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CERES-Maize: DESCRIPTION, ASSESSMENT, AND LIMITATIONS FOR STUDIES OF LONG-TERM NITROGEN FERTILIZATION

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1. INTRODUCTION

The short term consequence of a given fertilizer strategy influences the soil nitrogen status and production of the current crop and perhaps the next crop. In the longer term, these decisions influence soil properties mainly via organic matter status. The N sub-model of CERES-Maize was developed to simulate soil N status and N uptake in conjunction with the simulation of cereal yields. The aim of this present paper is to assess this model in dealing additionally with the long term effects on organic matter. To do this we simulate continuous maize for 100 years at Katherine with various N fertilization and residue-return strategies.

2. DESCRIPTION

The CERES N sub-model (Godwin et al. 1984) was developed from PAPRAN (Seligman and van Keulen 1981). The N sub-model used in EPIC has the same origin. Its conceptual merits are that it deals explicitly with the important processes in the N balance, which gives it some potential generality, but does so at a level of organization that makes supply of information and measurements of state variables technically feasible and generally affordable.

Table 1 summarizes the model's representation of various nitrogen transformations and transfers, as well as the ways water movement and root growth influence these.

Beginning with Jenny (1941), predictions of long-term trends in organic nitrogen have been made by variations of the equation:

$$\frac{dN}{dt} = A - kN$$

where

N = amount of soil organic N
A = annual rate of addition of N
k = annual decomposion rate constant

Table 1. Summary of model's representation of processes.

1.	Runoff	USSCS Curve Numbers
2.	Soil water/drainage	Multilayer profile Cascading water movement Rate constant for least permeable layer
3.	Leaching	f (drainage)
4.	Mineralization/ Immobilization	Two organic N pools: Fresh (FOM), humic (HUM) Decay from FOM = f (temp., water, C/N) Decay from HUM = K Additions to HUM = 0.2 * mineralized N from FOM
5.	Fertilizer N	Immediate entry to NO3 + NH4
6.	N uptake	f ([NH4], [NO3], soil water, root density)
7.	Root development	Depth = f (Thermal time, maximum depth) Density = f (Partitioned assimilate, soil water, N, assigned relative root density profile)
8.	Nitrification	f ([NH4], soil water, temp., ph)
9.	Denitrification	f (water content > field capacity, temp., soluble C)

In Australia, J.S. Russell has used this approach to extrapolate in time the results from various long-term experiments. The conceptual model as presented by Russell (1981) is a helpful starting point for considering the N simulation model used in CERES maize (Fig. 1). The state variables are soil organic matter and plant yield, and flows between them are governed by two coefficients which are determined for a specific treatment-site data set. For comparison, Figure 2 is a diagram of the CERES model. In addition to soil organic N and plant N (plant yield implied), state variables include fresh organic N and mineral N. As in the Russell model, decomposion of stable organic N is regulated by a single rate constant. The main departure from the Russell model is elaboration of processes that produce and decompose plant matter in response to weather, soil, and management variables. This provides a potential for increased transportability, calibration using data from short-term experiments, and ready alteration of management variables.

3. ASSESSMENT

For this paper we have used the version of the CERES-Maize model which is in the process of being tested and calibrated at Katherine. Although we don't have data on long term trends of either soil N or crop yields, inspection of the output of long term simulations for "reasonableness" provides a preliminary assessment of model performance. In addition to varying annual fertilizer N input, we have independently varied (a) the proportion of crop residues returned and (b) the humification rate constant, i.e. the proportion of N from fresh residues that goes into the humic pool ("b" in Fig. 2).

Figure 3 plots simulated annual values for humic N and maize grain yield for 100 years. All crop residues were returned, and 20% of N mineralized from fresh residues was assumed to be humified (b = 0.2). Without fertilizer, humic N declined 60%; with 100 kg or more of fertilizer N, decline was only 40%. In all treatments, humic N was still declining after 100 years. Grain yields declined over the period without fertilizer, but there is no indication of this when fertilizer was added.

While the return of residues would be expected to favour organic matter levels, in mixed crop-livestock systems crop residues are often grazed. Figure 4 shows the effect of removing 90% of stover. Compared to humic N trends with 100 N and all stover returned, decline due to stover removal was greater than that due to failure to supply fertilizer. Stover removal had only a small effect on crop yield at 100 N, but a very significant effect at zero N, with grain yields approaching zero after 80 years.

Realistic values for the rate constants for mineralization and humification (a and b, Figure 2) are obviously important to realistic simulation of trends in humic N. We have found that the value of "a" in the model (Jones and Kiniry 1986) closely predicts annual mineralization increments under bare fallow measured at Katherine by Wetselaar (1967). We have no check on "b", the humification constant. The value in CERES-Maize (Jones and Kiniry 1986) is 0.2, and Lucas et al. (1977) use 0.3. Since we have no basis for confidence in the default value of 0.2 for the Katherine system, we have conducted a test of sensitivity of trends in humic N to this parameter using additional values of 0.3 and 0.4. The large effect of varying "b" on humic N (Fig. 5) demonstrates the importance of a reliable value for use of the model for this purpose. Maintenance of humic N at Katherine with 100 kg fertilizer N and all residues returned requires a value for "b" of about 0.4.

The simulated crop yields are generally consistant with measured experimental crop yields at Katherine. The magnitude of the long term effect of stover return is lent credibility by the fact that functions for transfer of N from plant to soil are mechanistic and not heavily reliant on fitted coefficients.

4. LIMITATIONS

The most conspicuous limitations of the model for long term studies of soil organic matter relate to its origin as a mineral N generator for crop growth over periods of a few years. This application has low sensitivity to errors in rate of humification. Nor is it important that the humic N mineralization rate constant represents a weighted average of the rate constants of several fractions of organic N. However for long term studies these limitations are important. The importance of realistic values for the humification constant, b, was demonstrated (Fig. 5).

The simulated pattern of change with time in total organic N must be expected to be distorted by the oversimplification of treating a wide range of soil organic compounds as a single humic pool with a constant mineralization rate. Curvilinearity in such first-order kinetics results only from a decline in the amount of organic N to be mineralized. In reality, those materials with the highest decomposibilty decline first and fastest, an asymtote is approached as recalcitrant humis predominates. The curves produced by CERES are much flatter that those produced by models such as that of Parton et al. (1983) where pools are less aggregated (cf. RKJ Myers, this workshop).

A further important limitation is the absence of a means for loss of N via erosion. Although this is not a limitation in EPIC, considering the high information requirements of the treatment of erosion in EPIC, simple deductions for average annual erosion loss, e.g. Lucas et al. (1977), would be an important improvement where the omission of an erosion loss term results in a serious underestimate of N loss.

5. REFERENCES

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6. LEGEND OF FIGURES

Figure 1. State variables and transfers in simple analytical model. (Transfers without coefficients are implied).

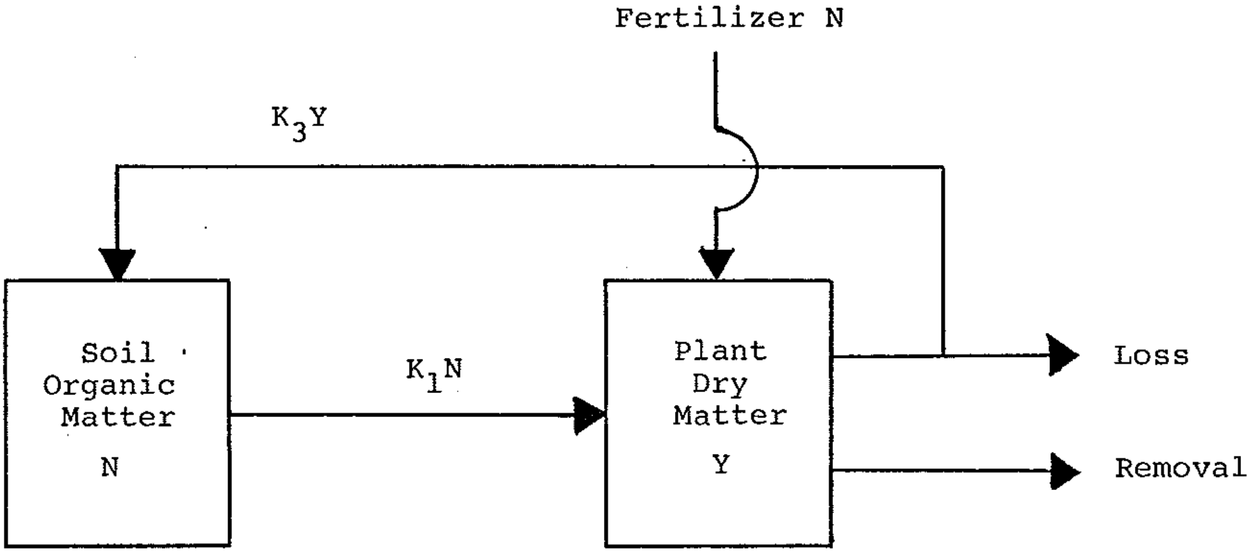
Figure 2. State variables and transfers in CERES N model.

Figure 3. The effect of fertilizer N rates on simulated soil humic N and maize grain yields for a 100-yr period at Katherine, N.T. (b = 0.2, all stover returned).

Figure 4. The effect of maize residue return on simulated soil humic N and maize grain yields for a 100-yr period at Katherine, N.T. (b = 0.2).

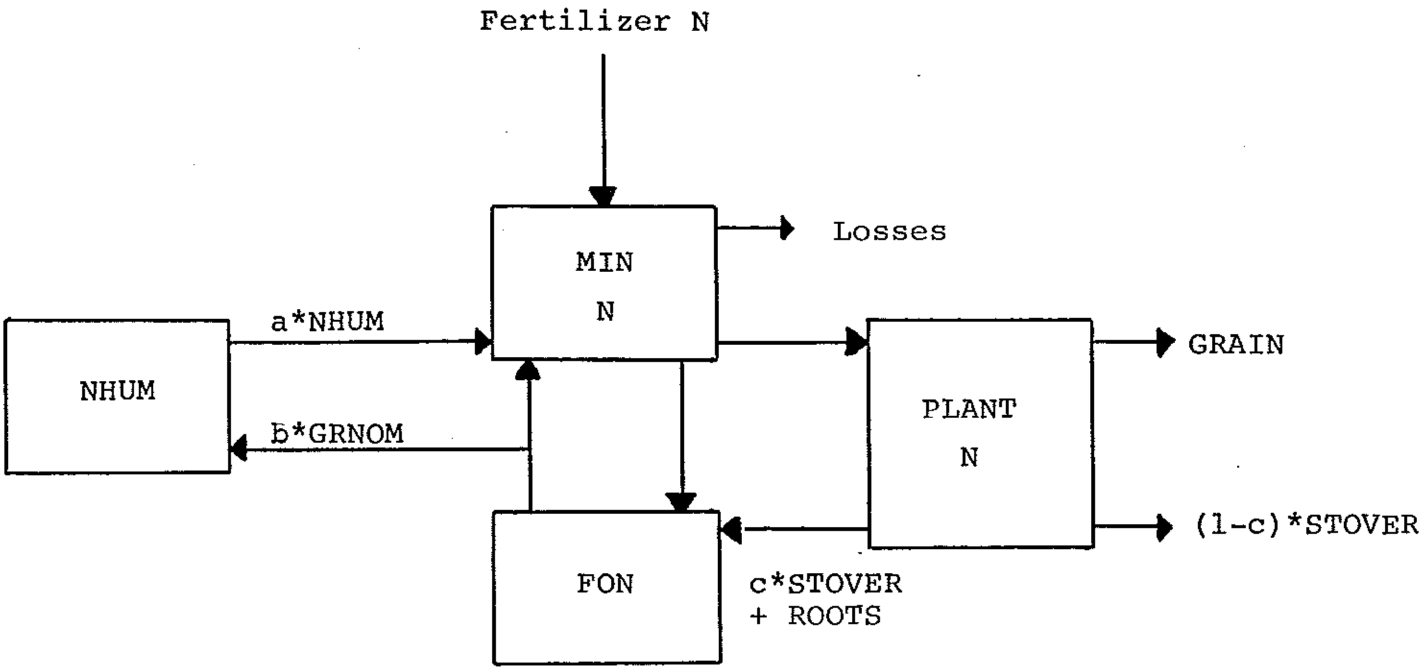
Figure 5. The effect of the value of the humification constant in CERES ("b" in Fig. 2) on simulated trends in humic N for a 100-yr period at Katherine.

Figure 1.



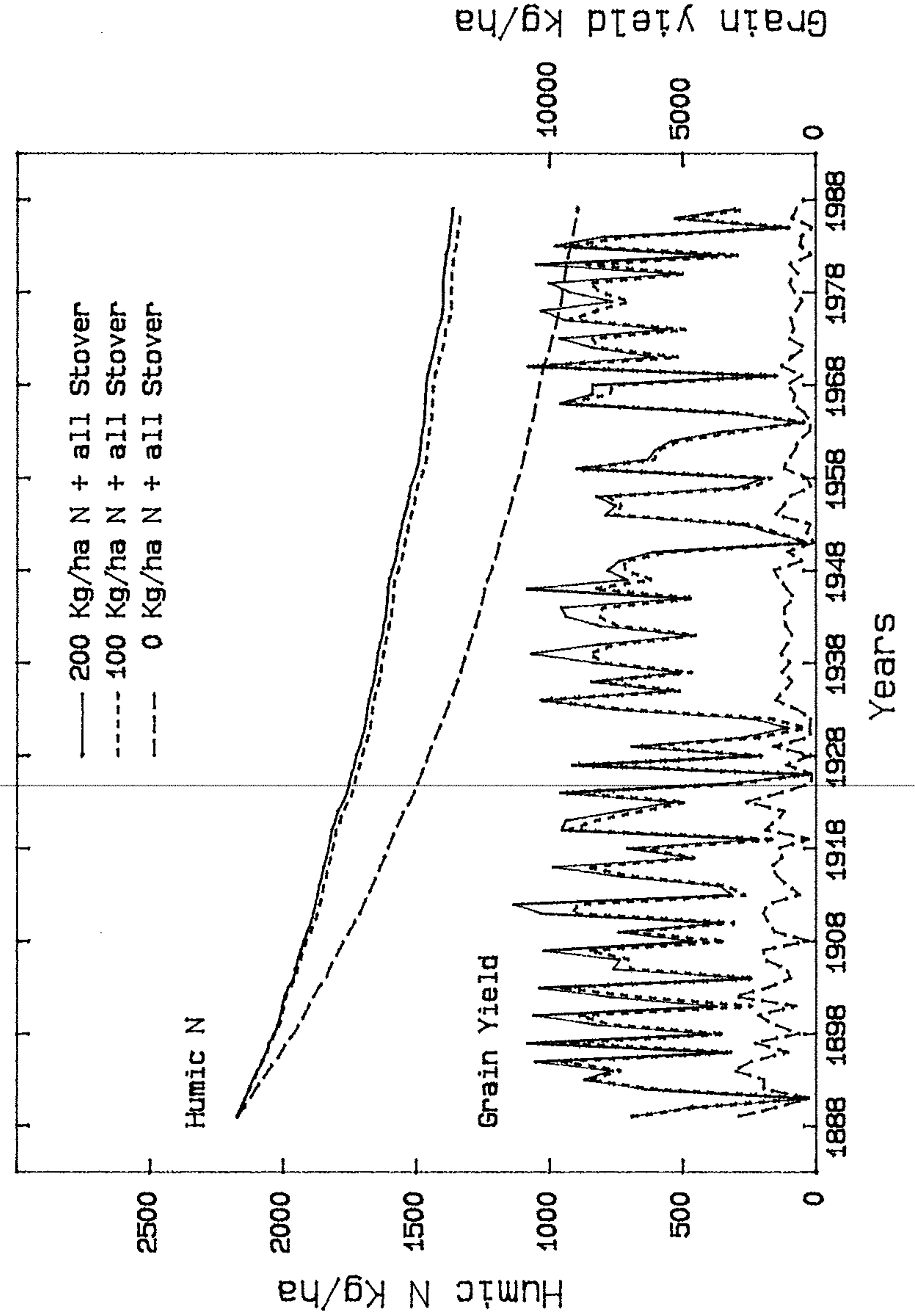
From: Russell (1981)

Figure 2.



N State Variables and Transfers in CERES

Figure 3.


Grain yield Kg/ha
10000
5000
0
200 Kg/ha N + all Stover
100 Kg/ha N + all Stover
0 Kg/ha N + all Stover
Humic N
Grain Yield
1888
1898
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Years
2500
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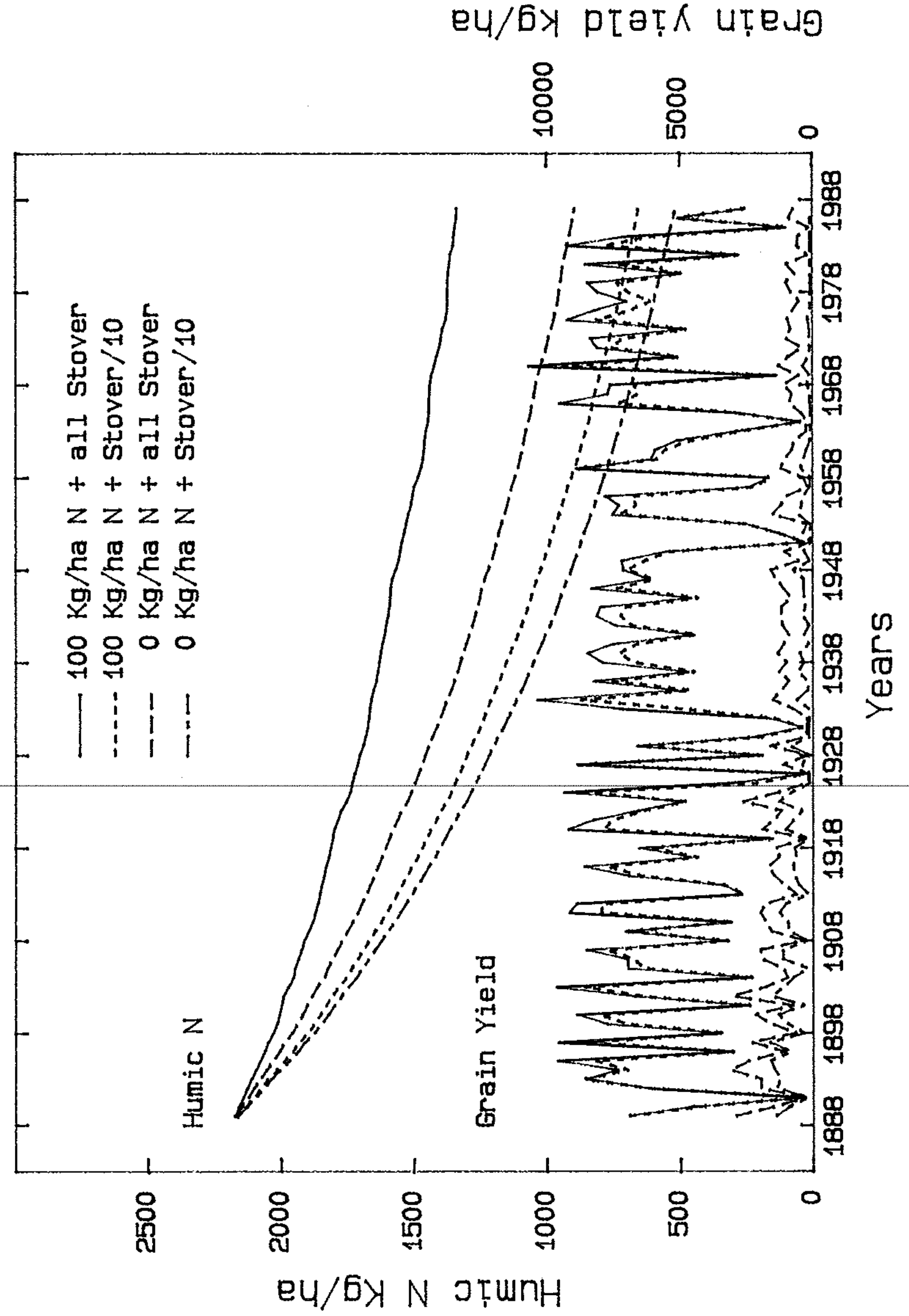
Humic N Kg/ha

Figure 4.


Humic N Kg/ha
Grain yield Kg/ha
Years
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1888
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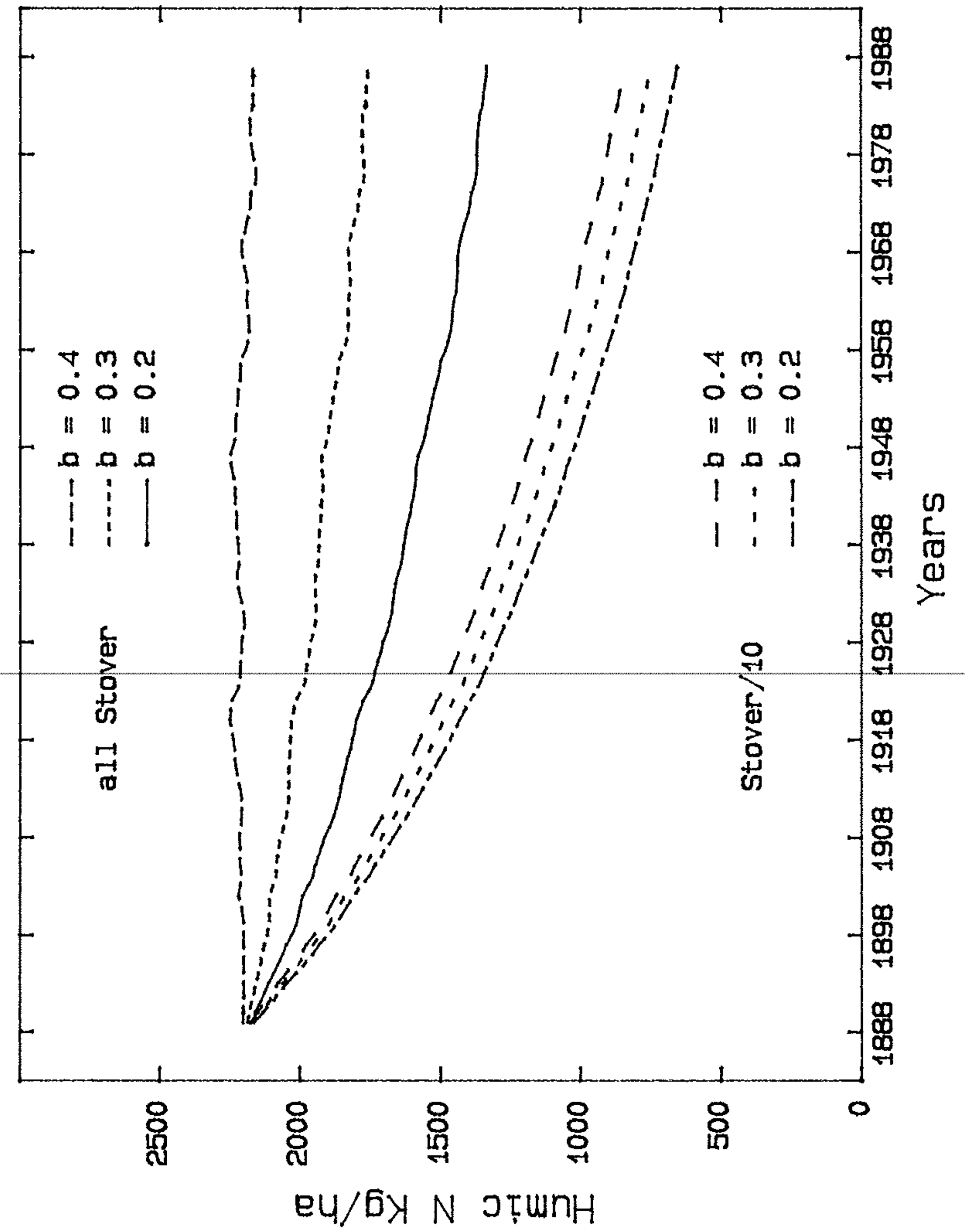
1918
1928
1938
1948
1958
1968
1978
1988
Humic N
Grain Yield
100 Kg/ha N + all Stover
100 Kg/ha N + Stover/10
0 Kg/ha N + all Stover
0 Kg/ha N + Stover/10

Figure 5.


Humic N Kg/ha
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