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Conceptual GIS derivation and spatial modelling of abiotic covariates influencing maize-*Striga* dynamics[1]

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The spatial scale of a model for description of the maize-*Striga* system has been extended. The model uses abiotic covariates transformed according to the different physiological responses of maize and *Striga*. The driving covariates may be derived from geographically distributed data sets. A digitized area in Mauretania, used as an example, combines the relevant attributes, while local references result in different submodels for the environmental variables. This additional information allows different simulations, reflecting the underlying structure of the area, but these are characterized by a degree of uncertainty. A second process for the description of the post-maturity behaviour of *Striga* seed is added (derived from a Negative Binomial Distribution), and the GIS formation is used as a platform for simulating regional dispersal. The generated pattern, over time and space, was plausible, reflecting certain views on spatial heterogeneity. The system offers scope for development of spatially related control strategies. The implementation of a point model at regionalized scale shows advantages and limitations: the system is strongly dependent on the quality and accuracy of the underlying point model; requirements for simplicity, precision and computer capacity have to be reconciled.

Introduction

The parasitic weed *Striga hermontica* is one of the numerous factors which limit food production in the Sahel region. An existing population model, based on discrete age- and time-dependent structures, reflects the developmental dynamics of this weed and outputs a description of the seed bank over time. The parameters of the model have been identified on the basis of measurements done by the International Institute of Tropical Agriculture (IITA), resolving the additive factors of the surrounding environment. Our aim is, at a theoretical level, to generalize these unknown elements on a regional scale. Geographical references can then be the basis for modelling the natural spatial dispersal of a process first modelled at one point. The development of *Striga* includes both parasitic and autotrophic developmental stages. Therefore, the results obtained may be useful for similar modelling of weed or pest problems on a regional scale.

Requirements

The point model

The existing *Striga* model is based on a combination of discrete and continuous model compartments. It models the maize-*Striga* system quantitatively and qualitatively over time. The dynamics of *Striga* is constructed on an age-structure Leslie model (Richter & Söndgerath, 1990), while the host growth process is established using a simple system of differential equations. The model components are linked by a host-parasite function (Schmidt, 1992) controlling the development probabilities of the host and parasite in an interactive way.

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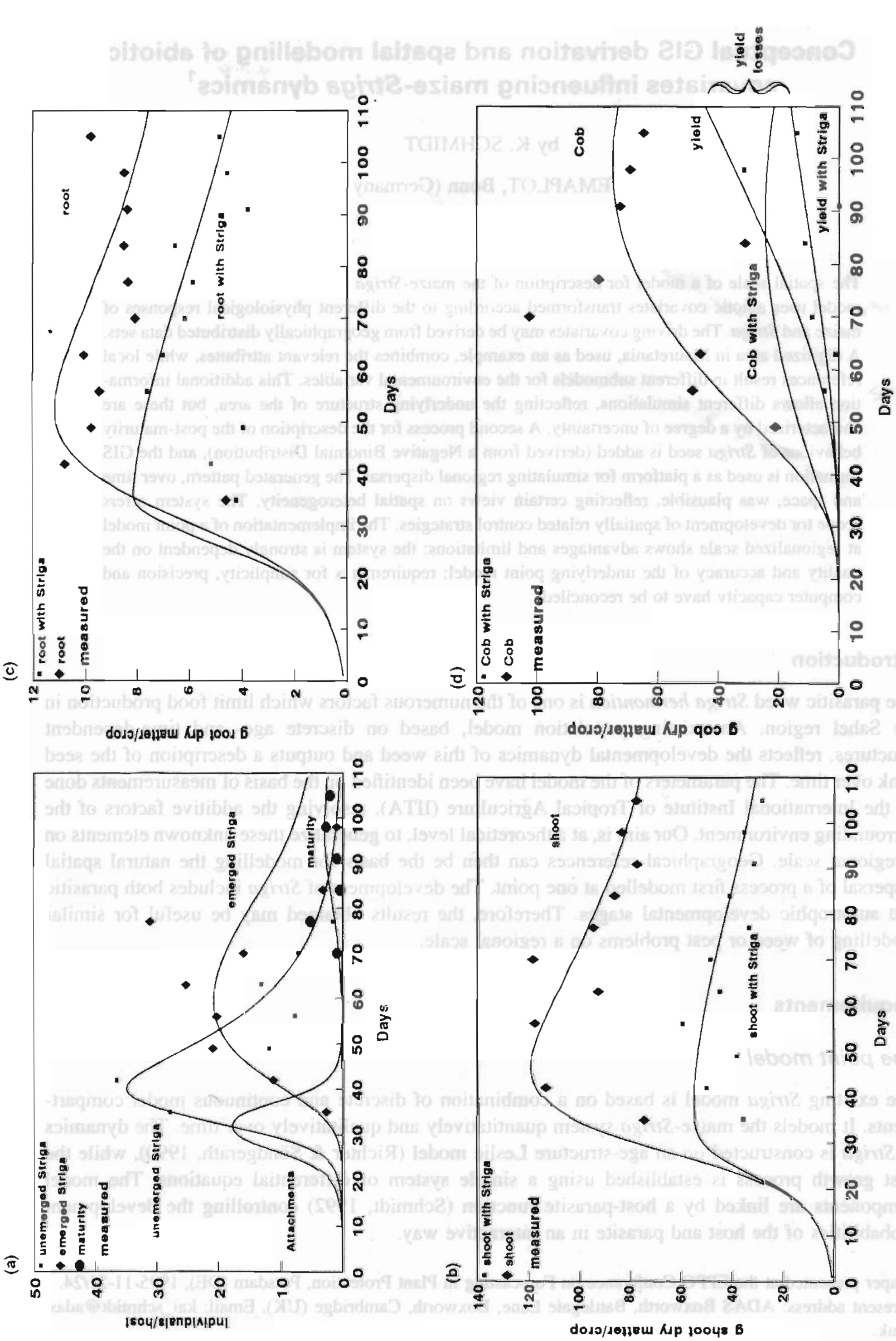


Fig. 1. Simulation of *Striga*-maize dynamics. (a) *Striga* stage dynamics; (b) shoot dynamics with and without *Striga* infestation; (c) root dynamics with and without *Striga* infestation; (d) cob dynamics with and without *Striga* infestation.

The external driving variables are abiotic factors like temperature and soil moisture, together with anthropogenic impacts like the maize cultivar or sowing density used. The effects of single abiotic covariates on physiological growth processes depend on the underlying biotope. So the model has been set up for a particular case: the light, sandy soils preferred by *Striga*. The factors of temperature, soil moisture and soil type, and their assumed interactions, are considered only for these light soils.

Figure 1 gives an example of a simulation over one season, compared with observed data. The dynamics of *Striga* development are shown as well as the development of shoots, roots and cobs of the maize host. All these parts of the system are linked, so that the four graphs represent one fit. The same set of parameters can be used to reflect different situations observed in different years. The point model thus allows long-term simulations over several years of monoculture. Different values of the variables (temperature pattern, soil moisture, sowing density, cultivars) lead to different equilibrium densities of the seed bank of *Striga*. These simulated equilibrium densities are strongly idealized, but represent the range of natural variation. The model can also link initial seed density of *Striga* to expected crop losses under different environmental conditions.

Geographically based systems and integration of dynamic point models

A GIS (Geographical Information System) combines the possibilities of classical data bank analysis with geographically referenced output. Furthermore, information can be prepared graphically, and the user has numerous possibilities for linking or counting existing information, for logical connection of spatial attributes and for statistical analysis. Basic information about the use of GIS has been presented by Burrough (1986). GIS represents a possible platform to regionalize population models, while spatial attributes can be assigned to the change of development rates of point models. Additional attributes may be soil types, topographic factors or the interaction of different biotopes within an observed region. The combination of thematic maps allows the partial identification of single influencing factors on the probability of development and assumed neighbourhood effects.

The application of the general GIS philosophy (IDRISI, 1992) has led to some first conceptual uses of the statistical tools of GIS in integrated pest management problems. A theoretical creation of an 'intelligent' information system has been presented by Coulson (1992). Such information systems are theoretically possible and there is a real need to expand the theory of integrated pest management to ecotope scales (Coulson, 1992). However, success depends on the accuracy of the model and on the constancy of parameters in different field situations. Each enlargement of the resolution of the model increases the complexity of interpretation and the variance of the underlying observations. Unknown compensations and overlapping influences can also bias the measurements. Possible sources of error may not be identified and validations may fail to take account of the entire interacting system at the surveyed scale. Such holistic investigations cannot explain a pest problem, because they only open a small window of unknown interactions and take no account of dynamic effects. Thus, pest models can theoretically be expanded by GIS implementation, but the weak points of the underlying model may remain hidden.

Fundamental principles of model application and regionalization

A possible way of considering external variables further is shown in Fig. 2. At the present stage of development, this includes the Leslie model at the centre, the abiotic and anthropogenic input resulting in quantitative descriptions of the host-parasite dynamics, the dynamics of the *Striga* seed bank over several years and characterization of the crop-loss relationship. Two new compartments have been added to the system. The 'GIS' compartment contains the assignment of the spatial attributes which are relevant for determining the spatially distributed driving variables. The information flow demonstrates the source of further parameters and the types of responses which are possible. The last compartment of the spatial dispersal of the seed bank will be elaborated later.

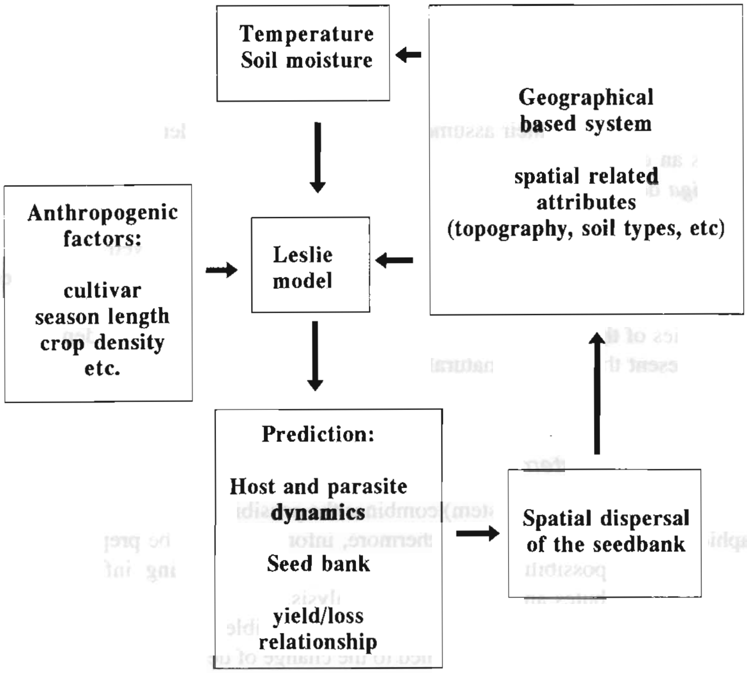


Fig. 2. Flow diagram illustrating the links between the Leslie model and a GIS.

Thematic map resources

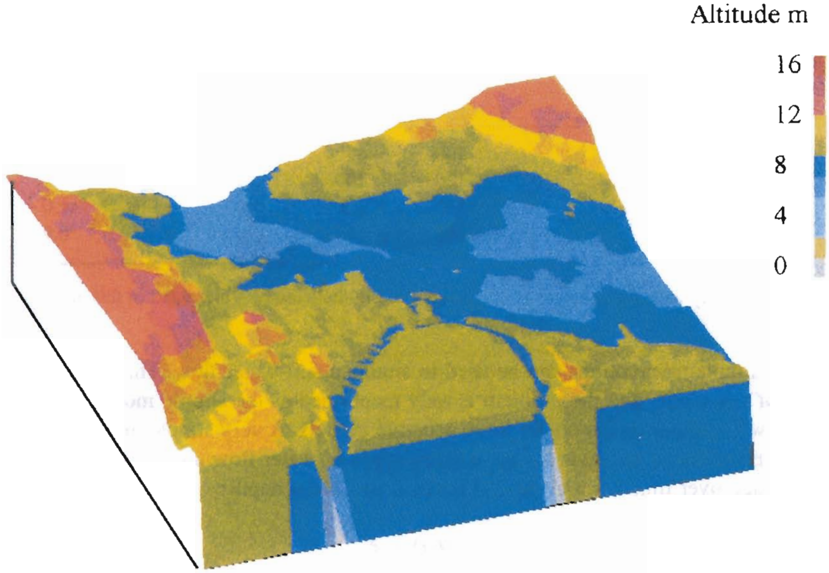
The grid-based 'IDRISI' GIS (IDRISI, 1992) offers several training maps. One of these digitized examples has been used to extrapolate the model. The geographical background describes a flooding area located on the Senegal River. The part of Mauritania concerned is also available with different thematic and overlaying maps. Figure 3a shows the topography of the research area, with the relief shown out of proportion. The distribution of soil types within the region has been digitized in a further map (Fig. 3b). With additional information on the average seasonal flooding level, a region for agricultural production can be extracted. The necessary procedures for merging maps and constructing graphs are tutorial examples of the IDRISI program and are introduced in the manual.

Further abiotic covariates

Two further factors must be included in the maize-*Striga* model: first the different growth behaviour and yield of maize in relation to different soil types, second the different evapotranspiration processes within the region and soil types. A special soil temperature can be expected for each soil type. However, the essential information for this is missing, and this problem can only be noted without being taken into account. The main point of interest is the effect of soil type and soil moisture in influencing host development rate.

It is assumed that the soil water capacity is filled up to 100% once a season by flooding. The area is defined by the underlying altitude. External rainfall events can be excluded from the desert location in Mauritania. A partial water flow may be assumed from the topography. The hot climatic conditions cause strong evaporation, and a certain proportion of the soil water will diffuse from the top of the soil profile to lower layers. Soil-water flow processes are in fact very complex, varying with time, and depending on crop growth, crop canopy and temperature. Despite this complexity,

(a)



(b)

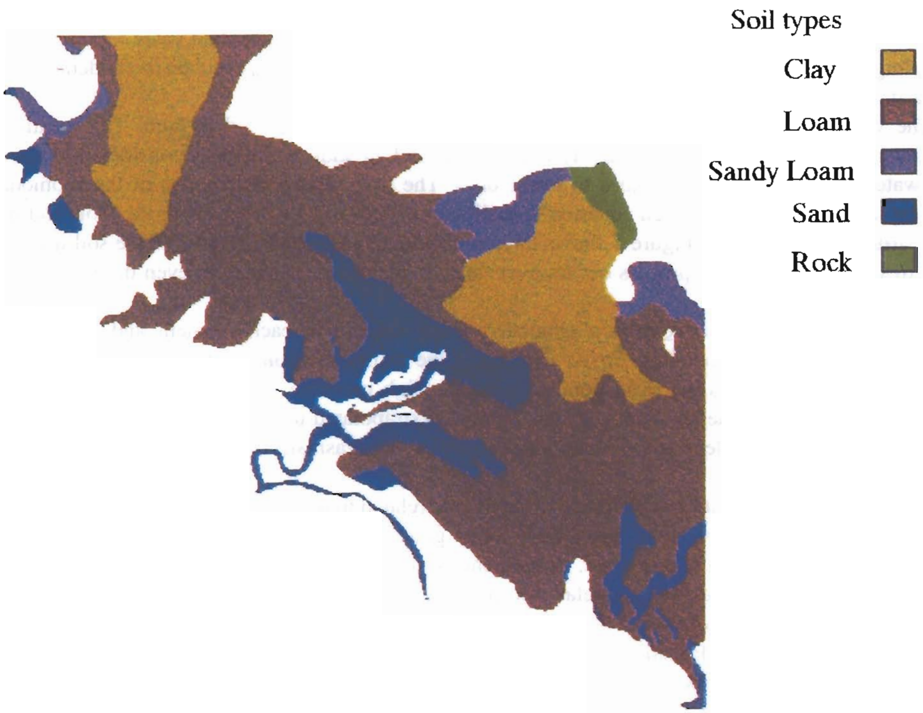


Fig. 3. (a) Topography of the digitized area, blue colors indicate the flooded area. (b) Soil type distribution within the flooded area (IDRISI, 1992).

Table 1. Values of H_{crit} and of the soil identifier H_{rate} used in operating the point model for *Striga* development in the GIS system (see Equation 1)

Soil type	1	2	3	4	H_{rate}
Sand	100	85	<u>60</u>	<u>50</u>	0.6
Sandy loam	120	100	<u>75</u>	<u>65</u>	0.8
Loam	140	120	<u>100</u>	<u>90</u>	1.0
Clay	160	<u>140</u>	<u>120</u>	<u>110</u>	0.9

Only underlined values of H_{crit} were used in the examples presented in this article.

only very simple assumptions can be used to simulate soil-water flow. This aspect is not the main purpose of this study, and the problem is only mentioned as the simple model could eventually be replaced, with greater precision, by more accurate models. A very simple, time-related, exponential function (Equation 1) accounts for the various types of water flow and simulates the water content in percentage over time for a given soil horizon (0–20 cm depth):

$$H(t) = e^{-(t/H_{crit})} \tag{1}$$

The different altitudes of the region, the different water capacities and the different transpiration rates for each soil type are summarized as the time-related variable H_{crit}. The values shown in Table 1 are related to the relevant differences in the factors described, and the absolute value represents the coupling to the biological response of the Leslie model. The value of H_{crit} is subjectively determined from the average growing season.

The value of H_{crit} rises when the potential water capacity of the soil is high. The locations considered in the region are at relatively low altitude and an additive factor is considered to allow for water flow from higher altitudes to lower ones. The time-related trajectories of the submodel are depicted in Fig. 4. The given equation is easily computed over the area, using the tools and the map arithmetic of IDRISI. Figure 5 shows three moments of simulated water flow: the soil initially fills to 100%; a drying-out process occurs over time; at the end of the season, even the heavy soils dry up.

This simple procedure provides a simulated water volume at each moment and location in the research area. In modelling *Striga* dynamics, the transformation of the water content to a physiological response is the main point of interest. High moisture content retards the growth of *Striga* (Egley, 1990). The behaviour of sandy soils is extrapolated to other soil types. The assumed conditions of irrigation lead to a low initial probability of parasitism by *Striga* and to slow initial establishment.

The maize yield capacities of different soil types are related to nutrient and moisture contents. The effects of these also have to be simplified. Since good soil quality increases the rate of maize development, resulting in higher yield, an elementary solution is to multiply the moisture response function by a further factor (H_{rate}), related to the soil type. The values of H_{rate} are also shown in Table 1. The relationship between soil moisture and a biological response can be described by a double Weibull function (Equation 2). H_{min} and H_{max} determine the upper and lower boundary of the development rate with respect to the soil moisture conditions H(t):

$$f(H(t)) = H_{rate} \cdot \left(1 - e^{-(H(t)/H_{min})^{\alpha}}\right) \cdot e^{-(H(t)/H_{max})^{\beta}} \tag{2}$$

All parameters may be estimated by appropriate experiments. The assumption is made that the area is flooded once, during the course of a single rainy season. The amount of irrigation is sufficient for crop production in the season and no external rainfall is expected.

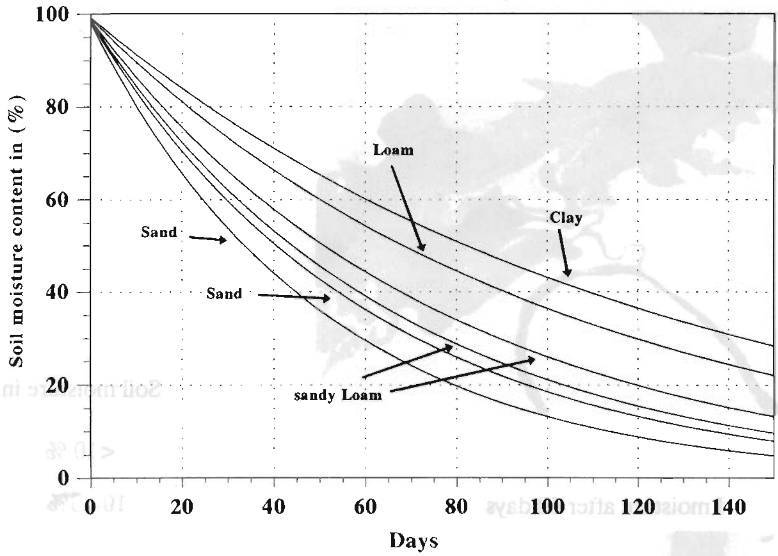


Fig. 4. Simulated time courses of soil-moisture conditions with respect to soil type.

Integration to GIS

Once the inputs have been decided, the simulation model has to be implemented in GIS. The submodels generate a simulation of the total research area correlated to spatial attributes, expressed as a new thematic map.

Numerical realization and problems

Further assumptions have to be made, because of a lack of information. Only the example in Fig. 1 will be considered. The temperature pattern is kept constant, and the variables are subject to the simplifications described above. In effect, the infinite possibilities for simulating the dynamics in relation to year (e.g. environmental influences), type of rotation, cultivar, plant density, etc., are reduced to one case, for which the information is available. This has an additional advantage. In theory, the simulation model must be applied for every point in the region with respect to all attributes. With a modelled area of about 400×500 pixel (corresponding to a real area of 62 km^2 in our example), the production of a single map would need at least 15 days to simulate one year or season. The use of a single known combination provides the climatic conditions and anthropogenic factors in advance, leaving the initial *Striga* seed density at each point and the different moisture conditions as the only variables. If discrete classes of initial densities are defined, a stand-alone simulation of all conceivable combinations and all classes of densities can be done. The results of this initial simulation are stored in a summary matrix. The attributes from each map coordinate can then be used to produce a map by accessing the summary matrix. This procedure reduces the generation time for a single map drastically, with little loss of information.

Area simulation

An initial map was built, containing 1000 seeds per m^2 for each pixel. A simulation over 10 years of maize monoculture yielded three equilibrium densities (Fig. 6). These results reflect the conceptual construction of the model. A comparison with the map of soil types (Fig. 3b) indicates that at the end

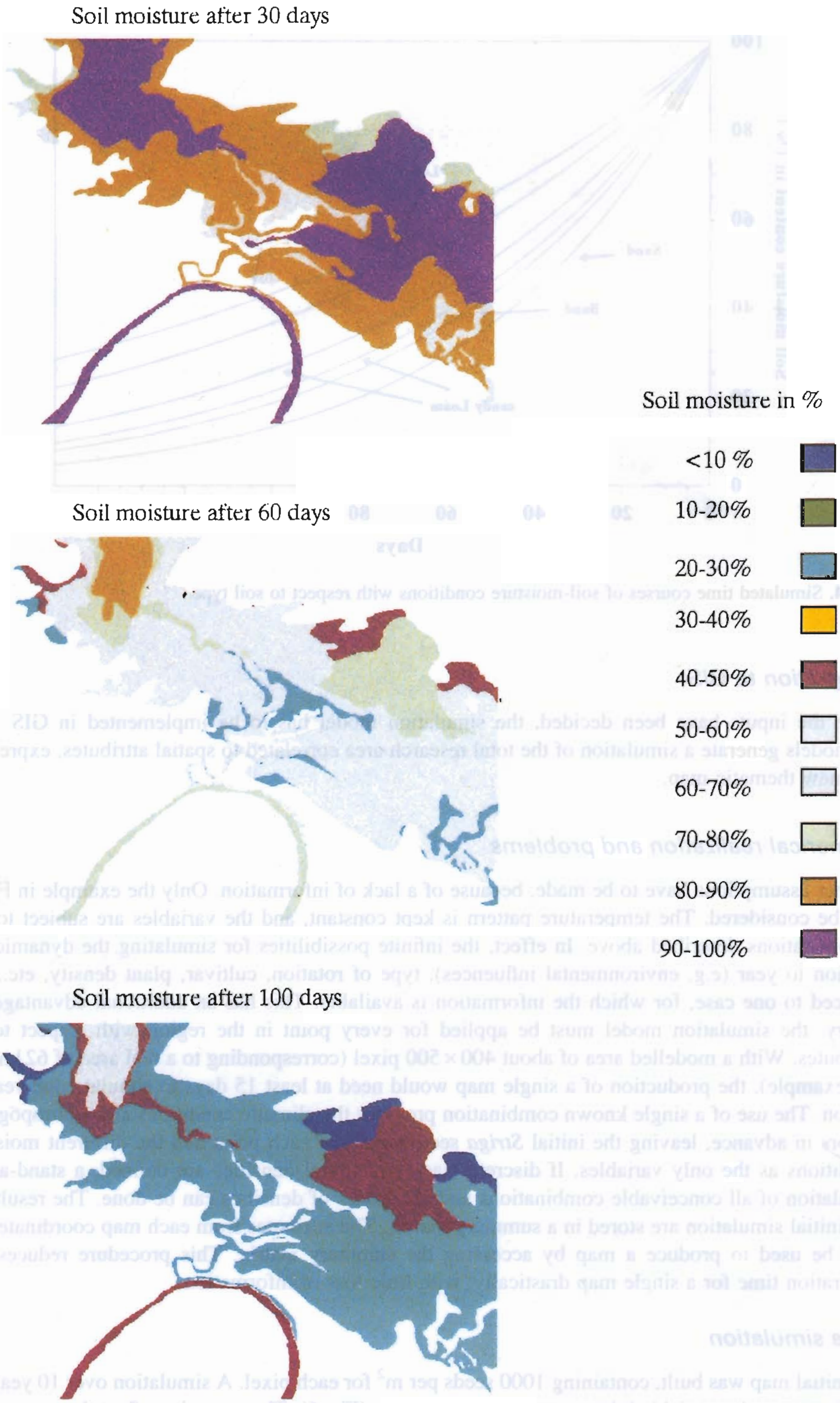


Fig. 5. Seasonal soil-moisture dynamics in the area.

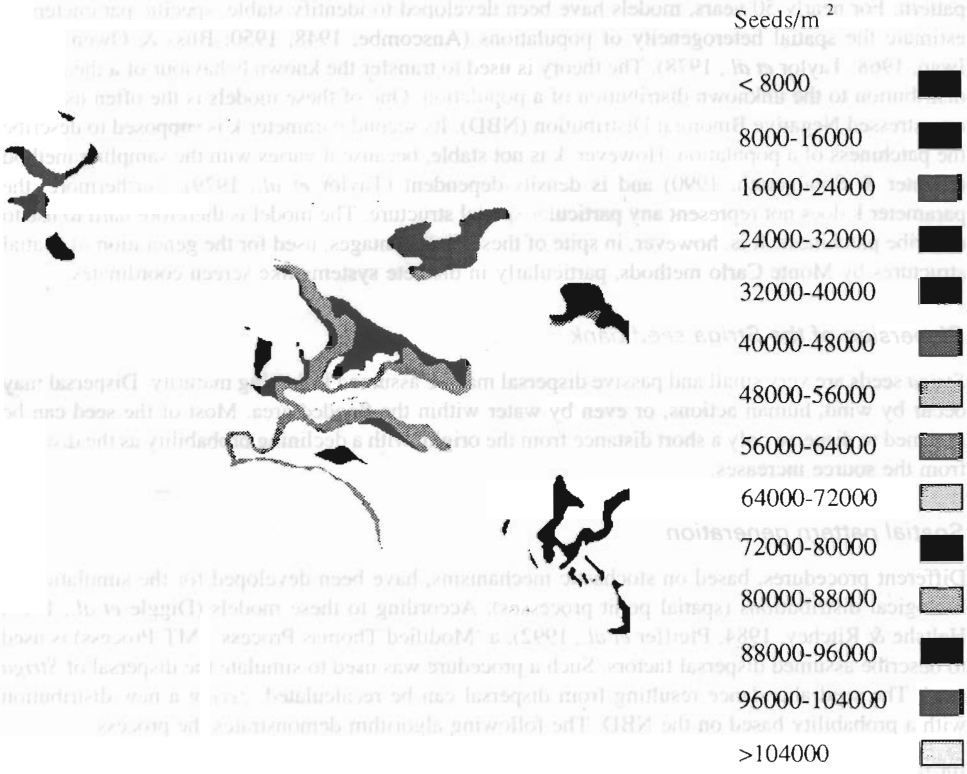


Fig. 6. *Striga* seed-bank density and distribution after 10 years of continuous maize.

of this period *Striga* is confined to light soils only. The final densities of the seed bank given by the model were in fact much lower than those observed in nature. This is probably due to the way in which soil moisture was modeled. Within the sites with light soils, a further ranking was observed. *Striga* seed yielded up to 96 000 seeds per m^2 on light loamy soil compared with 80 000 seeds per m^2 on sandy soils. This can be explained by the positive growth conditions of the host and the improved water supply at the end of the season on loamy soils. In addition, a further distinction may be based on topography. The heavier sites at lower altitude did not allow successful establishment of *Striga*. The higher water content of these soils retarded initial *Striga* development, shortening the available development time.

Spatial distribution processes

The observed pattern generated on the map (Fig. 6) presents no real advantage in view of the massive time and computer requirements of the simulation. The finite possible combinations, with resulting multiplication rates and equilibrium densities, could be produced one-dimensionally and transferred to the map afterwards. This would give the same result and reveal the same clear-cut regions of infestation. The apparent boundaries would not be observed in nature and may indeed be artefacts caused by the numerous simplifications used.

Surveys of pest problems in natural habitats are characterized by soft transitions and stochastic fuzziness. There are numerous reasons for this phenomenon, which can be summarized in the terms spatial distribution or dispersion and a number of statistical tools are available to describe spatial pattern. For nearly 50 years, models have been developed to identify stable, specific parameters to estimate the spatial heterogeneity of populations (Anscombe, 1948, 1950; Bliss & Owen, 1958; Iwao, 1968; Taylor *et al.*, 1978). The theory is used to transfer the known behaviour of a theoretical distribution to the unknown distribution of a population. One of these models is the often used and overstressed Negative Binomial Distribution (NBD). Its second parameter k is supposed to describe the patchiness of a population. However, k is not stable, because it varies with the sampling method (Richter & Söndgerath, 1990) and is density-dependent (Taylor *et al.*, 1979). Furthermore, the parameter k does not represent any particular spatial structure. The model is therefore hard to use to describe patchiness. It is, however, in spite of these disadvantages, used for the generation of spatial structures by Monte Carlo methods, particularly in discrete systems like screen coordinates.

Dispersion of the Striga seed bank

Striga seeds are very small and passive dispersal may be assumed following maturity. Dispersal may occur by wind, human actions, or even by water within the flooded area. Most of the seed can be assumed to disperse only a short distance from the origin, with a declining probability as the distance from the source increases.

Spatial pattern generation

Different procedures, based on stochastic mechanisms, have been developed for the simulation of biological distributions (spatial point processes). According to these models (Diggle *et al.*, 1976; Heltshe & Ritchey, 1984; Pfeiffer *et al.*, 1992), a 'Modified Thomas Process' (MT-Process) is used to describe assumed dispersal factors. Such a procedure was used to simulate the dispersal of *Striga* seed. The seed abundance resulting from dispersal can be recalculated, giving a new distribution with a probability based on the NBD. The following algorithm demonstrates the process:

```
for i: = 1 to nx do begin
        for j: = 1 to ny do begin
                for k: = 1 to Z_i,j do begin
                        n: = i + D*sin(φ);
                        m: = j + D*cos(φ);
                        NEWMAP_n,m: = NEWMAP_n,m + 1;
                end;
        end;
end;
```

with

nx,ny	numbers of points in x and y direction (500 × 400)
$Z_{i,j}$	*Striga* seed abundance at location i,j
ϕ	uniform distributed random number of the interval 0,180°
D	negative binomial distributed random number with $(0, \sigma^2)$
n,m	new coordinates of the current seed
NEWMAP	matrix of the new thematic map

The transformation provides the new coordinates of the current seed, while the distance D (average movement from the origin to the new position) can be determined with the following probability and the two given moments:

$$f(D) = \binom{k + D + 1}{D} \cdot \left(\frac{\mu}{k}\right)^{D} \cdot \left(1 + \frac{\mu}{k}\right)^{-D-k} \qquad D = 0, 1, 2, \ldots \tag{3}$$

with

$E_{(D)} = \mu = 3$; $V_{(D)} = \sigma^2 = \mu + (\mu/k)$; $k = 1.6$; units: pixel

The NBD random numbers are generated by uniformly distributed random generators. Both the random numbers introduced above are produced once per iteration. No limitation exists for the direction of the dispersal process, but changing the interval of variable can allow for topographic slopes or prevailing wind direction. The variable NEWMAP is the newly produced map containing the distributed seed bank. The procedure given above generates an actual seed abundance for each point (n,m). The individual seed comes from different directions and different origins (i,j). It is assumed that vitality is not influenced by origin or unknown neighbourhood effects, so that each seed remains able to develop with the same probability in the following season. This procedure is not included in IDRISI, but the open software structure of the GIS allows implementation of external subroutines written in different programming languages.

Simulation of spatial structures

The distribution of the seed bank is therefore simulated in a two-step procedure. The first step generates the basic map, the second step adds the dispersal algorithm and recalculates the distribution of the seed bank. The resulting map can then be used as the initial map for the Leslie model, to simulate subsequent years of maize production.

Figure 7 shows part of a 15-year simulation with a continuous crop of maize. An initial infestation level of 1000 *Striga* seeds per m^2 provided the basis for successful establishment on the light soils (Fig. 7a), as already shown in Fig. 6. As the duration of continual crop production increased, the seed bank approached equilibrium density. The final density was determined by soil type, environmental and migration processes. After 7 years, a stable balance was observable on the sites with light soil and a typical spot pattern was observed. *Striga* was also able to establish at appropriate density levels on the upper loamy soils (Fig. 7b). *Striga* could only establish successfully on suppressive soils if seeds were continuously supplied from conducive soils or hot spots, provided that the supply was higher than the suppressive effect of these soils. The spatial structure became clearer with increasing time (Fig. 7c). In addition, an unexpected phenomenon appeared. The continuous seed flow from the highly infested soils resulted in such high densities that *Striga* established itself on suppressive soils. This occurred when the multiplication rate exceeded the total effect of the reducing factors. After 15 years, a new equilibrium density was reached over the whole area (Fig. 7d). Continuing the system did not lead to any further change in distribution or abundance within the single regions or, in other words, emigration and immigration processes were in balance. The only exception was that *Striga* no longer persisted on deeper loamy soils or on clay, though the higher loamy soils were colonized to an economically significant extent. The topographic conditions were initially reflected in observable layering of density, but the simulated dispersal led to completely new structures, not explainable in terms of the topography. Thus, this one-dimensional stochastic procedure generated repeatable heterogeneity, offering a logical and biological solution for the patchiness. Although many assumptions were made and a very simple mathematical base was used, the resulting dispersion dynamics of the seed bank were plausible, reflecting certain views on spatial heterogeneity.

Geographical distribution of yield/loss relationship

The underlying point model included the possibility of simulating individual yield structures in relation to infestation levels and past climatic conditions. The maximum potential yield of maize can be assumed to be about 8 t ha^{-1}, according to the results of the IITA. This maximum may be the limit of potential yield (Fischer & Palmer, 1984) and an overestimate for Africa. Figure 8 shows the distribution of potential maize yield in the investigated area, dependent on soil type and soil moisture dynamics but without *Striga* infestation. Considering the infestation levels as shown in Fig. 7d would mirror the yield losses, respectively, but the thematic map would remain difficult to interpret in detail. Listing the yield/loss relationships in a table is more accurate (Table 2). IDRISI includes a procedure for extracting the values from the map, by summing the single yield/soil type combinations to classes.

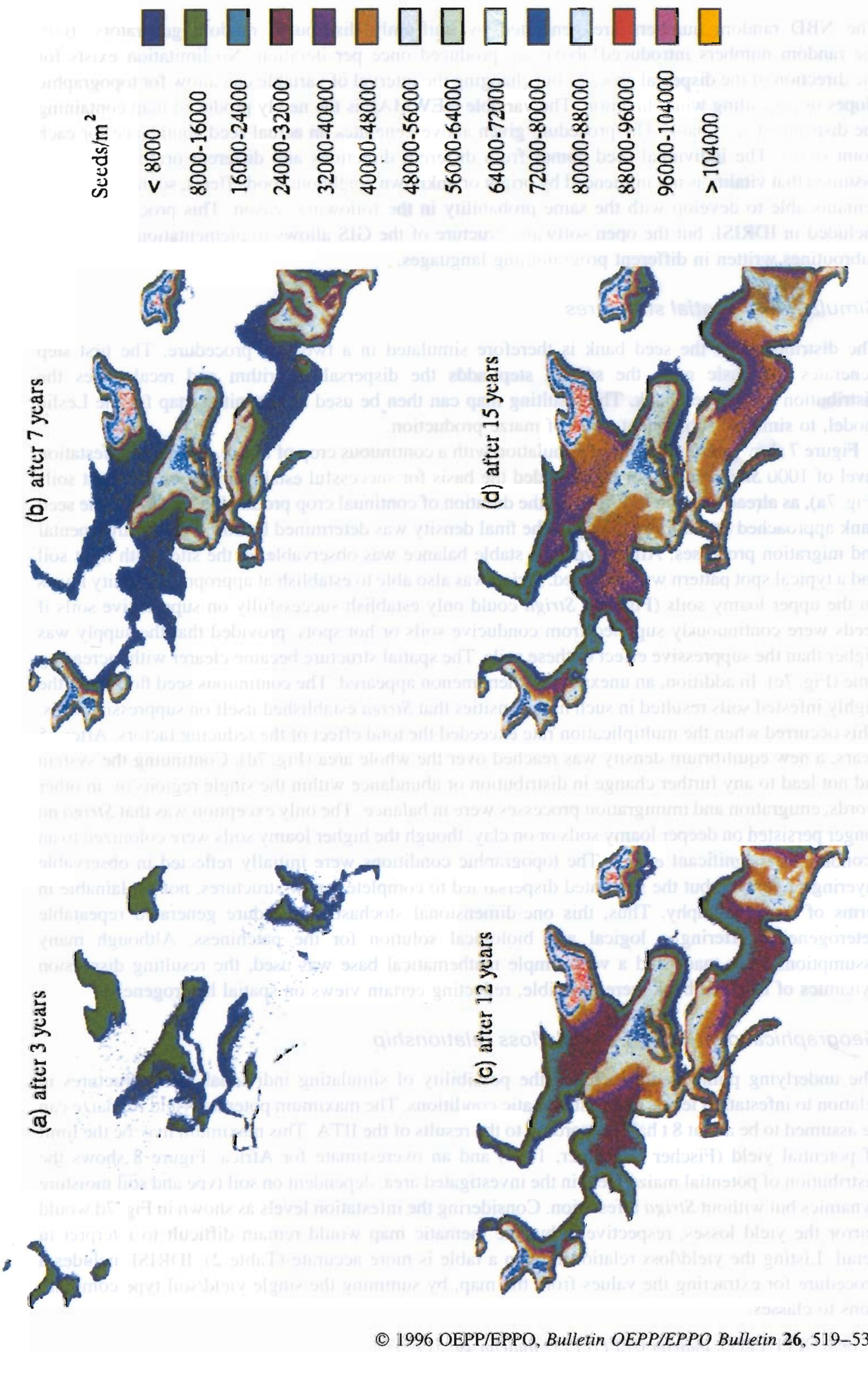


Fig. 7. *Striga* seed-bank density and distribution after 3, 7, 12 and 15 years of continuous maize and simulated dispersion dynamics.

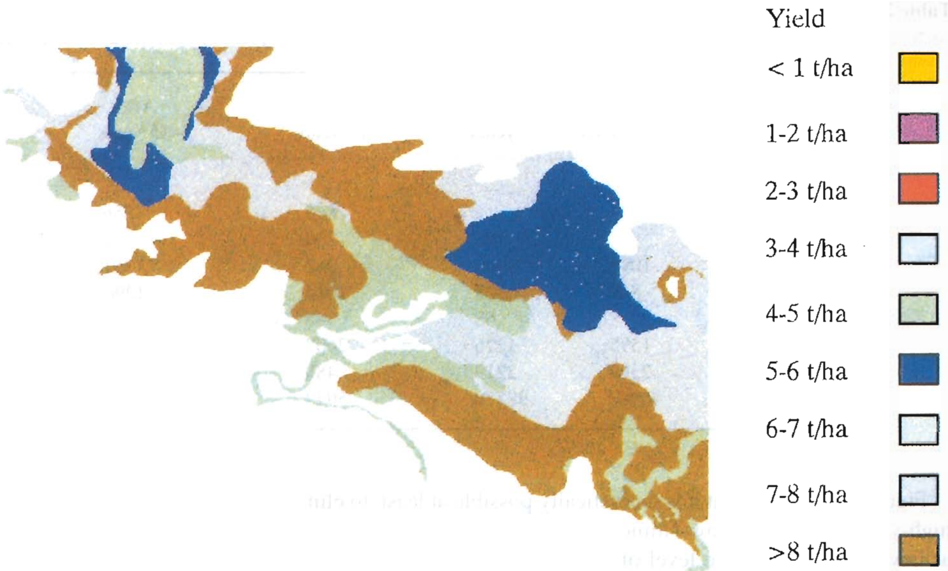


Fig. 8. Potential maize yield distribution without *Striga* infestation.

The irrigated area has a potential yield of nearly 41 000 t of maize under optimal environmental conditions, in the absence of *Striga*. Total yield is distributed according to the main soil types, with low yields associated with sandy soils and high yields with loamy soils (Fig. 8). As time passes, yields reflect the increasing density of *Striga,* decreasing on sandy soils from 4–5 to 2–3 t ha^{-1}, while the seed density increased from 1000 to 70 000–90 000 seeds per m^2 on these sites. Increasing monoculture led to the establishment of *Striga* on the higher altitude soils, with corresponding yield decreases and optimal yields no longer attained. The loss of 2 t was related to a *Striga* density of between 30 000 and 40 000 seeds per m^2. Total *Striga*-related crop losses reached about 16–17%. This value in fact appears rather low, and does not reflect the known damage potential of *Striga*. However, the test area is not optimal for *Striga*, and maximum infestation levels are not observed. Furthermore, the average value is distorted by the distribution. On light soils, losses rose to 50%, while other regions remained without any losses. *Striga* infestation reduced yields by about 2 t ha^{-1}, at very different infestation levels. This result shows the disadvantage of estimating generalized crop losses on a large scale when the underlying distribution is not known. The absolute values will almost certainly not be realistic.

The development of site-specific control strategies

The sensitivity of *Striga* to irrigation offers possible space-specific control strategies dependent on natural resources. These could include a second flooding within the season, the use of short-season cultivars or a combination of the two. The second flood approach could be considered as introducing a soft increase of the H_{crit}-value (Equation 1). Simulated irrigation did not avoid establishment on light soils, but lower equilibrium densities and later spread resulted in a plateau of *Striga* infestation on high-yield sites, with final densities possibly lying below a threshold level. The best results were obtained with short-season cultivars of maize (90–95 days) within the potential multiplication areas or on light soils, combined with additional flooding (Fig. 9). In this case the maize is used as a catch crop. *Striga* was able to start its life cycle, but the time required for maturity was not reached and potential multiplication was avoided. Maximum densities were nearly halved on the loamy soil, while *Striga* was totally suppressed on sandy soils.

Table 2. Distribution of potential maize yield in the region (number of ha, out of the total of 62 km^2, falling in each yield class) in relation to the development and dispersal of *Striga* over 15 years of continuous monoculture

Yield (t ha^{-1}) After 15 years	Initial (without *Striga*)	After 5 years	After 10 years	After 15 years
<2				
2–3			845	856
3–4		192	230	232
4–5	1091	1060	362	351
5–6	849	928	1014	1290
6–7		68	346	1227
7–8	1595	1226	2607	1759
>8	2369	2219	488	177
Total (t)	40967	38379	35927	34236

Figure 9 illustrates that it is theoretically possible at least, to eliminate populations of *Striga* in the high-yielding areas on low-altitude loam by controlling *Striga* populations in the hotspots. This is achieved by reducing the level of dispersal from soil types which favour *Striga* development into areas which are not favourable. The expected lower yield of short-season cultivars must be balanced

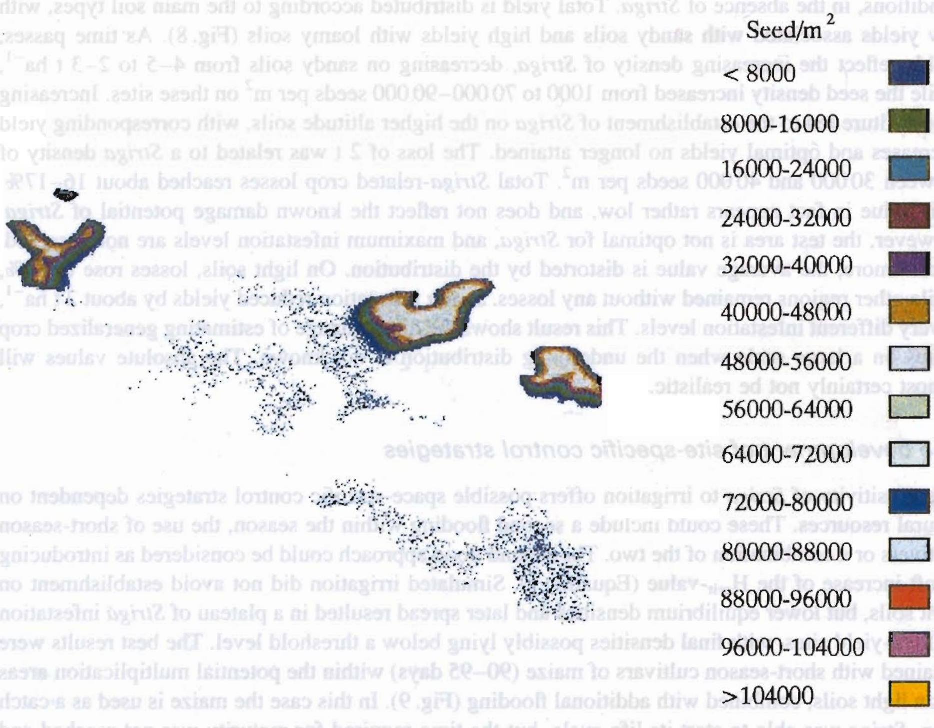


Fig. 9. *Striga* seed-bank density and distribution after 12 years with control strategies (additional irrigation and short-season maize cultivars).

against the positive effects on high-yield sites in the neighbourhood. These examples show how control strategies can be developed for individual localities in geographically based systems, especially if threshold levels can be defined more closely.

Discussion

The application of point models in a GIS demonstrates the advantages and limits of this procedure. Many aspects of GIS applications and philosophy are not used, while the static applications of GIS are applied to dynamic processes. The graphical output and the available map arithmetic of a GIS offers much additional information, but this cannot be considered in the present case. In fact, only a few of the data-manipulation possibilities of GIS were used, and the GIS was just used as a platform, providing the necessary information for input and regionalization of the point model. The changes of the abiotic variables with time were calculated from simple models and derived from the spatial georeferences. The modelling of dispersal using the NBD is based on theoretical considerations, and not on any background of biological observations. Other discrete or continuous distributions could just as well have been used.

Applying the point model in a GIS gave additional information for integrated pest management. Consideration of effects in space and time led to different outcomes with respect to the biology and management of *Striga*. Economic indices such as threshold levels could be determined in more detail, and neighbourhood effects could be considered in the pest management. However, some of the results were contrary to accepted existing knowledge on *Striga*.

Even with constant climatic conditions and a single representative production system, the model outputs were characterized by large variances. One can imagine what an enormous and unexplainable variance would be created if all input factors were varied for each coordinate (pixel), e.g. different crop rotations, cultivar selection, host-plant density and climatic conditions of the different years. However, all these factors were kept constant and only one of the infinite number of possible combinations was used. As a result, one can hardly dare to generalize from this single case to reality. On the other hand, Fig. 7a–d includes a massive density of information, such as would never be available from traditional research and surveys. In reality, large-scale investigation of *Striga* or any other pest problem is based on extensive field observations. The results may be influenced by subjective factors or, particularly in Africa, by the local infrastructure of roads and pathways.

It must be stressed that the theories developed in this paper do not give any new knowledge on the biology of *Striga*. Assumptions, of unknown biological background, are made on the spread of the pest, and the results reflect only these assumptions. The maize-*Striga* system is simply used as a test case for GIS implementation, and the conclusions could be just as relevant to other weed or pathogen problems. Nor does the example provide special information for Mauritania. The model could be transferred to any other scale or geographical site, relevant for *Striga* infestation.

The hypothetical derivations obtained in this work should lead to further research. If the factors influencing dispersal within a region were known, the point model could be used to identify the correct theoretical basis of dispersal processes in *Striga*. On the other hand, it must be recognized that this example of a GIS-based analysis of a pest problem does not lead only to theoretical conclusions, but also to the calculation of a very detailed solution. Numerous simplifications and assumptions had to be made on processes like soil water dynamics and possible interaction and compensation effects. To allow for these factors properly would call for more accurate modelling, which is at present impossible because of the computer time needed and because of the great variability of the input data. The model parameters cannot be adequately estimated, so the possibilities of error in the final output are enormous. The application of point models to GIS, as done in this article, should be interpreted very cautiously, and the reader should not be misled by the beauty of the images into believing that they necessarily correspond with any reality.

Dérivation conceptuelle SIG et modélisation spatiale des covariables abiotiques influençant la dynamique de *Striga* sur maïs

L'échelle d'un modèle de description du système maïs-*Striga* a été élargie. Le modèle utilise des covariables abiotiques transformées selon les réponses physiologiques du maïs et de *Striga*. Les covariables principales peuvent être dérivées de séries de données distribuées géographiquement. Une zone numérisée de Mauritanie, utilisée comme exemple, combine les caractéristiques considérées, alors que les références locales donnent différents sous-modèles pour les variables environnementales. Ces informations supplémentaires permettent diverses simulations, reflétant ainsi la structure sous-jacente de la zone, mais ces simulations sont caractérisées par un degré d'incertitude. Une deuxième procédure (dérivant d'une distribution binomiale négative) décrivant le comportement après maturité des graines de *Striga* est ajoutée à la première, et les informations SIG sont utilisées pour simuler la dispersion régionale. L'ensemble obtenu, dans le temps et dans l'espace, est plausible, et reflète certaines hypothèses d'hétérogénéité spatiale. Le système ouvre une perspective de mise au point de stratégies de lutte en fonction de la localisation. L'application d'un modèle ponctuel à l'échelle régionale montre des avantages et des limites: le système dépend fortement de la qualité et de la précision du modèle ponctuel sous-jacent; les exigences de simplicité, de précision et de capacités informatiques doivent être conciliées.

Концептуальное установление GIS и моделирование в пространстве абиотических ковариантов, влияющих на динамику кукуруза-*Striga*

Пространственный масштаб модели для описания системы кукуруза-*Striga* был расширен, В модели используются абиотические ковarианты, преобразованные в соответствии с различными физиологическими реакциями кукурузы и *Striga*. Управляющие ковариаты могут быть выведены из наборов географически распределенных данных. Оцифренная зона в Мавритании, используемая в качестве примера, представляет собой сочетание соответствующих атрибутов, в то время как местные показатели дают различные подмодели для переменных, определяемых окружающей средой. Дополнительная информация допускает различные варианты моделирования, отражающие подстилающие структурные особенности зоны, однако они характеризуются определенной степенью неопределенности. Был добавлен второй процесс для описания поведения семян *Striga* после достижения ими степени зрелости (выведенный из негативного биномального распределения) и установление GIS используется в качестве платформы для моделирования разброса в масштабах региона. Сгенерированное в пространстве и времени распределение было вероятным, отражая тем самым определенные взгляды на однородность в пространстве. Система дает возможность разработки связанных с пространством стратегий борьбы. Использование точечной модели в масштабе, приведенном к масштабу региона, представляет собой определенные преимущества; ограниченность системы сильно зависит от качества и точности подстилающей точечной модели; требования простоты, точности и быстродействия компьютера должны быть также приняты во внимание.

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