A SIMULATION MODEL OF HUMAN RESOURCE USE

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TECHNICAL REPORT - 58

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March 1990

INTRODUCTION

A comprehensive model of human resource use incorporating the following features has been developed: (i) a number of harvesters, (ii) a number of resources, (iii) a number of sites with a variety of geometrical configurations, (iv) allocation of available effort between territorial defence and resource harvesting, (v) Usurpation of resources, (vi) exchange of resources, (vii) migration of the harvesters, (viii) a variety of social interactions amongst the harvesters including kinship and reciprocation, (ix) birth and death rates dependent on success in acquisition of resources. This simulation model involving about 1000 Fortran IV statements has been made operational. Obviously, a series of submodels have to be investigated one by one. The first problem taken up for investigation is whether a harvester can arrive at the optimal harvesting strategy based on information relating to yield and effort levels alone. It has been shown that any simple algorithm tends to result in over-exploitation and resource exhaustion. Only a very long range averaging process can permit the harvester to arrive at the optimal effort. This is unlikely to obtain in practice

MAIN FEATURES OF THE MODEL

The central features in the model are different habitats, renewable resources and the harvester population.

There are NYS habitats or sites. These sites are distributed in the space on x,y plane which are separated from each other as given by the distance matrix DST.

The renewable resources characterized by growth rate GR are distributed on different sites. Each site has a carrying capacity CKR for the resource and a threshold value DR below which a resource cannot be harvested. The initial level VR of the resource on each site and the transport cost of the resource over unit distance are specified at the initial time.

Harvester population may be thought of as individuals, households and communities. They are located in different sites and are characterized by genotype IGN. Thus there are NGEN different number of genotypes on each site I. At a given site, each genotype has a different number of harvesters IGEN. Thus the total number of harvesters on a given site is the sum of all harvesters belonging to different gentypes existing on that site NXH(I).

At a given time, each harvester has a location as its head quarters IHQ. This is essentially a site or habitat located on the space. Each harvester has a certain wealth WLTH either earned by own labour or through social exchange and a minimal need for the resource. Each harvester is related to other harveters by bonds of alliance given by the alliance matrix ALPH or $[\alpha_{ij}]$. Harvester i is cooperative with the harvester j if α_{ij} is positive and antagonistic if α_{ij} is negative.

Each harvester on each site puts efforts to exploit the resource to its benefit. This is specified in the model as the harvesting effort HR , war effort WR and the resource defence effort DF. Harvesting effort is the proportion of the effort devoted by the harvester to harvest the resource. War effort is the proportion of the effort devoted to usurp the wealth from other harvesters. Rest of the effort is devoted to counter the war efforts exerted by other harvesters.

RESOURCE DYNAMICS OF THE MODEL

Resources are utilized by the harvesters to their benefits. The proportion of the resource j at site i, exploited by the harvester k (effective harvesting effort EH in the model) is determined as the function of the harvester's actual harvesting effort AH and its and other harvesters' defence harvesting effort BH.

$$AH_{i,j,k} = WLTH_{i,k} * PR1_{i,j,k,it} * HR_{i,k,it}$$

$$BH_{i,j,k} = WLTH_{i,k} * PR2_{i,j,k,it} * DF_{i,k,it} \quad (1)$$

where

PR1 = Proportion of the wealth used for actual harvest

PR2 = Proportion of the wealth used to defend the resorce

The effective harvesting effort of the harvester is now given by

$$EH_{i,j,k} = AH_{i,j,k} * (1 - \exp(-X))$$

where

$$X = \frac{\sum_{k1}^{NXH(i)} \alpha_{i,i,k,k1} * BH_{i,j,k}}{\sum_{k1}^{NXH(i1)} | \alpha_{i,i1,k,k1} | * BH_{i,j,k}} \quad (2)$$

α = alliance of the harvester with other harvesters.

Total harvesting effort of all the harvesters for each resource on each site is determined as the sum of the effective harvesting efforts of all the harvesters.

$$TOTH_{i,j} = \sum_{k=1}^{NXH(i)} EH_{i,j,k} \quad (3)$$

The total yield from a given resource on a given site is given by

$$YIELD_{i,j} = (VR_{i,j} - DR_{i,j}) * (1 - \exp(-TOTH_{i,j}/(VR_{i,j}+DR_{i,j}))) \quad (4)$$

$YIELD_{i,j} = 0$ if the resource level $VR_{i,j}$ goes below the threshold $DR_{i,j}$ below which a resource cannot be harvested. This yield is shared among all the harvesters in proportion to their effort. The individual yield of each harvester is now given by

$$YK_{i,j,k} = YIELD_{i,j} * EH_{i,j,k} / TOTH_{i,j} \quad (5)$$

As a result of the harvest, the level of the resource at each site becomes

$$VR_{i,j} = VR_{i,j} - YIELD_{i,j} \tag{6}$$

Resources migrate from one site to another in some proportion. After migration the resource at each site grows according to the equation

$$VR_{i,j} = VR_{i,j} + VR_{i,j} * GR_j * (1 - VR_{i,j} / CKR_{i,j}) \tag{7}$$

This resource is used by the harveter in the next time step.

The yield acquired by the harvester is transported to its head quarters. The total yield received by each harvester from a resource pooled from all sites is given by

$$BTOT_{i,j,k} = \sum_{i1}^{NYS} (YK_{i,j,k} - TR_j * DST(i1, IHQ(i,k))) \tag{8}$$

Wealth of each harvester depends on the minimal need for the resource. It is given by

$$WLTH_{i,k} = \sum_{j}^{NZR} BTOT_{i,j,k} / NEED_{i,j,k} \tag{9}$$

Harvesters who belong to the same alliance group usurp the wealth from the harvesters who are the members of a less powerful alliance. The collective power of each alliance of the harvesters is given by

$$PW_{i,k} = \sum_{j}^{NZR} WLTH_{i,j} * WR_{i,j} \qquad (\text{if } \alpha_{i,j} > 0) \qquad (10)$$

After usurpation, we have the final wealth position of each harvester. If a harvester has gained wealth over previous time step, it stays put, otherwise it settles randomely in any of the available habitat.

A harvester risks death depending on its wealth relative to the maximum wealth.The dead harvester being removed, the survivors are renumbered appropriately and are characterized by head quarters,genotype,war effort,harvesting effort and wealth. Surviving harvesters do or do not reproduce depending on their wealth and luck. Reproduction is simple binary fission. Both daughter harvesters inherit half the wealth and all other properties of the parent. The harvesters ,then decide on the harvesting effort and the resource defence strategies for the next time step so that it can exploit the resource at the optimal level. The functional flowchart of the model is included in the appendix A.

MAIN OBJECTIVES OF THE MODEL

The model aims to explore questions of the type :

(1) How an individual can learn to exploit a resource at an optimal level ? It can be trial & error , social learning or insightful learning etc.

(2) What is an optimal level if there are many sites and many resources ?

(3) Can a group exploit the resource at an optimal level ? How are co-operative and non- cooperative solutions arrived at ?

OPTIMUM HARVESTING EFFORT

To explore the first question, we considered a simple case wherein only one resource at a single site is harvested by a single harvester. Naturally, there is neither harvester migration nor resource migration. Further, the harvester is restricted from reproduction and is assumed to be immortal. We are interested in how a harvester decides on the optimum harvesting effort strategy. By optimum harvesting effort, we mean the harvesting effort corresponding to maximum yield on a sustainable basis.To get the optimum harvesting effort, we solved the equations (1) through (10) numerically for steady state for a given carrying capacity of the site for the resource, the threshold below which the resource cannot be harvested, need of the harvester for the resource and intrinsic growth rate of the resource.

Steady state curves for yield and resource levels are contained in the figures 1.0 to 1.9. The figures 1.0,1.1,1.2,1.3 & 1.9 show that as the need of the harvester for the resource increases, the optimum harvesting effort also increases irrespective of the intrinsic growth rate of the resource. The figures 1.0,1.1,1.2,1.3,1.4,1.5 show the influence of the growth rate of the resource on the maximum yield one can obtain. As the growth rate of the resource increases, the maximum yield obtained also increases irrespective of the need of the harvester for the resource. As we increase the value of the threshold below which a resource cannot be harvested, the optimum harvesting effort also increases though there is no change in the corresponding or the maximum yield obtained. This is shown clearly in the figures 1.6,1.7,1.8,1.9 . Thus the optimum harvesting effort depends on the need of the harvester for the resource and the quantity of the resource that is available for harvesting while the maximum yield obtained varies directly as the intrinsic growth rate of the resource.

Table 1 summarizes the optimum harvesting effort and the corresponding yield for different values of intrinsic growth rate of the resource, the need of the harvester for the resource and the thrshold below which a resource cannot be harvested.

OPTIMUM HARVESTING EFFORT STRATEGY

Harvester uses various methods to exploit the resource at the optimal level for its benefit. One of these methods is the trial & error method. In this method , the harvester learns to exploit the resource based on its past experience. This essentially requires the information on the harvesting effort and the corresponding yield or wealth obtained at the previous two consecutive time steps. Now, the harvester decides on the new harvesting effort strategy as follows:

(a) It increases the harvesting effort if the increase in the harvesting effort has increased the wealth OR the decrease in the harvesting effort has decreased the wealth .

(b) It decreases the harvesting effort if the increase in the harvesting effort has decreased the wealth OR the decrease in the harvesting effort has increased the wealth.

Let HR_t & HR_{t-1} be the harvesting efforts at time t & t-1 time steps.

Let W_t & W_{t-1} be the corresponding Wealth or yield. Then the new harvesting effort at time t+1 is given by

$$HR_{t-1} = HR_t + \Delta H_{new}$$

ΔH_{new} is +ve if $\Delta H_{old} >= 0$ & $\Delta W >= 0$

or

if $\Delta H_{old} < 0$ & $\Delta W < 0$

ΔH_{new} is -ve if $\Delta H_{old} >= 0$ & $\Delta W < 0$

or

if $\Delta H_{old} < 0$ & $\Delta W \geqslant 0$

where $\Delta H_{old} = HR_t - HR_{t-1}$

$\Delta W = W_t - W_{t-1}$

Resource information in determining the new harvesting effort is of no use because it gives the same result as the wealth or yield information does.

Several methods are proposed to calculate the value of ΔH_{new} .

Method 1:-

In this method, we calculate ΔH_{new} as

$$\Delta H_{new} = C * \Delta W$$

where C is a constant and the harvesting effort is altered every time step based on the above criteria. For different initial conditions of resource level,wealth and harvesting effort and different values of C , this method did not yield the optimum harvesting effort.

Method 2:-

$$HR_{t+1} = HR_t + C * \Delta W / \Delta H_{old}$$

To start with, we assumed one harvesting effort held constant at HE1 for T time steps. Then we assumed another harvesting effort held constant at HE2 for the same T time steps. The wealth W1 & W2 corresponding to the harvesting efforts HE1 and HE2 are noted at the end of T time steps. Then ,the new harvesting effort HE3 is derived as

$$HE3 = HE2 + C * \Delta W / \Delta H_{old}$$

where $\Delta H_{old} = HE_2 - HE_1$

$\Delta W = W_2 - W_1$

Now set $HE_1 = HE_2$ and $HE_2 = HE_3$

The above steps are repeated till the wealth or the Yield stabilizes. The value of C is held constant through out the experiment.

This method failed as the harvesting effort did not reach the optimum value for different initial conditions of harvesting effort, resource level and wealth and for different values of C.

Method 3:-

$$HR_{t+1} = HR_t + SLF$$

where, $SLF = C * \Delta W / \Delta H_{old}$ and $-0.1 < SLF < 0.1$

In this method, we fixed the lower & upper bounds on the sloping function SLF to be -0.1 & +0.1 , in addition to all the steps of method 2. This method also failed in reaching the optimum harvesting effort.

Method 4:-

$$HR_{t+1} = HR_t + C * \Delta W / \Delta H_{old}$$

In this method, the value of C is altered in some proportion whenever $\Delta W / \Delta H_{old}$ changes the sign and all the other steps of method 2 are retained. Harvesting effort reached the optimum value after a large number of time steps and for a long time interval T(= 20 time steps).

Method 5 :-

$$HR_{t+1} = HR_t + C * \text{Sign} (\Delta W / \Delta H_{old})$$

This method includes all the steps of method 4 except that here we consider the sign of $\Delta W / \Delta H_{old}$ which essentially gives the direction in which harvesting effort should be altered and C gives the magnitude by which it should be altered.

The results for the time interval T=15 or 20 show that the harvesting effort stabilizes at the optimal value considerably at a faster rate where as for time interval T=10, the harvesting effort did not reach the optimal value though it stabilizes.This is shown clearly in the figures 2.1 to 2.10 which contain the time trajectories for different initial conditions of wealth , resource level , harvesting effort and varying C in different proportions for a given carrying capacity of the site,the need of the harvester for the resource and the threshold below which a resource can not be harvested

REFUGIUM PROBLEM

This includes the investigation of the role played by a portion of the resource which is not harvested, in determining the optimal harvesting effort.Here, we assume the resource at one site is exploited out of two sites and a fraction of the resource is allowed to migrate from one site to another site every time step.

As earlier the equations (1) through (10) are solved numerically for the steady state to get the optimal harvesting effort for different carrying capacities of the two sites for the resource and for different proportions of migration of the resource for a given growth rate of the resource and given need of the harvester for the resource. The resource at site 1 is allowed for maximum exploitation by keeping the threshold below which a resource can not be harvested at zero. The steady state curves for the carrying capacities 2.25&2.25 ,3.0&1.5 and 1.5&3.0

of the two sites and for migration levels 75%,50% & 25% are contained in the figures 3.1 to 3.9 .

The steady state curves for yield in figures 3.1 to 3.3 show that when the resource migration is at lower rate(25%),the yield obtained is maximum if the resource at the smaller site is harvested, the optimum harvesting effort being comparitively high. These figures also contain the steady state curves for resource levels at two sites which indicate that if the resource migration is at lower rate, then the resource at two sites are not completely wiped off even if the harvester puts more and more effort in harvesting the resource. On the other hand, the steady state curves for resource in the figures 3.4 to 3.9 show that if the resource migration from two sites is comparitively at higher rate, then the resource at two sites get completely wiped off as the harvester puts more and more harvesting effort.

Table 2 summarizes the optimal harvesting effort and the corresponding yield obtained for three different carrying capacities of the sites for the resource and three different proportions of resource migration. It is clear from the table that if the carrying capacities of the two sites ,exploited and unexploited are equal, then the yield obtained at the exploited site is maximum when the rate of resource migration from the two sites is 50% .

If the carrying capacity of the exploited site is less than the carrying capacity of the unexploited site then the yield obtained is maximum when the resource migration is at lower rate. The optimum harvesting effort in this case, is on the higher side. As the migration rate of the resource increases, the yield obtained at the exploited site decreases along with the optimum harvesting effort. This is clearely brought up in the figure 4.3 where in the carrying capacity of the exploited site is 1.5 which is less than the carrying capacity of the unexploited site (=3.0).

It is just opposite if we consider the larger carrying capacity site is harvested while the smaller carrying capacity site is untouched by the harvester .This is shown in the figure 4.2 where in the carrying capacity of the exploited site is 3.0 and that of the unexploited site is 1.5 . The yield obtained at the exploited site is maximum when the rate of migraion of the resource is very high (i.e., at 75%) from both the sites.

TABLE - 1

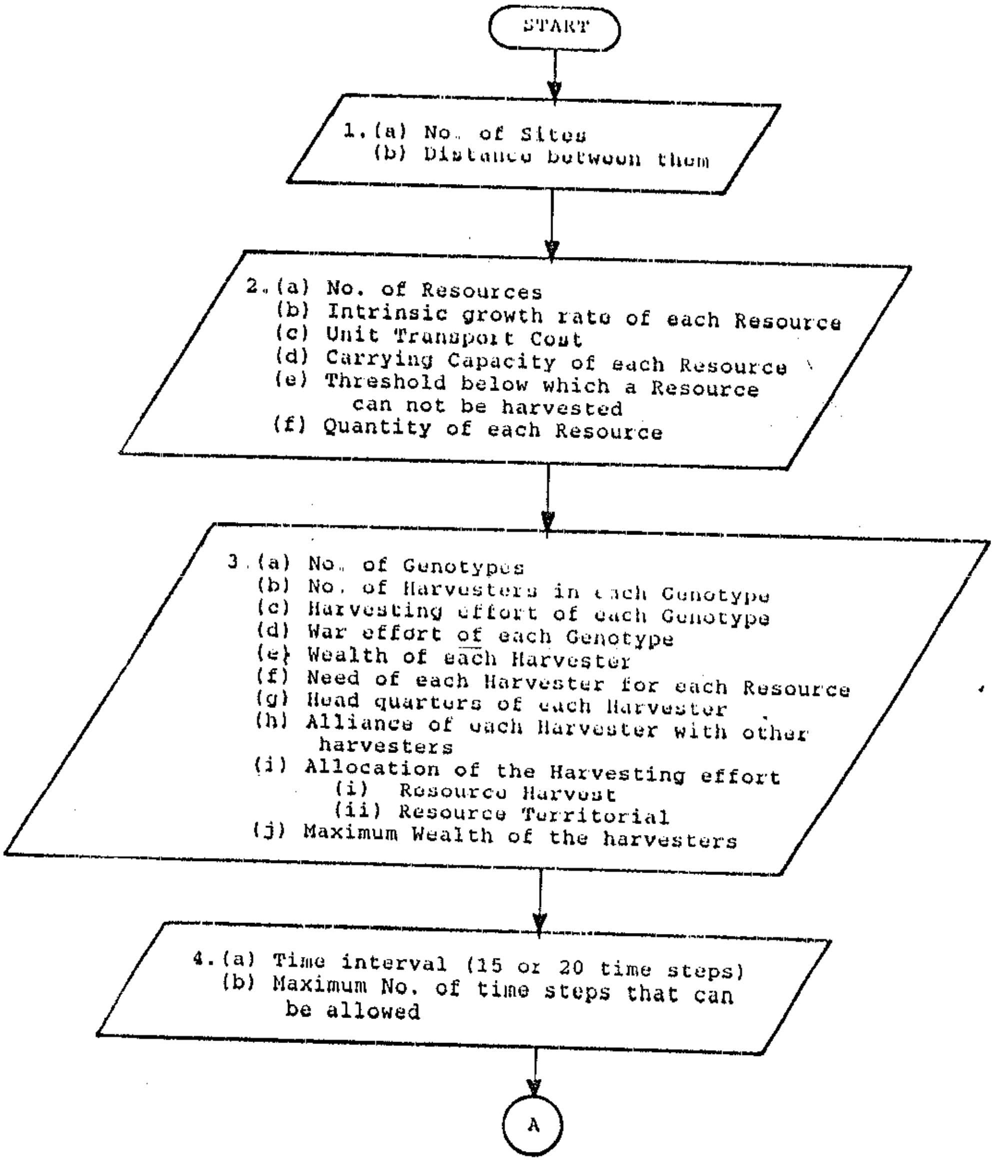
Sl. No.	GIR	NEED	THRESHOLD	OPTIMUM HR EFFORT	RESOURCE	YIELD
1.	1	0.1	0.4	0.295	1.1278	0.3750
2.	1	0.2	0.4	0.59	1.1278	0.3750
3.	2	0.1	0.4	0.29	1.5	0.75
4.	2	0.2	0.4	0.58	1.5	0.75
5.	3	0.1	0.4	0.29	1.8779	1.1250
6.	4	0.1	0.4	0.295	2.2471	1.5
7.	1	0.1	0.0	0.12	1.186	0.37
8.	1	0.1	0.5	0.395	1.1276	0.3750
9.	1	0.1	0.6	0.575	1.1256	0.3750
10.	1	0.2	0.5	0.795	1.1244	0.3750

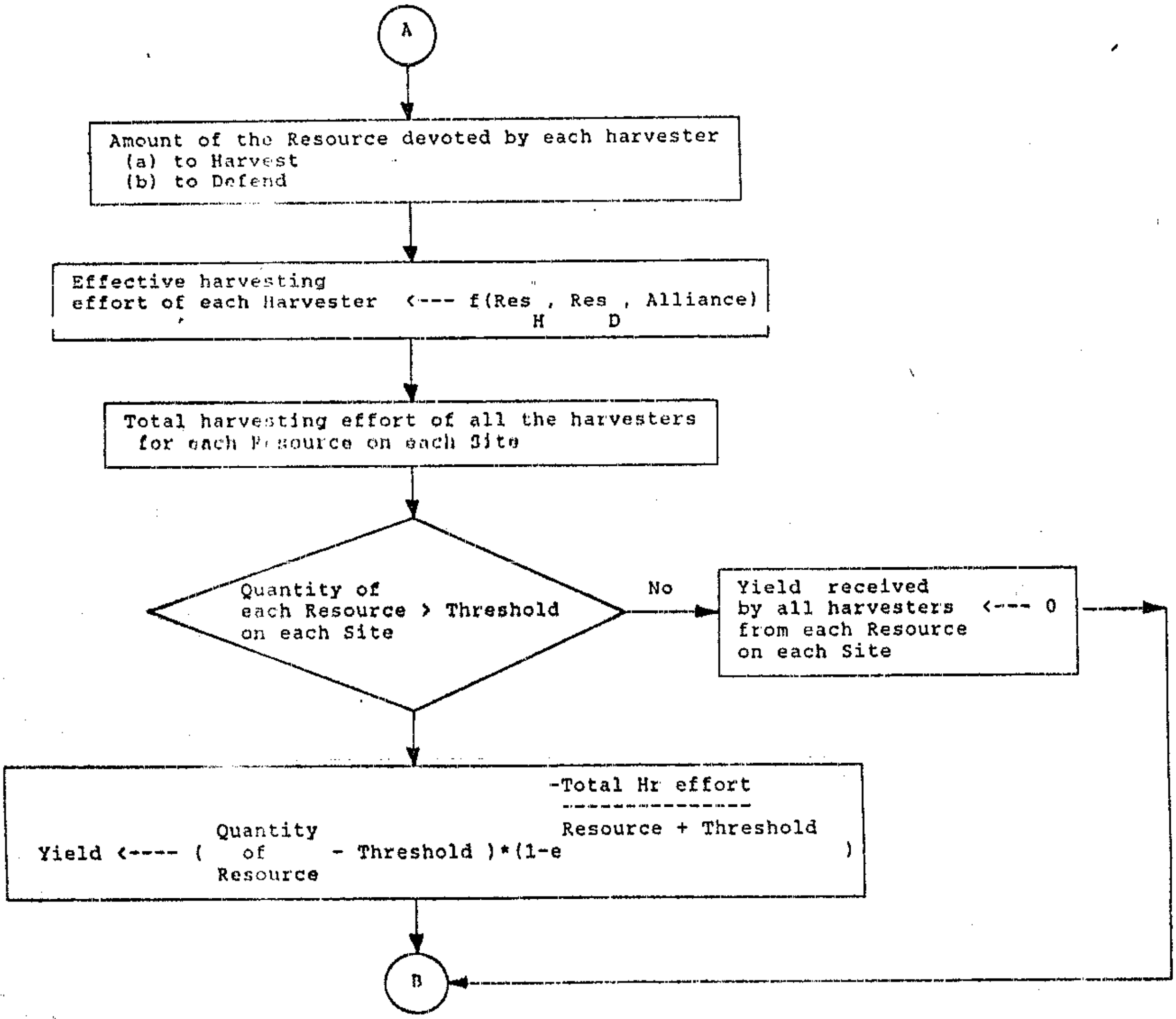
TABLE - 2

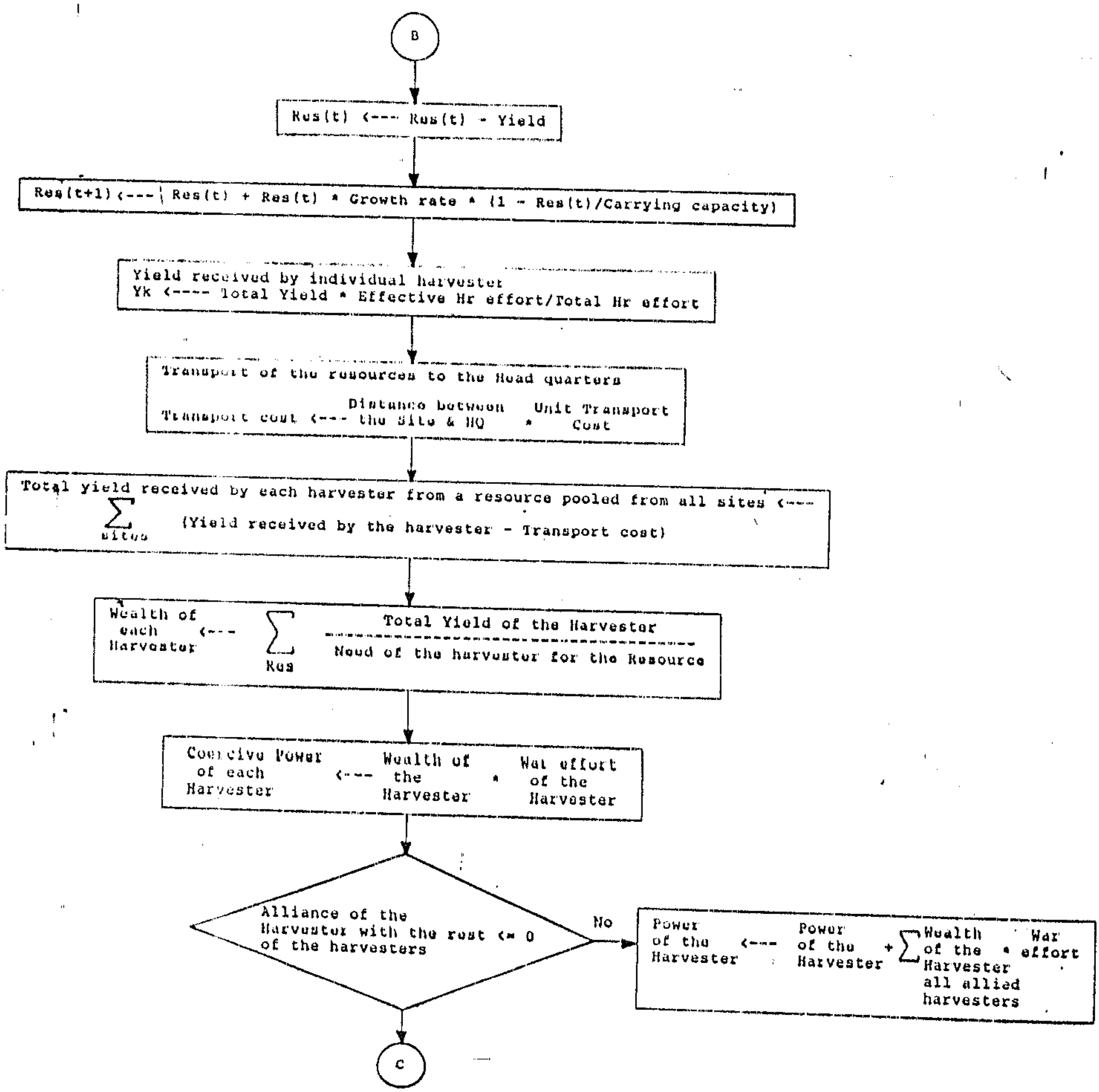
Sl. No.	Carrying capacities		Proportion of Migration Everytime step	Optimum Harvesting effort at Site 1	Resource level at site 1			Yield at Site 1	Resource level at site 2		
	Site 1	Site 2			After harvest	After migration	After growth		After harvest	After migration	After growth
1.	2.25	2.25	0.75	0.155	0.7833	1.3348	1.8777	1.09437	1.5186	0.9672	1.5186
			0.50	0.165	0.5599	1.1224	1.6849	1.1249	1.6849	1.1224	1.6849
			0.25	0.17	0.4241	0.8455	1.3733	0.9492	2.1098	1.6883	2.1098
2.	3.0	1.5	0.75	0.15	0.7633	1.1263	1.8297	1.0664	1.2473	0.8843	1.2473
			0.50	0.16	0.5532	0.9109	1.5453	0.9920	1.2686	0.9109	1.2687
			0.25	0.135	0.9345	1.0720	1.7609	0.8264	1.4843	1.3469	1.48437
3.	1.5	3.0	0.75	0.155	0.5334	1.0780	1.3813	0.8478	1.2595	0.7149	1.2595
			0.50	0.185	0.3323	0.9985	1.3323	0.9999	1.6646	0.9985	1.6646
			0.25	0.765	0.0004	0.6670	1.0374	1.0370	2.6668	2.0002	2.6668

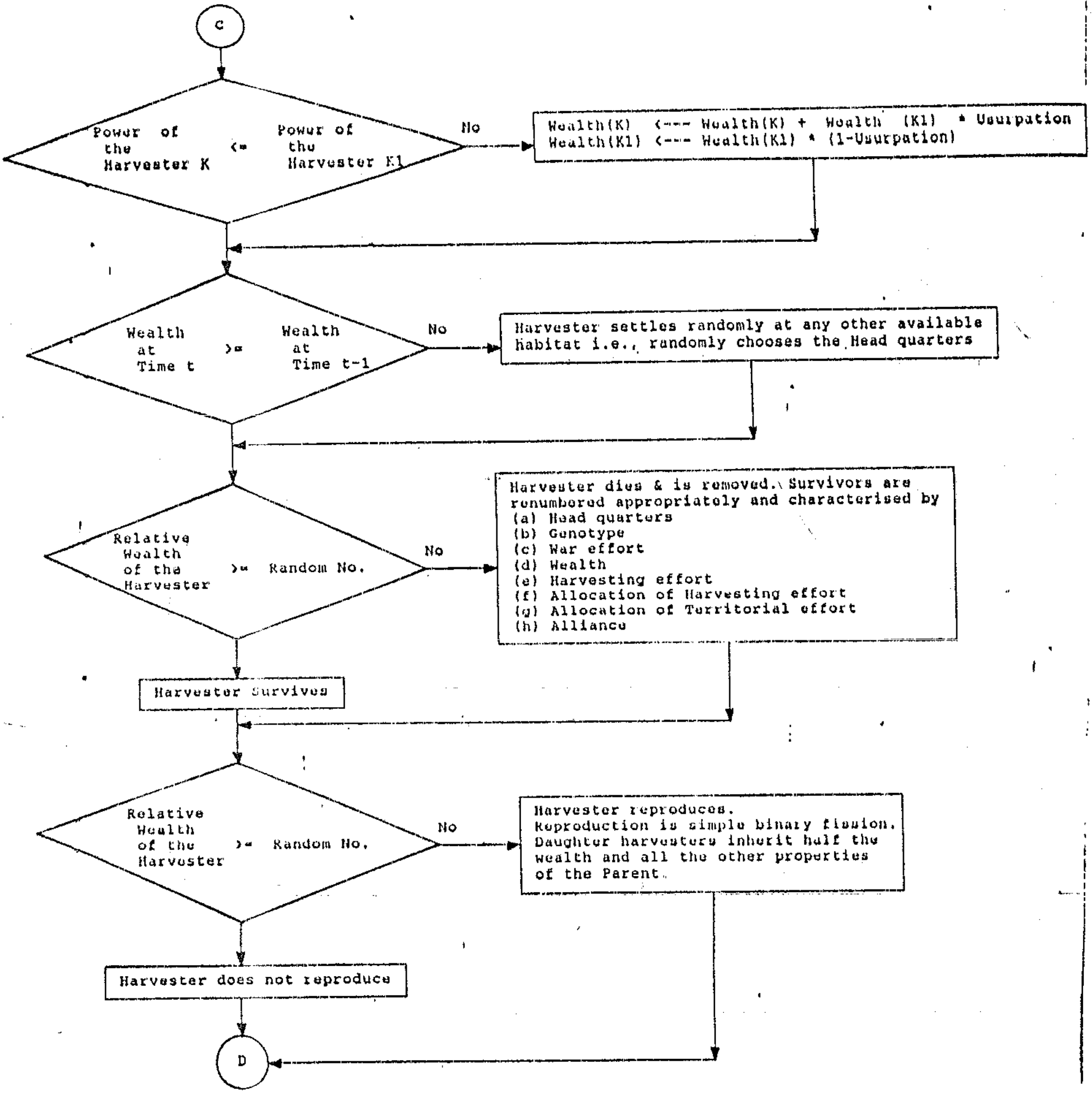
No. of Sites = 2
No. of resources = 1
Threshold below which a resource cannot be harvested = 0.0
Need for the resource = 0.1
Harvesting is at Site 1.

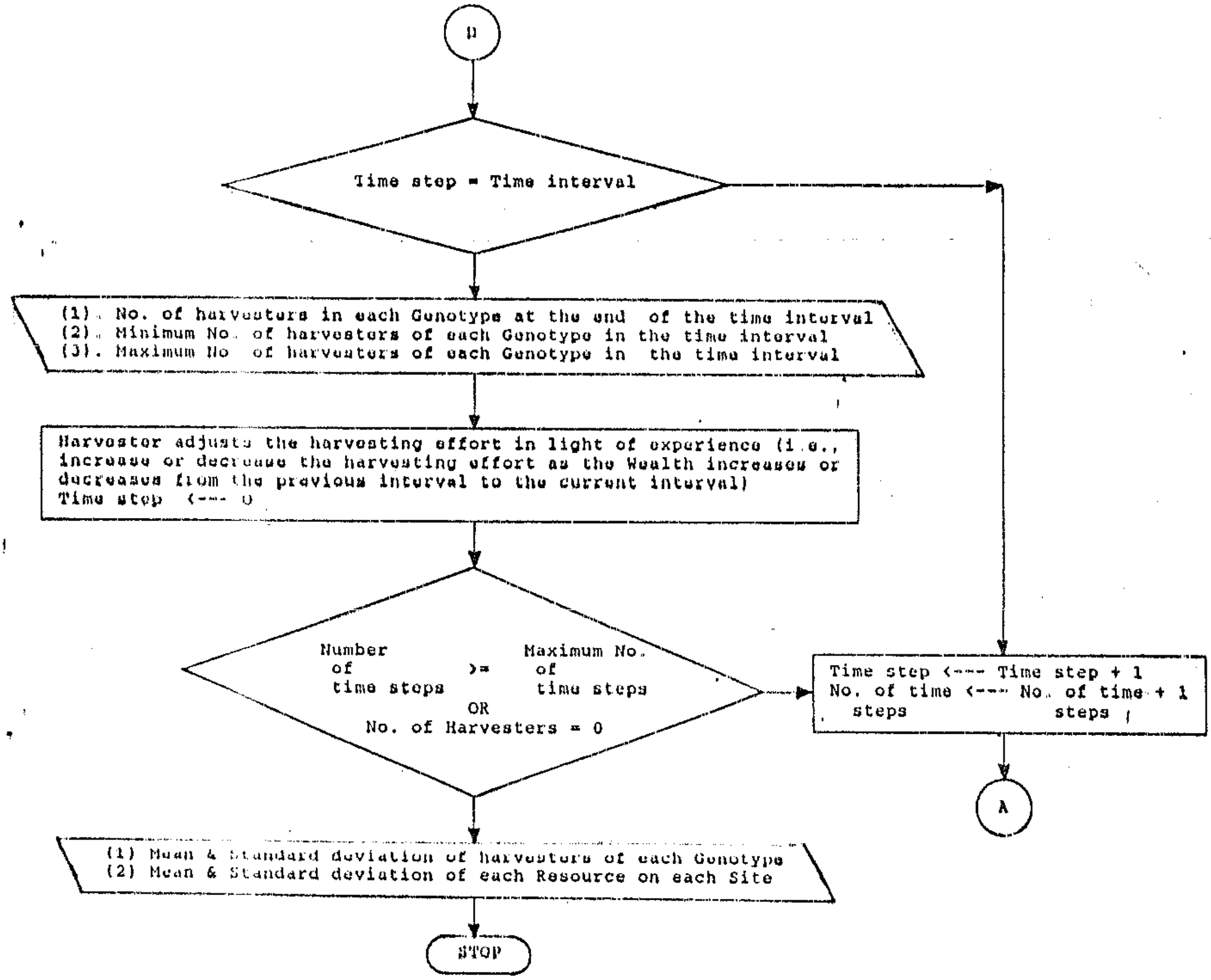
FUNCTIONAL FLOW CHART OF GRUSE MODEL



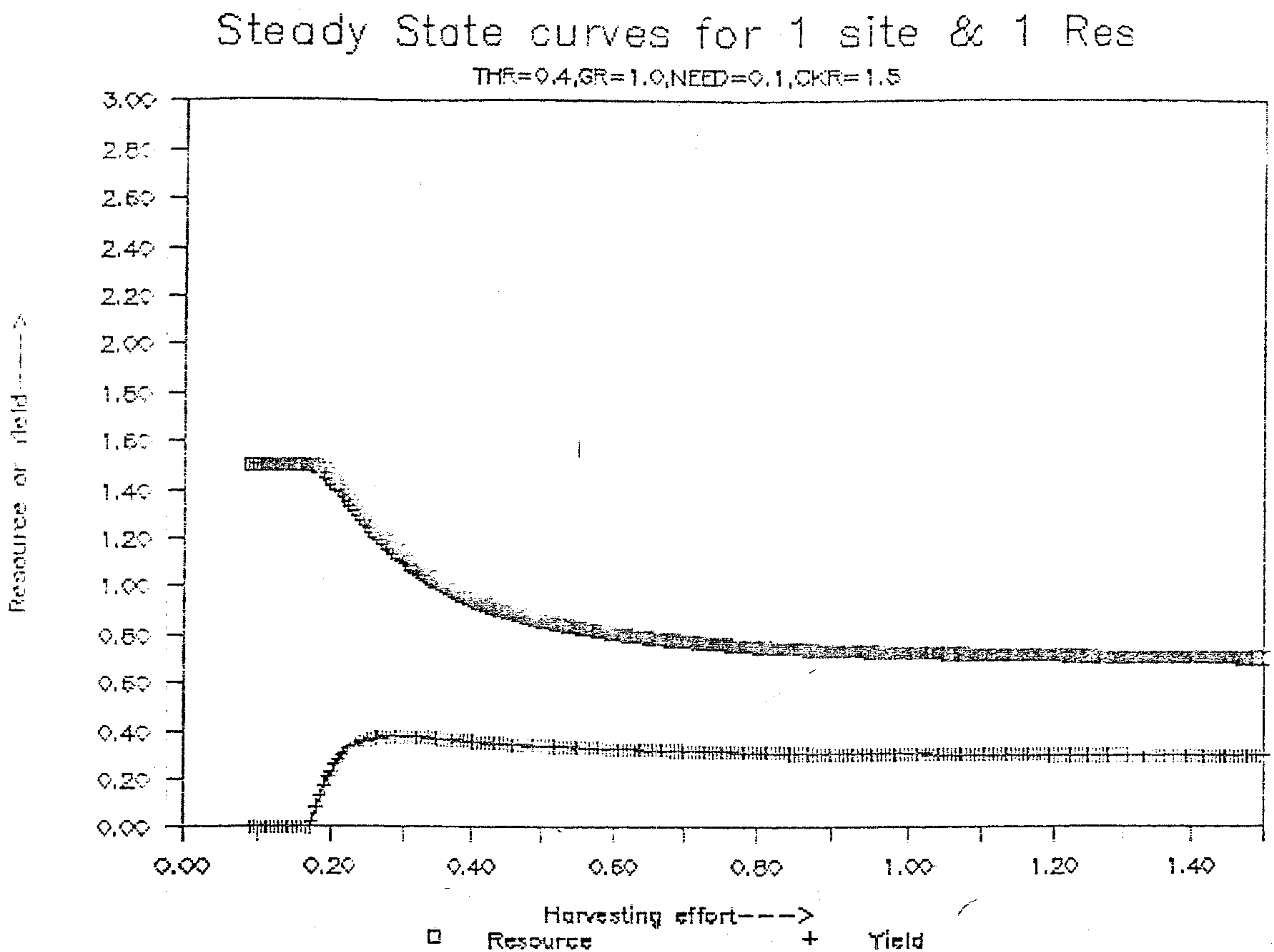

A
Amount of the Resource devoted by each harvester
(a) to Harvest
(b) to Defend
Effective harvesting effort of each Harvester <--- f(Res H , Res D , Alliance)
Total harvesting effort of all the harvesters for each Resource on each Site
Quantity of each Resource > Threshold on each Site
No
Yield received by all harvesters from each Resource on each Site <--- 0
Yield <---- (Quantity of Resource - Threshold)*(1-e -Total Hr effort / Resource + Threshold)
B


B
Res(t) <--- Res(t) - Yield
Res(t+1) <--- Res(t) + Res(t) * Growth rate * (1 - Res(t)/Carrying capacity)
Yield received by individual harvester
Yk <---- Total Yield * Effective Hr effort/Total Hr effort
Transport of the resources to the Head quarters
Transport cost <--- Distance between the Site & HQ * Unit Transport Cost
Total yield received by each harvester from a resource pooled from all sites <---
∑ sites (Yield received by the harvester - Transport cost)
Wealth of each Harvester <--- ∑ Res Total Yield of the Harvester / Need of the harvester for the Resource
Coercive Power of each Harvester <--- Wealth of the Harvester * War effort of the Harvester
Alliance of the Harvester with the rest <= 0 of the harvesters
No
Power of the Harvester <--- Power of the Harvester + ∑ Wealth of the Harvester all allied harvesters * War effort
C


C
Power of the Harvester K <= Power of the Harvester K1
No
Wealth(K) <--- Wealth(K) + Wealth (K1) * Usurpation
Wealth(K1) <--- Wealth(K1) * (1-Usurpation)
Wealth at Time t >= Wealth at Time t-1
No
Harvester settles randomly at any other available habitat i.e., randomly chooses the Head quarters
Relative Wealth of the Harvester >= Random No.
No
Harvester dies & is removed. Survivors are renumbered appropriately and characterised by
(a) Head quarters
(b) Genotype
(c) War effort
(d) Wealth
(e) Harvesting effort
(f) Allocation of Harvesting effort
(g) Allocation of Territorial effort
(h) Alliance
Harvester Survives
Relative Wealth of the Harvester >= Random No.
No
Harvester reproduces.
Reproduction is simple binary fission.
Daughter harvesters inherit half the wealth and all the other properties of the Parent.
Harvester does not reproduce
D

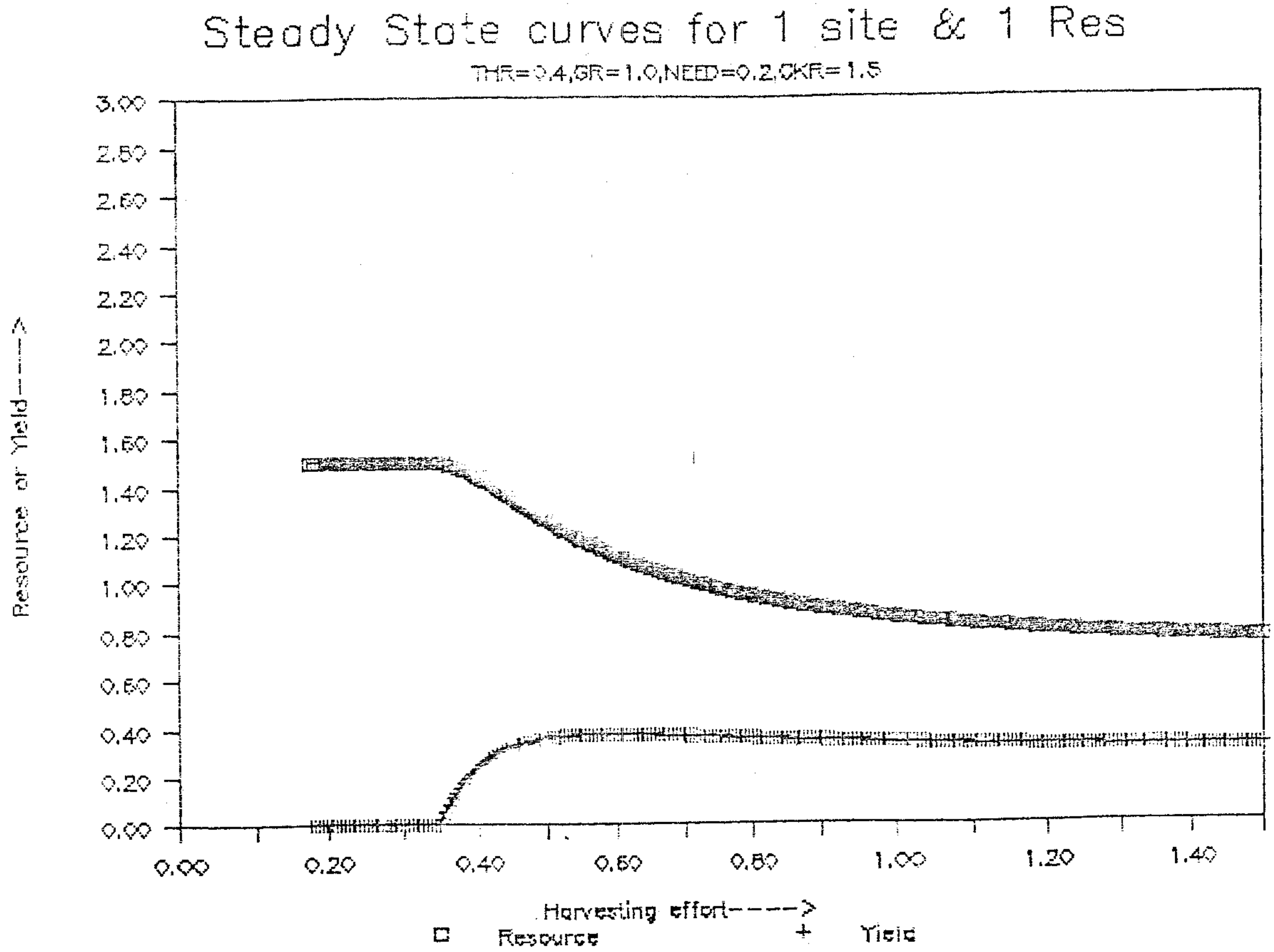

B
Time step = Time interval
(1). No. of harvesters in each Genotype at the end of the time interval
(2). Minimum No. of harvesters of each Genotype in the time interval
(3). Maximum No of harvesters of each Genotype in the time interval
Harvester adjusts the harvesting effort in light of experience (i.e., increase or decrease the harvesting effort as the Wealth increases or decreases from the previous interval to the current interval)
Time step <--- 0
Number of time steps >= Maximum No. of time steps
OR
No. of Harvesters = 0
Time step <--- Time step + 1
No. of time steps <--- No. of time steps + 1
A
(1) Mean & Standard deviation of harvesters of each Genotype
(2) Mean & Standard deviation of each Resource on each Site
STOP

ONLY



Steady State curves for 1 site & 1 Res
THR=0.4,GR=1.0,NEED=0.1,CKR=1.5
Resource or Yield---->
Harvesting effort--->
Resource
Yield

FIG 1.0



Steady State curves for 1 site & 1 Res
THR=0.4,GR=1.0,NEED=0.2,OKR=1.5
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Resource or Yield----->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort---->
Resource
Yield

FIG. 1.1.

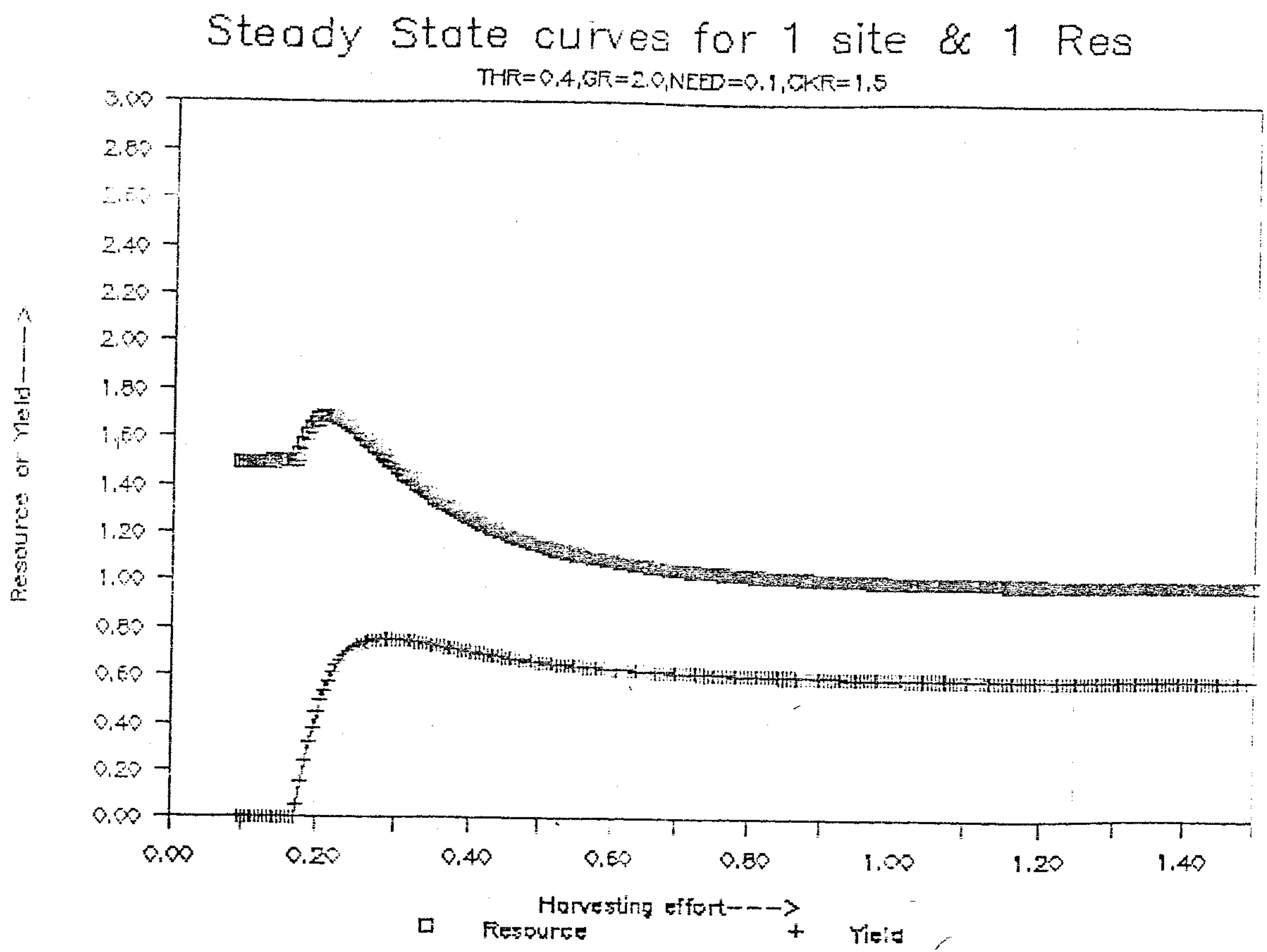

Steady State curves for 1 site & 1 Res
THR=0.4,GR=2.0,NEED=0.1,CKR=1.5
3.00
2.80
2.40
2.20
2.00
1.80
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Resource or Yield--->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort--->
Resource
Yield

FIG. 1.2

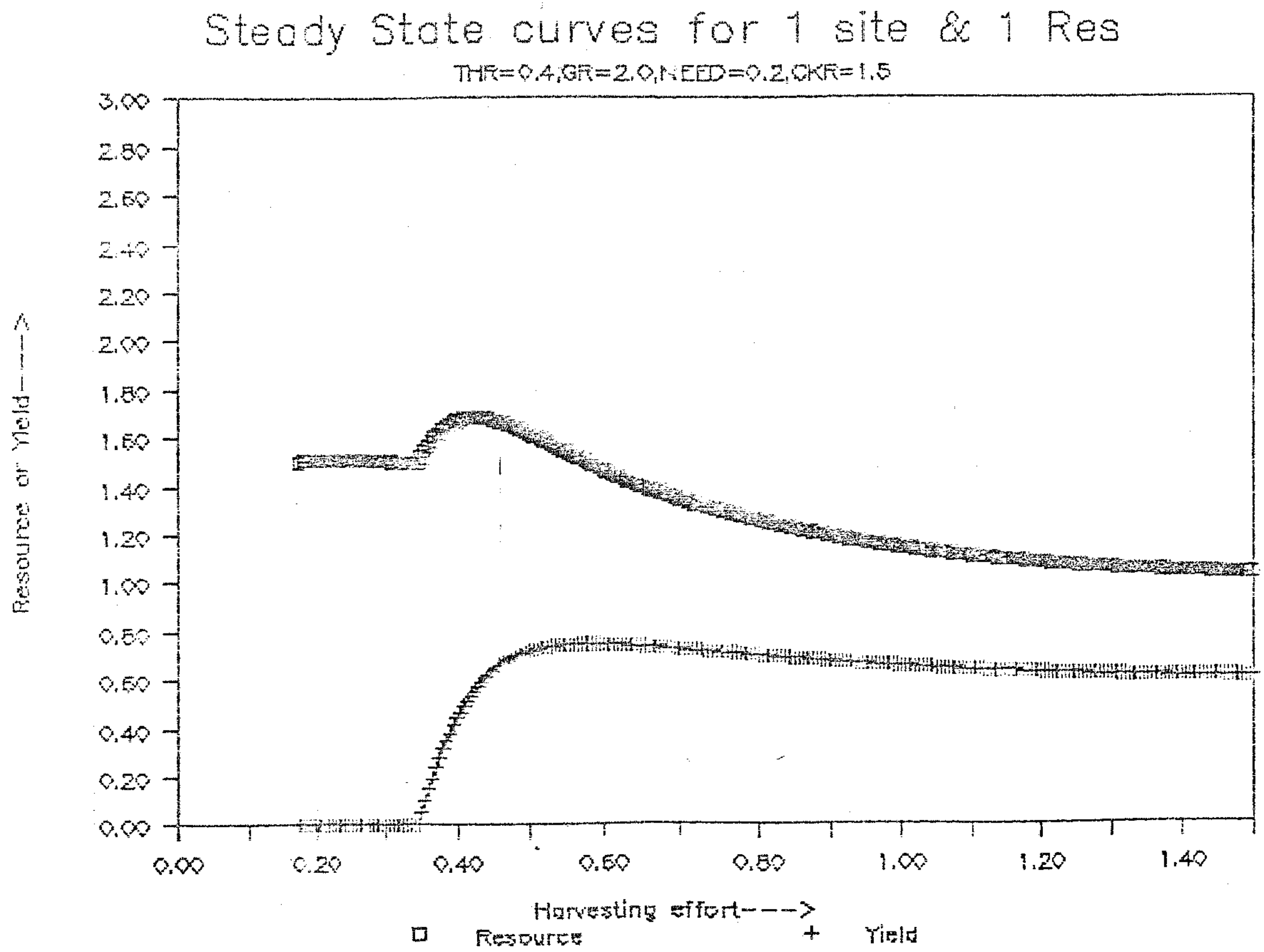

Steady State curves for 1 site & 1 Res
THR=0.4,GR=2.0,NEED=0.2,CKR=1.5
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Resource or Yield--->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort--->
□ Resource
+ Yield

FIG. 1.3

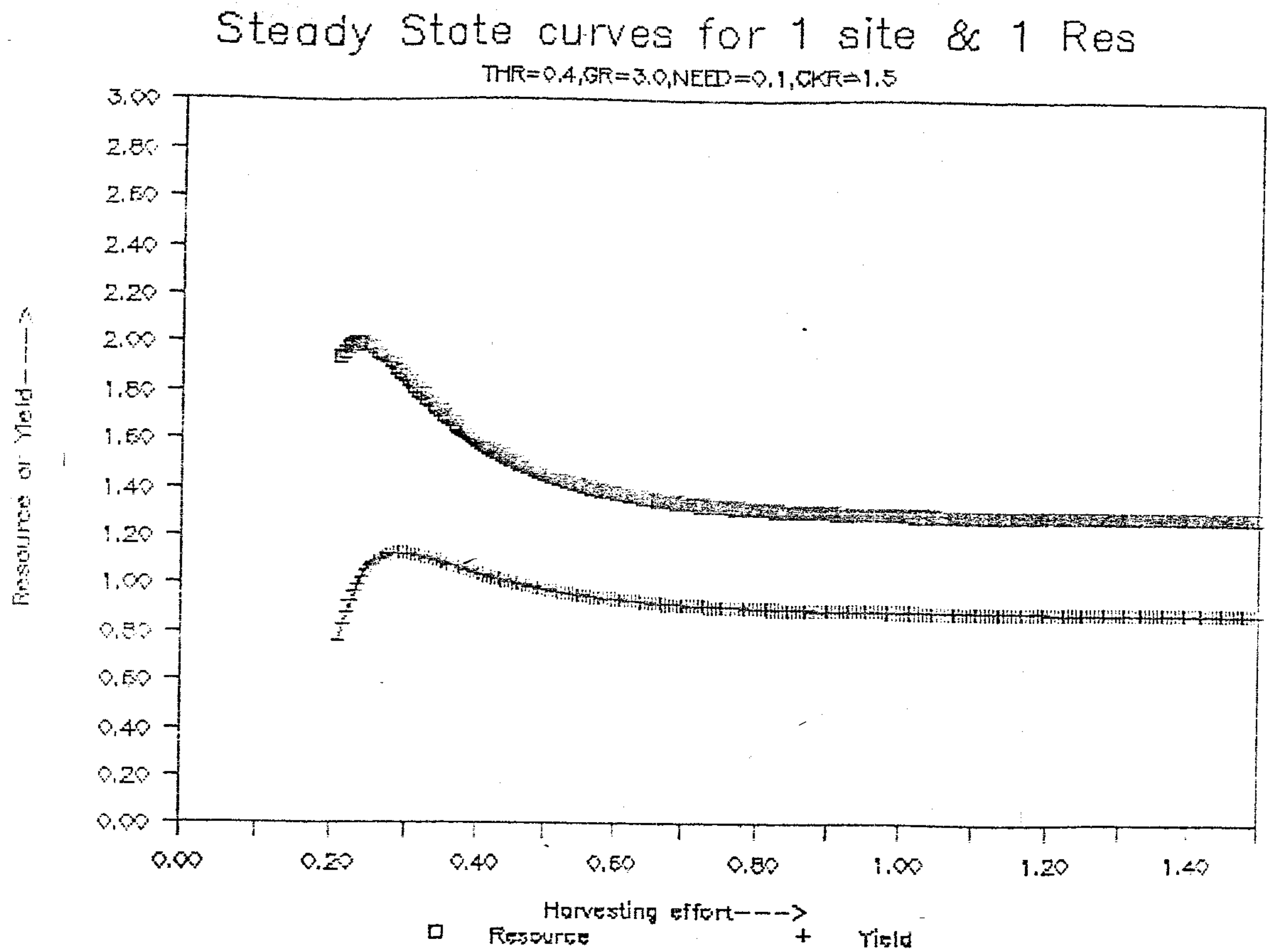

Steady State curves for 1 site & 1 Res
THR=0.4,GR=3.0,NEED=0.1,CKR=1.5
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Resource or Yield--->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort--->
Resource
Yield

FIG. 1.4

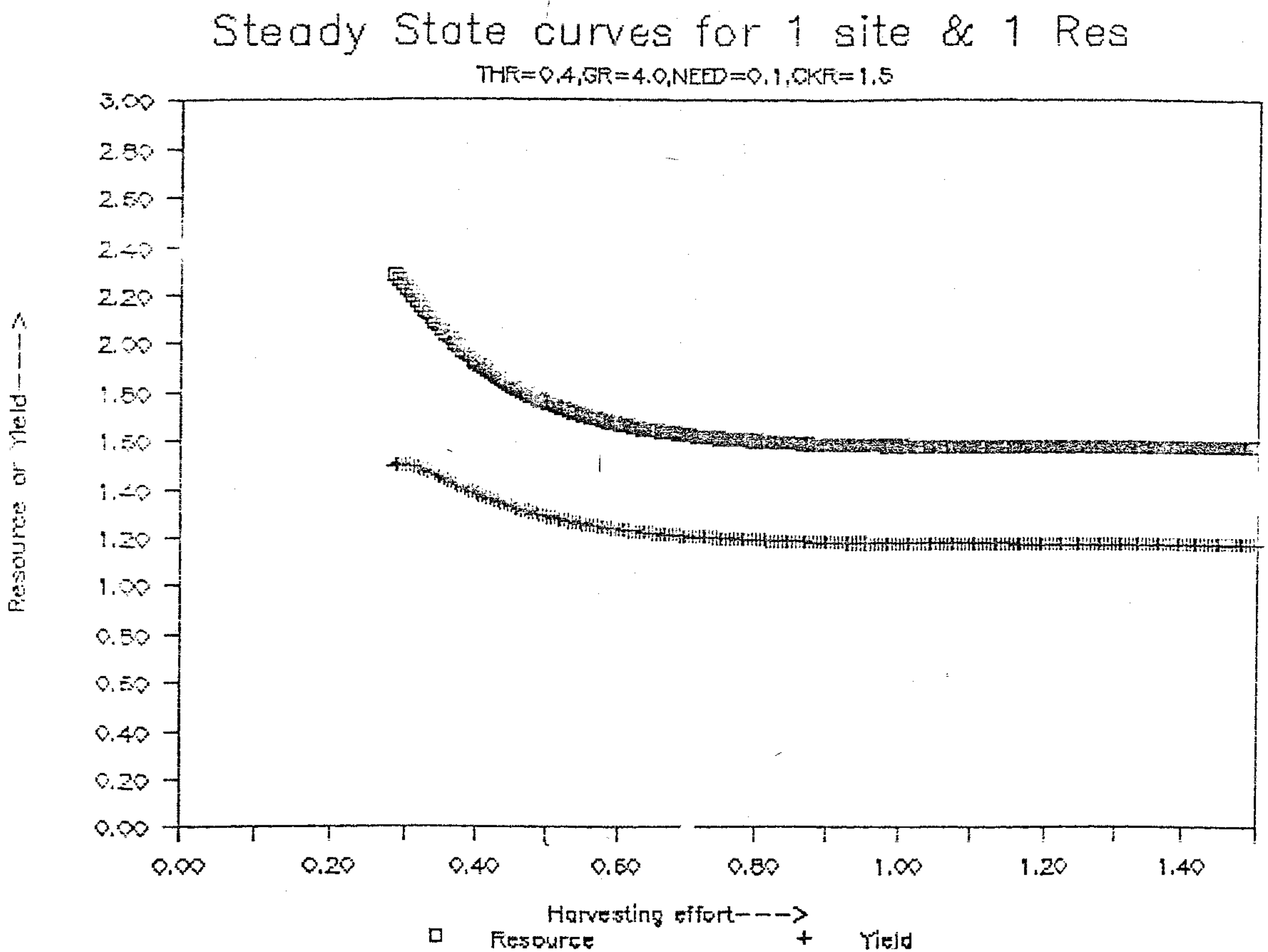

Steady State curves for 1 site & 1 Res
THR=0.4,GR=4.0,NEED=0.1,CKR=1.5
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Resource or Yield--->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort--->
Resource
Yield

FIG. 1.5

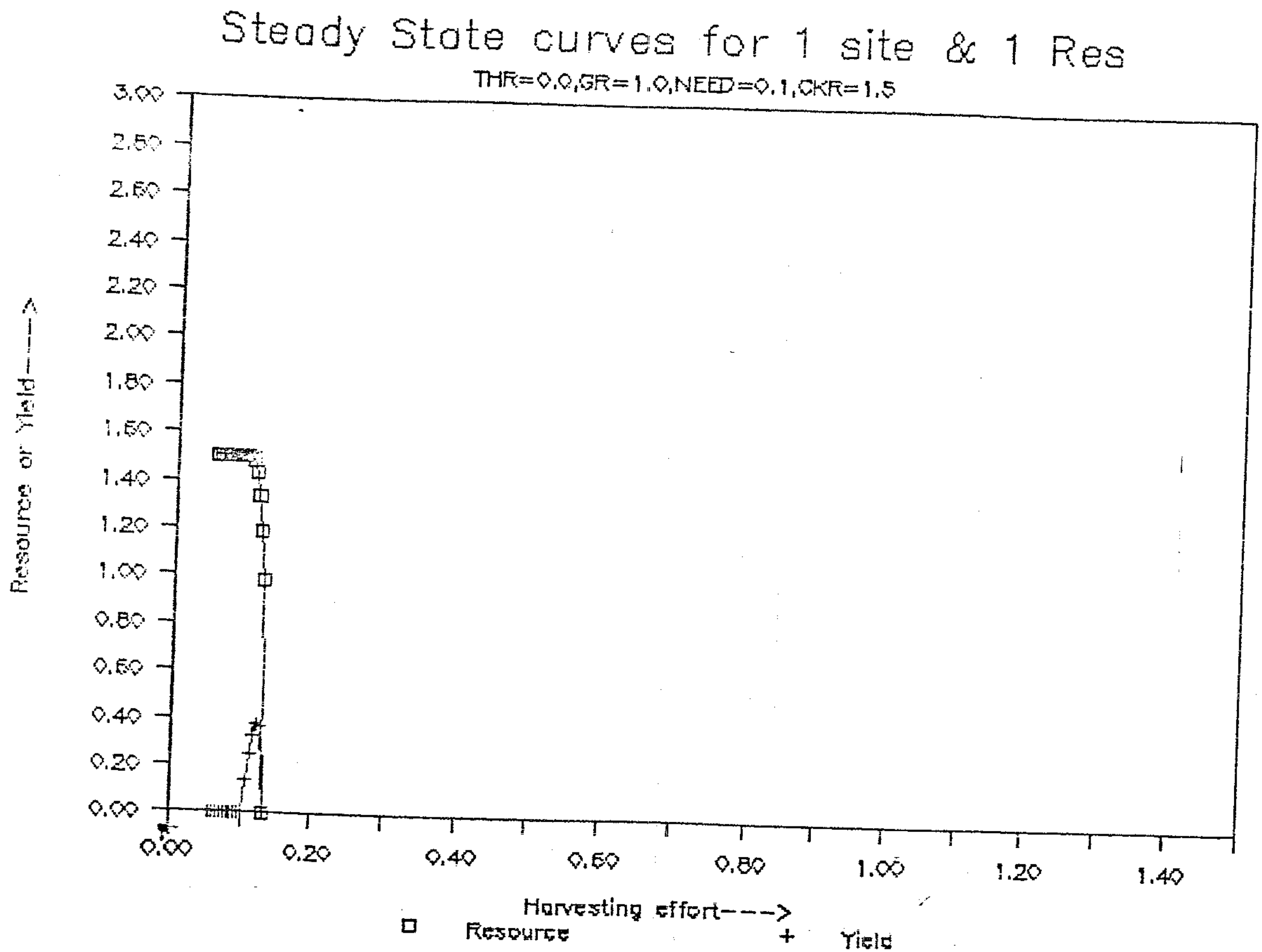

Steady State curves for 1 site & 1 Res
THR=0.0,GR=1.0,NEED=0.1,CKR=1.5
Resource or Yield--->
3.00
2.50
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort--->
Resource
Yield

FIG. 1.6

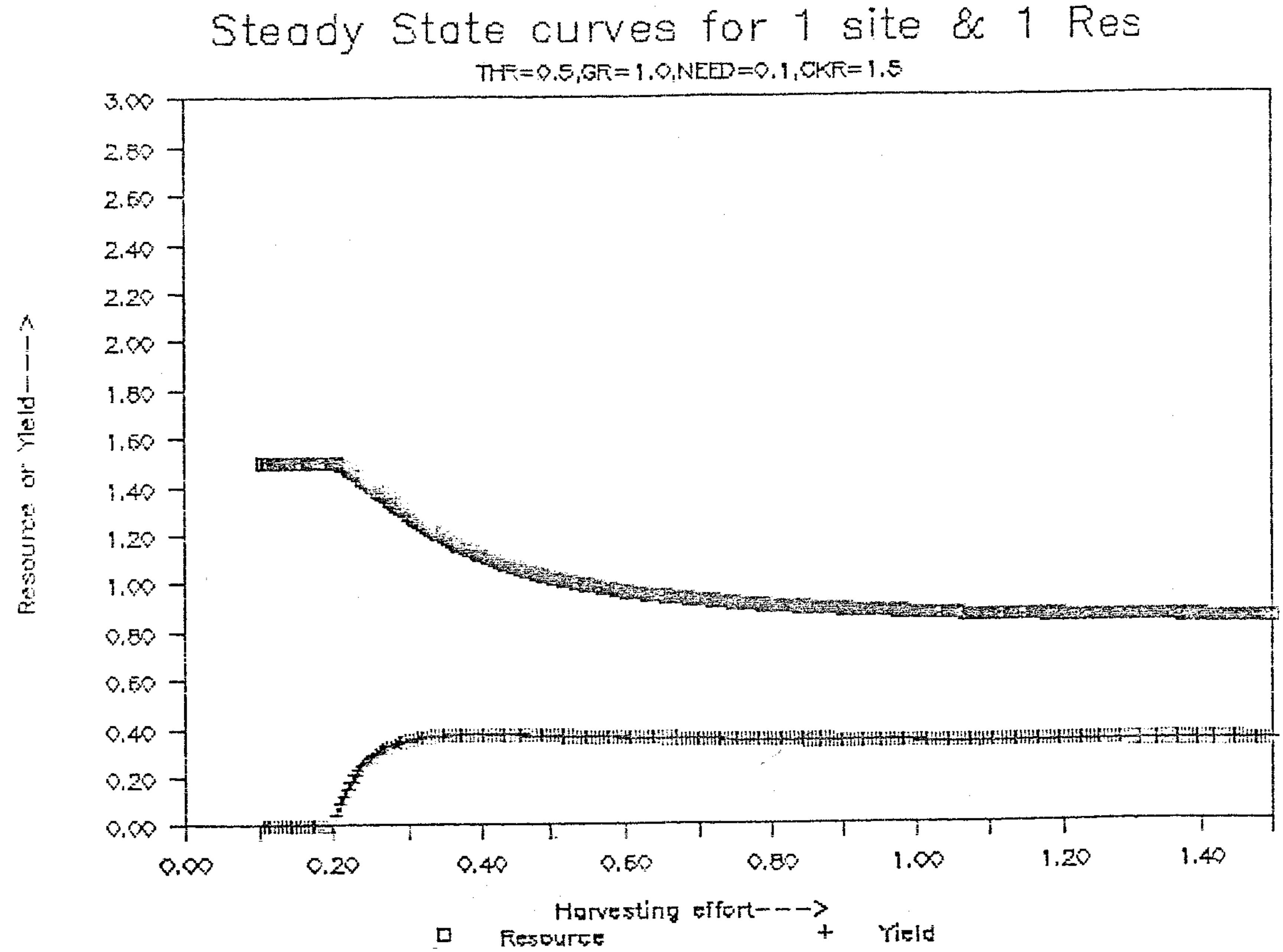
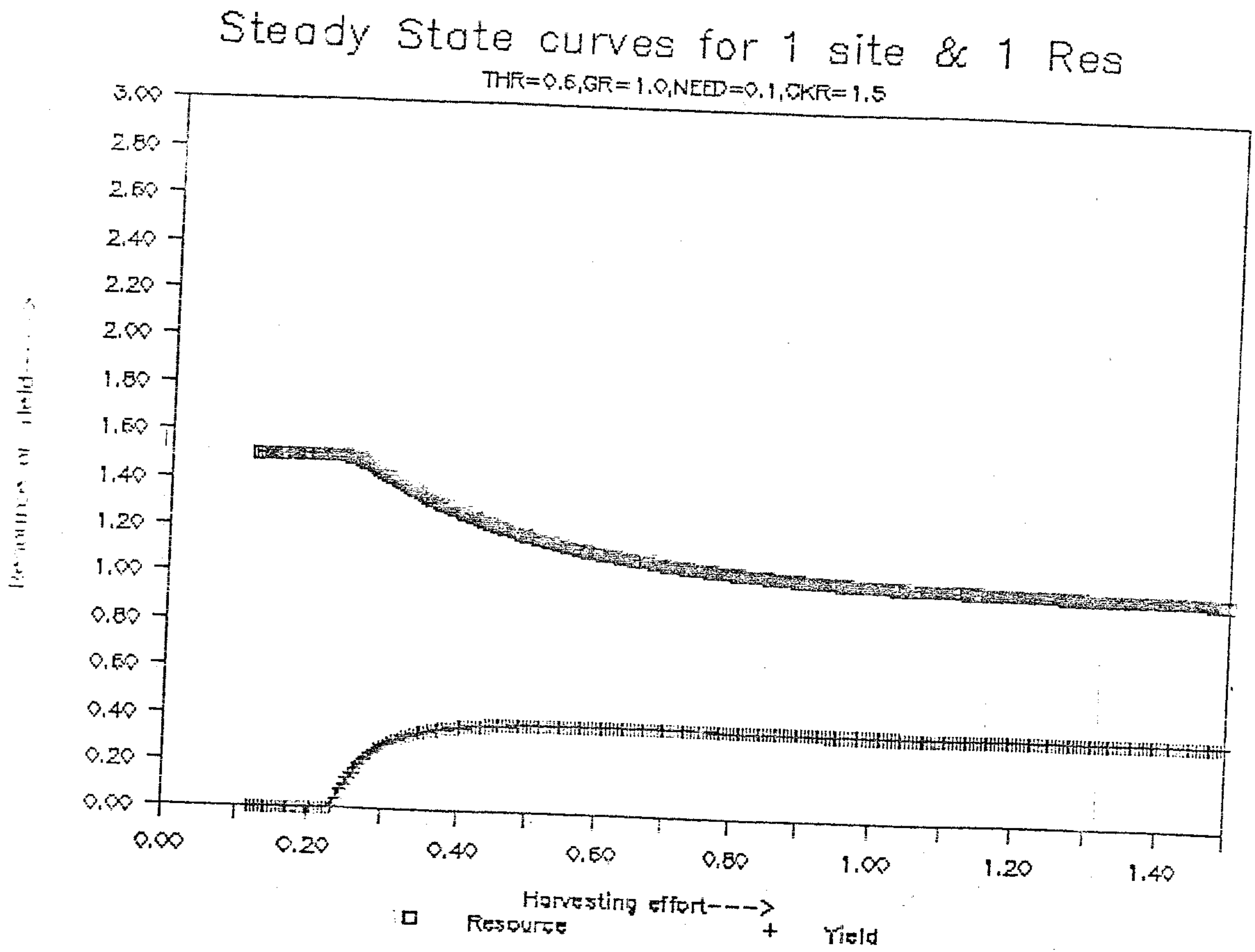

Steady State curves for 1 site & 1 Res
THR=0.5,GR=1.0,NEED=0.1,CKR=1.5
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Resource or Yield--->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort--->
□ Resource
+ Yield

FIG. 1.7



Steady State curves for 1 site & 1 Res
THR=0.6,GR=1.0,NEED=0.1,CKR=1.5
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort--->
Resource
Yield

FIG. 1.8

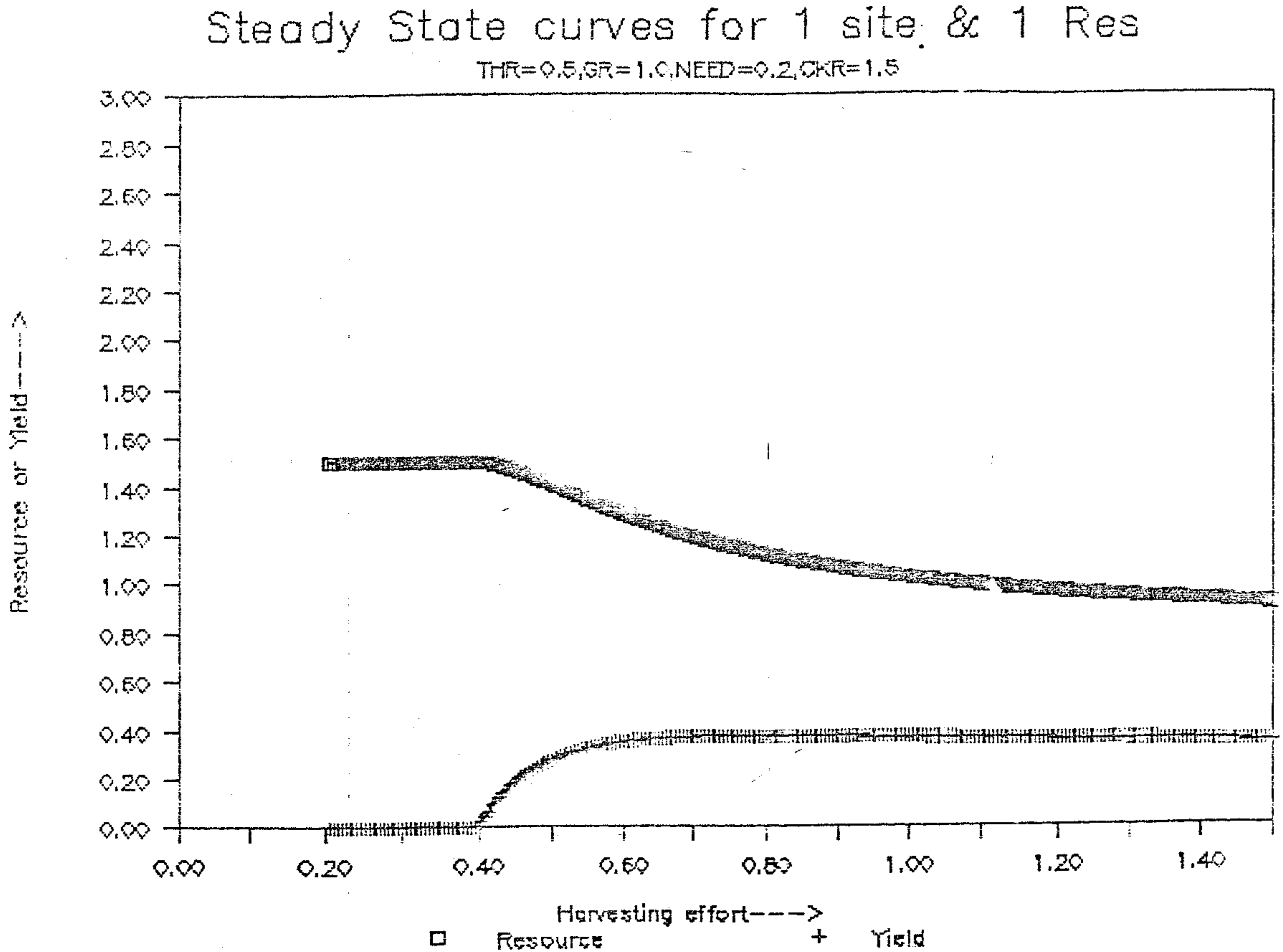

Steady State curves for 1 site & 1 Res
THR=0.5,GR=1.0,NEED=0.2,CKR=1.5
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Resource or Yield--->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting effort--->
Resource
Yield

FIG. 1.9

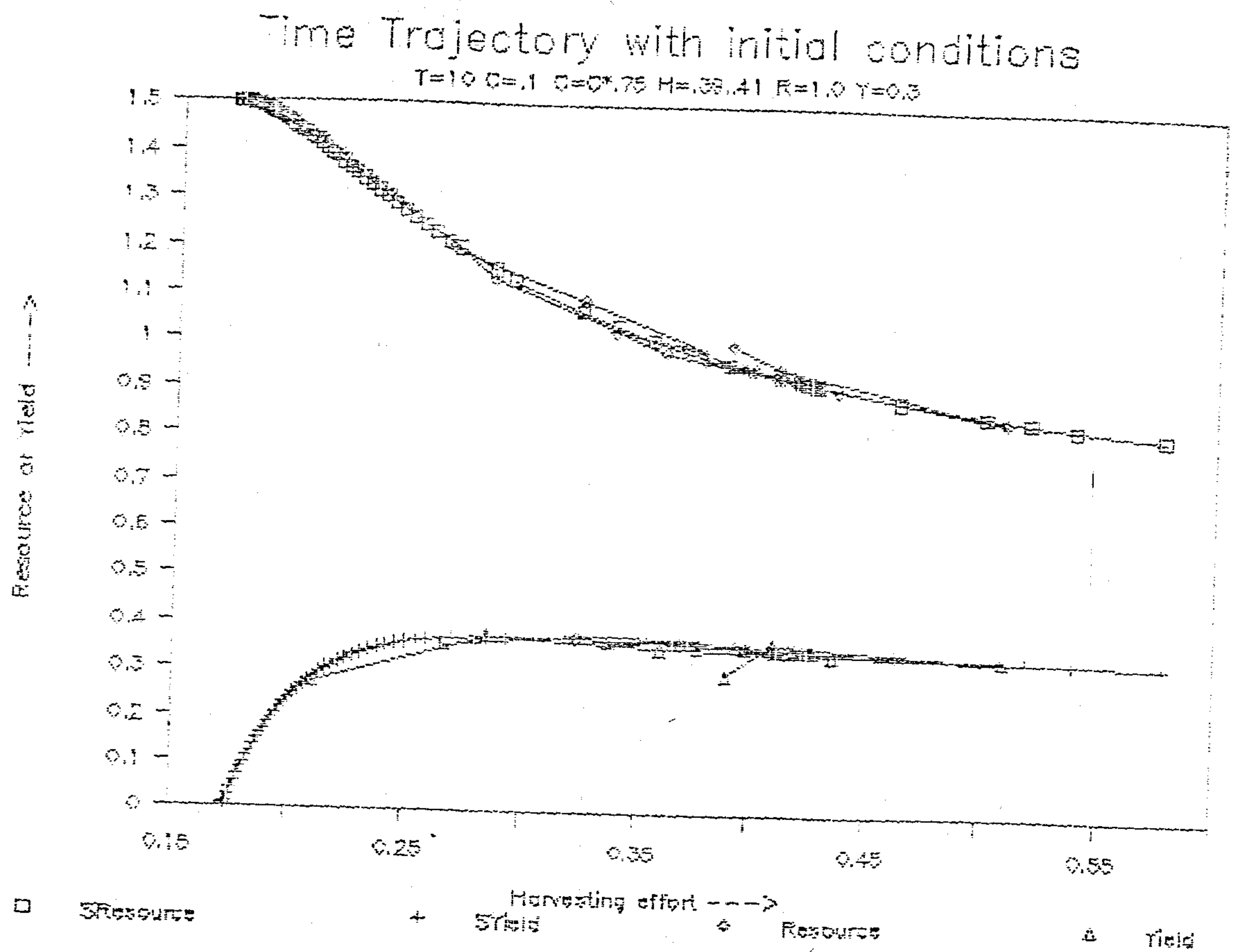

Time Trajectory with initial conditions
T=10 C=.1 C=C*.75 H=.39.41 R=1.0 Y=0.3
Resource or Yield ---->
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.15
0.25
0.35
0.45
0.55
Harvesting effort --->
5Resource
5Yield
Resource
Yield

FIG. 2.1.

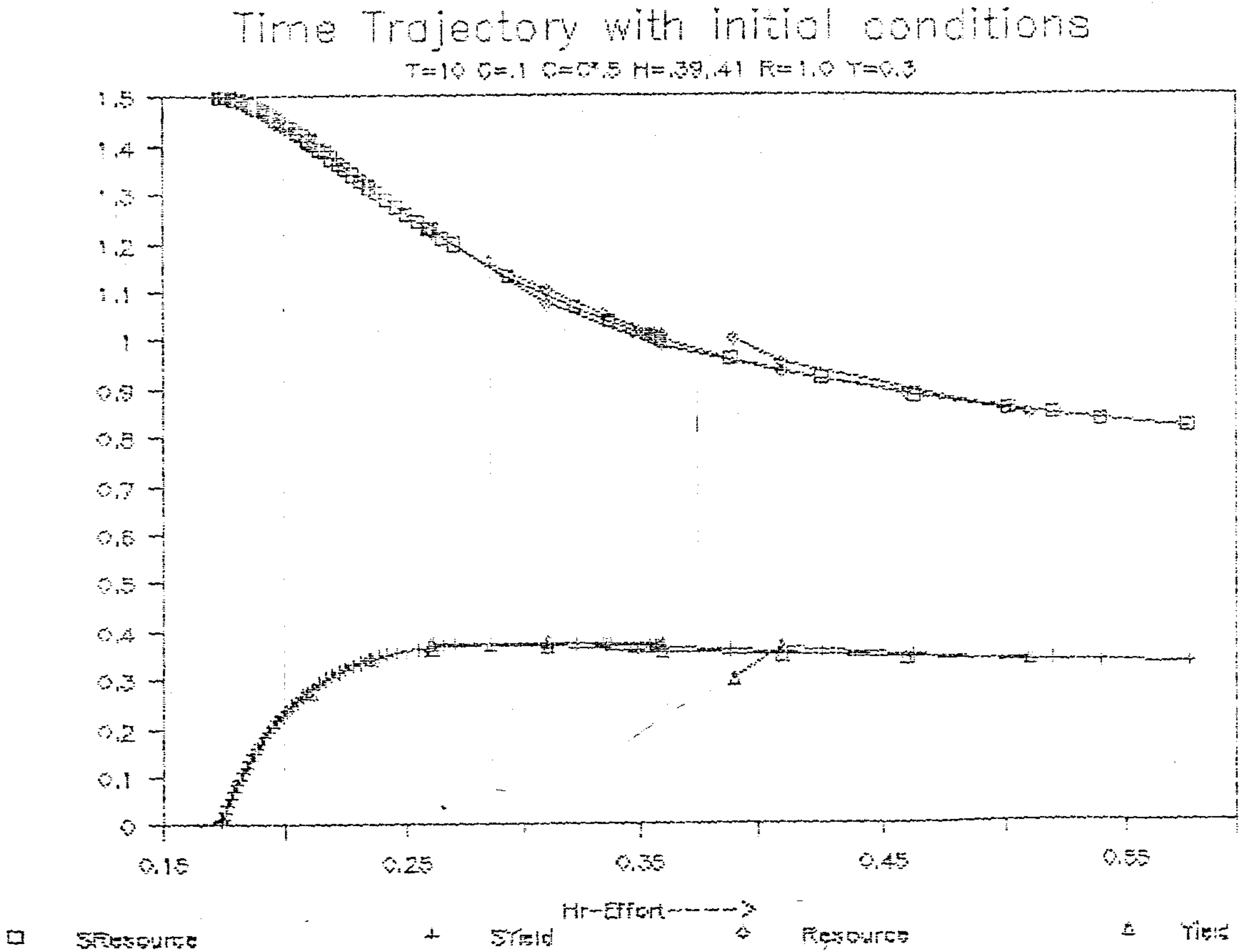

Time Trajectory with initial conditions
T=10 Q=.1 C=0.5 H=.39,.41 R=1.0 Y=0.3
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.15
0.25
0.35
0.45
0.55
Hr-Effort------>
SResource
SYield
Resource
Yield

FIG. 2.2

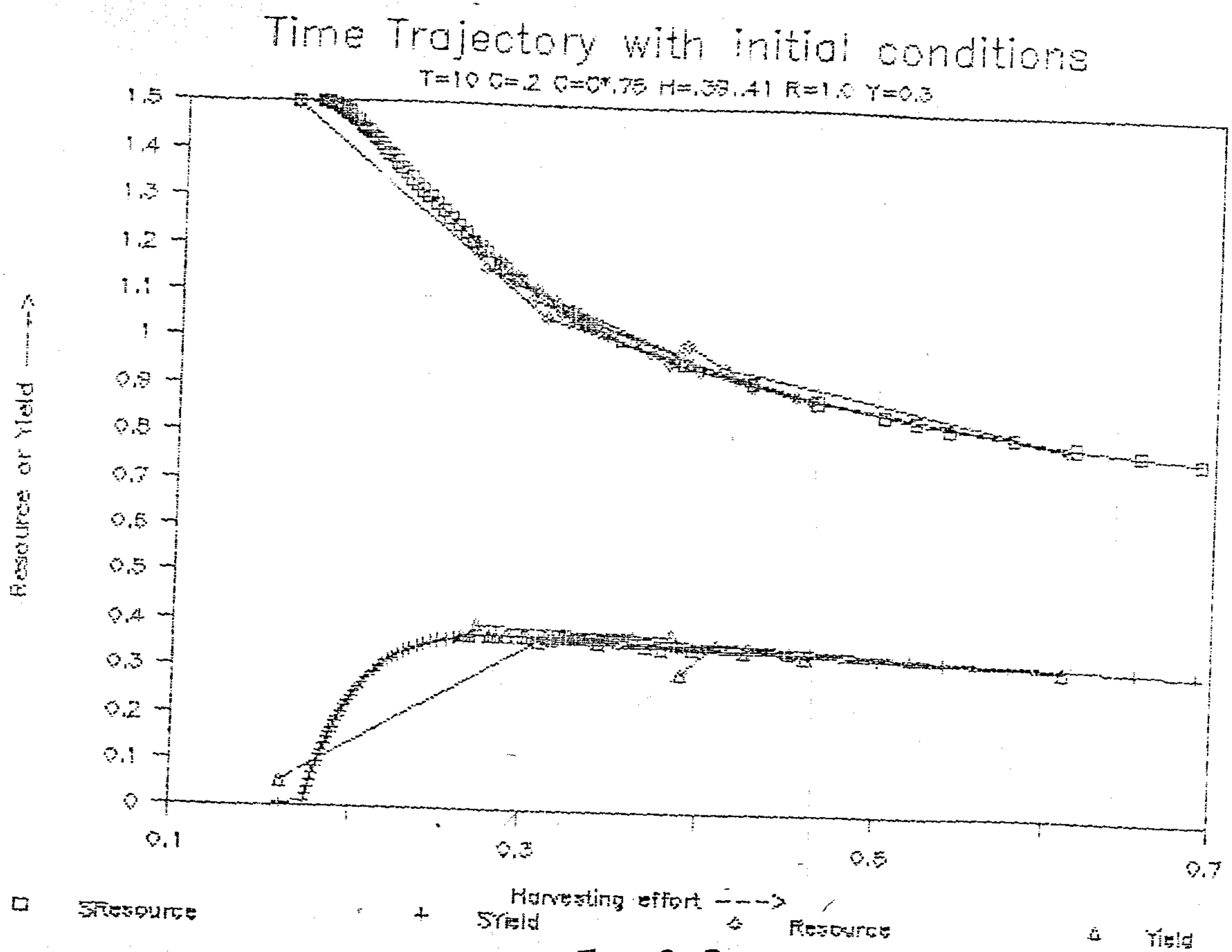

Time Trajectory with initial conditions
T=10 C=.2 C=0*.75 H=.39..41 R=1.0 Y=0.3
Resource or Yield ---->
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.3
0.5
0.7
Harvesting effort ---->
SResource
SYield
Resource
Yield

FIG 2.3

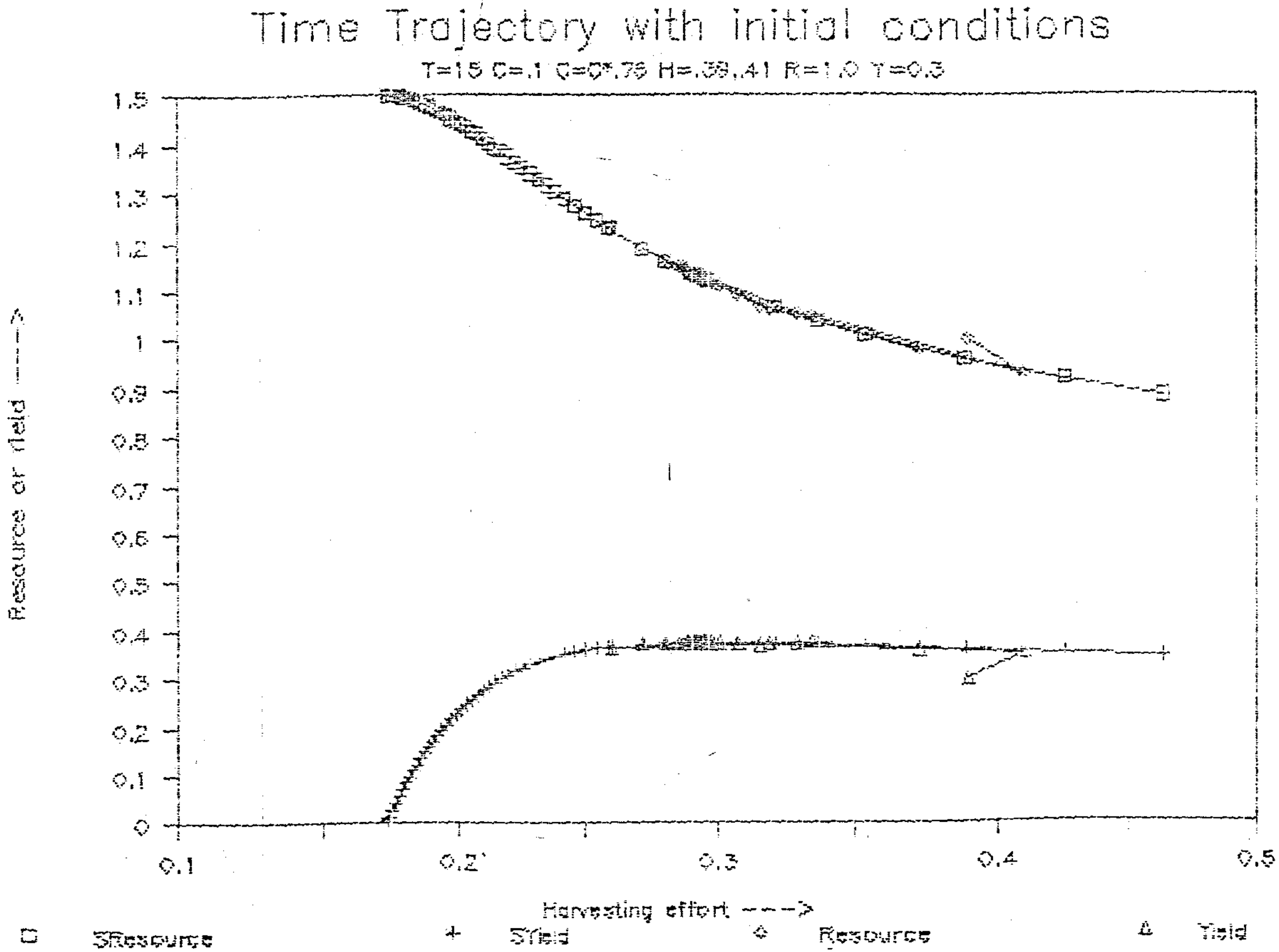
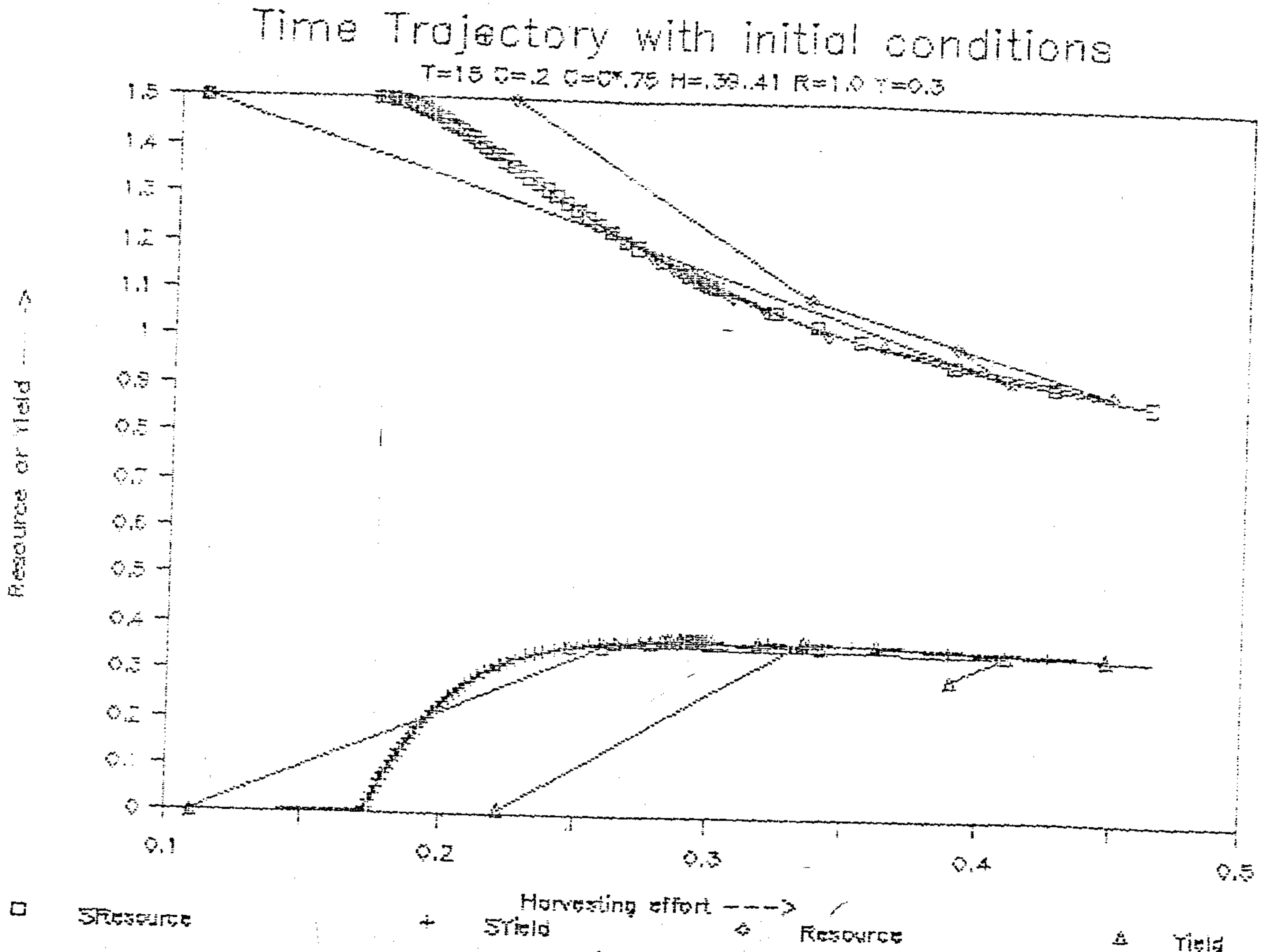

Time Trajectory with initial conditions
T=15 C=.1 Q=0*.79 H=.38,.41 R=1.0 Y=0.3
Resource or Yield ---->
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
Harvesting effort ---->
SResource
SYield
Resource
Yield

FIG. 2.4



Time Trajectory with initial conditions
T=15 D=.2 C=0*.75 H=.39.41 R=1.0 Y=0.3
Resource or Yield ---->
Harvesting effort ---->
SResource
SYield
Resource
Yield

FIG. 2.5

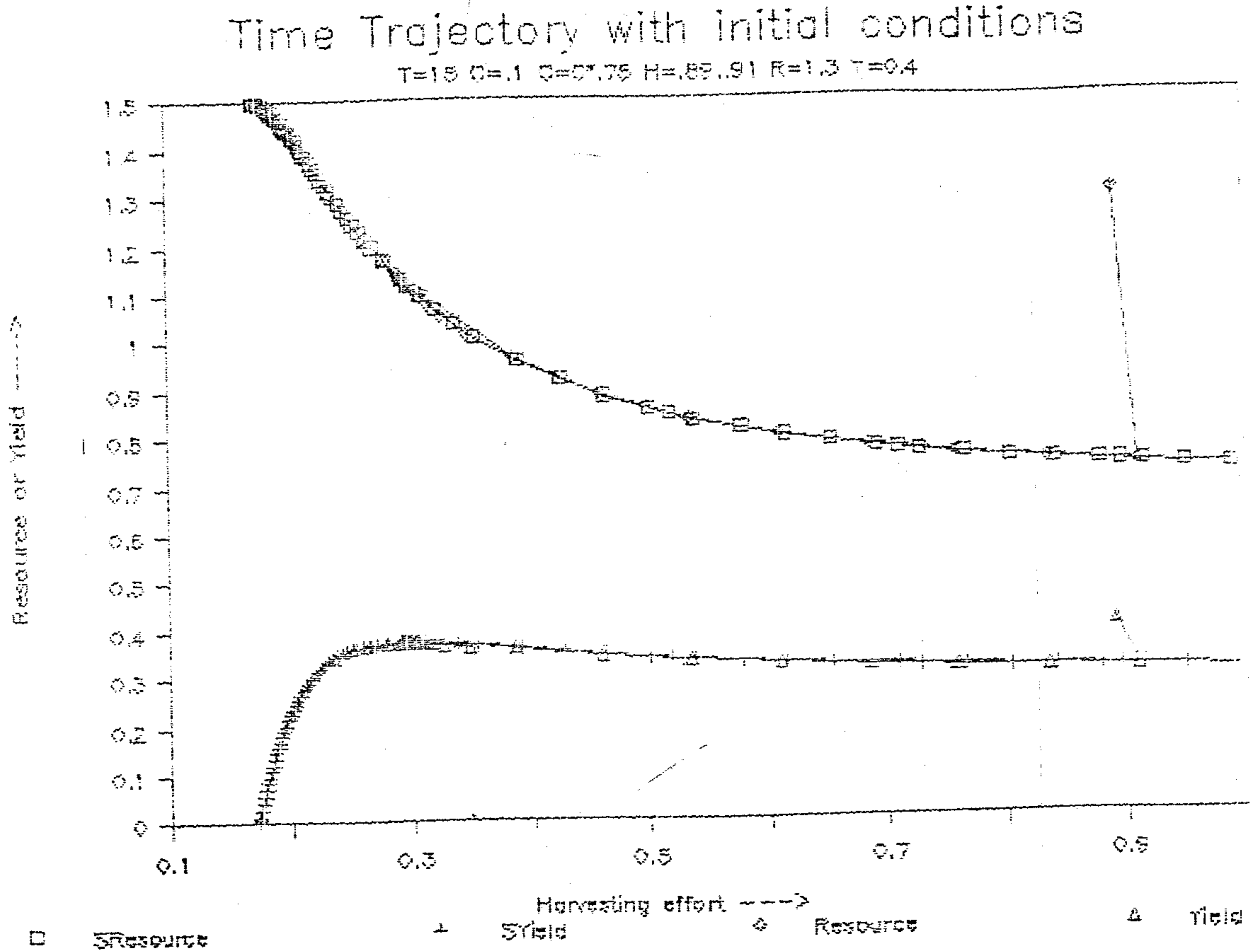

Time Trajectory with initial conditions
T=15 C=.1 Q=.75 H=.89,.91 R=1.3 T=0.4
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Resource or Yield ---->
0.1
0.3
0.5
0.7
0.9
Harvesting effort ---->
SResource
SYield
Resource
Yield

FIG. 2.6

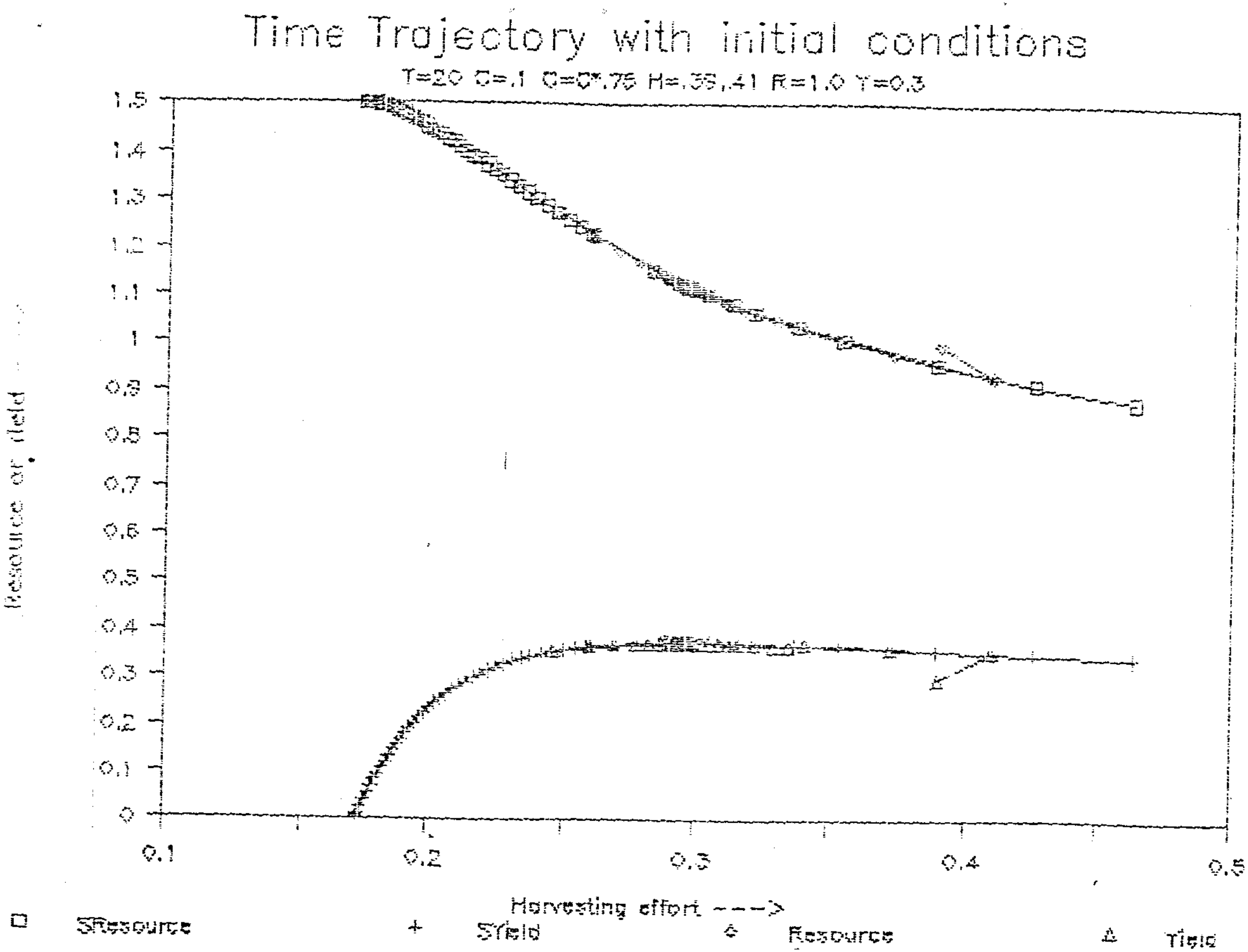

Time Trajectory with initial conditions
Resource or Yield
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
Harvesting effort --->
SResource
SYield
Resource
Yield

FIG. 2.7

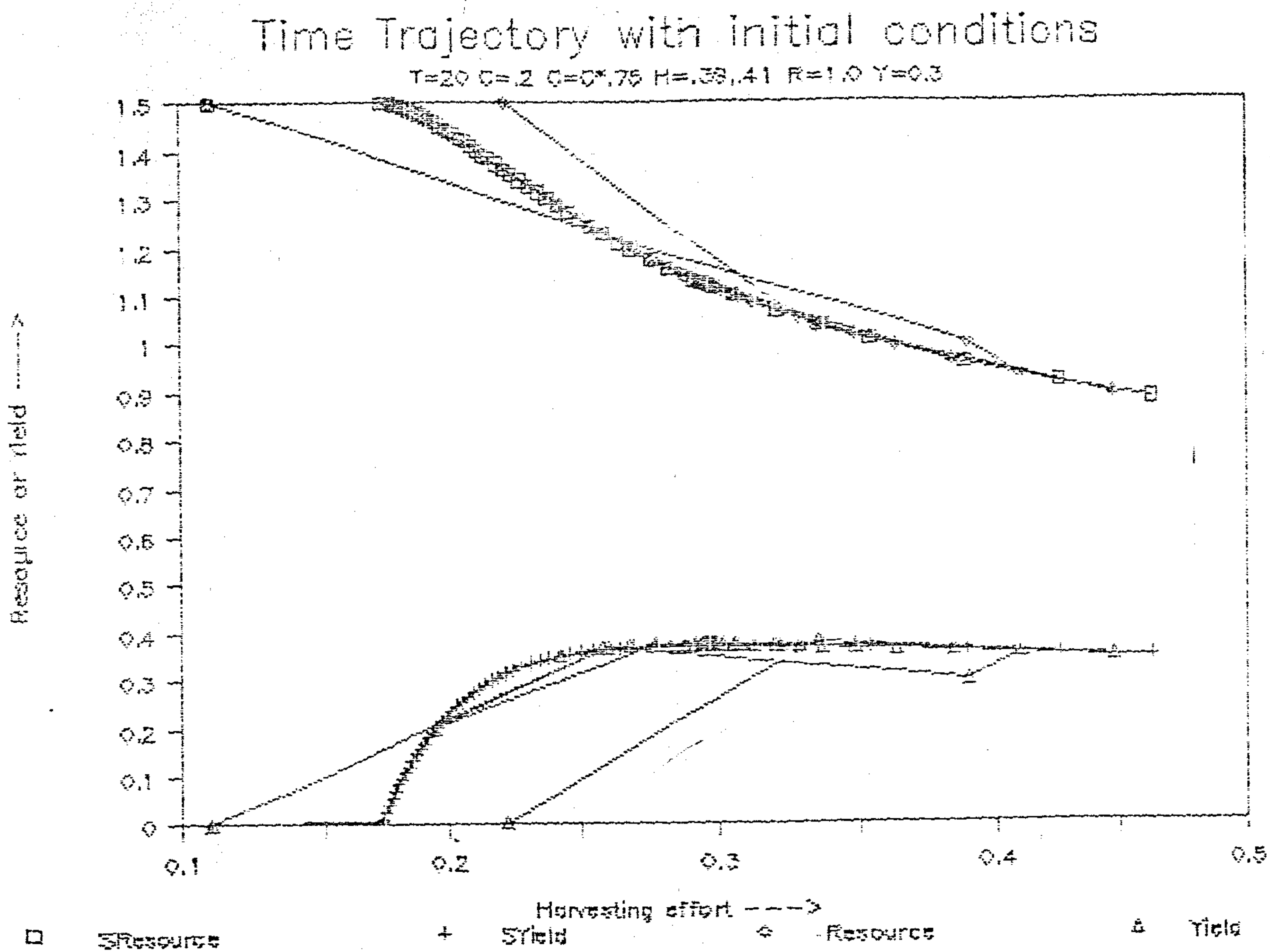

Time Trajectory with initial conditions
T=20 C=.2 C=C*.75 H=.38,.41 R=1.0 Y=0.3
Resource or Yield ---->
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
Harvesting effort ---->
SResource
SYield
Resource
Yield

FIG. 2.8

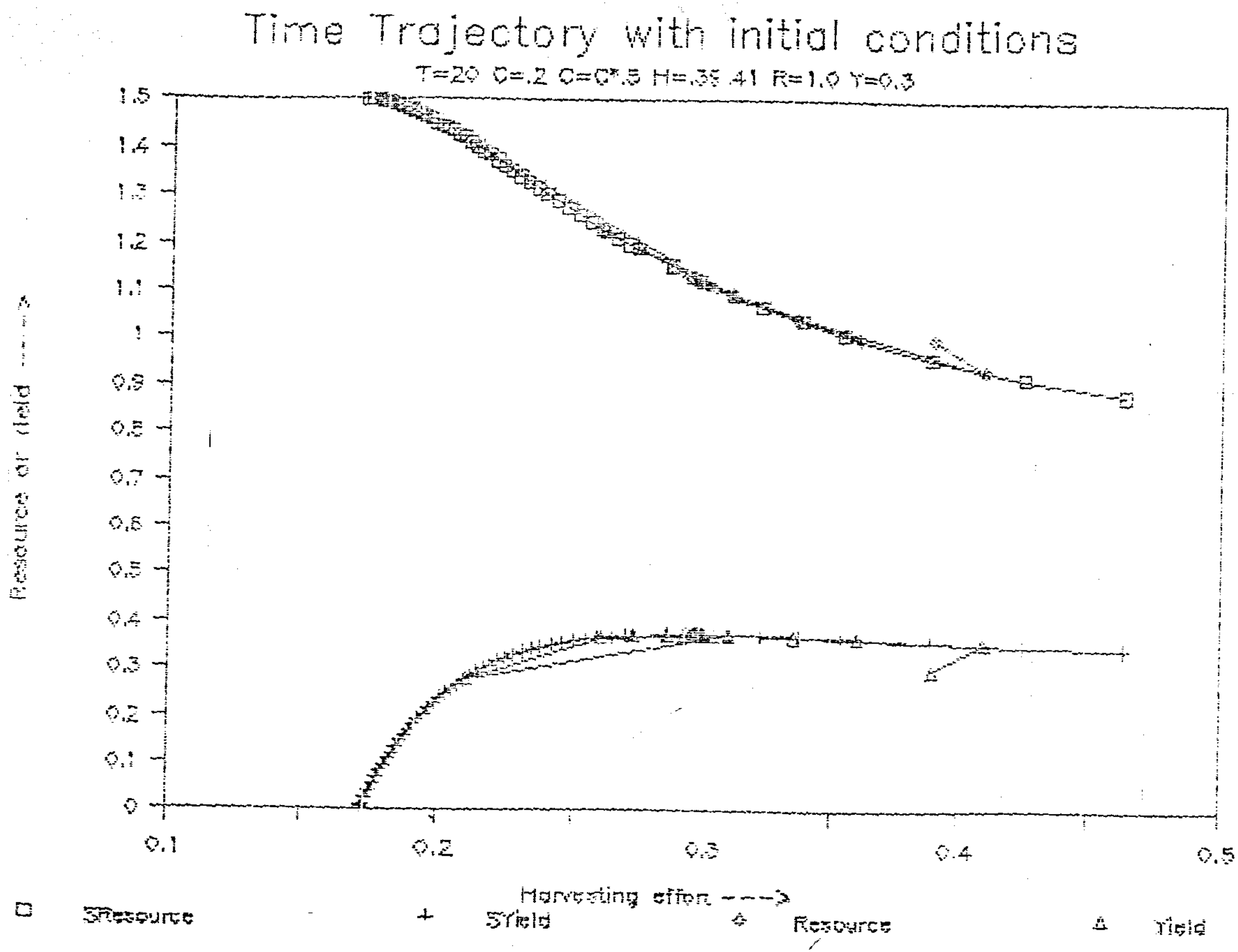
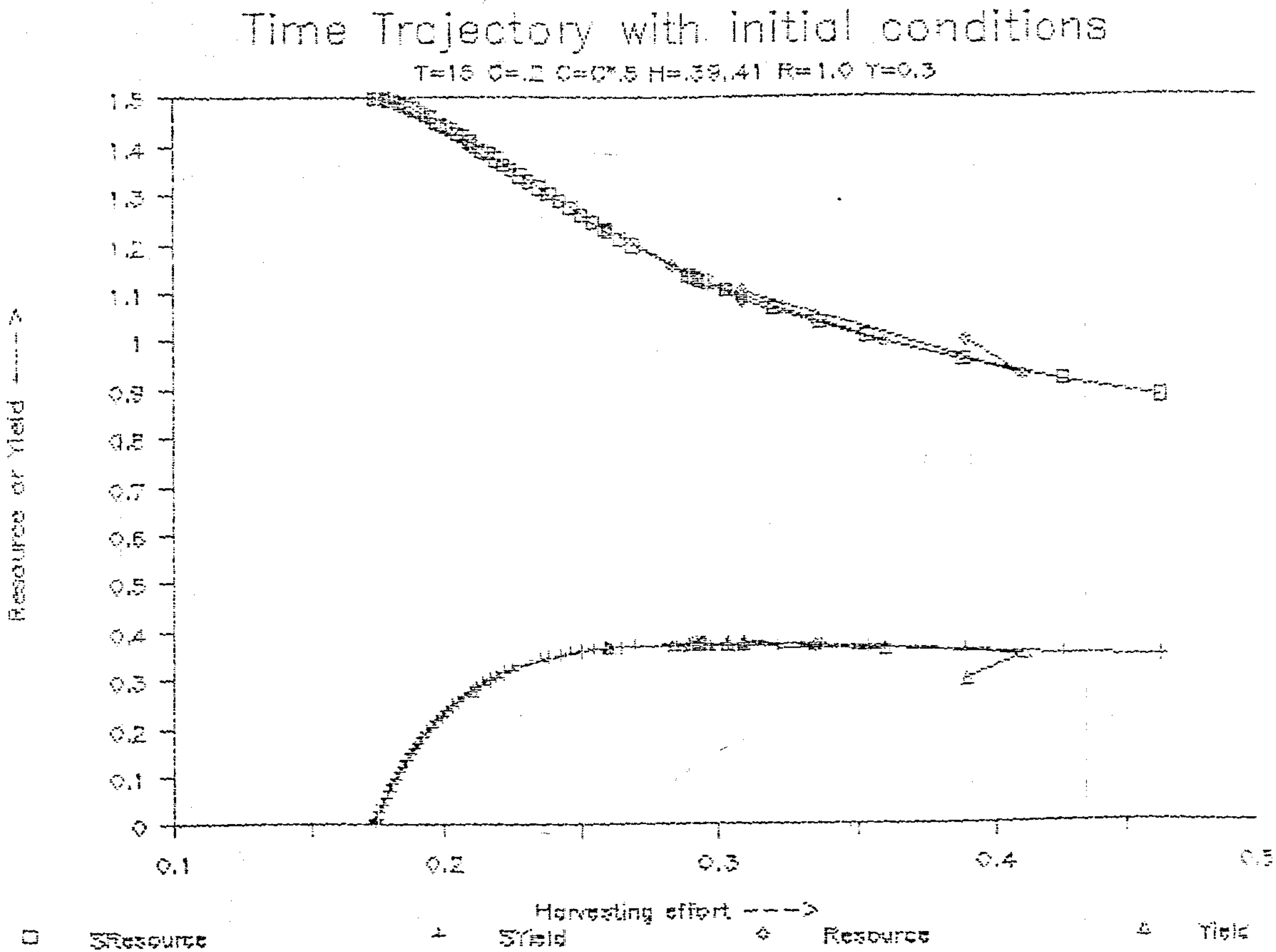

Time Trajectory with initial conditions
T=20 C=.2 C=C*.5 H=.35 .41 R=1.0 Y=0.3
Resource or Yield --->
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
Harvesting effort --->
5Resource
5Yield
Resource
Yield

FIG. 2.9



Time Trajectory with initial conditions
T=15 δ=.2 C=C*.5 H=.39,.41 R=1.0 Y=0.3
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Resource or Yield ---->
0.1
0.2
0.3
0.4
0.5
Harvesting effort ---->
SResource
SYield
Resource
Yield

FIG. 2.10

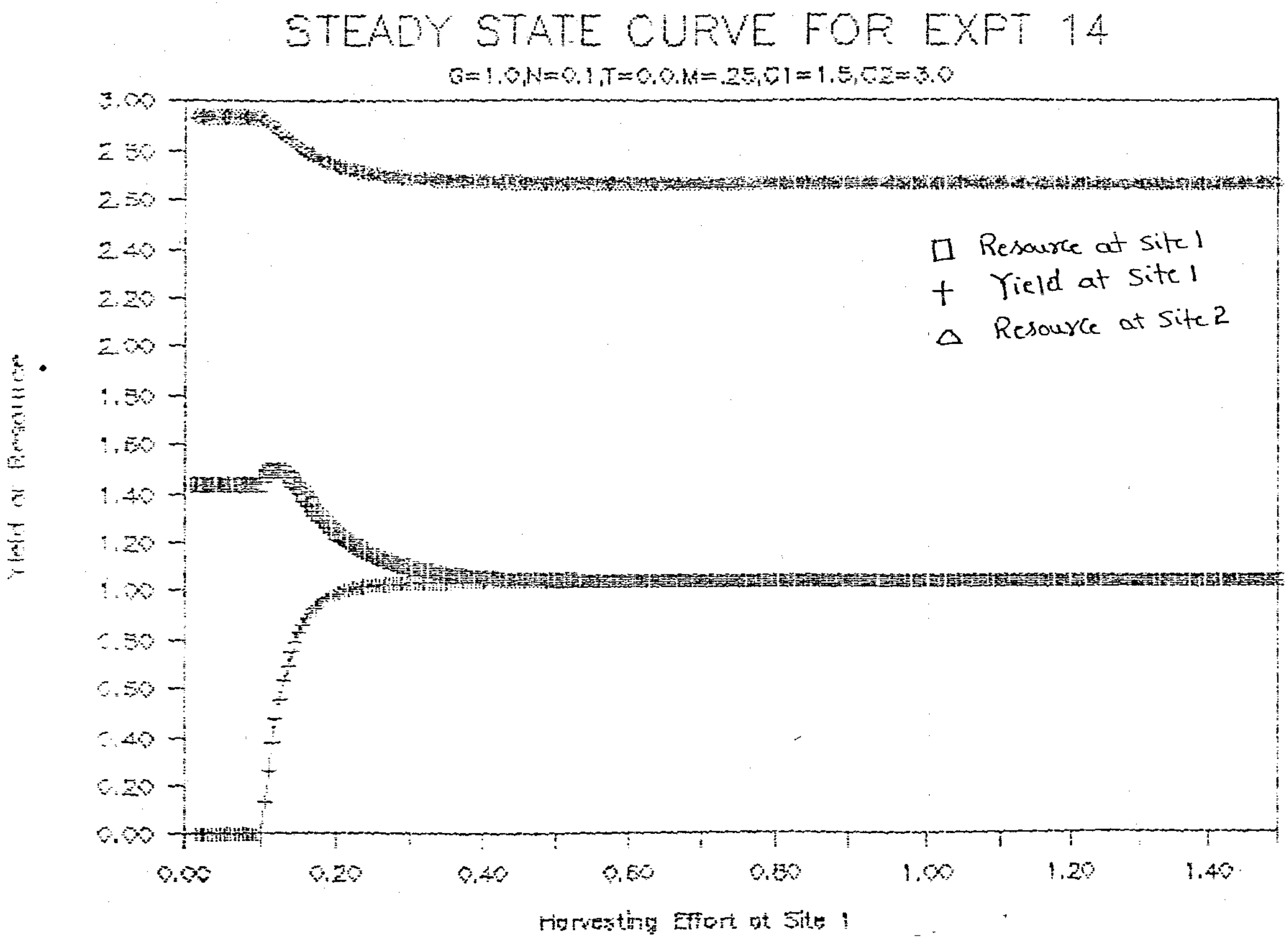

STEADY STATE CURVE FOR EXPT 14
G=1.0,N=0.1,T=0.0,M=.25,C1=1.5,C2=3.0
Resource at site 1
Yield at Site 1
Resource at Site 2
Harvesting Effort at Site 1
Yield or Resource
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40

Fig. 3.1

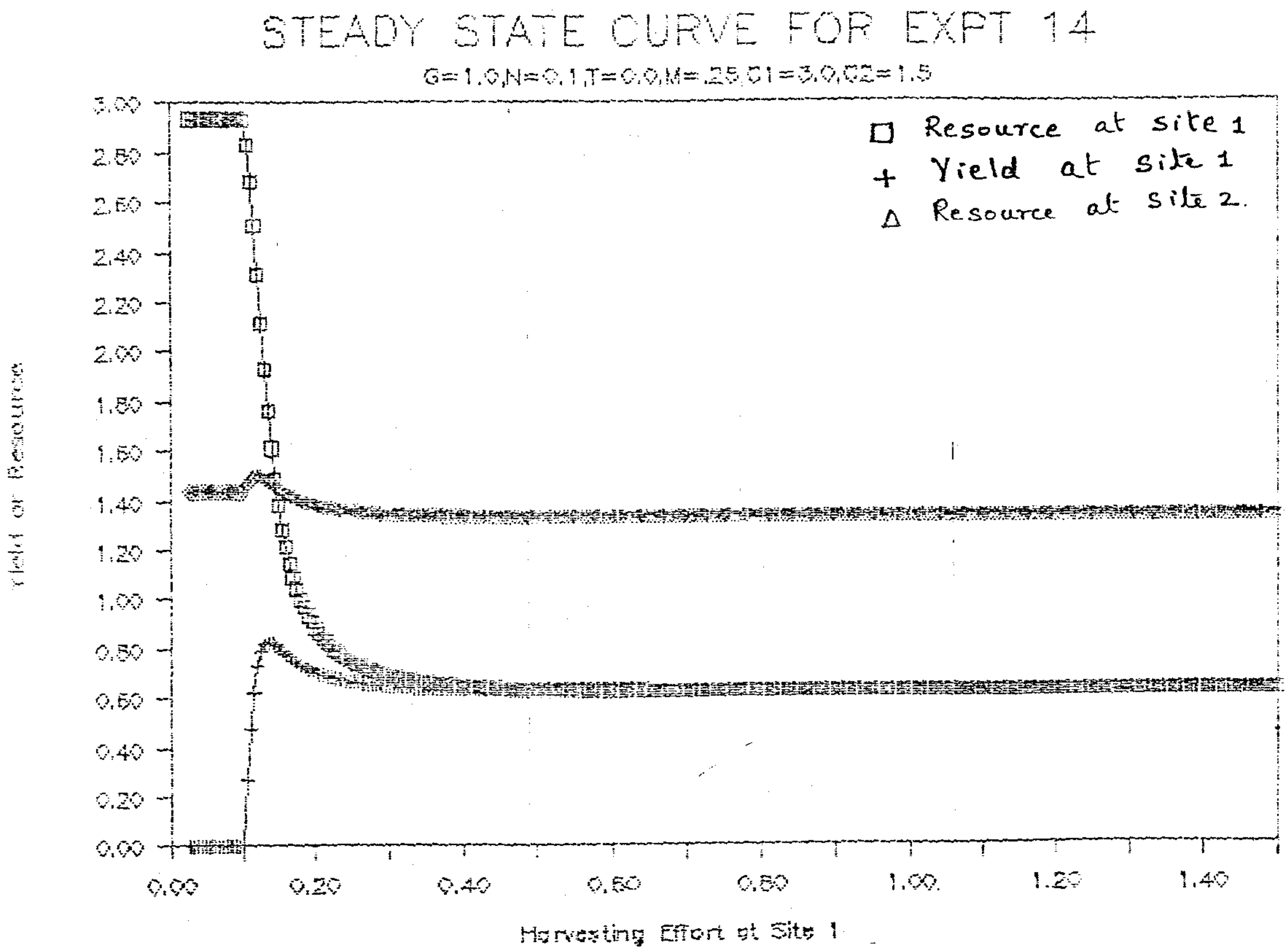

STEADY STATE CURVE FOR EXPT 14
G=1.0,N=0.1,T=0.0,M=.25,C1=3.0,C2=1.5
Resource at site 1
Yield at site 1
Resource at site 2.
Yield or Resource
Harvesting Effort at Site 1
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40

FIG. 3.2

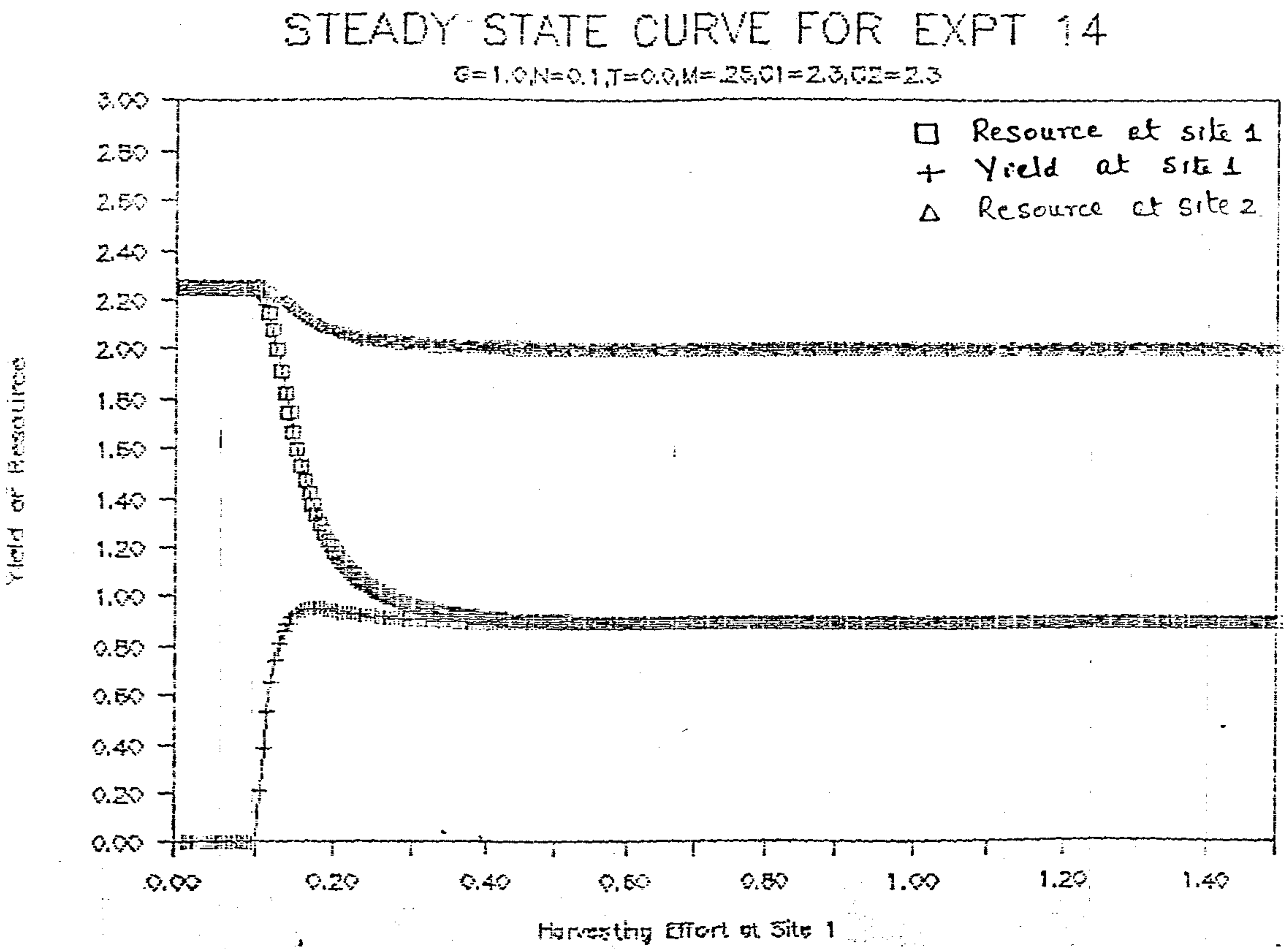
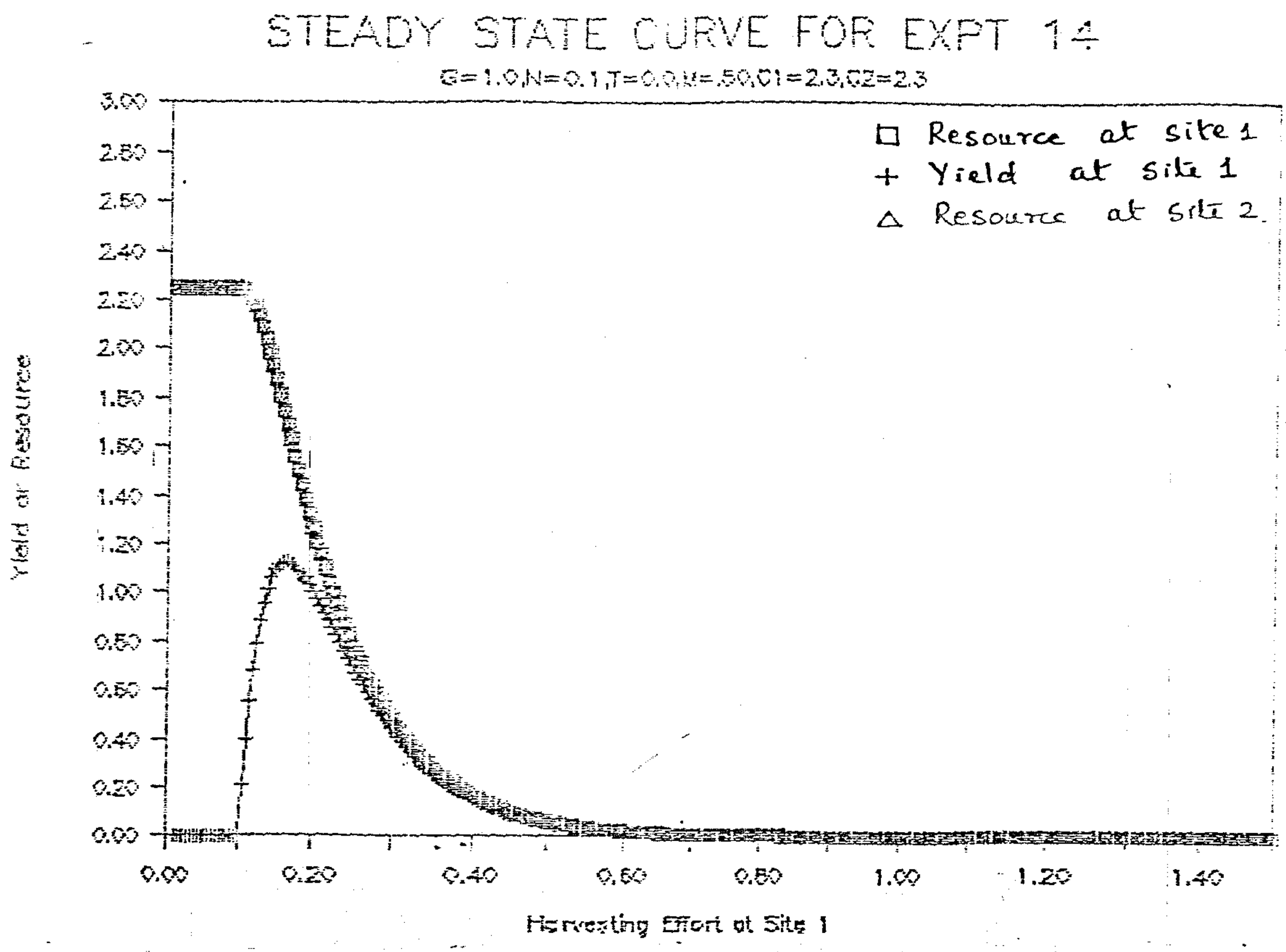

STEADY STATE CURVE FOR EXPT 14
G=1.0,N=0.1,T=0.0,M=.25,C1=2.3,C2=2.3
Resource at site 1
Yield at site 1
Resource at site 2
Yield of Resources
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting Effort at Site 1

FIG. 3.3



STEADY STATE CURVE FOR EXPT 14
G=1.0,N=0.1,T=0.0,M=.50,C1=2.3,C2=2.3
Resource at site 1
Yield at site 1
Resource at site 2
Yield or Resource
Harvesting Effort at Site 1

FIG 3.4

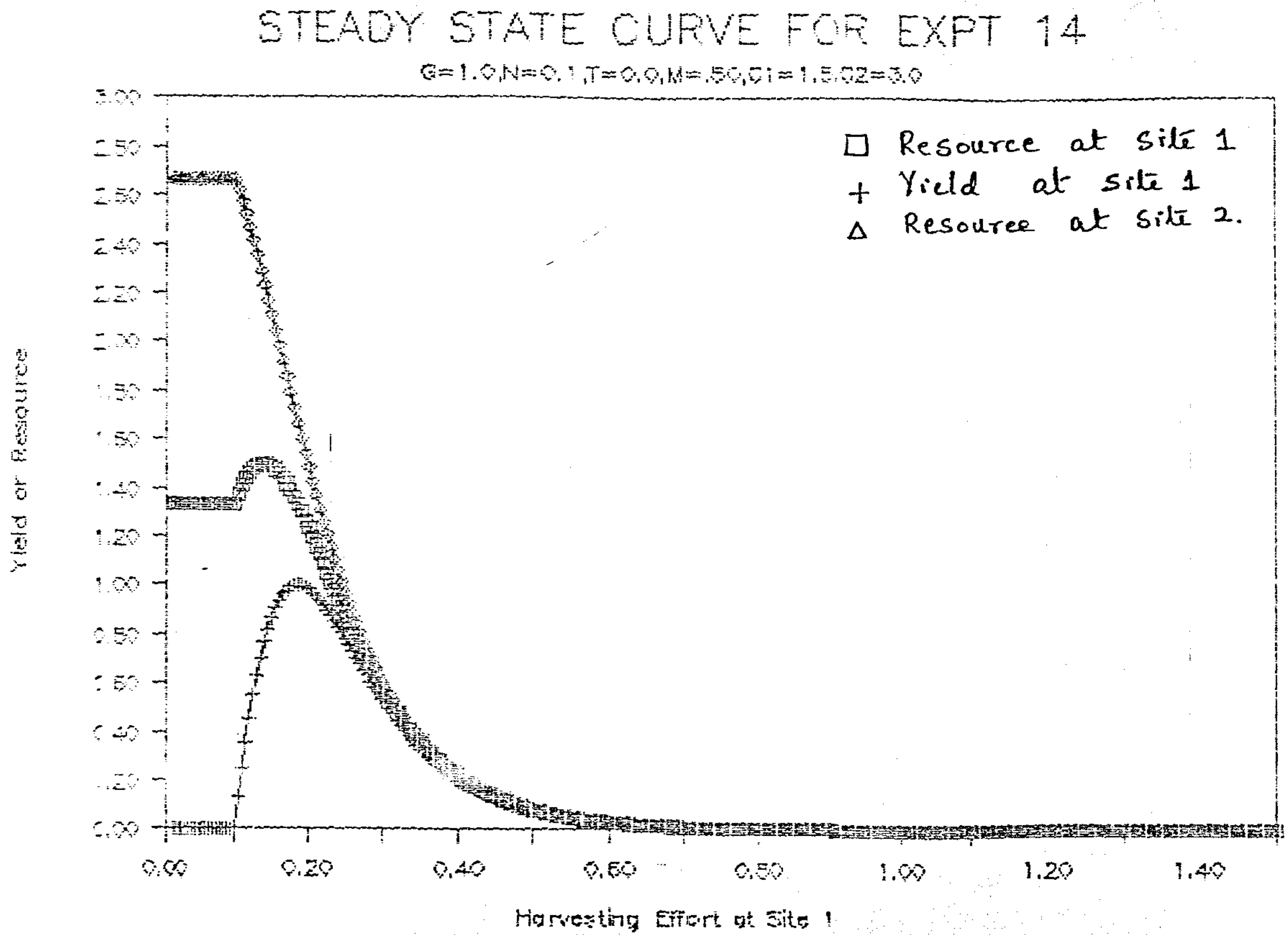

STEADY STATE CURVE FOR EXPT 14
G=1.0,N=0.1,T=0.0,M=.50,C1=1.5,C2=3.0
Resource at site 1
Yield at site 1
Resource at site 2.
Yield or Resource
Harvesting Effort at Site 1
0.00
0.20
0.40
0.60
1.00
1.20
1.40

FIG 3.5

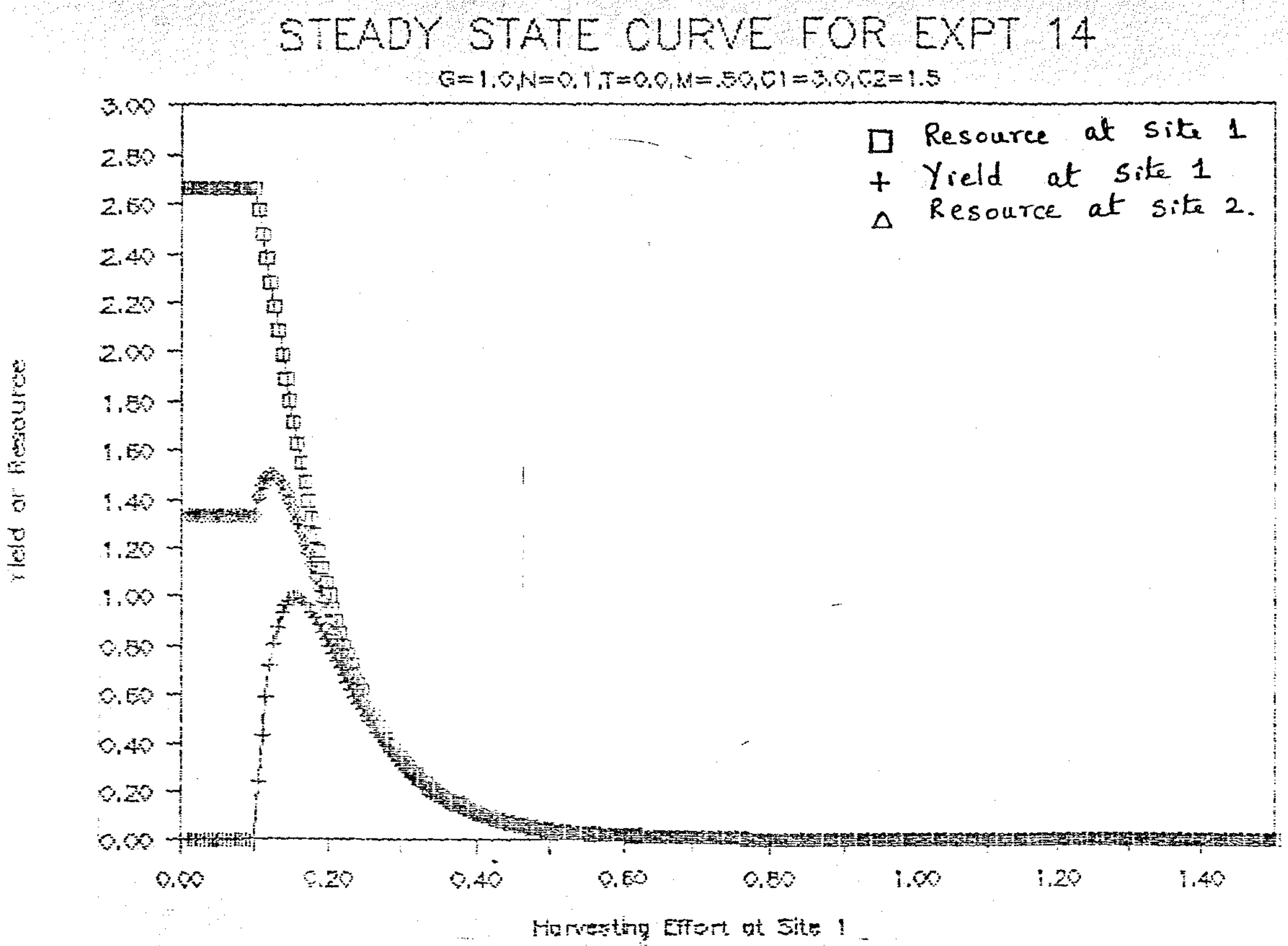

STEADY STATE CURVE FOR EXPT 14
G=1.0,N=0.1,T=0.0,M=.50,C1=3.0,C2=1.5
Resource at site 1
Yield at site 1
Resource at site 2.
Yield or Resource
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting Effort at Site 1

FIG 3.6

STEADY STATE CURVE FOR EXPT 14

G=1.0,N=0.1,T=0.0,M=.75,C1=1.5,C2=3.0

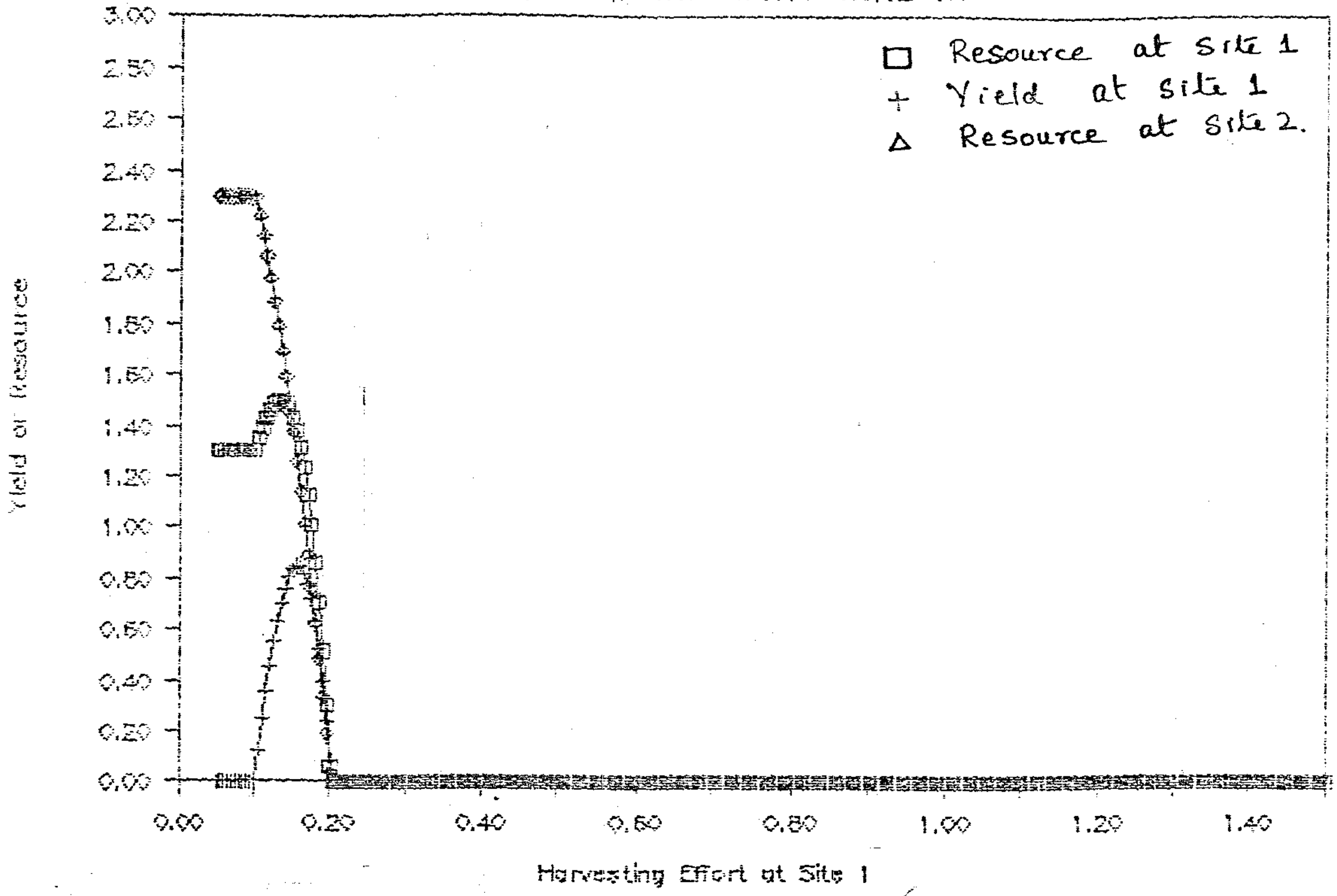


FIG 3.7

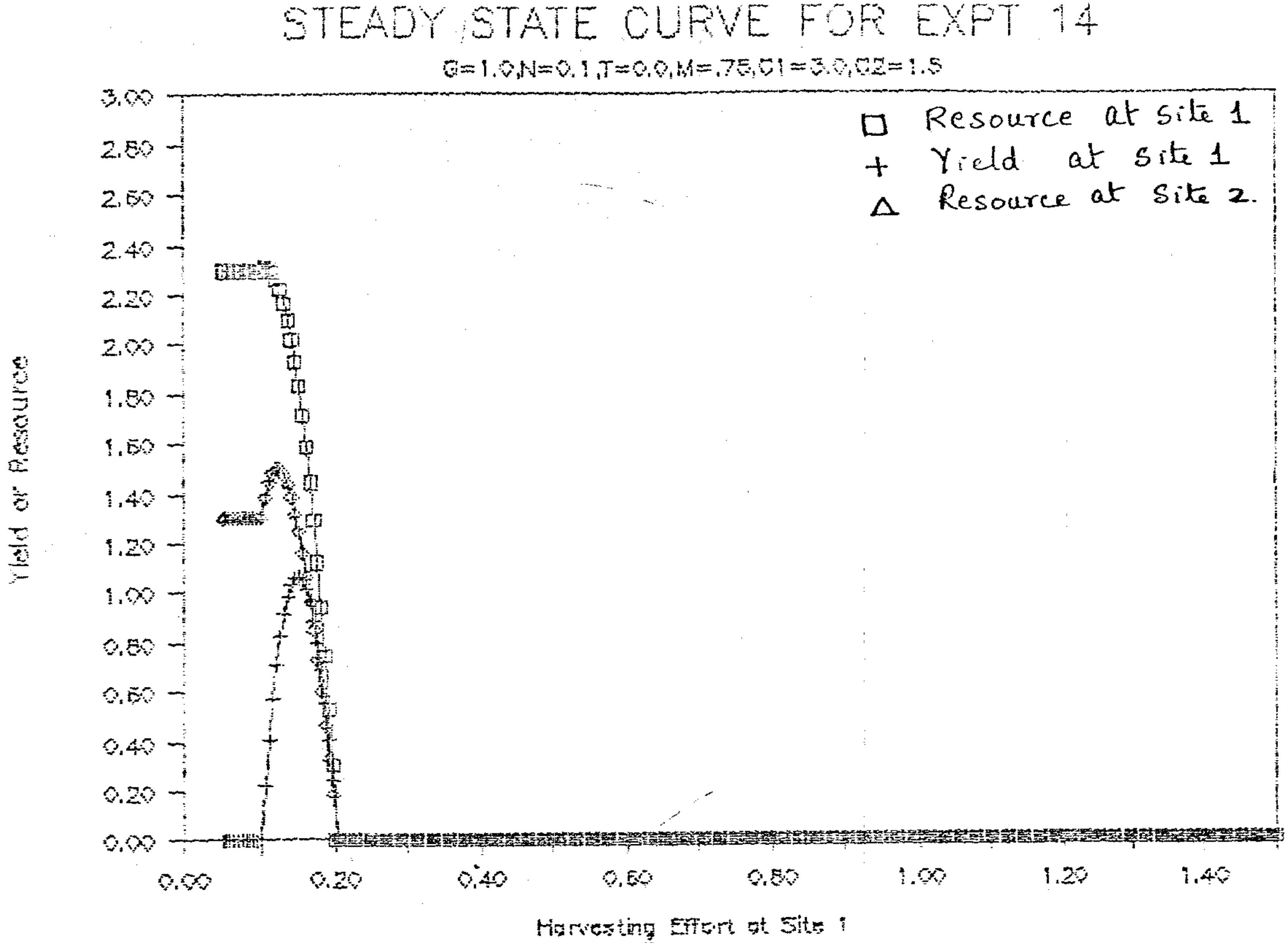

STEADY STATE CURVE FOR EXPT 14
G=1.0,N=0.1,T=0.0,M=.75,C1=3.0,C2=1.5
Resource at site 1
Yield at site 1
Resource at site 2.
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Yield or Resource
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting Effort at Site 1

FIG 3.8

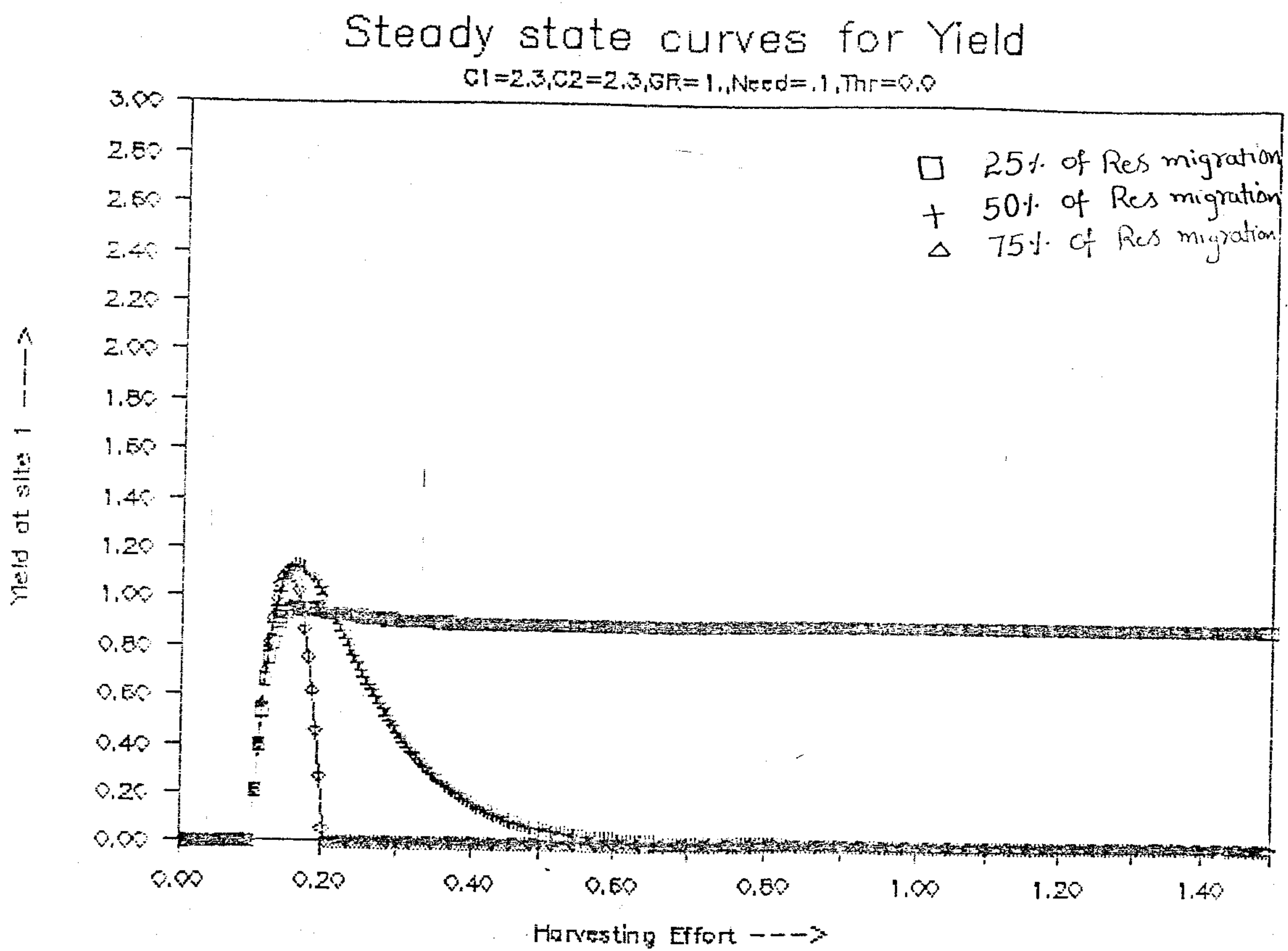

Steady state curves for Yield
C1=2.3,C2=2.3,GR=1.,Need=.1,Thr=0.0
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Yield at site 1 --->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting Effort --->
□ 25% of Res migration
+ 50% of Res migration
△ 75% of Res migration

FIG. 4.1

STEADY STATE CURVE FOR EXPT 14

G=1.0,N=0.1,T=0.0,M=.75,C1=2.3,C2=2.3

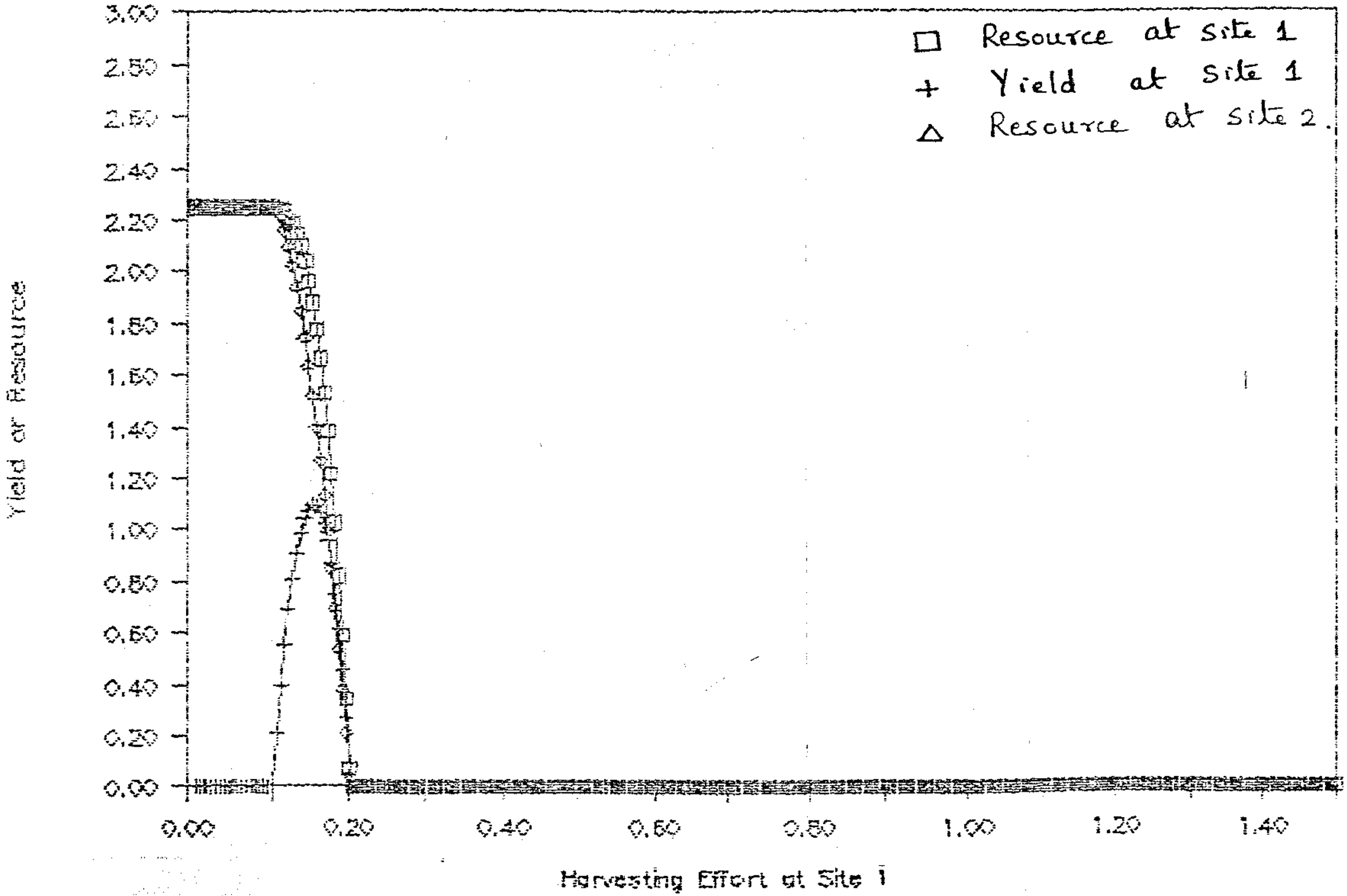


FIG 3.9

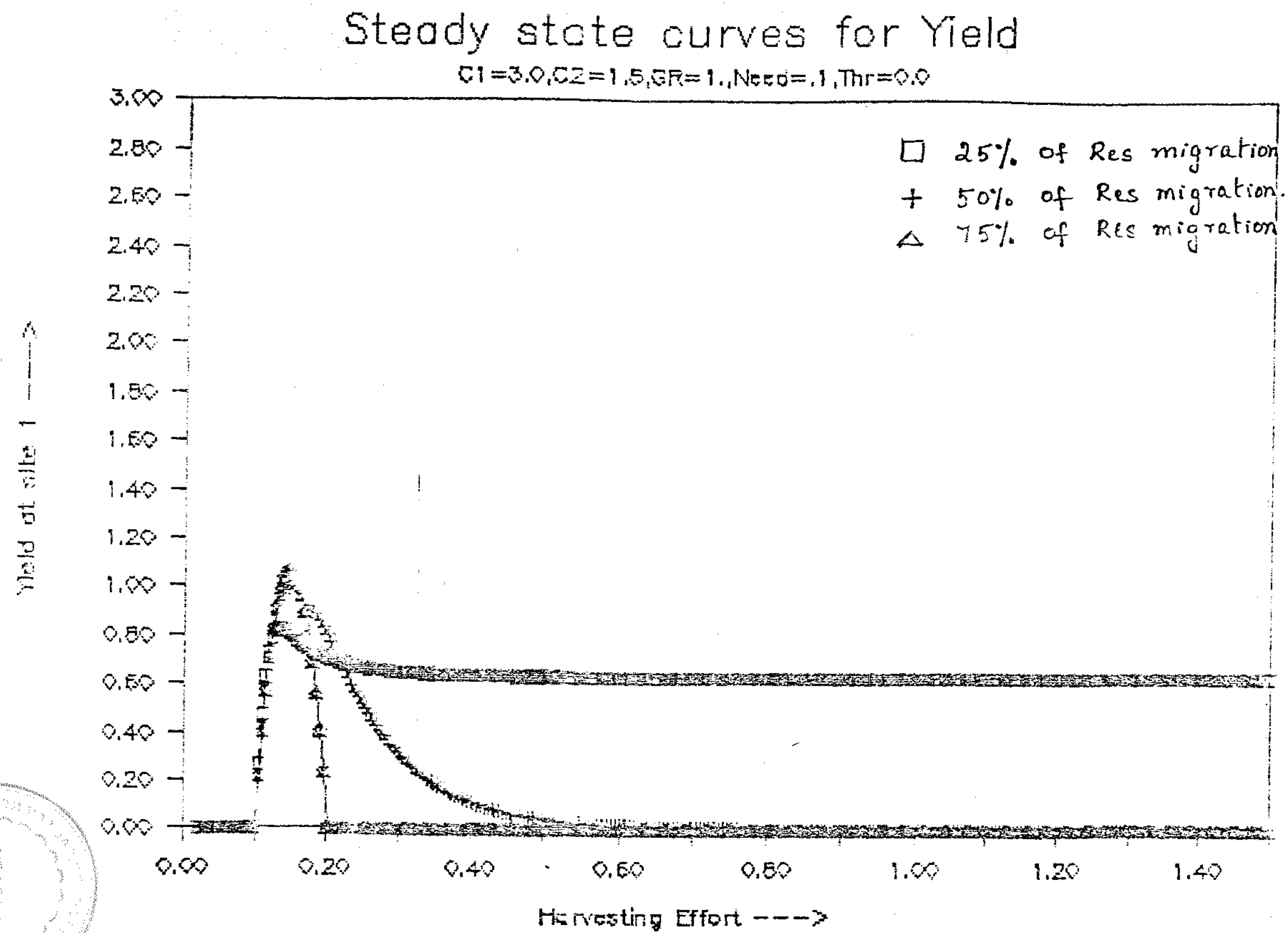

Steady state curves for Yield
C1=3.0,C2=1.5,GR=1.,Need=.1,Thr=0.0
□ 25% of Res migration
+ 50% of Res migration.
△ 75% of Res migration
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Yield at site 1 --->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Harvesting Effort --->

FIG 4.2

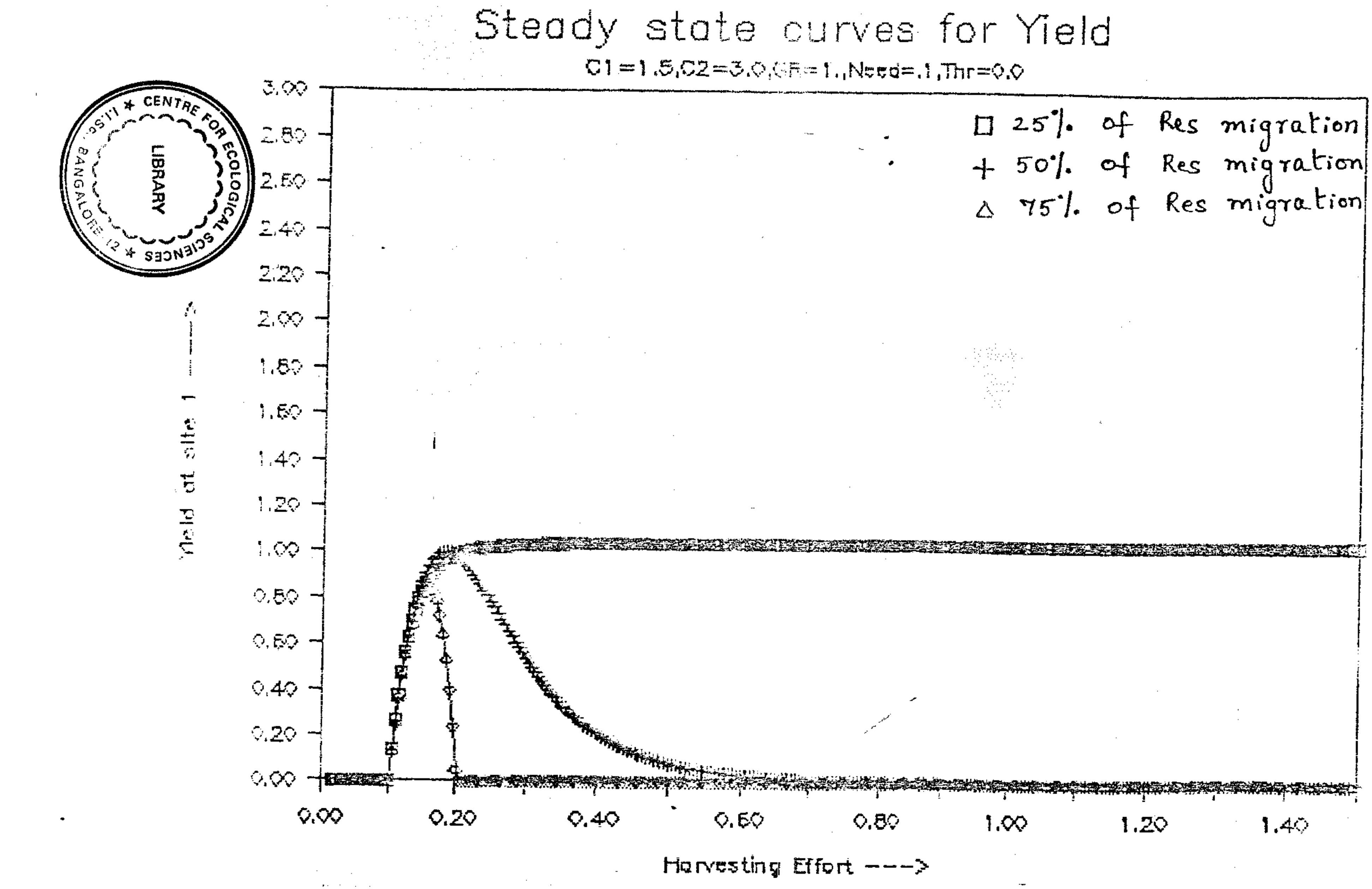

Steady state curves for Yield
C1=1.5,C2=3.0,GR=1.,Need=.1,Thr=0.0
□ 25% of Res migration
+ 50% of Res migration
△ 75% of Res migration
Yield at site 1 --->
Harvesting Effort --->
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
2.80
3.00

FIG. 4.3