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No. 9

# LIVESTOCK-CROP INTERACTIONS

## THE CASE OF GREEN STAGE BARLEY GRAZING

by
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## ABSTRACT

Immature barley crops are frequently grazed by sheep in the winter months then left to mature for grain harvest. ICARDA is conducting research on several aspects of this phenomenon, including breeding efforts to produce superior "dual-purpose" barley cultivars, experiments on agronomic practices and physiological processes, and socio-economic surveys and analyses of the larger barley/sheep production contexts.

This paper complements the above research by specifying a bio-economic model which links grazing and feed purchase decisions to farm tenure arrangements, alternative feed prices, crop growth conditions, and crop and sheep responses to various grazing intensities. In the process of outlining such an explicit model, gaps in our knowledge come into focus. This should stimulate constructive criticism of the model and support the aim of making ICARDA's research efforts on "dual-purpose" barley and sheep husbandry more effective.

# LIVESTOCK-CROP INTERACTIONS: THE CASE OF GREEN STAGE BARLEY GRAZING

## I. INTRODUCTION

In Syria, sheep are frequently allowed to graze fields of immature barley during the winter months. The barley is then left to recover and is later harvested for grain and straw.[1/] The impact of this grazing on crop yields, sheep production and farmers' incomes is very complex. Until now, there has been no research to define the systematic relationships behind the decisions farmers make about green-stage grazing of barley. The paper addresses these issues and attempts to answer the question: "Why do farmers allow this grazing to occur even when it causes crop damage?"

ICARDA is giving attention to many aspects of dual-purpose barley production. Barley breeders recognize the "dual-purpose" role of this crop in many parts of the region, and they are working to improve cultivars by selecting types on the basis of green forage as well as grain yields. Agronomists are carrying out studies on the effects of early grazing and, at the same time, animal scientists are seeking ways to improve sheep production in systems which use barley as a forage and also winter supplement feeds. The comprehensive 1981/82 barley survey in Syria, conducted by ICARDA economists, focused many questions on the practice of green-stage grazing.

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1/ Farming Systems Research Program, 1980, p 106.

A better understanding of farmers' decisions on green-stage grazing will allow more productive coordination of the Center's several research efforts on the subject. Thus, the objective of this paper is to provide a systematic framework which links our fragmented knowledge of the various relationships which affect farmers' decisions. The major influences in decisions on whether, and at what intensity, to allow green-stage grazing fall into four categories:

1. land and livestock ownership patterns,
2. the availability, quality and price of alternative feed-stuffs,
3. the expected economic response of sheep production to different diets which combine straw, green-stage grazing and purchased feeds, and
4. the effects of various grazing intensities on the harvest value of the barley crop given different growing conditions.

Complex tenure arrangements in which green-stage grazing privileges and harvest benefits are divided between three parties are commonly found in Northeastern Syria. This pattern of conflicting interests is associated with the predominance of early grazing in that area (Table 1).

The simpler case, where sheep and the barley crop are managed by one farmer for maximum combined profits, is developed in this paper first. Items 2, 3 and 4 above are defined as functional relationships in Section II. These allow theoretical pinpointing of optimal grazing intensities and feed purchases for the profit maximizing crop-livestock manager in Section III. Finally, Section IV treats the complex case of conflicting interests common in green-stage grazing under sharecropping arrangements.

Table 1 Estimated frequencies of green stage barley grazing in two regions of Syria.[a]

| Green stage grazing | NORTH EASTERN REGION Hassakeh, Deir ez Zor and Raqqa (percent of barley farmers)[b] | WESTERN REGION Aleppo, Homs, Hama and Idleb (percent of barley farmers)[b] |
|---|---|---|
| Practised every year | 41.7 | 0 |
| In good or very good years | 22 6 | 14.5 |
| Sometimes or rarely | 1.2 | 10.9 |
| Never practised | 34.5 | 74.6 |

[a] Weighted estimates derived from data given by Ahmed Mazid and Kutlu Somel, Further Results from the Barley Survey, unpublished memorandum, FSP/ICARDA, 16 May 1982 (mimeo).

[b] Barley farmers with rainfed crops in rainfall zones 2, 3 and 4 only.

The various bio-economic relationships are given as explicit algebraic functions for several reasons. They allow us to define unambiguous decision rules for optimal grazing intensities and feed purchases over a wide range of prices, growing conditions and crop and sheep response characteristics. Explicit functions also have the advantage of helping constructive criticism lead to improved specification of the system's relationships. An attempt to explicitly describe a system's structure can lead to rapid identification of gaps in our knowledge, providing a clearer focus for establishing future research priorities.

## II. FUNCTIONAL RELATIONSHIPS

### A. Sheep productivity responses to energy intake

We assume that a farmer could maintain ewes, in late pregnancy and early lactation, on a diet of cereal straw. Considering the price of supplementary feed and the growing condition for his barley crop, the farmer wants to determine the best combination of green-stage grazing and feed purchases. He knows that nutrition of his ewes will affect milk production and reproductive performance as well as the mortality levels and weight gain of the lambs. Thus, he must consider the expected benefits of improved nutrition against the expected costs.

The gross revenue from sheep production is defined as a curvilinear function of metabolizable energy (ME) intake added to a maintenance ration of cereal straw. The gross revenue function below summarizes the economic values of all the aspects of expected productivity mentioned above at different levels of ME intake. Gross revenues increase with added increments of ME until an additional unit of ME gives no extra benefits. The following quadratic form[1/] was chosen for the gross revenue function:

$$R = m + uX - fX^2$$

where $R$ = gross revenues from the flock, in Syrian Lira (SL),

$X$ = the amount of ME intake added to the maintenance diet (in megajoules),

and the parameters $u, f > 0$ and $m \gtrless 0$.

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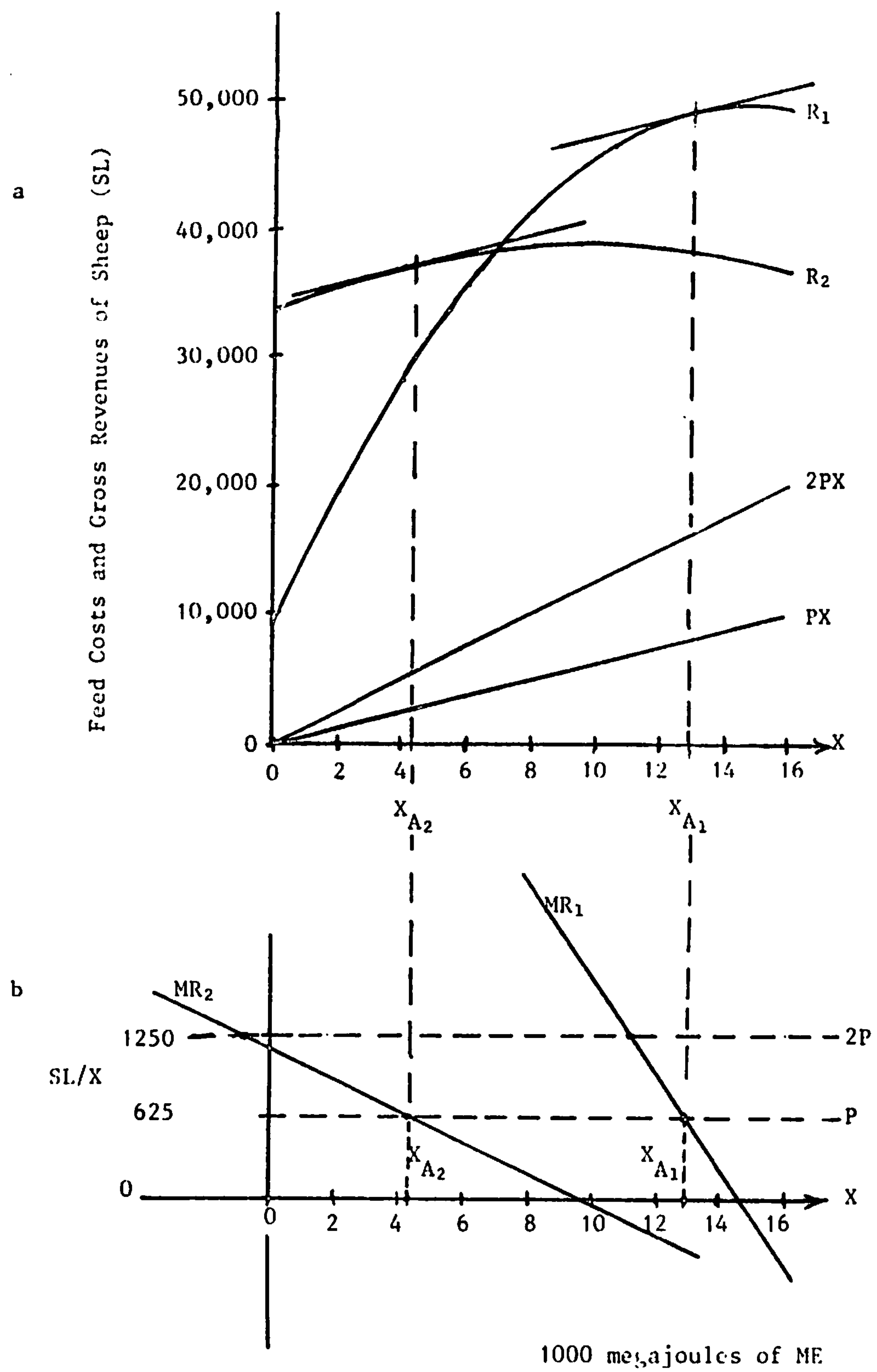
1/ This form of equation was selected for its simplicity in relating changing rates of output response to the level of a single input variable, in this case, ME (see Dillon and Hardaker, 1980, p 105). In practice, output depends upon the physiological status of the animal (pregnant, lactating, dry, etc.), the pattern of feeding of individual animals and the overall energy concentration of the diet (Capper, 1982). These refinements, which would significantly affect numerical applications of the decision model, are not dealt with in this paper.

Due to differences in lamb and milk prices and differences in the basic condition and responsiveness of various flocks, the gross revenue curves will differ between flocks; for any given flock, they will also differ over time. Thus, no attempt is made to estimate the parameters of this function since such estimates would be specific to individual flocks and particular price conditions. It is only the general shape of these functions that is of importance.

Two hypothetical gross revenue curves, $R_1$ and $R_2$, are plotted in Figure 1-a. Curve $R_1$ shows spectacular increases in gross revenue from the first increments of ME and reaches a peak at about 14.5 units of ME. The $R_2$ gross revenue curve shows a very weak response to the first units of ME and reaches its peak at less than 10 units of ME. The cost of purchased feed is shown as the line PX (price times quantity).

Since supplementary feed is not free, the farmer will not choose to feed at the maximum of the gross revenue curve. If green stage grazing is not available, the farmer will feed supplements only to the point where he maximizes his net benefits, i.e., gross revenue minus feed costs. This will be the level $X_A$ (about 13 units of X for $R_1$ and slightly more than 4 units of X for $R_2$) at which expected marginal revenue equals the price per unit of ME (Figure 1-b). Marginal revenue is defined as the slope of the gross revenue curve (i.e., its first derivative: $dR/dX = u - 2fX$).

Figure 1. Gross and Marginal Sheep Revenues for Determining Optimal Supplementary Feed Purchases



If the price of supplements were doubled (2P), the farmer facing the $R_1$ gross revenue curve would only reduce his feed purchases from about 13 to 11 units of ME. However, the farmer with the gross revenue curve $R_2$ would now find the price of feed so high that he would not purchase any. These are optimal solutions given the assumptions on cost and revenue relationships and the objective of profit maximization from sheep production (see Appendix A for a mathematical explanation).

## B. Grazing cost surface

Another main structure in the present analysis is the grazing cost surface. The surface is shown in three dimensions: (1) barley crop growing conditions, (2) intensity of grazing, and (3) the cost of grazing in terms of reductions in the economic value of the mature crop (Figures 2 and 3). Thus, grazing costs depend on growing conditions and grazing off-take for a particular barley cultivar.[1/]

For a given growing condition, the cost of grazing is taken to be a function of grazing off-take, measured in units of metabolizable energy (ME) per hectare:

$$C = a + b(X-d)^2$$

where C = the reduction in the economic value of the mature barley crop 2/ due to green-stage grazing, Syrian Lira (SL) per ha,

X = the amount of ME taken by grazing sheep (in megajoules per ha), and

parameters a, b and d vary according to the growing conditions.

(The mathematics of changes in parameters, a, b and d are discussed in Appendix B).

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1/ Cereal Improvement Program, 1982, p 9.

2/ Includes the expected value of the after-harvest residues or, as an alternative to harvest, the direct grazing value of the mature standing crop. For a more detailed treatment of these values see Nordblom, T.L., Livestock-Crop Interactions: The Decision to Harvest or to Graze Mature Grain Crops. Discussion Paper No.10, ICARDA, (forthcoming).

**Figure 2.** Green Stage Grazing Cost Surface: Loss of Mature Harvest Value as a Function of Grazing Intensity and Growing Conditions.

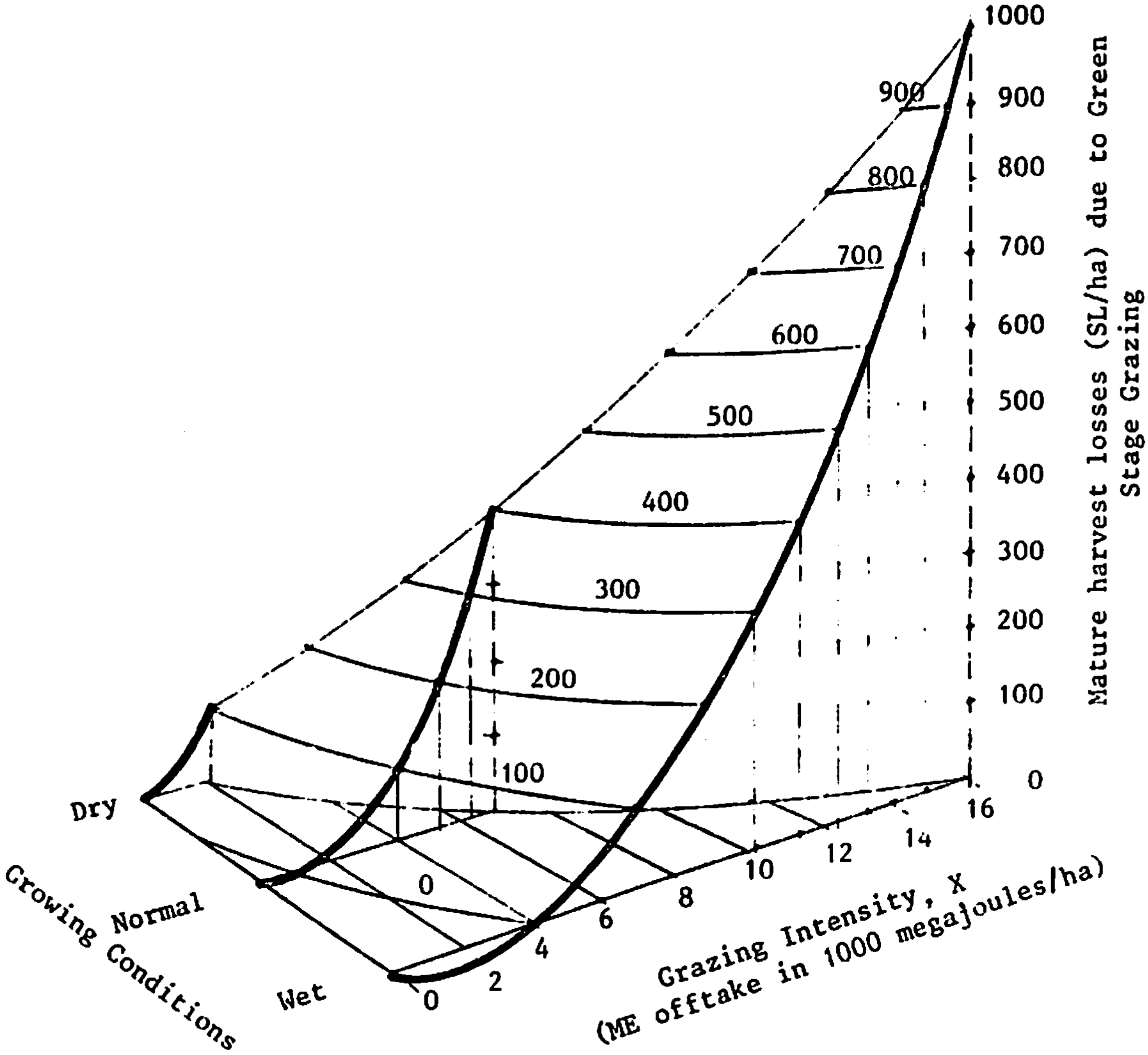
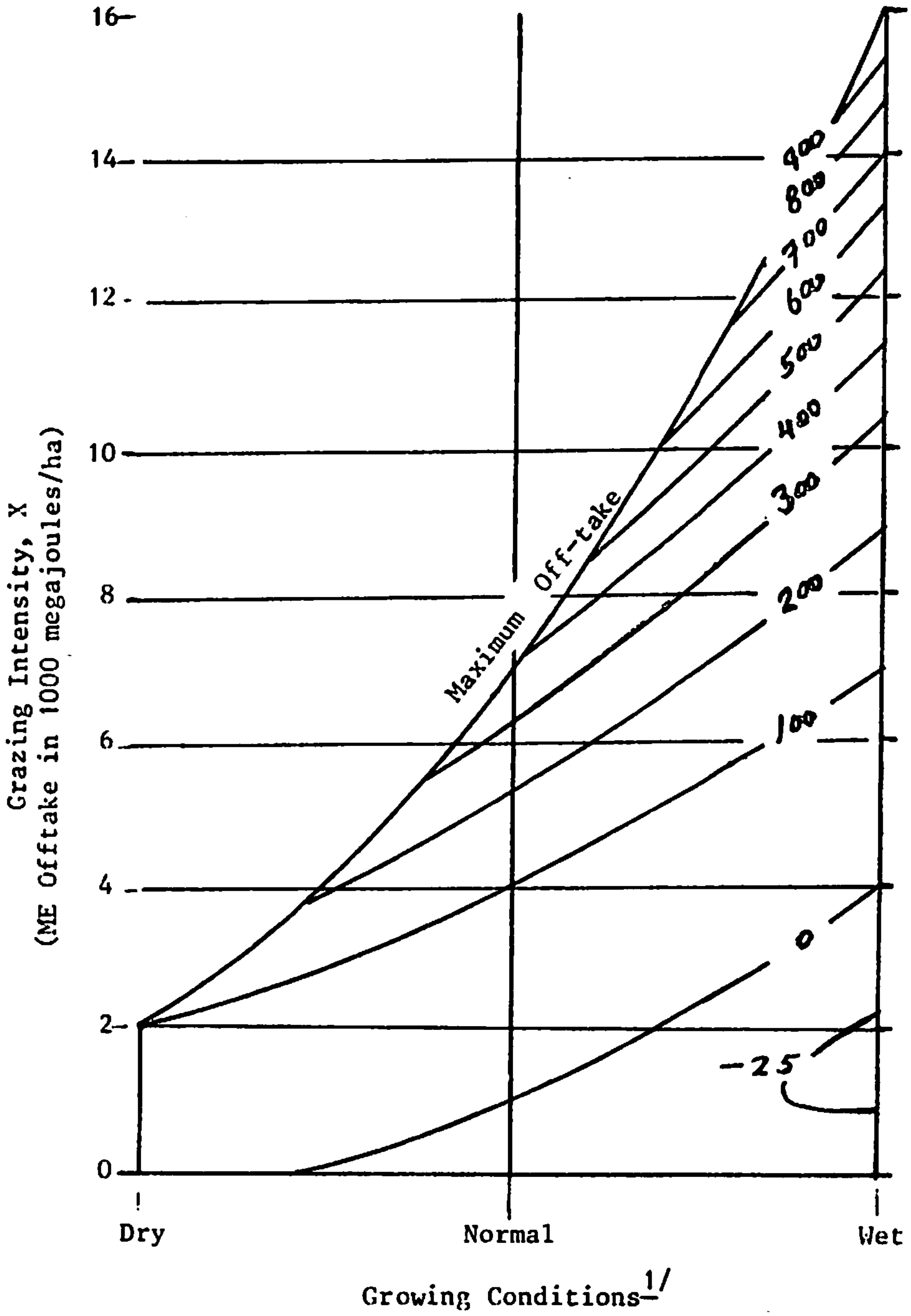
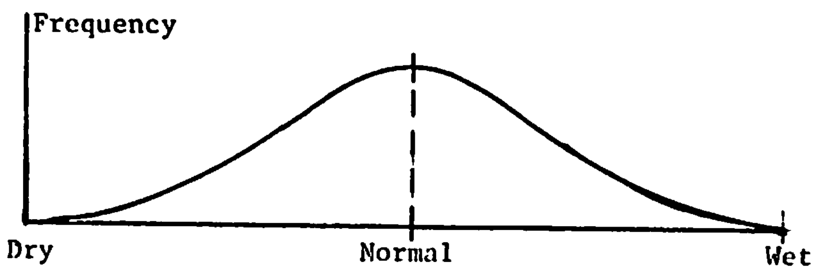


Figure 3. Cost Contour Map (in SL/ha) for Green Stage Grazing Intensities under Different Growing Conditions.




1/ The cost surface is truncated at both the dry and wet extremes of the growth condition distribution.

The cost of a given level of grazing off-take will depend on the crop's growing conditions before, during and after grazing. Many complex physiological processes which determine the responses of barley plants to various weather and grazing sequences are glossed over by the cost surface concept. Growing conditions are shown on a gross index, scaled from "dry to wet." The grazing intensity dimension is expressed in megajoules of metabolizable energy off-take per hectare. Repeated grazings and regrowths are not taken into account explicitly, but might be expressed as increasing off-take levels which reach an upper limit for the particular growing conditions. At the upper limit of grazing off-take, grazing costs are also at their maximum: complete loss of the mature crop (see maximum off-take curve in Figure 3).

The cost surface allows both the expression of a benefical effect on the crop by grazing at a certain level in a wet year, and destruction of the crop if the same grazing level were allowed under dry conditions. Under the driest conditions, neither the maximum grazing off-take nor maximum crop losses are great, since the mature crop would be quite poor. Under the wetter growing conditions we can expect the greatest potential off-takes and costs. Interestingly, under these growing conditions, the mature crop may be improved,[1/] or only slightly reduced, by moderate grazing (Figures 2 and 3). In this example grazing intensity less than four thousand megajoules per hectare increases yields at harvest; in this range, harvest losses are negative.

The cost of a small increase in grazing is called the marginal cost and is expressed as the value of crop loss due to an additional unit of ME off-take; it is the rate of change in grazing cost. The quadratic form assumed for the grazing cost functions conveniently yields straight, upward sloping, marginal cost lines (as $MC_1$ and $MC_2$ in Figure 4). This serves to simplify the graphical presentations.

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1/ As when grazing enhances tillering or prevents lodging.

## III. OPTIMAL GRAZING INTENSITIES

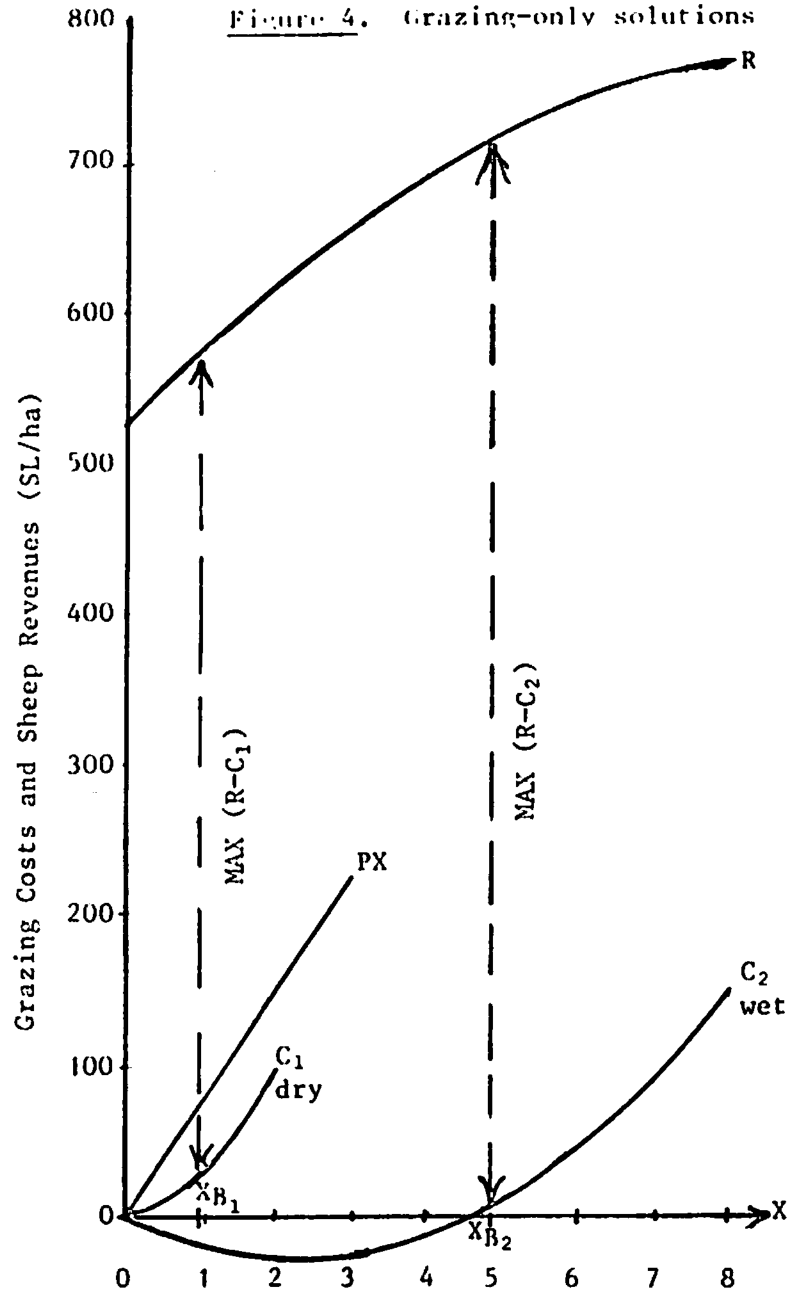
The functional relationships developed above can now be used to solve for optimal grazing intensities. The case of optimal supplementation when no grazing is available was covered in the previous section (page 6). The case when no supplements are available is presented next. This is followed by the case of combined supplementation and grazing. In turn, specific examples are presented for four possible types of solutions for profit-maximizing crop-livestock owners. Finally, a system of general optimization rules is summarized in a decision-tree format.

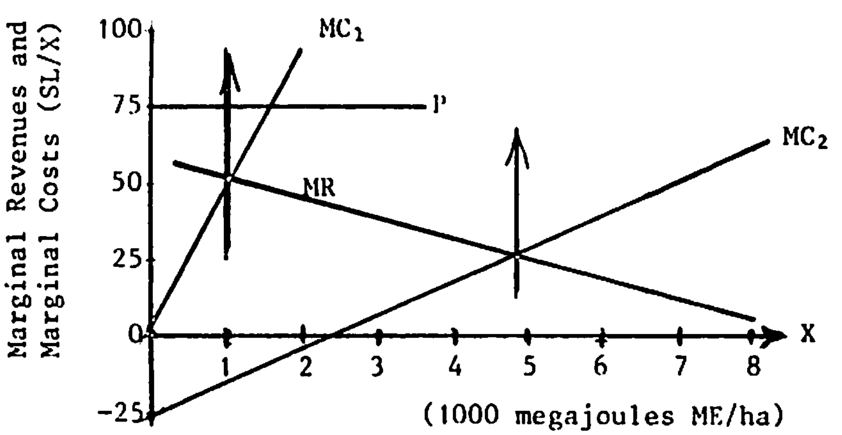
### A. Optimal green-stage grazing with no supplements available

When grazing is available, but the cost of purchased supplementary ME is too high (i.e., not available except at great expense of time, energy and/or money), the farmer would try to balance sheep revenues with an optimal level of grazing intensity. The problem is to find the grazing level which gives the greatest differences between expected gross revenues and grazing costs. This will be the point $X_B$ at which the marginal revenue from sheep production equals the marginal grazing cost (see Appendix C for the mathematical explanation). Examples of such "grazing only" solutions, under "dry" and "wet" conditions, are shown in Figure 4.

Gross revenues for sheep production are expressed hereafter on a per hectare basis for consistency with the grazing cost units. Total sheep revenues and total purchased feed costs were used to explain the "purchase only" decision above (page 6) but since a limited area of barley is owned by the farmer, his feed purchase and grazing decisions will be the same whether expressed on a per hectare or on a total basis.

Figure 4. Grazing-only solutions



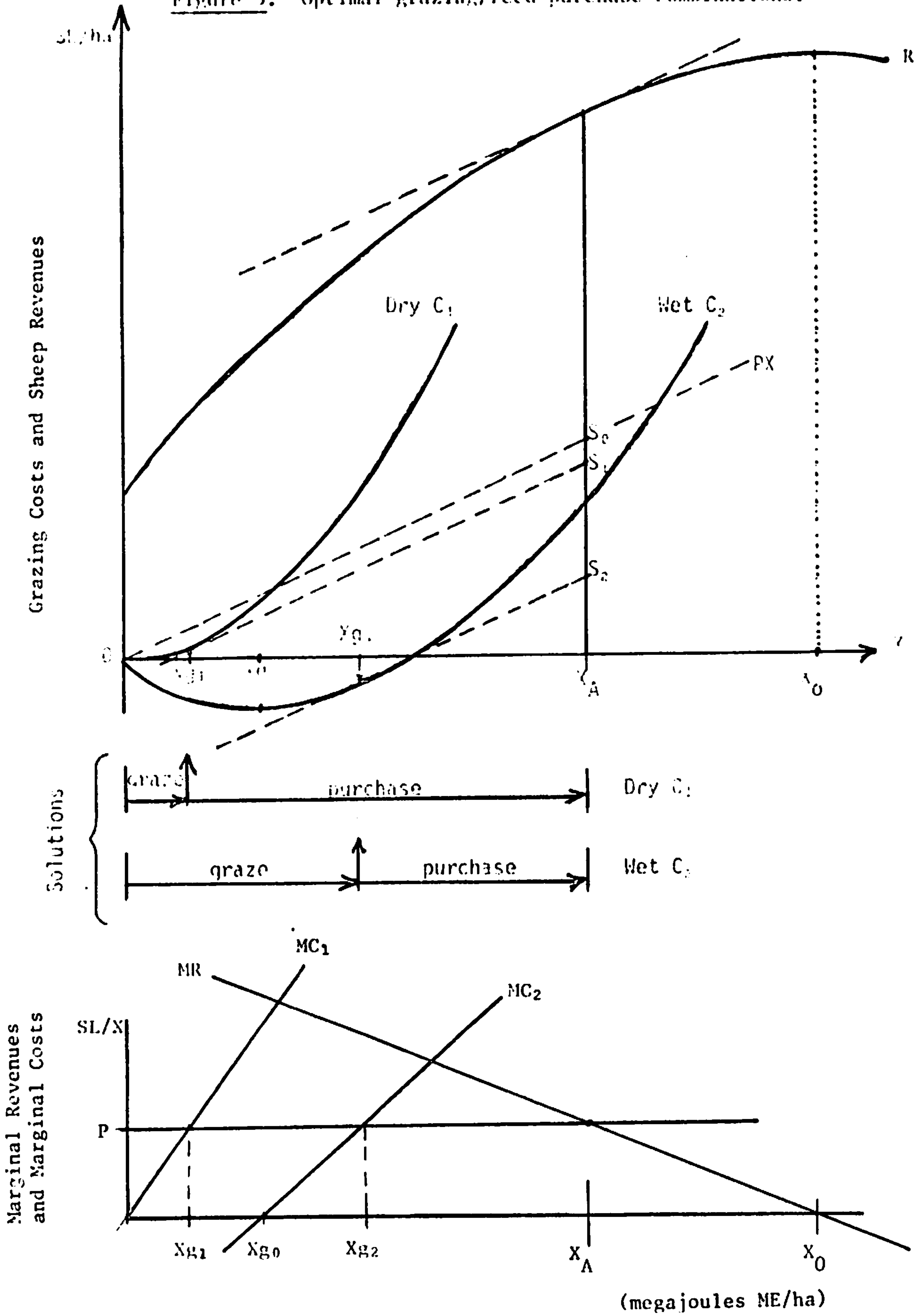
## B. Optimal grazing/feed purchase combinations

In order to select the most profitable levels of ME from two sources, grazing barley and feed supplements, amounts are chosen to equate their marginal costs with marginal revenue. Grazing is profitable up to the point at which the marginal cost of its ME equals the price of purchased ME, if marginal revenues are greater or equal to the marginal cost of grazing at that level.

Two hypothetical grazing cost situations, $C_1$ under dry conditions and $C_2$ under wet conditions, are shown in Figure 5. At point $X_A$, marginal revenue equals the price per unit (the marginal cost) of purchased ME. Recall that $X_A$, in the form of purchased ME, would be the desired level of supplements if no green-stage grazing were available. At $X_A$ the vertical distance between the sheep revenue curve (R) and the feed cost line (PX) is maximized. If cheap enough green-stage grazing is also available, even greater profits are possible. The points $Xg_1$ and $Xg_2$ are the grazing levels at which the price (P) of purchased ME equals the marginal grazing cost under dry and wet growing conditions, respectively.

In the case of the dry condition cost curve ($C_1$) grazing at any level would damage the crop. Nevertheless, given the price of supplements, the farmer would choose to graze the crop at the level $Xg_1$ and purchase $X_A-Xg_1$ of supplement. This combination would give him the most profitable crop-livestock balance (see Appendix D for the mathematical explanation). Compared to a "purchase only" solution, profits would be increased by the amount $S_0-S_1$. $S_1$ is the sum of the opportunity costs of grazing $Xg_1$ and the cost of purchasing $X_A-Xg_1$ of supplements. Higher prices for supplements would make even higher levels of green-stage off-take acceptable.

Figure 5. Optimal grazing/feed purchase combinations.



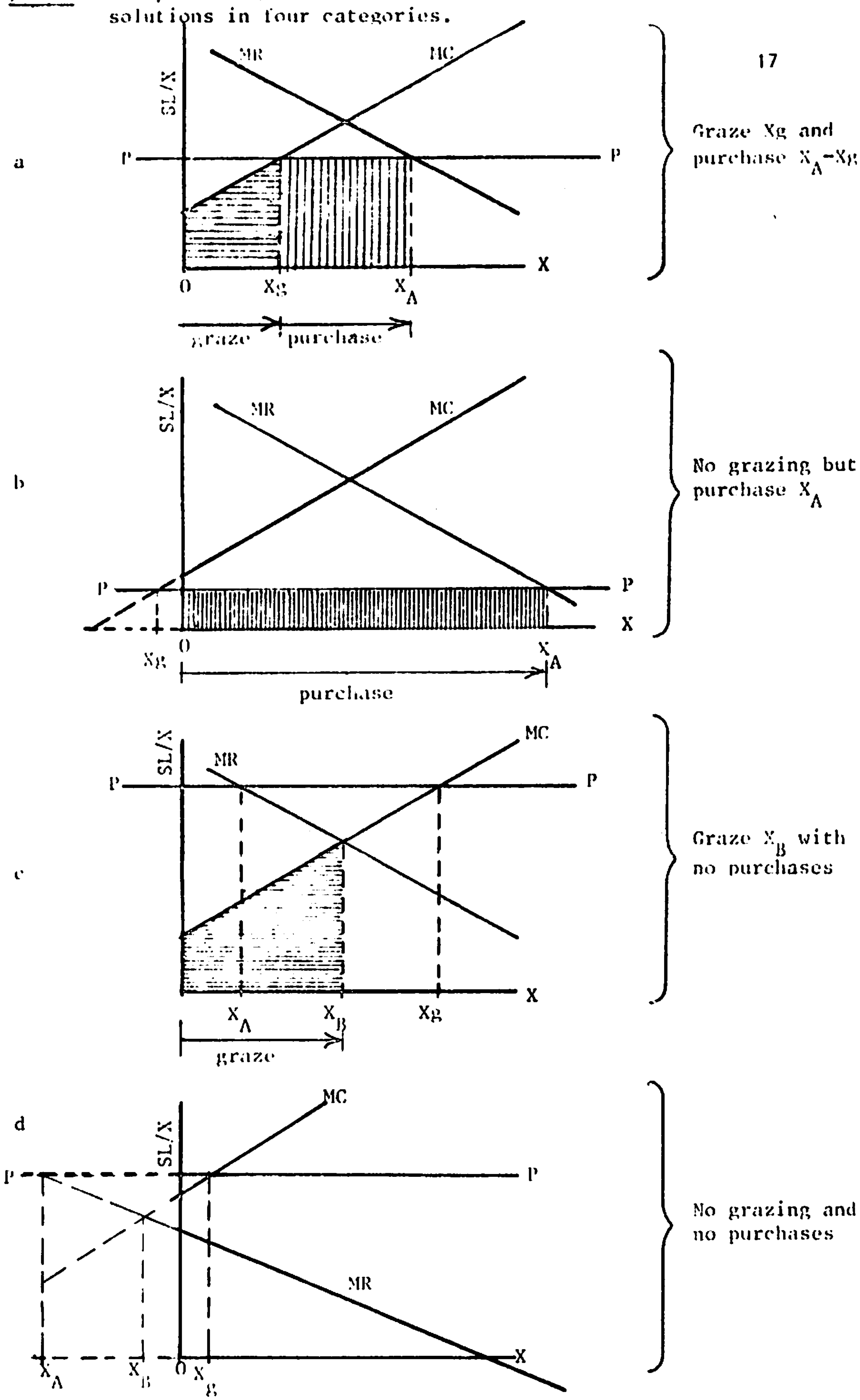
In a wet year, when green-stage grazing increases, rather than damages, crop yields the advantages of a combined crop-livestock operation are most obvious. Consider the cost curve $C_2$ in Figure 5: grazing at $Xg_2$ is the point at which the marginal cost of grazing equals the marginal revenue from the sheep and the price of purchased ME. $S_2$ is the sum of the cost of purchasing $X_A$-$Xg_2$ of ME and the benefit of grazing $Xg_2$. The farmer's income increases by $S_0$-$S_2$ when he grazes his barley crop at the green-stage rather than only feeding supplements.

An extreme case would be where supplements are free (i.e., P=0). In a wet season, $C_2$, the optimal combination would be to graze $Xg_0$ (where maximum crop benefits are achieved) and feed $X_0$-$Xg_0$. However, this is only a theoretical option that would not be found in practice since even feeds that are free have opportunity costs, i.e., they could be used beneficially in other ways.

C. Profit maximization summary for barley and sheep managed by one farmer

Green-stage grazing and feed purchase decisions for profit maximization were developed in the preceding sections. Particular cost and revenue relationships are required in order for the optimal solution to include both grazing and supplementary feed purchases, otherwise the optimal choice will fall into one of three classes of "corner solutions": (1) purchase only, (2) graze only, and (3) neither. A specific example of marginal conditions representing each type of solution is given in Figure 6.

**Figure 6.** Examples of green stage grazing/feed purchase solutions in four categories.



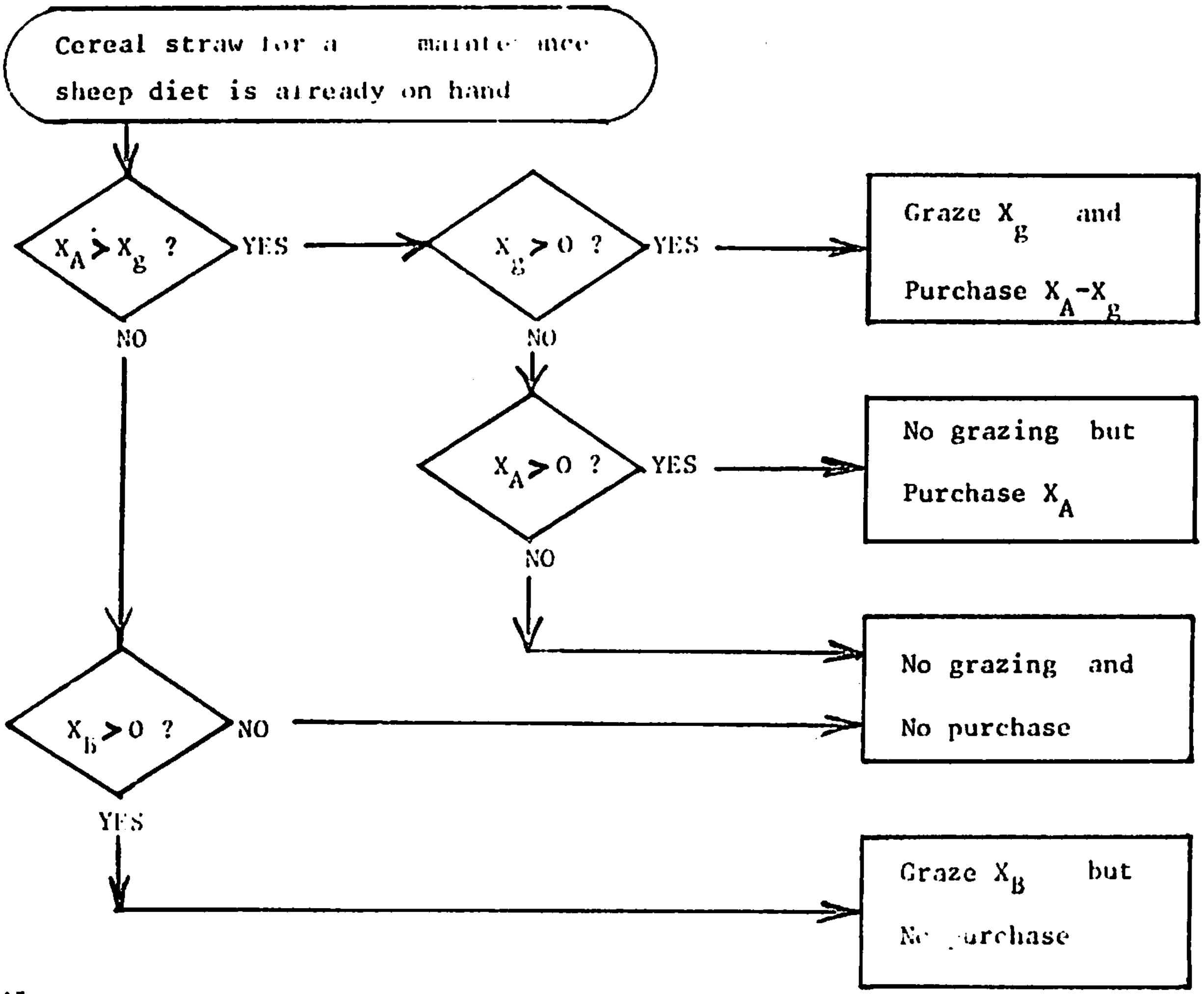
The marginal revenue and marginal grazing cost conditions are identical in Figures 6-a, 6-b and 6-c, the element which differs between them is the price of supplementary ME. A moderate price of purchased ME in Figure 6-a leads to an optimal choice of combining some grazing ($X_g$) with some purchases ($X_A$-$X_g$). Given MR and MC lines which intersect at some positive level of ME, a shift in the price of purchased ME will lead to a new optimal combination. In Figure 6-b, the price of purchased ME is so low, relative to grazing costs, that a "purchase only" solution is optimal. In contrast, the very high price of purchased ME in Figure 6-c leads to a "graze only" optimal solution.

Finally, a situation with low expected marginal revenues, high expected grazing costs and a high price for purchased ME is shown in Figure 6-d. No combination of purchases or grazing will add to the farmer's profits in this case. His optimal solution will be to simply continue feeding a maintenance diet of straw.

The shaded areas in Figure 6-a, 6-b and 6-c represent the total costs of grazing and purchases at the levels shown. The areas below the MR lines, and above the shaded areas, represent the maximum possible net benefits from grazing and ME purchases in each case.

Assuming the barley-sheep producer faces the simple revenue and cost scenarios described above and strives to maximzie his crop-livestock profits, we can define general rules for optimal green-stage grazing and ME purchases. These are summarized in an analytical decision tree format, with tests for the marginal conditions which lead to the four classes of solutions (Figure 7). Tests are required in all pathways to prevent any solution where input levels are negative.

Figure 7. Summary of optimal green stage grazing/feed purchase solutions for a profit-maximizing sheep/barley farmer.




Where:

X = amount of metabolizable energy (ME, in megajoules per ha.) from green stage grazing or purchased feed supplementary to a maintenance diet.

P = price per unit of ME in purchased supplementary feed.

$X_A$ = the level of ME intake at which the marginal revenue from sheep 1/ equals P.

$X_g$ = the level of ME intake from grazing at which the marginal cost of grazing 2/ equals P.

$X_B$ = the level of ME intake from grazing at which the marginal cost of grazing equals the marginal revenue from sheep.

Assuming:

1/ marginal revenue from sheep is a decreasing linear function of ME intake.

2/ marginal cost of grazing is an increasing linear function of ME off-take by grazing.

While the decision pathways of Figure 7 lead to analytically optimal decisions, the actual situations of farmers are often far more complex. Most importantly, the uncertainties of crop and animal response, and the uncertainties of the economic values associated with these responses, add unknown elements of risk to the farmer's grazing and purchase decisions. On the other hand, farmers often find their range of options at any given moment severely constrained; as the season progresses new opportunities arise and old ones change their form and disappear. Urgent daily decisions are made gracefully on a "best guess" basis too complex to be mathematically analyzed.

## IV. CONFLICTS IN GREEN-STAGE GRAZING

The decision model developed above requires that both the barley crop and the sheep are managed by a farmer who wishes to maximize their combined profits. More complex systems, in which green-stage grazing privileges and crop harvest benefits are divided between three parties, have been reported over a wide area of Northeast Syria by Somel (1982). There may be no analytical optimum for grazing intensities under such tenurial arrangements, only gaming or political solutions.

There are many cases where sheep owners rent land from the government then rent the land to others on a share-cropping basis. In this way, sharecroppers who reside in nearby towns assemble large blocks of land for barley cultivation. They carry out the ploughing, sowing and harvesting operations. The sheep owners receive one-third of the grain yield as share crop rent but are also allowed to let their sheep graze the barley crop until early February, when they are required to remove their flocks from the barley growing area.

Heavy and extended grazing damages the barley crop. This explains why the barley producers insist on limiting the duration of grazing, but the fact that the sheep owners must be encouraged, sometimes by force, to remove their flocks also suggests they have incentives to stay longer.

The incentive structures of the barley producer and the sheep owner are portrayed in Figures 8 and 9, respectively. The grain yield level N is that expected from a given field in a particular year if no green-stage grazing were allowed. In this example a dry year is assumed and conditions are such that any amount of grazing will reduce harvest yields. As increasing grazing pressure reduces grain yields, the value of the barley producer's two-thirds share of the crop (price times 2/3 yield) falls along the line from G to 0 (Figure 8). The result will be a serious loss of profits because his variable costs only fall slightly. In fact, if grain yields are reduced below point B, his costs cannot be covered. The shaded area beyond B represents the range of yields over which the farming operation is profitable. Clearly, the sharecropper will prefer to minimize grazing.

The one-third share expected by the sheep owner is shown as the line OR in Figure 9. He could expect to receive R as his rent payment if no grazing takes place and if the non-resident sharecropper is allowed to harvest N kg of grain per hectare. However, by allowing his sheep to graze the barley lightly, the sheep owner may expect a larger benefit to his sheep productivity than the small loss of rent due to reduced grain yields. The trade-off between grain yield and gains in sheep value is represented by the curve SN in Figure 9. The reduction in marginal grazing value and of absolute grain yields, with increasing grazing intensity, is consistent with the grazing cost model developed in Section II. The total benefit curve SR (Figure 9) is the sum of the sheep owner's

**Figure 8**

Sharecroppers' viewpoint.

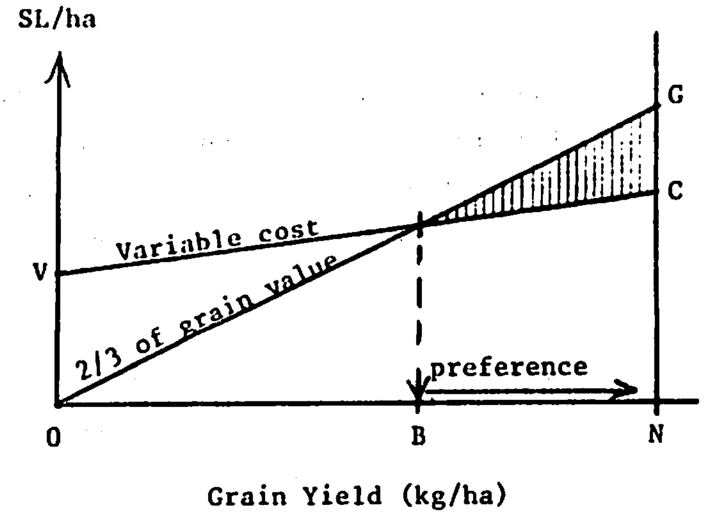



**Figure 9**

Sheepowners' viewpoint.

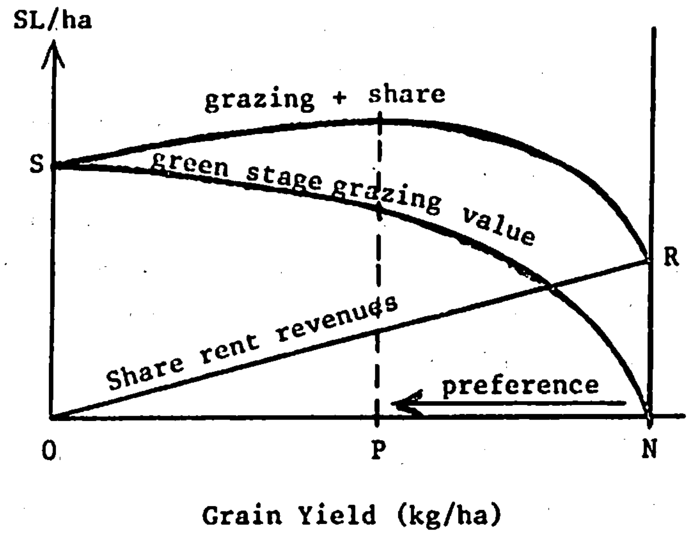
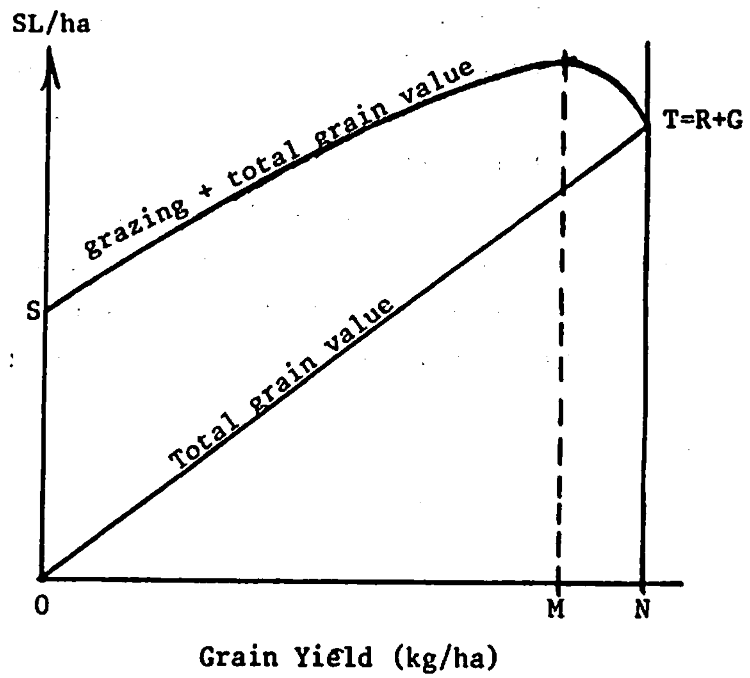



**Figure 10**

Aggregate production value.



share and the grazing value for each yield level. His total benefits are maximized at point P where grain yields have been reduced considerably from the no-graze level.

The conflict of interests between the two parties is now obvious; the sheep owner will prefer to graze the crop to the point where his expected benefits are maximized, while the non-resident sharecropper prefers no grazing at all.

However, there is a preferred solution from an aggregate point of view. The grazing value curvey SN (Figure 9) is added to the total crop value line OT in Figure 10, which results in the total grazing and grain value curve ST. This is the total market value for various combinations of grain production and grazing. The maximum aggregate value would be obtained by allowing grazing to the point M even though grain yields are reduced somewhat.

The law which requires grazing to stop on a given calendar date in effect comes close to achieving maximum output, but may never have complete success. This is due to the fact that the yield potentials and response relationships depend on prices and weather which vary from year to year and place to place. Nevertheless, the rule seems to embody a practical compromise between the conflicting interests. A rule which does allow some green-stage grazing of barley may be quite rational from the viewpoint of aggregate production value. Other socially desirable objectives regarding income distribution may also be met with such an arrangement.

Three additional insights may be drawn from the conflict model developed here. First, the position of the barley producer is risky in the sense that harvest yields must exceed a certain level (i.e., B in Figure 8) in order for him to cover his costs. Year to year variations in weather, and subsequent variations in the effect of grazing to a fixed calendar date, all add to the uncertainty he faces.

Second, the sheep owner's income from the barley increases with increasing proportions of yield potential harvested, but his grazing benefits decrease. Thus, he may feel relatively indifferent[1/] to a wide range of grazing-harvest combinations beyond some minimum level of grazing; at least he will be much less concerned than the sharecropper.

Finally, the sheep owner's incentives for grazing are likely to be influenced by the method used to determine the rent he must pay to the government. If his rent payments are proportional to grain yields, he will prefer to extract more grazing benefits and be less concerned with grain yields. In the extreme case of paying the entire one-third crop share as rent, he would choose to maximize the grazing benefits, and ignore the effects on grain yield. On the other hand, if he pays a fixed rent to the government it could, in the very poor years, result in greater losses to the sheep owner than if his rent were a fixed proportion of grain production.

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1/ See Dillon (1977, p 60) for further discussion of profit insensitivity to errors in input use with relatively flat response functions.

## CONCLUSIONS

Linkages have been specified between barley crop growing conditions, green-stage grazing costs, supplementary feed costs, sheep revenue responses to energy intake and crop-livestock ownership patterns to give optimal combinations of green-stage grazing and supplementary feed for sheep producers. Many questions are raised in light of these linkages and with regard to the inadequacy of our knowledge of some of the system's elements. The most difficult questions revolve around specification and estimation of the biological parameters of green-stage grazing responses of sheep and barley. Research already under way at ICARDA will partly be able to treat these questions.

One crucial set of questions involves the response of Awassi ewes, in advanced pregnancy and early lactation, to green-stage grazing. The parameters of this response are still in question. The performance of Awassi sheep is being studied with the experimental flocks at Tel Hadya in comparison to farmers' flocks. Increases in marketable lamb and milk production must be weighed economically against the extra inputs required.

Also, experiments on the effects of various cultural practices under different barley grazing scenarios have been conducted for several years by agronomists. This information can be combined with livestock data to study different management strategies.

Wide year to year variations in weather are a characteristic problem affecting dryland farming in the region. Soil and weather conditions, particularly the distribution of precipitation and temperature through the season, have a profound effect on grazing values, crop recovery and yields. Can the simple "dry, normal, wet" growing condition index used in this paper, be revised in light of these facts? Efforts of the crop physiologists to determine crop responses under different agronomic and grazing regimes and varying weather influences should continue.

The single manager and the two-party cases, discussed in this paper, both call for a "dual-purpose" barley cultivar which can provide nutritious green-stage grazing, then recover for grain production. Cereal breeders have already made progress in this direction. Farmers often allow repeated grazings at the green-stage and also attach considerable value to straw quality and yields, sometimes as much as to the grain itself. The timing, intensity and duration of green-stage grazing will affect the grazing value as well as the straw and grain yields. How do traditional and new cultivars measure up under the current grazing practices? Our cereal breeders should continue work on dual-purpose barleys giving more consideration to this question.

In addition to further development of a model of the green-stage grazing phenomenon with the ICARDA biologists, the economists need to (1) determine the distribution of green-stage grazing practices under the various tenure arrangements and (2) understand how harvest residues and the grazing of mature crop stands are negotiated between sheep owners and barley producing sharecroppers. Analysis of the data from the 1981/82 barley survey should partially answer these questions. A follow-up survey in specific geographic areas may answer the remaining questions on grazing practices and tenure arrangements.

Green-stage grazing is a common phenomenon in Northeast Syria and in this paper it is shown why rational farmers allow this, even when it decreases crop yields. It is clearly a mode of livestock-crop interaction which is employed to economically extract the most value from the land.

Somel (1982) has characterized the grazing practices of North-east Syria as "mining" operations. He has raised a warning flag on the long run degradation of soil fertility associated with continuous barley cultivation and over-grazing. This paper shows that in the short run, this "mining" can be profitable; altering such practices may be difficult indeed.

The models developed in this paper have tried to put in perspective the major factors that affect green-stage grazing decisions and point out some of the current limitations in our understanding of the process. Hopefully, the models will stimulate constructive criticism and lead to an improved understanding of the farming system, allowing more efficient orientation of ICARDA's research.

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# APPENDICES

## APPENDIX A Optimal Feed Purchases when Grazing is Not Available

Optimal supplementation, at feed price P, is a straightforward maximization problem under the assumptions given in the text:

Animal response = R = $m + uX - fX^2$, and
Supplementary feed cost = PX;

Such that profits from purchased supplements are given as

$$\P = m + uX - fX^2 - PX$$

The first order condition for maximum ¶ is to find X which satisfies $\frac{d\P}{dX} = 0$.

Set $\frac{d\P}{dX} = u - 2fX - P = 0$

and solve for X:

$$X = \frac{u-P}{2f} = X_A$$

Since f>0, by definition, the second order condition for maximum ¶,

$$\frac{d^2\P}{dX^2} = -2f<0 ,$$

is satisfied. Subject to the non-negativity constraint, therefore, ¶ is maximized at

$$X = MAX(0,X_A).$$

## APPENDIX B Grazing Cost Surface Mathematics

Grazing costs are defined in this paper as the discounted economic value of grain and crop residue foregone at harvest time as a function of metabolizable energy (ME) captured by green-stage grazing, a proxy for grazing pressure (intensity and duration). The growing conditions (i.e., dry, normal, wet) affect the shape of the function by changing its parameters. One set of parametric relationships, which conveniently yield the shape depicted in Figures 2 and 3, is described here.

Consider the family of upward opening parabolas in Figure B1. Each of the parabolas is defined by the functional form

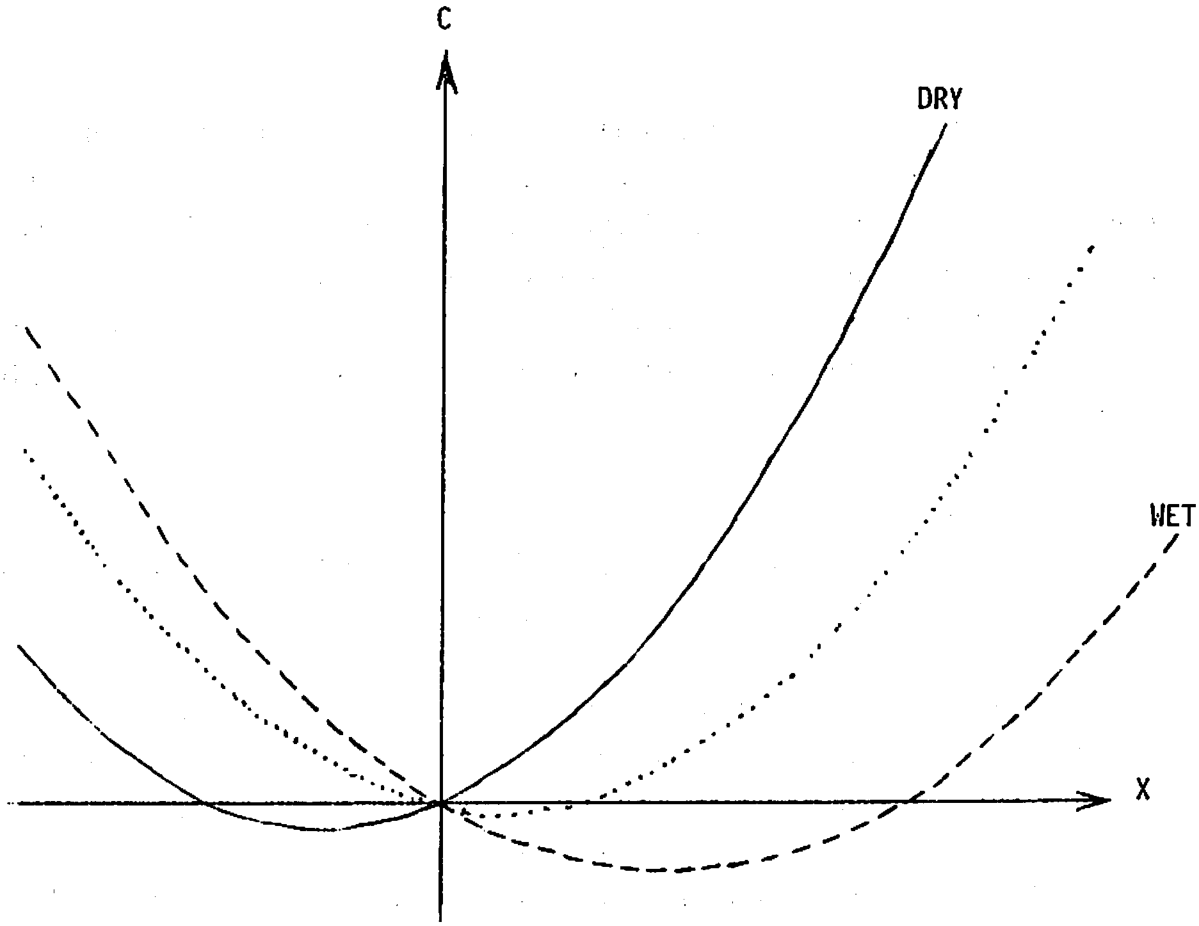
$$C = a + b(X-d)^2$$

but the values of parameters (a, b and d) for each are different. The effects of changes in each parameter are reviewed first.

The d parameter acts to shift the axis of the parabola to the right with improving growth conditions (i.e., it is an increasing function of $W_x$).

The b parameter acts to open, or widen, the parabola with improving growth conditions (i.e., it is a decreasing function of $W_x$). This is subject to the condition that b>0, to assure that the parabola always opens upwards.

FIGURE B1 A FAMILY OF PARABOLAS



The intercept (parameter a) is related to the other two parameters such that the parabola always passes through the origin. This is to satisfy the logical constraint that C=0 for X=0; that is, no grazing cost (or benefit) will be realized if there is no grazing. Thus, the value of the intercept is defined as:

$$a = -bd^2$$

The weather (or growing condition) index (Wx) is not specified explicitly in this paper. Only the vague terms "dry, normal and wet" have been used. More adequate specification of the functional relationships and estimation of the parameters could be the focus of a large research effort in the future. However, the present forms are considered adequate as vehicles for developing a simple theoretical framework for this complex subject.

Let the weather index Wx vary over the range of 1 to 10, with 1 being the worst (or driest), and 10 being the best (or wettest), growing conditions from the standpoint of effect of grazing on the subsequent crop.

The expected values of grain and residues at harvest time enter the grazing cost considerations in a fundamental way, through the parameters b and d. Thus, the functions which link weather to the model also embody economic values which will differ between farms and over time. No effort is made here to estimate the coefficients for a given farmer at a given time.

A numerical example is offered here to indicate the parametric relationships which will yield the desired shape for the grazing cost surface where

$$C = f(X, Wx).$$

Let $d = Wx - Y$

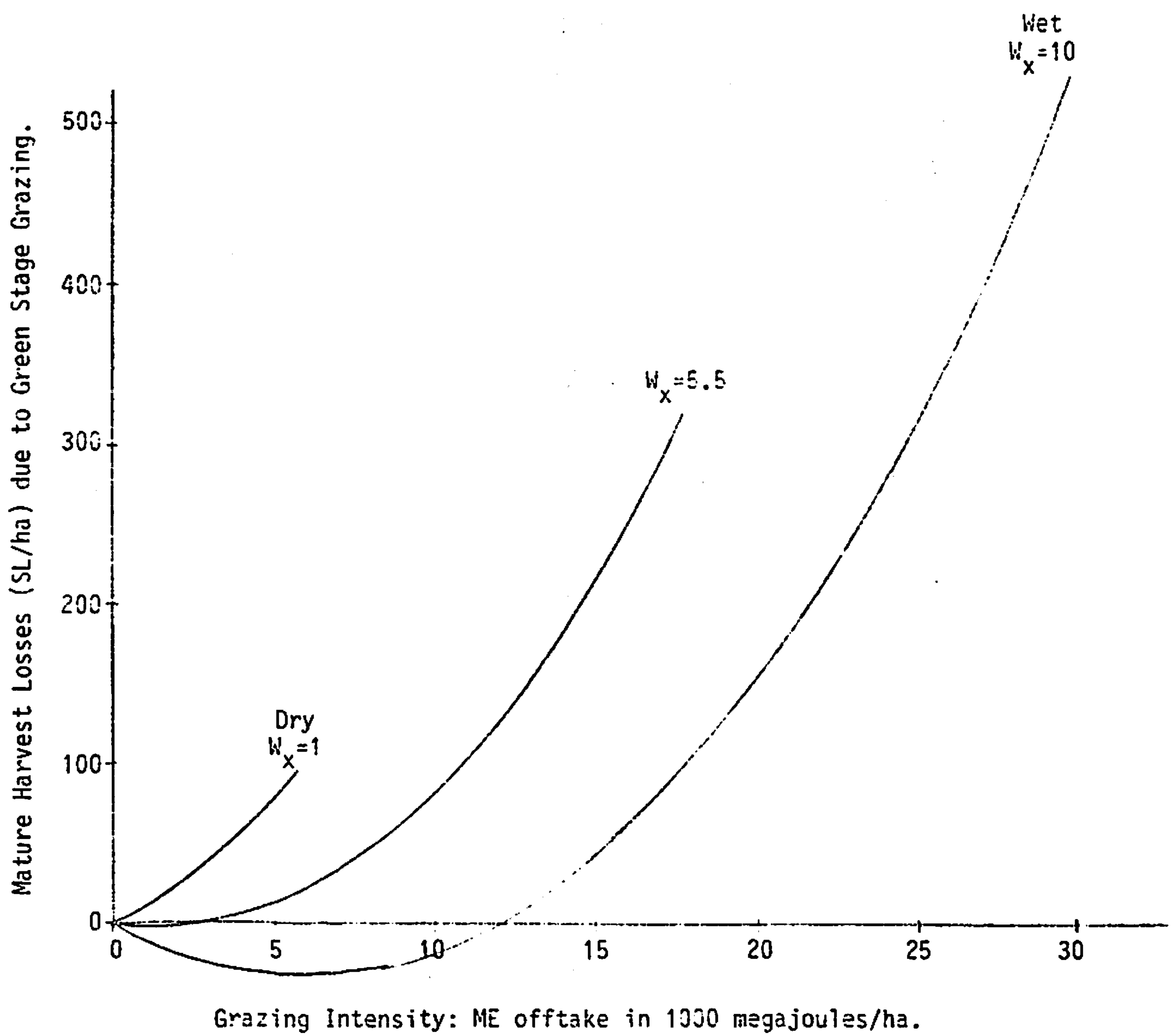
and $b = E - Z(Wx)$

such that pa.ameter values of Y=4, E=1.5 and Z=0.05, lead to the following cost function parameters under dry, normal and wet conditions:

| | Dry Wx=1 | Normal Wx=5.5 | Wet Wx=10 |
|---|---|---|---|
| d = | -3 | 1.5 | 6.0 |
| b = | 1.45 | 1.225 | 1.0 |
| a = | -13.05 | -2.756 | -36.0 |

Given the paramters listed above, cost curves are plotted in Figure B2. In this example each unit of X represents 1000 megajoules of metabolizable energy per hectare.

Figure B2. Hypothetical Examples of Grazing Cost Curves



## APPENDIX C    Optimal Grazing Levels when the Price of Supplementary Feeds is Too High

A "grazing-only" solution is sought when no other sources of supplementary ME are available, or when they are available only at high cost (i.e., if $X_A < Xg$[1]). In such cases one would wish to identify the grazing level which yields the maximum difference between the sheep revenue and grazing cost curves. Let this difference be called profit (¶) and find the maximum.

$$\P = R - C = m + uX - fX^2 - [a + b(X-d)^2].$$

To maximize ¶, find its first derivative with respect to X, set this equal to zero and solve for X.

$$\frac{d\P}{dX} = u + 2bd - 2(f+b)X = 0$$

$$X = \frac{u+2bd}{2(f+b)} = X_B.$$

Since f, b>0, by definition,

$$\frac{d^2\P}{dX^2} = -2(f+b) < 0,$$

which satisfies the second order condition for a maximum at $X_B$.

As with the other grazing/feeding rules, only positive or zero values of $X_B$ are allowable as solutions. Thus, the optimal "grazing-only" rule is expressed as: if $X_A < Xg$, then graze

$$X = MAX(0, X_B)$$

where

$$X_B = \frac{u+2bd}{2(b+f)}$$

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1/ Xg = The level of grazing offtake at which the marginal cost of grazing equals the price of ME from purchased supplements (See Appendix D).

## APPENDIX D Optimal Combinations of Green Stage Grazing and Feed Purchases

In the case where $X_A > Xg > 0$, the farmer faces a situation in which a combination of feed purchases and green stage grazing most economically supplements a sub-maintenance cereal straw winter diet for sheep.

The marginal cost (P) of ME from purchased feed (its market price plus delivery cost per unit) is the maximum unit cost that would be paid for ME. The optimal ME intake ($X_A$) by the animals is determined as the point at which this marginal cost equals the marginal revenue from the animals. For a given set of weather conditions and prices, this optimal intake level ($X_A$) may be taken as a constant (K) in the calculations to find the minimum cost combination of grazing and feed purchases.

The sum (S) of feed purchase costs and expected opportunity costs of grazing may, therefore, be expressed as:

$$S = \text{grazing cost} + \text{price times purchased ME} = C + P(K-Xg)$$

that is,

$$S = a + b(Xg-d)^2 + P(K-Xg).$$

where:

$C = a + b(X-d)^2$ = cost of grazing X under the given growing conditions,
$P(K-Xg)$ = cost of supplementary feed purchases,
$Xg$ = the level of ME taken by grazing,
$K$ = the desired total ME intake level, $X_A$, at which the marginal revenue from sheep equals the price per unit of ME from purchased supplements. It is assumed that $X_A$ has already been computed and is positive.

To find the minimum cost combination of ME sources to make up the desired ($X_A$) total, take the first derivative of S with respect to X, set it equal to zero.

$$\frac{dS}{dX} = 2b(Xg-d) - P = 0, \quad \text{then solve for } Xg$$

$$Xg = (\frac{P}{2b}) + d$$

which is the optimal grazing level if $0<Xg<X_A$.

Since b>0, by definition, the second order condition for a minimum,

$$\frac{d^2S}{dX^2} = 2b>0$$

is satisfied.

The optimal grazing intake of ME (Xg) subtracted from the total supplementary ME intake ($X_A$) gives the difference to be supplied by purchased feed. In terms of the model parameters the optimal combination will be:

$$\text{graze} \quad Xg = (\frac{P}{2b}) + d, \text{ and}$$

$$\text{purchase} \quad (X_A-Xg) = (\frac{u-P}{2f}) - (\frac{P}{2b}) - d.$$