature (McCree, 1970; Murtagh et al., 1987), specific leaf areas decrease, thus producing thinner leaves, which when expressed on the basis of leaf number, decreased GDM production.

2.3.4. Grazing intensity

The effect of grazing intensity on the regrowth of kikuyu grass was also studied. Fig. 7 shows the effect of different levels of GDM utilisation on the subsequent growth of a kikuyu sward fertilised with 100 kg N/ha/year and grazed after 30 days, which would be a common strategy in the Poás region. The model shows that increasing the degree of utilisation of the pastures, as defined by the residual GDM after grazing, has a marked effect on the 30-day regrowth of the sward. Although the final instantaneous amount of GDM is relatively similar between the treatments, net growth was higher in the more intensively grazed sward. Similar observations have been made in temperate swards (Parsons et al., 1983, 1988). Since animals remove a greater fraction of the LAI at higher grazing intensities (Johnson and Parsons, 1985; Thornley and Verberne, 1989), the sward has more scope to regrow without the losses due to senescence or increased respiration associated with higher initial LAIs caused by sward underutilisation (Parsons et al., 1988). This also explains the lack of variation in green herbage mass in farms of the Poás region.
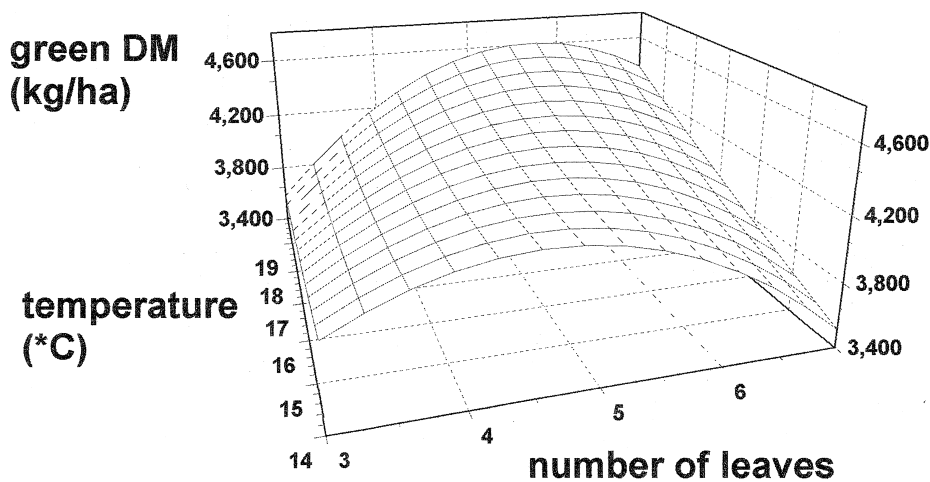

Fig. 6. The relationship between the number of leaves, temperature and green dry matter (DM) of a kikuyu pasture fertilised with 150 kg N/ha.
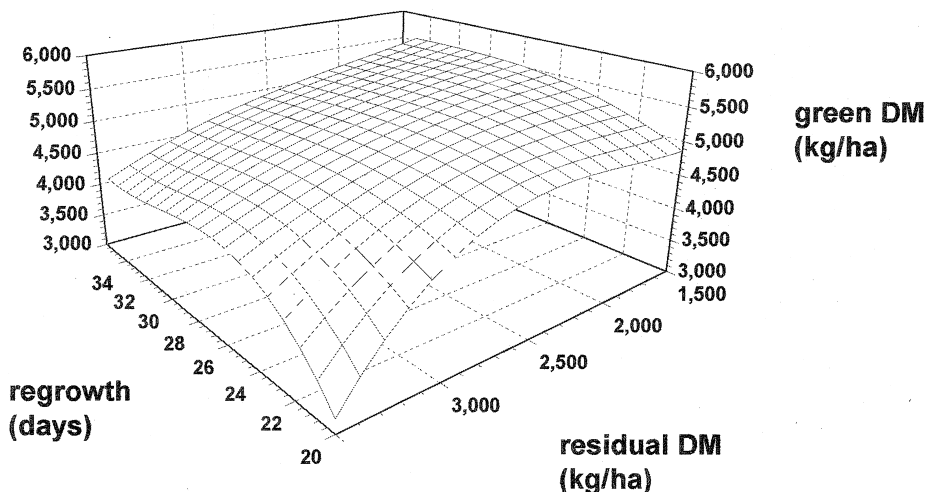
Fig. 7. Effect of residual herbage mass after grazing (residual dry matter [DM], kg/ha) on the regrowth of kikuyu grass.

The importance of the effects of tissue senescence on sward growth have not received enough attention in tropical grasses (Thomas and Asakawa, 1993) and they require further research, since increases in the efficiency of use of N fertiliser through grazing management may lead to reduced N applications. For example, in these simulations, all the pastures received the same amount of fertiliser but the net accumulation of material during the 30-day rest period was higher for the more intensively grazed sward, suggesting a better utilisation of the applied N. Reductions in leaching losses would occur if the pasture was maintained at high growth rates (Whitehead, 1995). Options like these have environmental implications that could be studied.

Information on the physiology of tropical grasses to conduct these type of studies is still incomplete, and a substantial amount of research needs to be done to gain understanding about their growth habits and responses to grazing. This would possibly lead to better management guidelines, as has been the case with temperate species (Parsons et al., 1988; Fulkerson and Slack, 1994; Wilkins, 1995).

3. Conclusions

This paper demonstrated how a grass growth and utilisation model can be used to derive practical management guidelines for kikuyu grass grazing systems in highland regions of Costa Rica.

The model showed to be responsive to some of the main interventions commonly applied by grazing managers to satisfy their systems objectives: fertiliser applications, control of stocking rates and paddock rotation lengths and how these interact with environmental variables (i.e. temperature in this case). The magnitude of these interactions seems to affect largely the growth and utilisation of kikuyu grass; hence

flexible management guidelines appear to be the key for optimising the utilisation of net herbage accumulation throughout the year. This also implies that management should be adjusted on an agro-ecoregional basis, even when relatively small climatic changes occur, as is the case in the Costa Rican highlands. Although rainfall is rarely limiting herbage growth, differences in ambient temperature due to altitude and their interaction with N applications suggest that rotation cycles can vary up to 10 days between regions and/or seasons.

Translating model outcomes from variables traditionally used in grazing experiments, but rarely measured on farm (i.e. GDM, LAI, leaf senecence), into morphological indicators such as number of live leaves appear to be sensitive enough to management practices and a step forward towards increasing the applicability of models for decision-support at the farm level.

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