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Dispersal in an Agricultural Landscape: Effect on the Economic Threshold in Crop Protection

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Abstract: The threshold concept has been the cornerstone in the Integrated Pest Management (IPM) development in the last 40 years. However this concept has been elaborate on a field by field basis, even though pests, diseases and weeds are propagated from field to field. Failure to account for landscape-level effects may disrupt the effectiveness of crop protection measures even if they are locally very effective. I present a simulation analysis of the effect of inter-field propagation of harmful organisms. The results indicate that harmful organisms dispersal between fields can result in complex interactions between their populations and that economic threshold concept may be inadequate at agricultural landscape scale.

Key words: Integrated pest management · complex dynamics · simulation · crop losses · control

INTRODUCTION

Pests, diseases and weeds (collectively, harmful organisms) have had a detrimental effect on crop yield since the beginning of agriculture. It had been estimated that about 42% of the attainable world production is lost as a result of attack by harmful species [1]. In the management of harmful species there is an ongoing need for methods and concepts that allow less costly control with less environmental impact.

The concept of utilizing economic threshold to provide a more rational way of making pest control decisions originated in the 1950s [2]. The first efforts were all directed towards more rational management of arthropods pests and the concept of economic threshold is now well established for integrated pest management programs for many arthropod pests [3, 4]. Economic threshold have also been developed as a component of decision making for other areas of crop protection such pathogens and weeds [5, 6]. The essence of the threshold concept is that control is applied only when the density of the harmful organisms exceeds a threshold density. The threshold concept provide a tool to decide whether or not to apply control measures by accounting cost and benefits of control in current crop. The threshold itself is the level of harmful specie attack of which the benefit of control just exceeds its control [7].

The importance of harmful organisms dispersal between fields has been recognized for a long time [8, 9]. However, there have not been experimental and even theoretical studies of how this inter-field dispersion can affect the use of economic threshold at field level. The explanation may be that the focus in crop protection is traditionally based on field level studies, which ignores the complex and interconnected agricultural landscape of which the field is a part. This field-centered approach is based partly on the need to reduce the complexity of the problem and partly on the fact that the farmer's decision making process is oriented toward the individual field. In this study, I examined how the economic threshold can be affected by dispersal, considering an agriculture landscape perspective.

THE MODEL

I model the agricultural landscape as comprised of four connected fields of both equal size and quality. We assume that the four fields are arranged sequentially, with migration restricted only to adjacent field in the sequence. We remove "edge effects" at either end of the line by assuming seed migrate between fields 4 and 1.

The population dynamics within each field are modeled using a discrete population model used in many areas of crop protection [10-13] and described by the equation.

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$$N_{i,t+1} = \lambda N_{i,t} (1+aN_{i,t})^{-b} \qquad I=1..4 ; I\neq j \tag{1}$$

Here, $N_{i,t}$ is the population in field I at time t; λ is the intrinsic per capita growth; *a* is the inverse of carrying capacity; b describe the form of competition within the population.

To allow the introduction of dispersal we express Eq. (1) as:

$$N_{i,t+1} = (1-d_i)\lambda N_{i,t} (1+aN_{i,t})^{-b} + d_j N_{j,t} \qquad i,j=1..4 ; I\neq j, \tag{2}$$

where, d is the transmission rate, which is proportional to the abundance of the population (density independent).

The control measure taken for the farmers is simulated through a parameter c indicating the fractional reduction in the intrinsic per capita growth [14].

$$N_{i,t+1} = (1-d_i)(1-c)\lambda N_{i,t} (1+aN_{i,t})^{-b} + d_j N_{j,t} \qquad i,j=1..4; I\neq j \tag{3}$$

The farmer's decision to spray or not spray is based in a threshold density (T) and can be modeled as binary variable,

if $N_{i,t} \geq T$: spray

otherwise: not spray

These farmer's actuation impose a discontinuity in the population dynamic. To example the model I used the following set of parameters (λ=30; α=0.1; b=1; c=0.9 and T=10 individuals field^{-1}) The model was run for 100 years.

RESULTS AND DISCUSSION

The properties of an isolate population described by Eq. (1) have been well studied [11]. The equilibrium point of the Eq. (1) is given by:

$$N^*= [\lambda^{1/b}-1]/ a \tag{4}$$

The stability of the equilibrium point is given by:

$$\theta<2 \quad \text{where} \quad \theta \equiv N^* F' (N^*) \tag{5}$$

In the absence of both dispersal and control Eq. (1) presents a stable equilibrium population of 290 individuals field^{-1}. The introduction of an annual control of 90% (c=0.9) results, as might be expected, in a reduction of the stable equilibrium population to 20 individuals field^{-1}.

The introduction of dispersal and an economic threshold introduces a variety of new behaviors into the model. Despite the use of a threshold control the populations are not driven, in general, under the considered threshold value of 10 individuals field^{-1}, even reaching values up 160 individuals field^{-1} (Table 1). Moreover, the average value in all the fields (Table 1) are bigger than the population reached with an annual control (20 individuals field^{-1}). Results shown that dispersal is an important factor to be considered in pest management and alter the threshold effect.

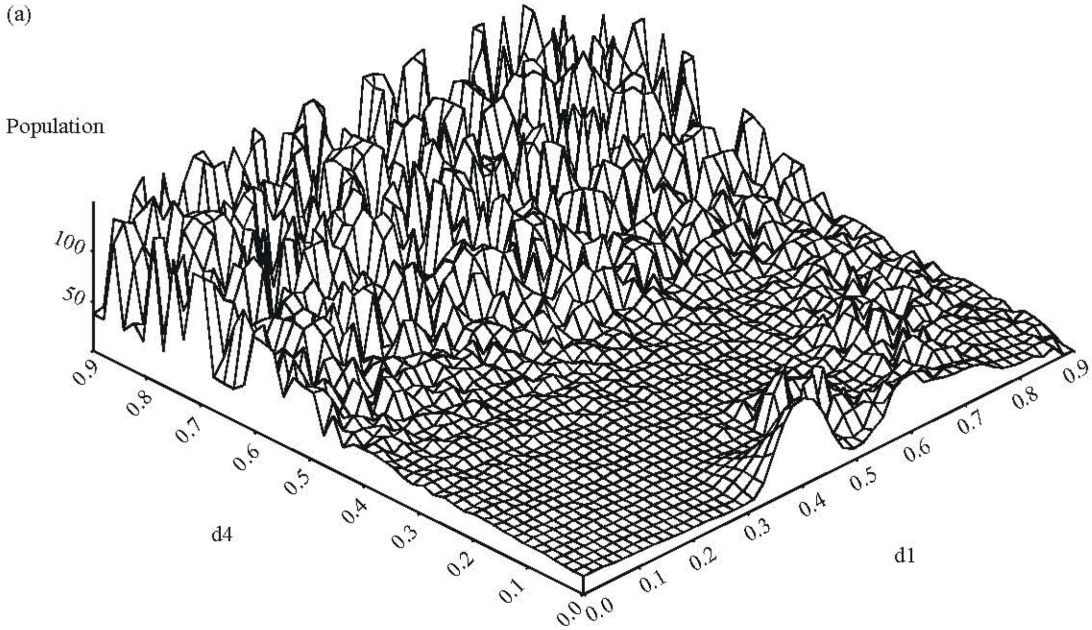
Two areas can be distinguished in Fig. 1a-d. The first area of interest corresponds to a huge area of stables equilibrium between a rate of dispersal of 0 and 0.40 and probably corresponds to a multiplicity of stable states [15]. We can see in Fig. 2 a example of such behavior. The second area of interest, between dispersal values of 0.40 and 0.9, shows a complex (cyclical) dynamic [16] that we can appreciate better in Fig. 3. The cyclical dynamics is a consequence of that the discontinuity imposed by the adoption of a discrete choice threshold. These phenomenons also have been pointed out for other authors in weed and disease control models [17-19].

These results suggest that the use of the economic threshold concept might be questioned in crop protection when consider a landscape point of view. Only in weed science such concept has been questioned recently [20] but principally based in different ecological

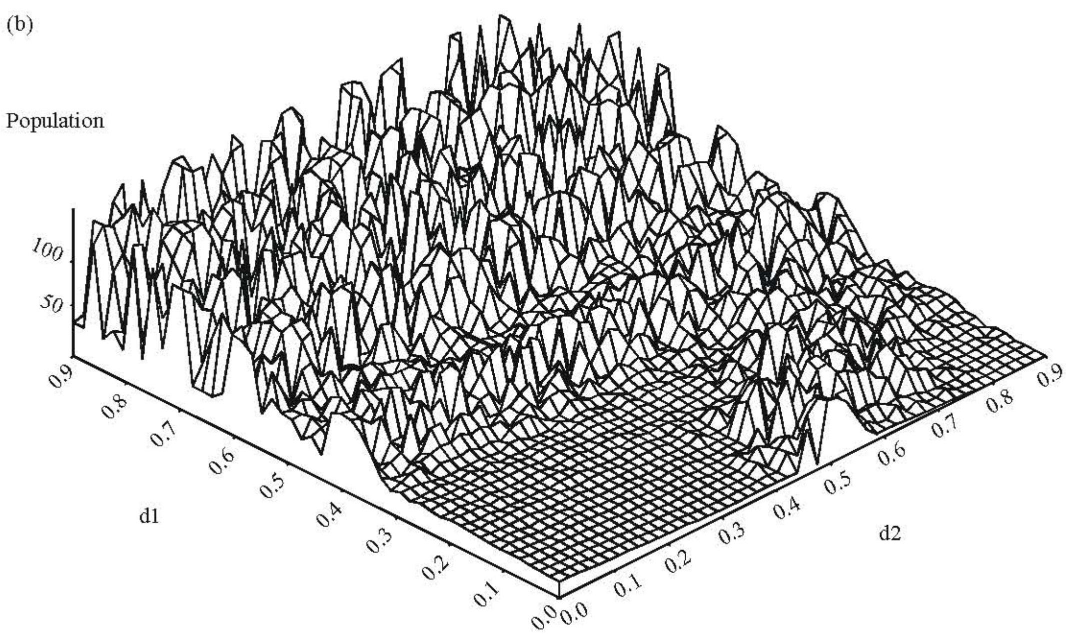
Table 1: Population summary (individuals field^{-1})

	Average	Variance	Max	Min
Field1	30.77	685.31	159.32	1.77
Field 2	31.20	890.49	160.82	3.59
Field 3	26.72	552.41	157.62	3.61
Field 4	25.42	473.07	157.80	3.58

(a)


Population
100
50
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
d4
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
d1

(b)


Population
100
50
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
d1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
d2

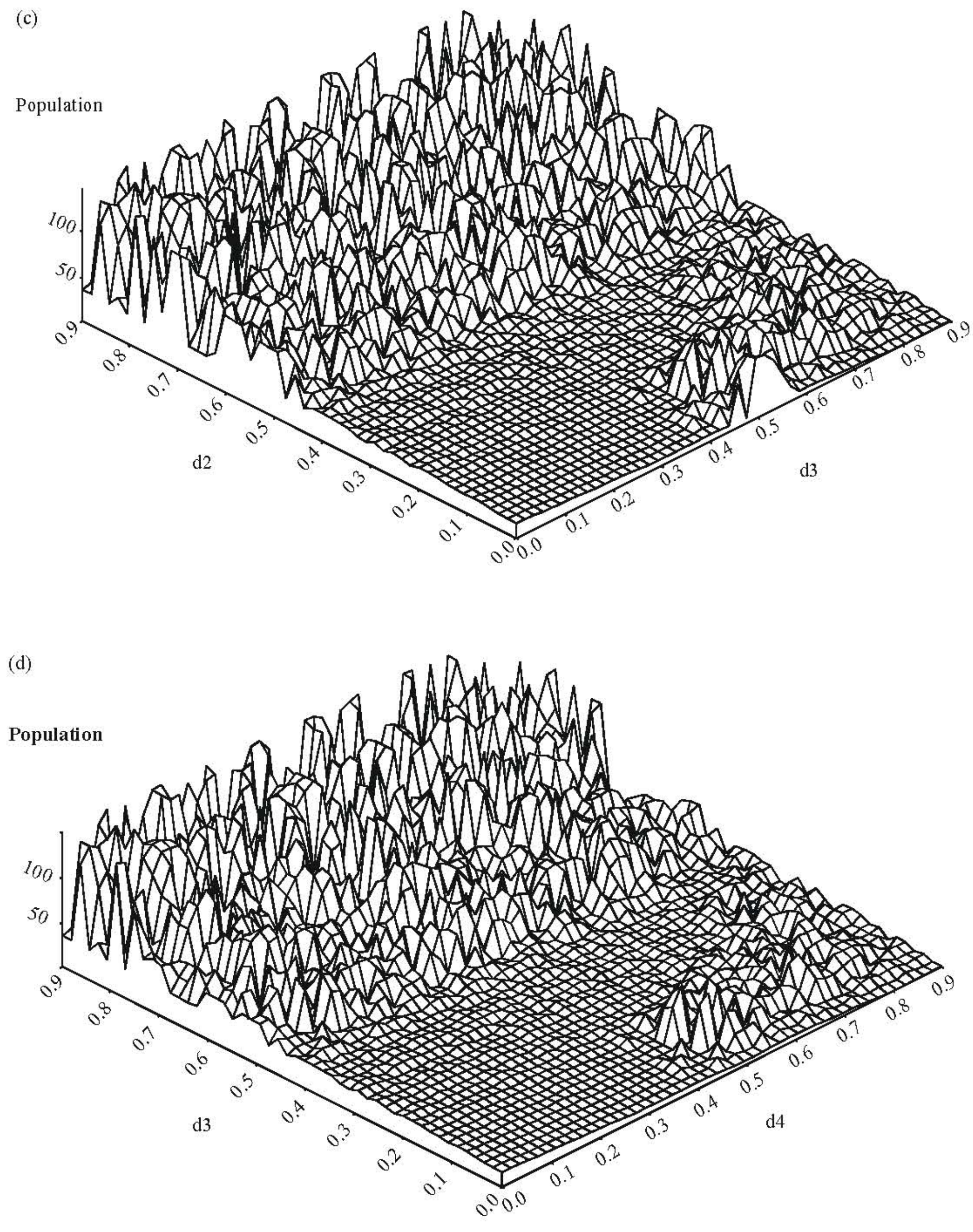


Fig. 1: Snapshot of population densities for different combination of dispersal rates (d_i)
a) field 1, b) field 2, c) field 3 and d) field 4 (λ=30; a=0.1; b=1; T=10)

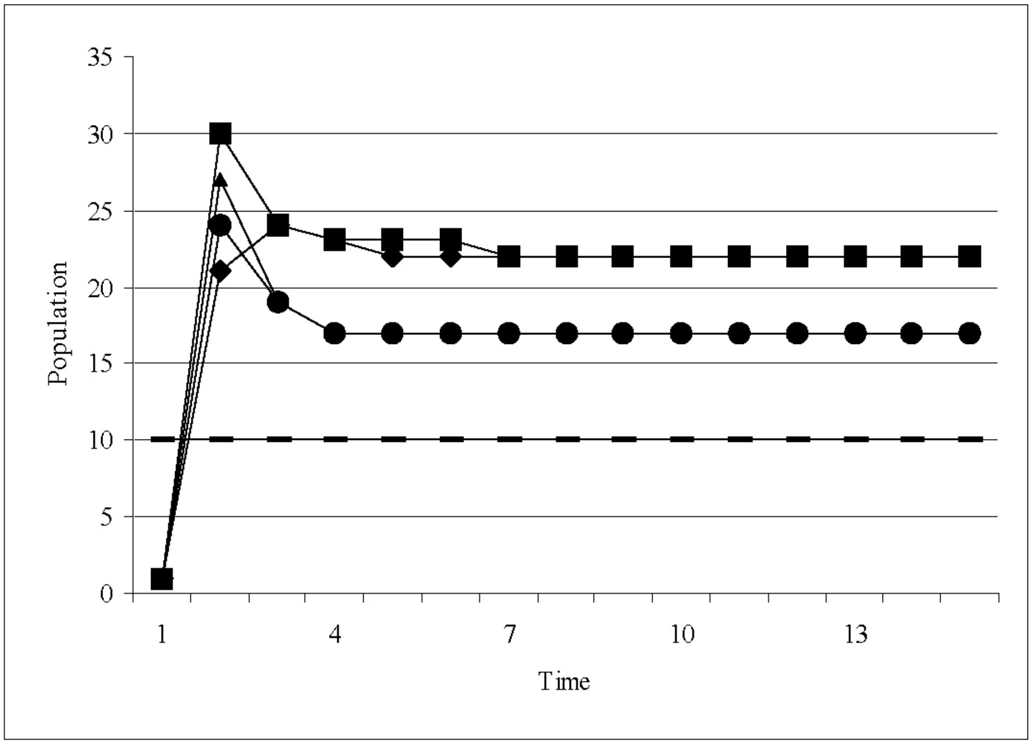


Fig. 2: Equilibrium dynamic: field 1 (◆), field 2 (■), field 3 (▲), field 4 (●), Threshold (−)
(d_1= 0.3, d_2= 0.2, d_3= 0.6, d_4= 0.5)

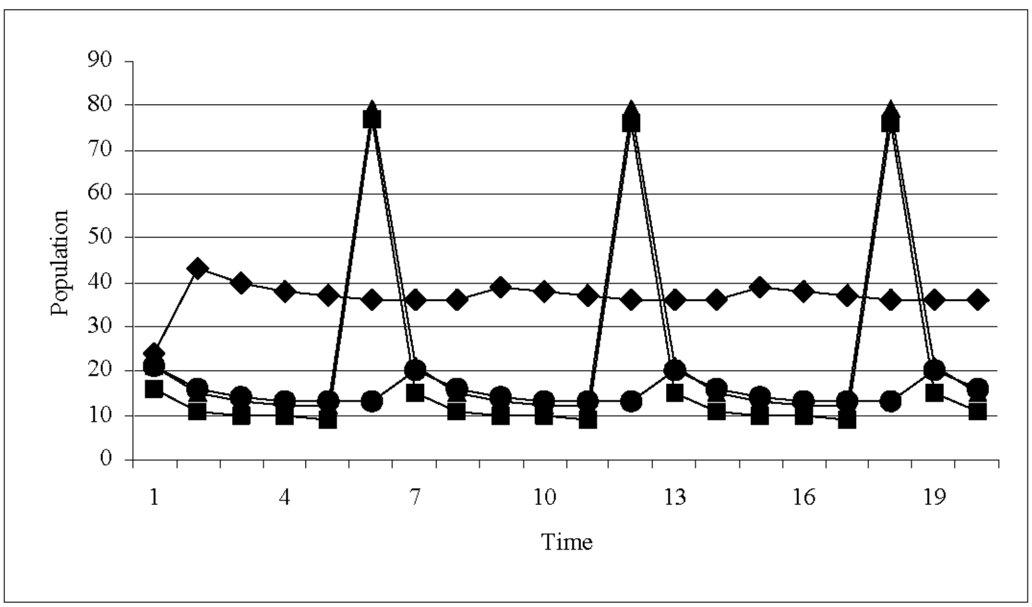


Fig. 3: Oscillatory dynamic: field 1 (◆), field 2 (■), field 3 (▲), field 4 (●)
(d_1= 0.6, d_2= 0.1, d_3= 0.3, d_4=0.8)

characteristics of weeds in relation to the insects more than the effects of dispersal.

It is known that insects, weeds and pathogens have specific biological characteristics, for instance most weed species have seed-bank. However, I have modeled the essential process of population dynamics of the such heterogeneous species. The result does not depend critically on our choice of the model to describe the density-dependent population dynamics. Extra simulations with different models produced similar conclusions. With the simplifying assumptions used here, I show that the use of economic thresholds in crop protection may be insufficient to control harmful species infestations in a situation of population dispersal between fields.

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