A PREDICTION MODEL FOR CROP YIELD IN MIXED CULTURE CROPPING SYSTEM

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ABSTRACT

This study uses analysis of variance technique to select important biological variables, which are used as explanatory variables in the multiple regression model. Linear multiple regression is found to be adequate in explaining the response in yield in terms of the selected characteristics : plant height (X_1), specific leaf weight (X_2), relative growth rate (X_3), and leaf water potential (X_4).

A simple diagramatic model depicting the direction and nature of the effects of the various factors under study is obtained from analysis of variance. From this diagram, important explanatory variables are filtered and are used to device a response model for the yield through comparative assessment of the explanatory variables from response equations.

An increase in plant height with a decrease in yield is explained very meaningfully by the Model ($R^2 = 0.802$) - about 80 per cent of the variation in yield is explained by the model in terms of plant height. Furthermore, the model explains adequately the interactive influences of the characters X_1, X_2, X_3, and X_4, with yield. All except plant height showed a positive relationship with yield. Increased or positive inter-relationship between yield with specific leaf weight, leaf water potential, relative growth rate at higher plant population is explained by the amellioration of water and light factors and the expression of yield per unit land surface area.

The approach of modelling plant processes through simple response diagrams and multiple regression analysis of the characters known to influence the process is more useful for researchers for prediction of crop yields with minimal measurements. The suggested model in this study is valid under the management and environment under which the study was carried; however similar models can be worked out for various conditions using a similar approach.

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INTRODUCTION

Crop models are a summary of selected empirical findings. They provide a framework within which the mathematical representation of the hypotheses concerning the behaviour of component process can act and interact. Since dynamic processes within a plant community and the interactions between plant and its environment are complex, modelling plays an important role in abstracting a system for what must be in each case a well-specified purpose. Such an approach helps in identifying problems. The development of computer models often involves diagramatic presentation of first step. The dynamic system modelling at various scale levels for example plant community or crop can be of some help in identifying and demonstrating major critical cause - feed back loops which may affect the functioning and dynamics of the ecosystem.

In the recent past, there has been considerable progress in the development of simulation models of crop growth and yield (Loomis et al 1979). Multiple regression techniques have been used in yield prediction in several crops (Jain et al, 1984). Such techniques rely mainly on the use of biometrical characters of the crops in monoculture systems. In mixtures, the productivity is confounded by the interactions between component species, climate, weather and management. Intercropping introduced anatomical and physiological diversity between the cohabiting species. In this study, analysis of variance technique was used to select important variables which were then used as explanation of variables in the multiple regression model. Linear multiple regression is assumed to be adequate to explain the response in yield in terms of some of these selected characteristics. From the

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comparative analysis of the various factors affecting yield and other factors, a response interaction system is obtained. A simple diagramatic model which depends on the direction and nature of the various factors under study is presented. The diagram indicates how we can filter out important explanatory variables which we then use to obtain a response model for the yield. From the response equations we make a comparative assessment of the explanatory variables.

MATERIALS AND METHODS

Tha data used in this study was obtained from an experiment conducted on botanical garden of the University of Nairobi during the 1984 short rains (October to December). Using a split plot design, sorghum (Sorghum bicolor L) Var serena, soybean (Glycine max L Merril) Congo variety were grown in pure stands and two species mixtures at a population of 1:1 at varying plant densities. The densities designated as low density (LD), Normal density (ND) and High density (HD) each with a plant population of 66,666; 83,333; and 111,111 plant/hectare respectively.

The main plots and sub-plots were 8M x 5M and 4M x 5M respectively. These were randomized and replicated four times. Each sub-plot was separated from each other by a strip of bare soil of 75cm while the main plots with 1m width. The spacings were at 75cmx20cm; 60cmx20cm; and 45cmx20cm for sorghum and soybean either in mixtures or mono cultures. Initially the plants were planted two four, but after one week the plants were thinned to two plants per hole for each plant type. All other agronomic practices were kept at the optimum level.

Plant growth and yield measurements were taken at two week intervals starting from 21 days after planting. This included plant height, number of pods, number of branches, and dry matter production from which relative growth rate was calculated. At the closure of canopy; specific leaf weight, leaf water potential, were taken. Finally grain yield was estimated at physiological maturity of the two crops.

The analysis of variance was carried on the interaction between various characters; crop yield, intercropping, crop density, mass of pods head per plant, number of branches, pods/plant, plant height, relative growth rate, leaf water potential and specific leaf weight. These factors were chosen on the basis of their direct influence of plant productivity. Having filtered the important factors which influence yield via analysis of variance, the relationship of some of these factors to yield was assessed statistically by multiple regression analysis. The best equation of multiple regression of yield in kg/ha (Y) connected with these factors was obtained by assuming X_1, X_2, X_3 and X_4 (plant height, specific leaf weight, relative growth rate, and leaf water potential respectively) as independent variables and Y as the dependent variable.

The proportion of total variation in Y that is explained by the regression model was assessed on the basis of the co-efficient of determination R^2, for each model equation.

RESULTS AND DISCUSSION

Results of the analysis of variance indicated significant differences at 5% level between plant density/crop yield, plant height; intercropping/crop yield, plant height, relative growth rate, leaf water potential and specific leaf weight. The interaction effects between plant density and intercropping only showed significant differences with plant height. It is apparent that intercropping, plant height and crop yield tend to strongly influence the performance of sorghum and soybean. Based on this information of analysis of variance, a diagramatic response model (Fig. A) was drawn. The diagram illustrates that very important varables which influence crop yield are in order of imprtance; intercropping, and crop density. These treatments influencing crop yield was characters such as plant height, specific leaf weight, relative growth rate, and leaf water potential. The insignificance of interaction between crop yield - crop density, - and intercropping of weight of pods/plant, number of branches/plant, pods/plant, and sorghum head indicates that these characters may have very little effect on crop yield in this pattern of growth.

The multiple regression response model used in this analysis was of the form : $y = {}_{o} + {}_{2}X_2 + {}_{3}X_3 + {}_{4}X_4$ where the dependable variable Y is the crop yield in kg/ha and the 's refers to the coefficients of respective independent variables ($X_1X_2X_3$ & X_4 Table 1). The coefficients in the model equation refer to the rates of change in yield (Y) with respect to the variables of plant height (cm) (X_1), specific leaf weight (X_2), relative growth rate (X_3) and leaf water potential (X_4).

There was different responses at a varying plant populations amongst soybean and sorghum. The present analysis did not take into account the cropping pattern. The analysis was based on examining the two crops both in mixed and sole cultures. Yield decreaes with increasing plant height and relative growth rate as observed for soybean crop grown at low plant population (Table L). The only character which exhibited a similar phenomenon at normal and high density was plant height, the other characters, increased with corresponding increase in crop yield. The magnitude of these characters was more pronounced at normal plant density in contrast to the behaviour at other densities.

Increasing plant population would bring about more competition. Hnnce plant height to have shown an increase with a decrease in yield is in agreement with what is expected. This implies the model explains the plant behaviour meaningfully. The linear relationships is even stronger at this plant population ($R^2 = 0.802$) i.e. about 80% of the variation in yield is explained by the model.

In the cropping system of sorghum and soybean, the sorghum was the dominant crop. Thus, its behaviour would definitely be quite different from the soybean. At low plant density there was a decrease in crop yield with increasing plant height. This is in congrerence with the response of soybeans at similar spacing (Table 1). The character of plant height appears to be a strong character in determining the yield at this plant population)low density) is explained by about 55% ($R^2 = 0.5493$). Although plant height at low density in sorghum, had similar response as in soybean, the trend was reversed at normal density. There was corresponding increase in height with increase in yield. This implies that the chosen density by most farmers (i.e. normal) is the optimum with respect to the relationship between height and yield. The other characters in sorghum at normal density increased with concomitant decrease in yield. Thus the relationship of this characters to yield implies and increase does not in any way increase yield but decreases it. The variation of these characters are explained by the model by about 69% ($R^2 = 0.6859$).

The only character with a similar response as at normal density at high density is specific leaf weight i.e. increases in this character resulted into a decrease in yield, while other characters had a positive effect. The variation in this case is explained by about 68% ($R^2 = 0.6762$).

The present model explains some of the observed variations adequately. The interactive influences of the characters (X_1, X_2, X_3 and X_4) with yield tend to come out clearly. Under competition, plants tend to compete for light, as a consequence most of the assimilates are diverted into quick growth, resulting into spindle plants weak in nature. Such plants will not yield much. Plant height has come out in support of this. Although there were increases in plant height there was a corresponding decrease in crop yield in both crops, except at normal density. The model thus would be employed to predict what the yield would be from simple measurements of plant height at the end of closure of the canopy under cropping systems that are under competition.

Plant height and relative growth rate are related to growth. Thus the two variables are expected to have almost similar effect. Relative growth rate expresses how fast the plant grows. As stated above an influence of competition induces faster growth rates which in fact are abnormal in search for light. The available resources are more translocated to make the body frame at a arate unproportional to the normal rate of growth. Such switch from normality is expected to affect the final yield. Hence the observed increase in relativee growth rate with concomitant decrease in crop yield is best explained by the model. This is exhibited in the soybean but not in sorghum as the sorghum acted as the dominant crop in this type of cropping system.

Specific leaf weight, leaf water potential are closely related. Thus, their increase with increase in crop yield is quite in order. In cases however, where this is not true, the main factor to explain it may be intercropping and plant density. Although these characters are also related to plant height and relative growth rate, in cases where the latter two have a greater influence, the effects of the SLW and leaf water potential would be masked. This is illustrated by the percentage contribution to the variation in the case of soybean behaviour at low density (44%).

The inter-relationships of these four characters to yield is shown at normal density. All of them except plant height exhibited a positive relationship with yield. Thus, if proper planting density is selected for these crops a researcher or a farmer would predict the yield by simply measuring any of these characters.

Plants at higher density show more competition influence than at lower and normal density. It would be expected that such densities would have drastic influences on specific leaf weight, relative growth rate and leaf water potential. In contrast this is not the case. Our present analysis shows that these characters had a positive influence on yield except the plant height. Although the plants compete for light and other resources, it is apparent that at this density the competition is not so great to have detrimental effects on yield. Furthermore it has been suggested by Donald (1962) that mixing of crops ameliorates the conditions. Competition for water jwould be expected to be high at high density, but due to the amelioration effect, the opposite occurs. This partly explains what is observed in our model. Since the yield is expressed on area unit basis and as the plants per unit area increases with density, the positive relationship of yield with SLW, $_1$, relative growth rate maybe due to this. It is likely that yield per plant basis would show a different trend. The strong relationship between yield and the above characters is exemplified by the coefficient of determination of $R^2 = 0.802$.

Although sorghum is a dominant crop in the cropping system in question, the influence of plant density had a strong influence. Low density showed that height had a negative influence on yield. This further points to the strong influence the plant height has on yield, although at normal density plant height had a positive effect. No real explanation for the cause of increase in plant height with decrease in crop yield can be given. This could be possibly be explained by examining the cropping pattern. Increases in SLW, RGR, and $_1$ with decreasing crop yield is contrary to what would be expected. This would imply that at this density, the increases in this parameters do not do any good to the crop yield. Alternatively they may be due to the interrelationships between these variables or multicollinearity.

Specific leaf weight (SLW) at high density would be expected to be low. Thus although increase in this character would be expected to increase yield, this is not the case. Increased SLW implies compact packaging of the cells within the cells. Since competition for light is strong in stands at high density, increasing SLW would render most of the cells less accessible to light, and hence the resources uses in making heavier cells would be of no benefit to yield. This explains the observed behaviour of increase in yield with a corresponding decrease in yield.

The present approach to modelling of plant processes through a simplistic diagramatic and multiple regression analysis of the characters known to influence the process is more useful for researchers and farmers who might need to predict their crop yields. Most models available in the literature have been based on monocropping systems and their approach has assumed mainly mechanistic approach. It is apparent that from this analysis, further models can be formulated on more complex ecosystems. Some of the oints which could not be explained by the model is due to the multi-collinearity among biometrical characters, which in turn inflates variances. This maybe removed by the use of principle component technique.

The problem of multi-collinearity and other related problems will be dealt with in a future paper in which we will endeavour to develop simple but realistic predictive models appropriate for an emerging economy. We also intend to generalize the modelling approach discussed to include simulation models, useful in understanding dorminant response characters.

SUMMARY

This study uses analysis of variance technique to select important biological variables, which are used as explanable variables in the multiple regression model. Linear multiple regression is found to be adequate in explaining the response in yield in terms of the selected characteristics of : plant height (X_1), specific leaf weight (X_2), relative growth rate (X_3), and leaf water potential (X_4).

A simple diagramatic model depended on the direction and nature of the various factors under study of a response interaction system is obtained from analysis of variance. From this diagram, important explanatory variables are filtered and are used to device a response model for the yield through comparative assessment of the explanatory variables from response equations:

An increase in plant height with a decrease in yield is explained very meaningfully by the Model ($R^2 = 0.802$) about 80 per cent of the variation in yield is explained by the model in considering plant height. Furthermore, the model explains adequately the interactive influences of the characters of X_1, X_2, X_3 and X_4, with yield. All except plant height showed a positive relationship with yield. Increased or positive inter-relationship between yield with specific leaf weight, leaf water potential, relative growth rate at higher plant population is explained by the amellioration of water and light factors and the

expression of yield per unit land surface area.

The approach of modelling plant processes through simplistic response diagrams and multiple regression analysis of the characters known to influence the process is more useful for researchers and farmers for prediction of crop yields with minimal measurements. The suggested model in this study is valid under the management and environment under which the study was carried, however, similar models can be worked out for various conditions using a similar approach.

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TABLE 1: Multiple Regression equation, multiple correlation coefficient and percentage contribution towards seed yield in soybean and sorghum in sole and mixed crops

	Multiple Regression Equation	R	Proportion of variation R^2
Soybean			
LD	$Y = 1038.1092 - 8.3291X_1 + 103648.9630X_2 - 375.2659X_3 + 0.7382X_4$	0.6635	44.03
ND	$Y = 667.8076 - 28.0774_1 + 35261.3636\ X_2 + 4342.1443X_3 + 7.8886\ X_4$	0.747	55.79
HD	$Y = 1815.5437 - 33438.9245X_1 + 36438\ 5107X_2 + 1877.7342\ X_3 + 17.2689$	0.896	80.20
Sorghum			
LD	$Y = 1418.2571 - 18.3696X_1 + 27770.4321X_2 + 15382.4731X_3 + 8.2324X_4$	0.741	54.93
ND	$Y = 1671.7287 + 0.2312X_1 + 1049\ 3898.3X_2 + 4563.9786X_3 - 12.048285\ X_4$	0.830	68.59
HD	$Y = 14097.159 + 156.51462\ X_1 - 939151.591X_2 + 4788.50103\ X_3 + 20.46\ 8699\ X_4$	0.822	67.62

Where:-

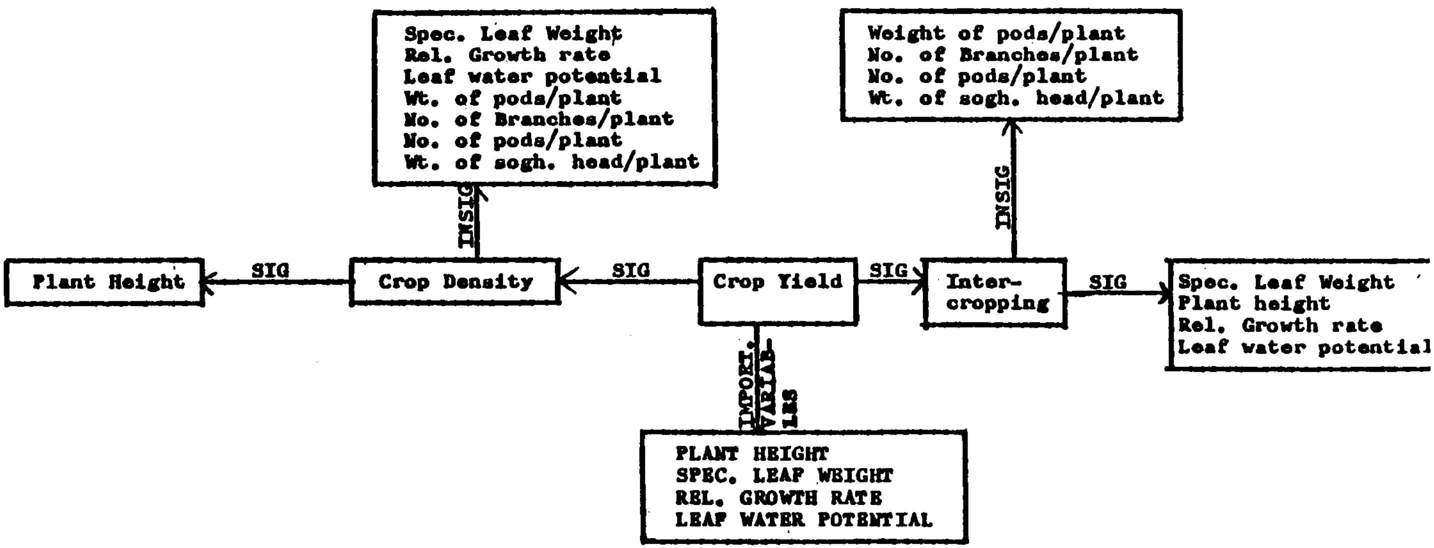
X_1 = height of plant/plant

X_2 = specific leaf weight (gcm^{-2})

X_3 = relative growth rate ($gwk^{-1}plant^{-1}$)

X_4 = leaf water potential (bars).

Figure 1. : A Diagramatic Representation of the interaction between yield and yield parameters



SIG = Significant at 5% level

INSIG = Insignificant at 5% level