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CHAPARRAL BURNS AND MANAGEMENT:

INFLUENCE OF SOIL MOISTURE AT THE TIME OF A PRESCRIBED CHAPARRAL BURN ON THE RESPONSE OF THE NATIVE VEGETATION FROM THE SEED BANK

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Funded by

California Endangered Species
Tax Check-off Funds
Contract No. C- 1483.3

June 1988

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ABSTRACT

Laboratory studies were conducted on seeds and soil seed banks of chaparral species to study the influence of soil moisture, heat intensity and duration on seed survival and germination. Chaparral species generally fall into two classes with respect to seed types found in persistent soil seed banks: 1) those that absorb moisture above ~20% of their dry weight; and 2) those that imbibe little or no water. Within each group, species differ in sensitivity to heat intensity, duration, and moisture conditions.

For seeds in the first class, (those absorbing moisture), mortality for a number of species increased at relatively low soil temperatures under moist conditions. More elaborate experiments used seeds of Adenostoma fasciculatum as a test species to examine the interaction among soil heat intensity, duration, and soil moisture. Even very low amounts of soil moisture (8%) significantly reduced germination at longer heat durations. By 22% soil moisture, germination ceased at all heat durations.

For seeds that do not imbibe water, soil moisture has no influence on immediate rates of mortality during soil heating, but moisture does reduce soil heat intensity that can reduce rates of germination due to stimulation failure ("heat scarification").

Current management practices often include burning while soils are moist; continuation of such practices will result in a loss in species diversity, principally species that are seed bank dependent. Because soil heat intensity, duration and soil moisture can affect vegetation regeneration success, they are therefore important factors to consider in chaparral management. Prescriptions for controlled burns must take these factors in account in order to provide managers with characteristics advantageous for vegetation regeneration, as well as for fire control.

A large number of species in chaparral of conservation interested are dependent on persistent seed banks. Generally, seed banks are relatively unstudied and therefore little considered when management plans are developed. A picture is now emerging, however, that seed banks are of fundamental importance in nearly every vegetation. Successful vegetation management will require understanding the dynamics of seed banks and factors which influence them, such as soil moisture during prescribed burns.

INTRODUCTION

Conservation of regional and local species diversity is a primary goal of many land managers. For this goal to be met, the response to particular management practices of the individual species comprising a vegetation must be understood (Keddy et al. 1988). Often, however, management is driven by a variety of competing goals. In some cases such goals may be in conflict with one another, but managers may be unaware of the conflict. A prime example exists in chaparral.

Chaparral is a vegetation of management interest in California for several reasons: 1) a number of listed rare, endangered, or threatened species are components of chaparral, e.g. 40 taxa of *Ceanothus* and *Arctostaphylos* are CNPS list 1B; 2) chaparral is one of the few lower elevation vegetations relatively unaffected by the large numbers of invasive species in California; and 3) chaparral is a flammable vegetation that is often managed as "fuel" and is burned under controlled conditions to reduce wildfire potential. It is this last goal that conflicts with conservation.

Managers often believe that chaparral is relatively unaffected by burns, because the vegetation is "fire-adapted". Because prescribed burns are less intense than many wildfires, soil is potentially conserved to a greater extent and there can be greater survival of resprouting species; prescribed burning under low intensity conditions, therfore, should be an ideal management practice for both safety and vegetation maintenance. In fact, "fire-adapted" is actually an over-simplification of a series of concepts. Chaparral is adapted to a particular fire regime. The fire regime consists of several characteristics: the type, season, intensity, frequency, and particular conditions of the vegetation and environment at the time of the fire (Gill 1975, Gill and Groves 1981, Parker and Kelly 1988).

Any large variance away from the natural fire regime can place the vegetation at some risk (Parker 1987a). Prescribed burning in winter and spring, in fact, was originally developed as a way of converting chaparral to grassland for grazing (Biswell 1974); currently it is being proposed as the most effective method to achieve both fire safety and vegetation maintenance. Arguments to this effect do not take into consideration species changes or losses under this type of management, recovery time, or patches exhibiting type-conversion. Prescribed burning of Adenostoma-Ceanothus dominated chaparral during winter has been abandoned in the Cleveland National Forest due to loss of seed bank-dependent Ceanothus from stands burned at that time (Tom White, USFS, personal communication). Conversions of chaparral to mixed shrub-grassland have occurred following prescribed burning in winter on serpentine chaparral in Marin County, even though maintenance of the vegetation was an objective (Parker 1987a).

In contrast to other mediterranean-climate shrub vegetations, chaparral contains a large number of species that depend upon soil seed banks for regeneration (Parker and Kelly 1988). Many of these species are of conservation interest (Parker 1987b). Seed banks are often a critical aspect of a vegetation not sufficiently considered when developing vegetation management plans (Keddy et al. 1988). Many rare and endangered species may be completely dependent upon persistent seed banks, and whose populations may be transient in relation to their seed banks (Keddy et al. 1988). Management of a vegetation must take into consideration the role of seed banks in community regeneration and maintenance in relation to both preferred and invasive species (Cavers and Benoit 1988, van der Valk and Pederson 1988).

One important concern of chaparral management is that prescribed burns are often conducted at a season of the year and under conditions that vary considerably from the natural fire regime. This can be important for species dependent upon seed banks for regeneration (Parker 1987b). Previous research has established that prescribed burns conducted in fall or winter when soils contain moisture can seriously reduce the response of the seed bank (Kelly and Parker 1984, Parker 1987a, 1987b). The purpose of this study is: 1) to establish what characteristics of moist soil affect viability of the chaparral seed bank, and 2) what types of species are most vulnerable to prescribed burning. These are both important considerations for managers, as conserving chaparral in the long-term will require informed management practices that include prescribed burning.

METHODS

Two experiments were conducted to test the combined effect of heat and moisture on seed germination. The first investigates the effect of different durations of heat on wet versus dry seeds of four post-fire herbaceous species. The second experiment investigates the interaction of heat duration and soil moisture conditions prior to heating on the germination of seeds of the chaparral dominant shrub _Adenostoma_ _fasiculatum_.

Experiment 1. - Herbaceous species.

Fresh seeds of four post-fire herbs _Emmenanthe_ _penduliflora_, _Chaenactis_ _artemisifolia_, _Phacelia_ _grandiflora_, and _Phacelia_ _parryi_ were collected in 1985 following a fire in the Santa Monica Mountains, California. The seeds were divided into three equal groups, two to receive different moisture and temperature treatments, plus a third group as control. The first group received a moisture pre-treatment consisting of a two-hour immersing in distilled water, enough to allow significant uptake (20% increase in weight of seed by water uptake) (see appendix showing % uptake by each species). The second group and the control group received no moisture pre-treatment.

Five heat treatments of 50, 65, 80, 95, and 110°C for thirty minutes were given to seeds of the moist and dry pre-treatent groups (n=200 each treatment combination). The control group (n=200) did not receive any heat treatment.

Each of the 200-seed treatments was placed in petri dishes between sheets of washed filter paper, 50 seeds per dish. Initial wetting was with an aqueous extract of charred wood (after Keeley et al. 1985), and was repeated several times during the experiment; otherwise the filter paper was kept moist but not overly saturated with distilled water. The dishes were incubated on a rotating schedule of two weeks at 5°C followed by three weeks at 25°C. Germination in each dish was scored at intervals of several days to one week, for 120 days, when germination in all treatments had ceased.

Experiment 2. -Chamise

For the second experiment, soil was collected from under individuals of _Adenostoma fasiculatum_ in an 35 year old stand which was >95% pure. Approximately 175 L of soil was collected from the top 5 cm to maximize seed content. The soil was allowed to air-dry for two weeks at room temperature, at which time the moisture content was determined to be 3% of the dry soil weight, and mixed thoroughly to ensure a homogeneous distribution of seed. The soil was then divided into four equal partitions, each of these further divided into six sub-samples. One of these subsamples in each group was kept at the air-dry 3% moisture level, the other five were manipulated to moisture contents of 7, 15, 22, 30, and 45% of dry soil weight. All sub-samples were incubated for one week at room temperature in plastic bags, to homogenize moisture levels and prevent moisture loss.

The sub-samples in three of the four groups were heated for 10, 20, and 30 minutes respectively, to a soil temperature of 100°C. The fourth group was not heated. The following chart represents the resulting heat-moisture combinations:

NO HEAT/3%	10 MIN/3%	20 MIN/3%	30 MIN/3%
NO HEAT/7%	10 MIN/7%	20 MIN/7%	30 MIN/7%
NO HEAT/15%	10 MIN/15%	20 MIN/15%	30 MIN/15%
NO HEAT/22%	10 MIN/22%	20 MIN/22%	30 MIN/22%
NO HEAT/30%	10 MIN/30%	20 MIN/30%	30 MIN/30%
NO HEAT/45%	10 MIN/45%	20 MIN/45%	30 MIN/45%

Each of the treatments were then spread over potting sand in standard half-flats, and placed in an unheated greenhouse. Germination of seedlings was recorded for each flat at intervals of 2-6 weeks, over a 270 day period. Data were analyzed using two-way ANOVA and Duncan's multiple range test.

RESULTS

Herbaceous Species

Seeds imbibed prior to heat treatments germinate at lower rates or not at all at progressively higher temperatures (Table 1). At low temperatures (50°C or below), no difference exists between moist pre-treated or dry seeds in their germination response.

For the species Chaenactis artemisifolia (Fig. 1) and Emmenanthe penduliflora (Fig.2), obvious differences exist in the response of wet and dry seeds to heating. The dry seeds of Chaenactis maintain relatively high levels of percent germination until the hottest treatment of 110°C. The pre-moistened seeds of this species decrease sharply after 50°C to slight (2.5% at 80°C) or no germination.

Emmenanthe penduliflora is similarly affected (Fig. 2), with moderate percentages maintained in the germination of dry seeds, except for a sudden increase in the 110°C treatment, contrary to the effect observed on Chaenactis. The wet seeds, in contrast, have a slower decrease in germination followed by a steep drop-off at higher temperature (0% at 95°C) than the comparable curve for Chaenactis.

The two Phacelia species gave results in which wet and dry seeds appear more similarly affected by heat probably due to the low rates of germination. Phacelia grandiflora (Fig. 3) showed a significant decrease in germination relative to the unheated control for both wet and dry seeds, although ultimately the curves diverge, with greater percent germination at the highest temperature recorded for dry seeds, and no germination for the wet seeds.

The germination of P. parryi (Fig. 4) was extremely poor even for the unheated control (all treatments below 7% germination). On the expanded scale of Fig. 4 a slight increase exists in the germination of wet seeds at intermediate heat levels, but otherwise a low germination percentage is apparrent, consistent with the response of the dry seeds. The differences, exaggerated at this scale, are too small to be significant.

Comparison of the germination response curves of all the dry seed treaments (Fig. 5) emphasizes the different responses of these four species. Under dry heat conditions, the curves remain essentially distinct, except between the two Phacelia species. The effect of a high (110°C) heat treatment on Emmenanthe and Chaenactis is also apparent, increasing the percentage of the former and decreasing that of the latter; this variation may not be significant, however, and may perhaps be due to variation in treatment conditions.

The generalized effect of mortality due to heating of wet seeds is evident in Fig. 6, showing the response curves for all the heat treatments of pre-moistened seeds. Both Chaenactis and Emmenanthe suffer large-scale mortality with increasing heat, albeit at different rates. For Chaenactis and both species of Phacelia, germination is problematical above 50°C, and by 95°C the highest level is 0.5% (for both Phacelia spp.).

RESULTS

Chamise

Germination Totals

Figure 7 shows the germination totals for the series of soil moisture levels for each heat treatment. There is a rapid decline in the response of all heat treated soils associated with an increase in the soil moisture content prior to heating, such that germination in heated soils of 22% soil moisture content or greater is insignificant or absent.

Germination of seeds from air dried soils (3% soil moisture) was highest following the two longest heat treatments (30 and 20 minutes). The ten minute heat treatment produced a response lower than that of the control. There is an apparent depression in germination in soils of 3% soil moisture and 10 minutes heat treatment, but with greater moisture content, the pattern of decline is similar to that of the 20 and 30 minute heat treatments. These differences illustrate that two seed types are produced by chamise, one type sensitive to heat and one type dependent upon heat to break dormancy. This will be discussed further later. Germination of the unheated control seed banks increased with greater moisture content, reaching a maximum at 22% and followed by a slight decline to 45%. All of these responses are distinctly different from that of the heat-treated soils occurred at higher moisture content levels.

Cumulative Germination

Figures 8-11 depict the cumulative germination of Adenostoma fasiculatum over the course of the experiment. Each graph represents one of the four heat durations (including the unheated control), and includes the curves for the six soil moisture levels of the soils prior to heating. Figure 8 shows the similar pattern expressed by each of the soil moisture levels in the unheated treatment, with a constant accumulation of seedlings with each successive sampling date.

Comparison of this figure with Figures 9-11 clearly show the suppressed germination or mortality of seeds in soil with higher moisture levels, contrasted with enhanced germination in soils of low moisture levels at the longest heat treatment duration (note the changes of scale in the Y-axis of each graph). The ten minute heat treatment caused diminished response in all soil moisture levels, especially at 22, 30, and 45%, where no seeds germinated (Fig. 9). This pattern was repeated at the longer durations of heating (Figs. 10 and 11), with little or no germination in the higher moisture levels, extremely poor germination in the 15% moisture level, but with an eventual increase in the response of the 3% and 7% moisture levels relative to the unheated soil. This increase in the totals for the thirty minute/3% and 7% treatments occurred in spite of their delayed response at the beginning of the experiment. In the unheated, ten and twenty minute treatments, germination was observed in the 3% and 7% by 21 days following initiation, but in the thirty minute treatment, no germination occurred before 50 days (Fig. 11).

Germination Rate

Another useful comparison of the response of Adenostoma fasiculatum is germination rate (#seeds germinating per day) of soils at each moisture level and heat treatment. These rates were calculated from the number of seeds that germinated per sampling interval divided by the number of days in that interval, or germination rate equals the number of seeds germinating per day. Again the response of the unheated soils appears distinct from the heat-treated soils. Two peaks are apparent in the unheated soil treaments at 165 and 275 days following initiation, where germination was at a maximum rate (Fig. 12). On most sampling dates, the highest rates are for the middle moisture levels, and the lowest rates are for the lowest and highest moisture levels.

In the heat treatments (Fig. 13-15), only the rates for 3% and 7% soil moisture are significant because of the extremely slow rates associated with the poor germination in the other moisture levels. However, a comparison of these two rate curves on the three graphs demonstrates an interesting pattern. The germination rate of the ten minute treatments is constant at first, followed by a period of rapid germination rate increase after about 240 days (Fig. 13). In the twenty minute treatments, the 3% moisture level shows a 165-day peak analagous to that of the unheated 3%, followed by a late increase (Fig. 14). In the thirty minute treatments, both the 3% and 7% moisture treatments have the same pattern of response as expressed in the unheated treatment, although terminating at a lower rate (Fig. 15).

DISCUSSION

Several conclusions are apparent from this study. One is that various species exhibit differences in sensitivity to heat intensity, duration, and moisture conditions. Thus even field responses of a theoretical uniformly-distributed seed bank would vary due to local site conditions during the fire. Making specific predictions for a single fire would be difficult.

These responses, however, illustrate that several characteristics, intensity, duration, and soil moisture, are important to consider in chaparral management. Currently, the prescription for a chaparral burn includes information that allows control of a fire, but not information on whether or not species will survive. Prescribed burns may provide managers with characteristics advantageous for seed survival in the soil (lower intensities and soil moisture also reducing intensity), but also can reduce seed bank response in other ways (increase in duration due to soil moisture, increase in temperature sensitivity of seeds when inbibed).

Heating of the soil under moist conditions is fatal for seeds of species that imbibe water under pre-fire conditions. The five species used in this study, *Chaenactis artemisifolia*, *Emmenanthe penduliflora*, *Phacelia grandiflora*, *Phacelis parryi*, and *Adenostoma fasciculatum*, are all examples of this type of species. Sensitivity to heat treatments occurred under moist conditions and was dependent upon the seeds taking up moisture to approximately 20% of seed dry weight. These seeds will take up the minimum amount of moisture in less than two hours under laboratory conditions. Burns under typical prescribed conditions would usually have moist soil and result in considerable mortality of seeds of these species.

Other species may have thick seed coats that require a heat treatment before the seeds can take up moisture. Examples of these would be species in the Fabaceae (legumes) or Convolvulaceae (Parker 1987b). An earlier study showed no difference between moist and dry pre-treatments in the germination response of species with thick seed coats (Parker 1987b). These species actually require relatively high intensity pulses or increased heat duration at lower temperatures in order to modify the seed coat to allow uptake of water and germination. Burns under prescribed conditions that would allow only a low intensity fire may result in little seed bank response of these species due to too low a temperature and a failure to stimulate germination. The example of the loss of Ceanothus from the prescribed burn stands in the Cleveland National Forest mentioned in the introduction was the result of too low an intensity to stimulate germination of Ceanothus seeds from the seed bank.

Although Adenostoma fasciculatum is not a species that will ever be considered rare or endangered in the near future, it represents a good indicator species of seed bank responses. The experiments carried out with seed banks of chamise indicated that soil moisture can have immediate effects on seed survival, even at extremely low moisture levels. Figure 8 illustrates this, showing that at 8% soil moisture, (not detectable by feel or look above air dried levels of 3-4%), in the 20 and 30 minute heat treatments germination was decreased by 15-50%. By soil moistures of 15%, little germination occurred in the 10 and 20 minute heat treatments and by 22% soil moisture, all heat treatments were negligible. Soil moistures must be considered as part of a burn prescription if conservation of species is an objective.

The seed bank responses of Adenostoma fasciculatum also illustrate another characteristic, that seed banks can be composed of more than one type of seed (Stone and Juhren 1953). In this case, the seed bank is composed in part of a transient portion that germinates readily without a heat treatment. This is the portion that germinates in the controls that received no heat treatments. The decline in germination at 3% soil moisture from no heat to 10 minutes heat duration demonstrates the loss in viability of the transient portion. The increase in germination percentages at 3% soil moisture with the longer heat treatments

(20 and 30 min) illustrate the stimulation of the persistent portion of the seed bank, the portion that remains dormant until heated. Thus, the response of chamise must be interpreted with respect to both portions of the seed bank. Any heat destroys the transient portion that germinates each year. This part of the seed bank would perish in any burn. Heat is required to stimulate the persistent portion of the seed bank. This is the portion that will survive a fire and generate any new individuals. This portion is, however, unlike the seeds of species with thick seed coats, very sensitive to soil moisture.

Another conclusion that can be drawn from this study is the fact that seed bank responses can be very complicated and respond to a large number of factors. Examining the rate of germination of chamise, for example, illustrates this. Two peaks of germination rates were observed. These occurred three months apart, at approximately a time with the same photoperiod on either side of midwinter (by daylength). Variation in the different treatments in having these peaks is a part of the complicated germination physiology of this species, but also represents changes in proportions of transient versus persistent seeds germinating. Both portions illustrate these peaks (compare no heat treatment with 20 or 30 minute treatments). Taken with the results of other studies, published or unpublished, suggests that seeds of chamise are sensitive to temperature, soil moisture, heat duration, chemicals leached from charred wood, and photoperiod. Other factors, such as cold temperature periods for stratification may also have an affect. Germination of chamise seeds has been "figured out" several times; each time more influences are discovered.

What are the implications for management? Seed physiology of native species has been studied in only a few cases (reviewed in Baskin and Baskin 1988). That it can be incredibly complex is generally the rule for species that produce a persistent seed bank. Chaparral contains a large number of species with persistent seed banks, most of which are completely dependent upon their seed banks to survive fire (Parker and Kelly 1988). These are the species of conservation interest. Management practices should duplicate natural disturbances or other influences as much as possible to avoid fatal errors. Chaparral, for example, should not be considered "fire-adapted", but fire regime adapted. This study has illustrated, along with other research, that any variation from the fire regime natural for chaparral can have a large and significant impact on the seed bank response and regenerative ability of the vegetation.

Prescribed burns will be necessary for chaparral management in the long run, if wildfires are suppressed. The prescription will have to include soil moisture conditions in relation to survival and stimulation of seeds in the seed bank in addition to conditions allowing control of the fire. Thus managers must work toward burning during dry conditions of the fall if possible, if not, then a long period following rains in the fall must be provided to allow drying of the upper soil column. Chaparral stands managed in urban areas should consider having buffer zones between protected areas and any urban development.

Continued practice of prescribed burns when soils are moist can be predicted to have several affects, generally a gradual loss of species dependent upon seed banks and their replacement primarily by woody or herbaceous species that do not depend upon seed banks, which may result in type conversion. Even though species with seeds having thick seed coats do not suffer mortality during burns under moist conditions, fire intensity may be too low in some cases to stimulate their germination.

Finally, some general conclusions can also be suggested. One is that community ecology, with respect to managing vegetation, is still in its beginning stages. The continued usage of phrases like "fire-adapted" confuses the actual circumstances. But the development of the fire regime concept, important for management of fire-prone vegetation, occured due to management errors. Many other ecological concepts are currently under scrutiny for masking greater complexity. A general conclusion might then be that any management intervention should be applied with caution, should be considered experimental, and should be monitored and have control areas. This is not to suggest that areas should not be actively managed, but that management should proceed carefully and look for hidden complexity.

Another general conclusion is really derived from the reasons motivating this type of study. Generally, seed banks are a relatively unstudied component of vegetation, and thus are little considered when management plans are developed. This stage of the plant life cycle can be of critical importance whenever vegetation management practices place species at risk. A picture is now emerging that seed banks are of fundamental importance in nearly every vegetation (see Leck et al. 1988).

The role of the seed bank, its size, factors which stimulate germination, conditions affecting seedling establishment and survival, and alternative persistent stages of plants must be carefully understood for successful management (Keddy et al. 1988, Parker et al. 1988b).

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Table 1. Germination percentages of wet and dry seeds of four herbaceous species after different temperature treatments. The 25 degree treatment is an unheated control, therefore, only one value is given.

TEMP. (C)	25	50	65	80	95	110
CHAENACTIS						
WET	84.5	69.5	89.0	76.5	99.0	45.5
DRY		72.5	0	2.5	0	0
EMMENANTHE						
DRY	63.5	50.5	59.5	53.0	53.5	95.5
WET		62.5	59.5	45.5	0	0
P. GRANDIFLORA						
DRY	2.5	2.5	2.0	1.0	1.0	0.5
WET		1.5	5.0	6.0	0.5	0
P. PARRYI						
DRY	30.5	12.0	9.5	2.0	7.5	17.5
WET		6.0	3.5	8.5	0.5	0

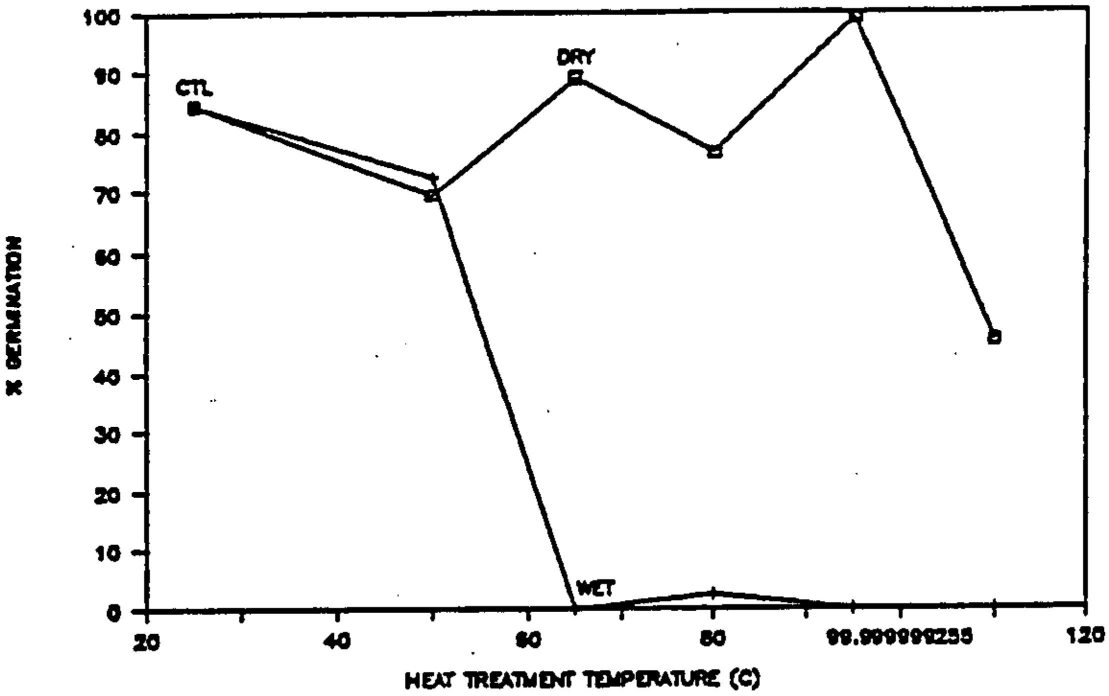

Figure 1. Germination response of *Chaenactis artemisifolia* seeds to varying temperatures. Seeds were presoaked in water or left dry prior to heating.

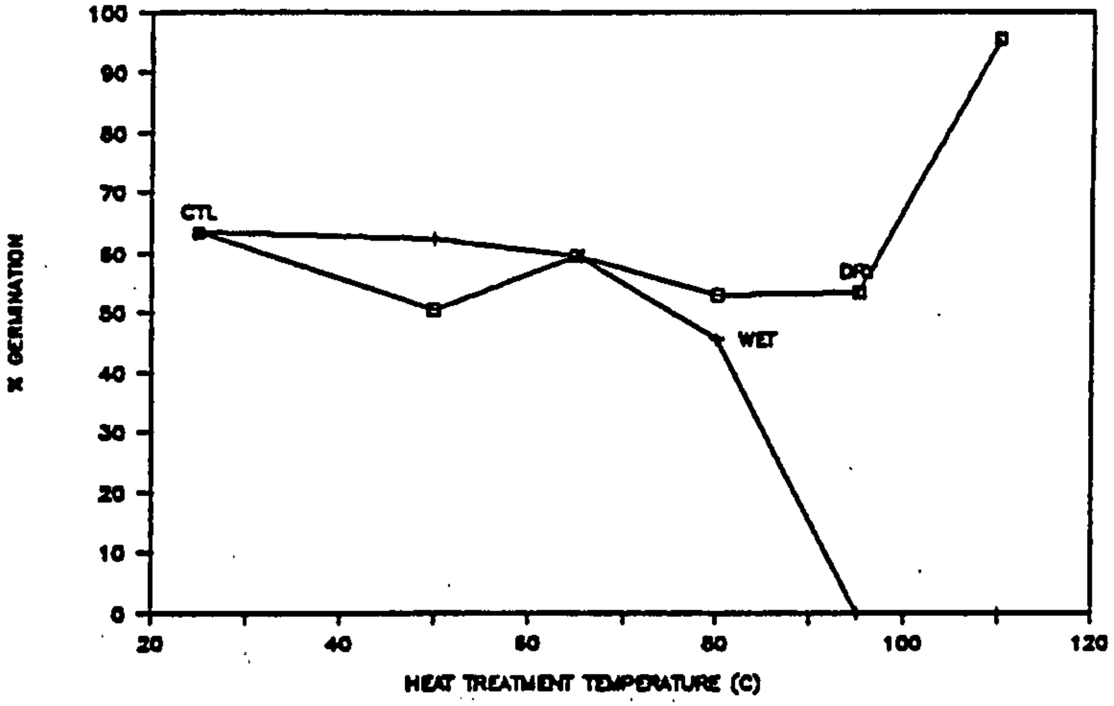

Figure 2. Germination response of <u>Emmenanthe penduliflora</u> seeds to varying temperatures. Seeds were presoaked in water or left dry prior to heating.

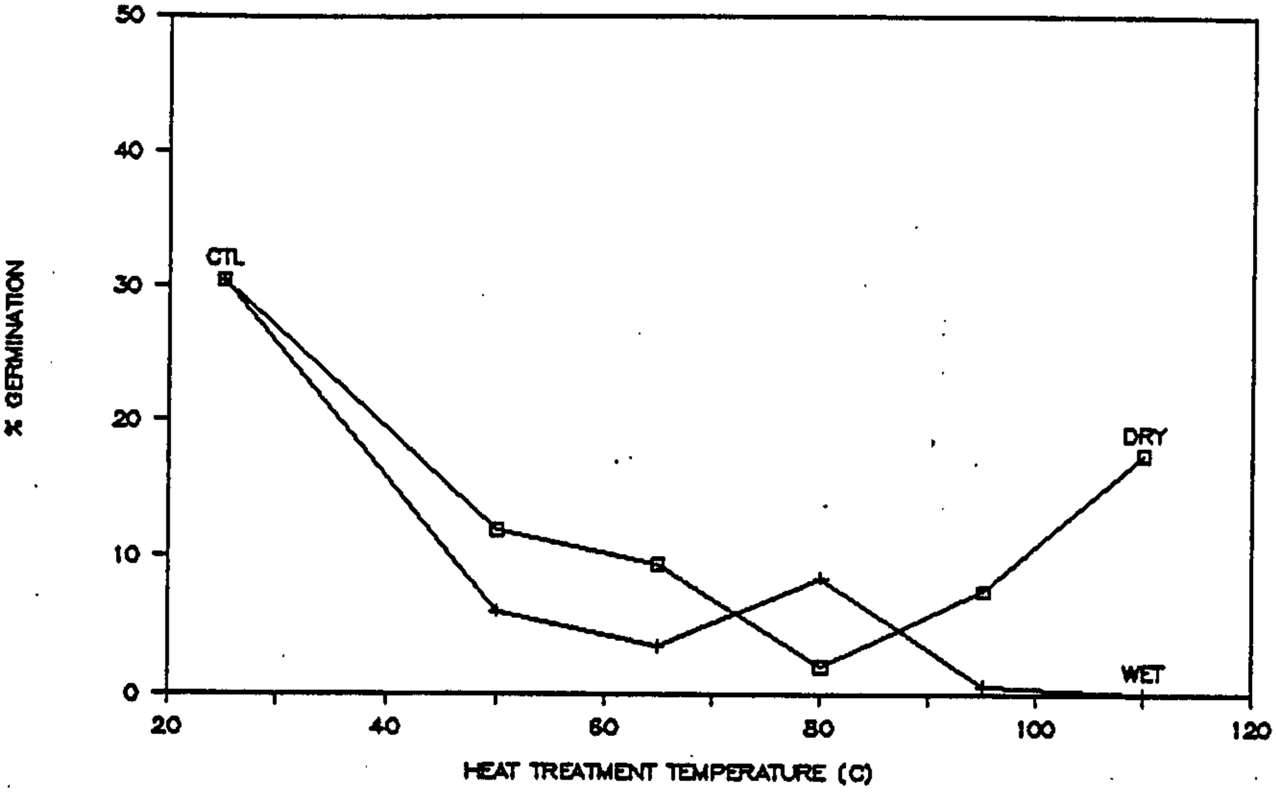

Figure 3. Germination response of Phacelia gradiflora seeds to varying temperatures. Seeds were presoaked in water or left dry prior to heating.

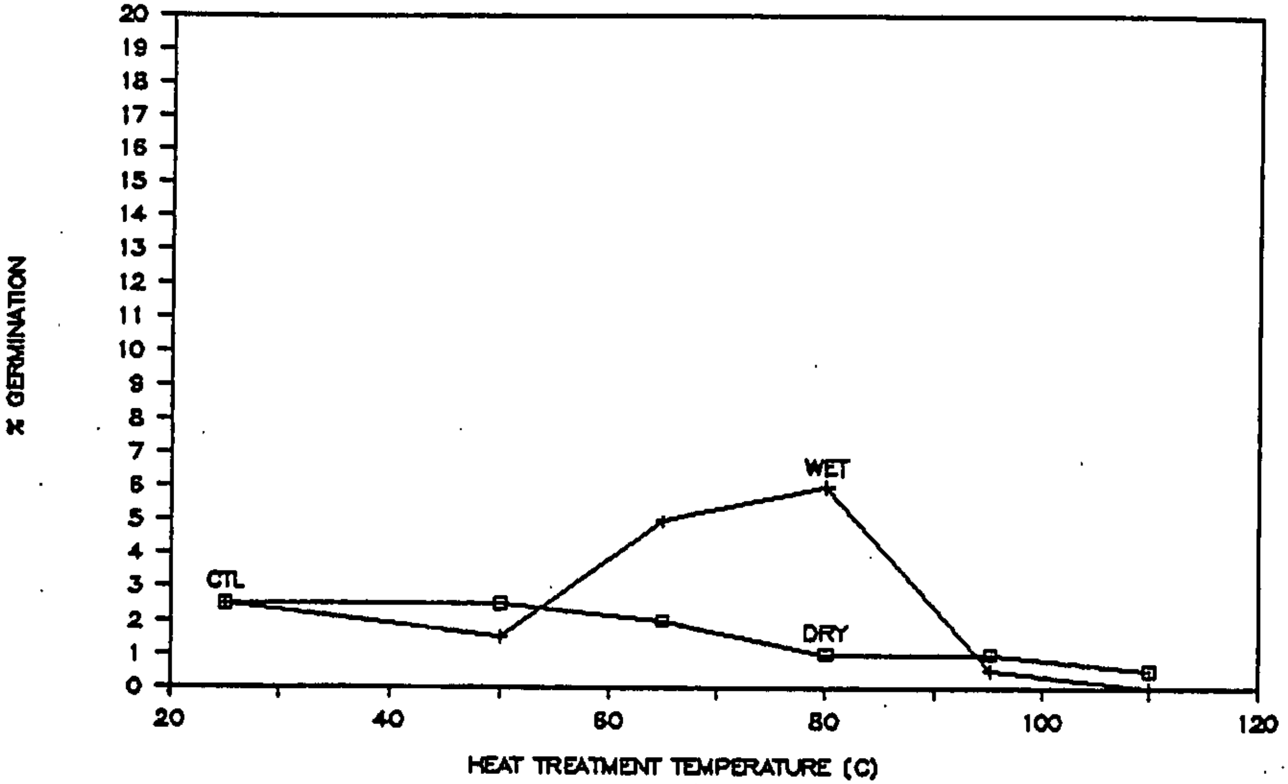

Figure 4. Germination response of _Phacelia parryi_ seeds to varying temperatures. Seeds were presoaked in water or left dry prior to heating.

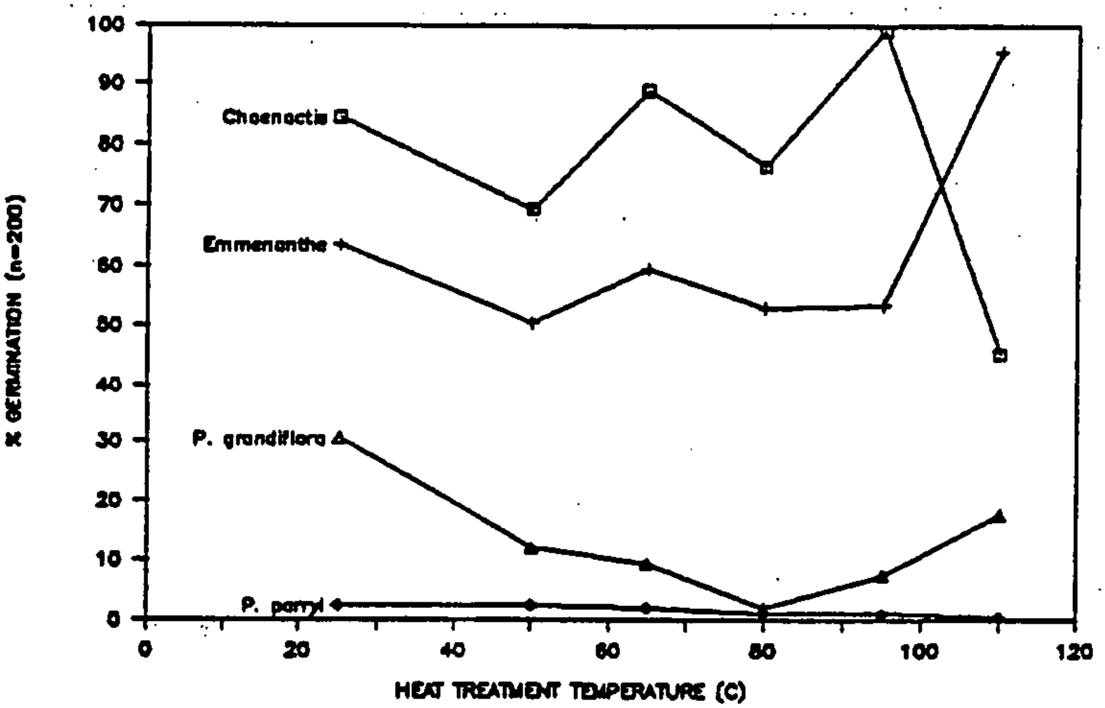

Figure 5. Germination responses of 4 herbaceous species to varying temperatures. Seeds were heated under dry conditions.

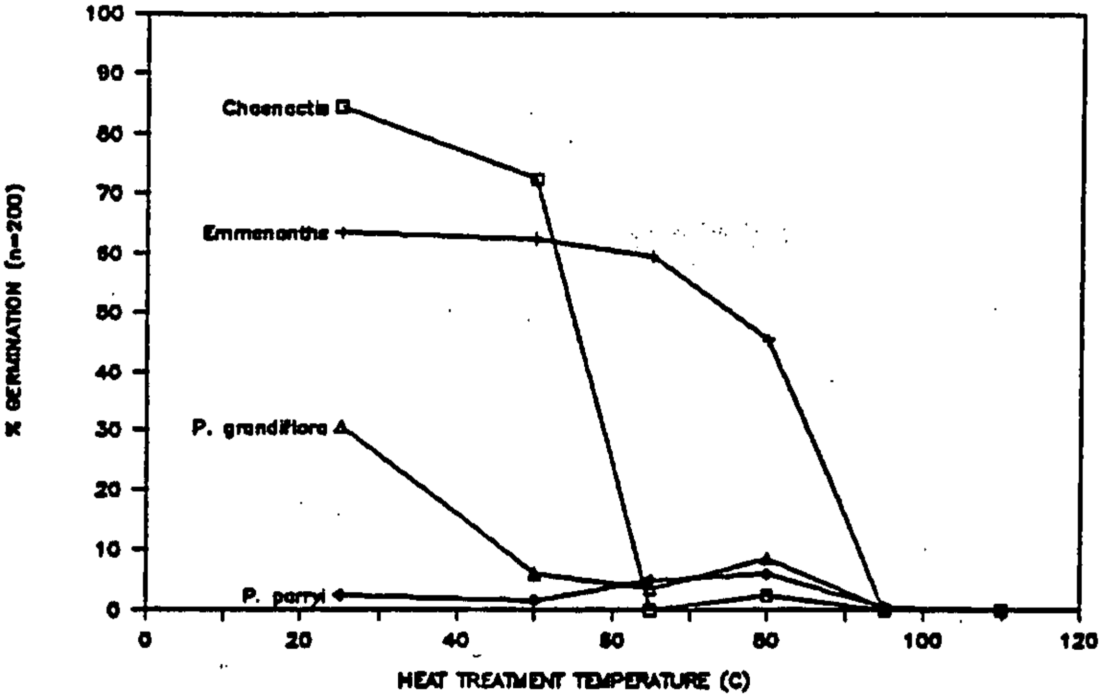

Figure 6. Germination responses of 4 herbaceous species to varying temperatures. Seeds were presoaked in water prior to heating.

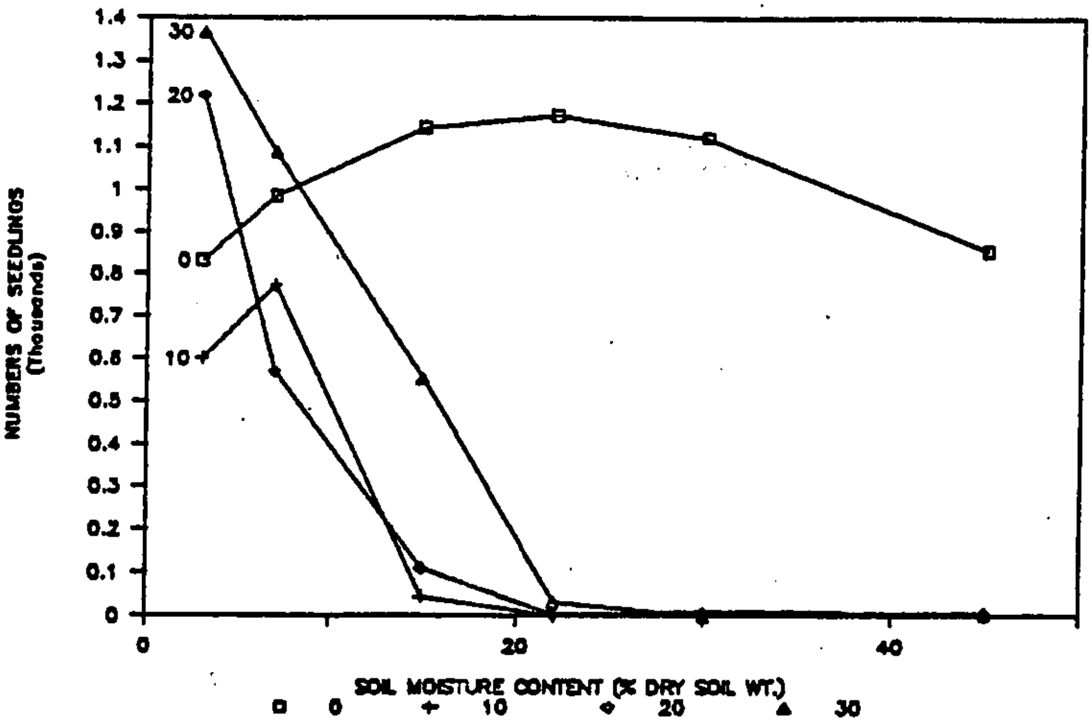

Figure 7. Germination of seeds of *Adenostoma fasciculatum* from soil seed banks. Soils containing seeds were heated for varying durations, 0, 10, 20, and 30 minutes at 100 C (labeled on lines). Soils differed in soil moisture content, 3, 8, 15, 22, 30, and 45% soil moisture (x-axis).

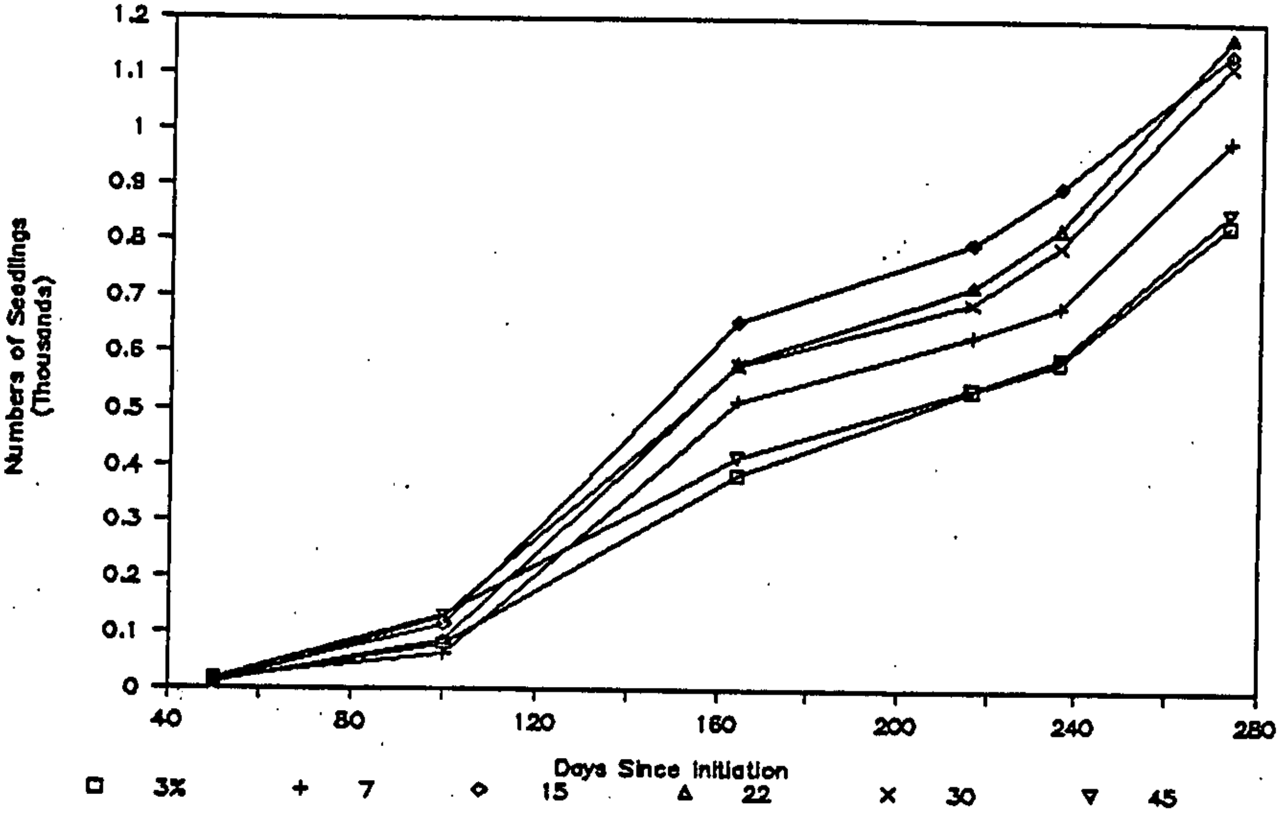

Figure 8. Cumulative germination of chamise seeds from soils receiving no heat treatment (duration of the experiment 9 months). The different lines indicate different soil moisture conditions one week prior to placing soils in trays in the greenhouse, symbols of these moisture levels are indicated below the x-axis.

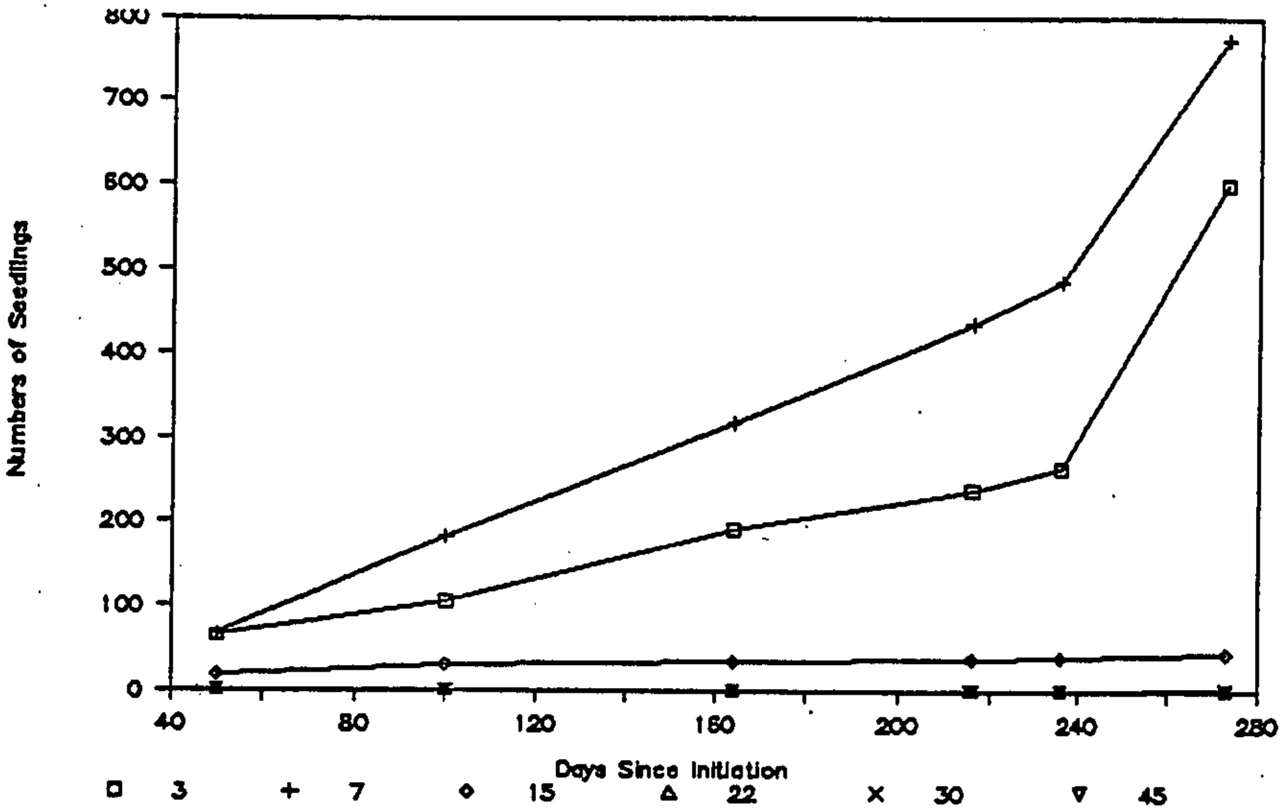

Figure 9. Cumulative germination of chamise seeds from soils receiving 10 minute heat treatment (duration of the experiment 9 months). The different lines indicate different soil moisture conditions one week prior to placing soils in trays in the greenhouse, symbols of these moisture levels are indicated below the x-axis.

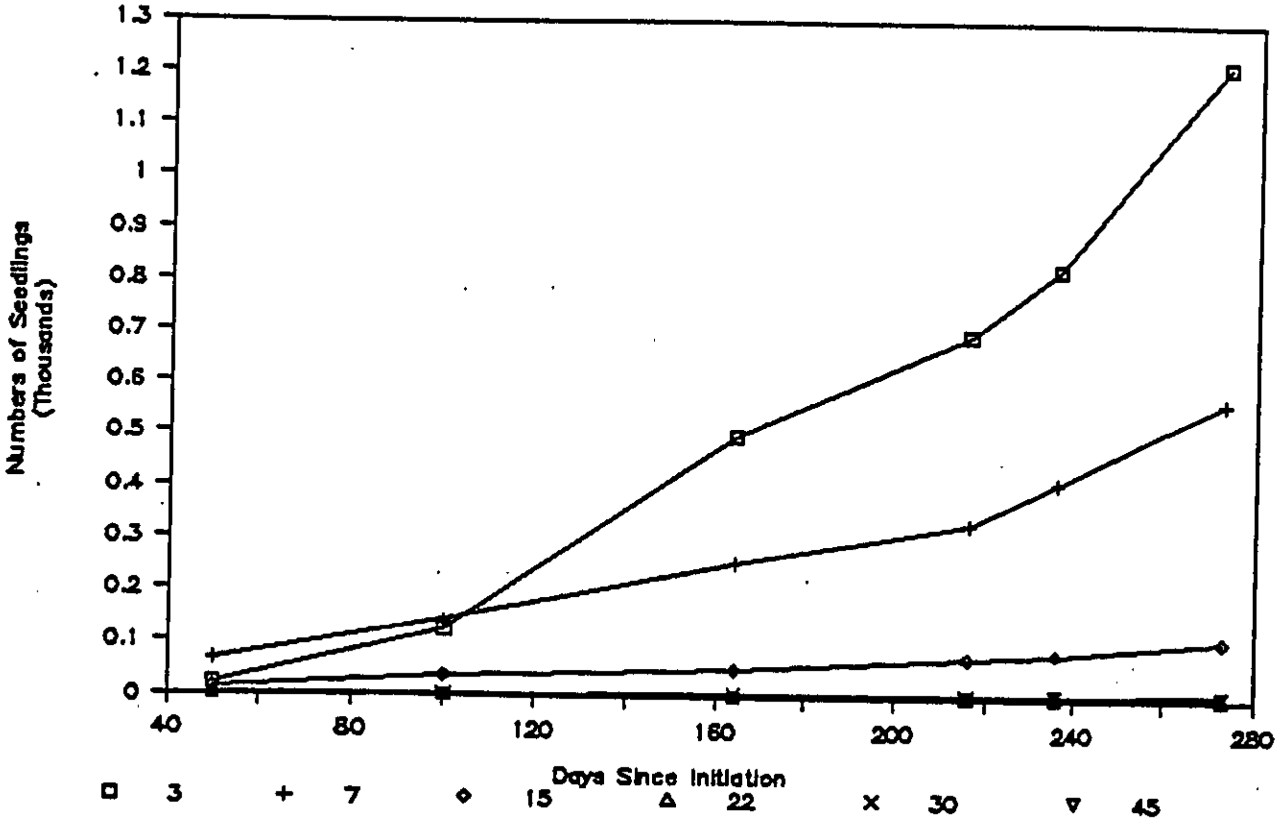

Figure 10. Cumulative germination of chamise seeds from soils receiving 20 minute heat treatment (duration of the experiment 9 months). The different lines indicate different soil moisture conditions one week prior to placing soils in trays in the greenhouse, symbols of these moisture levels are indicated below the x-axis.

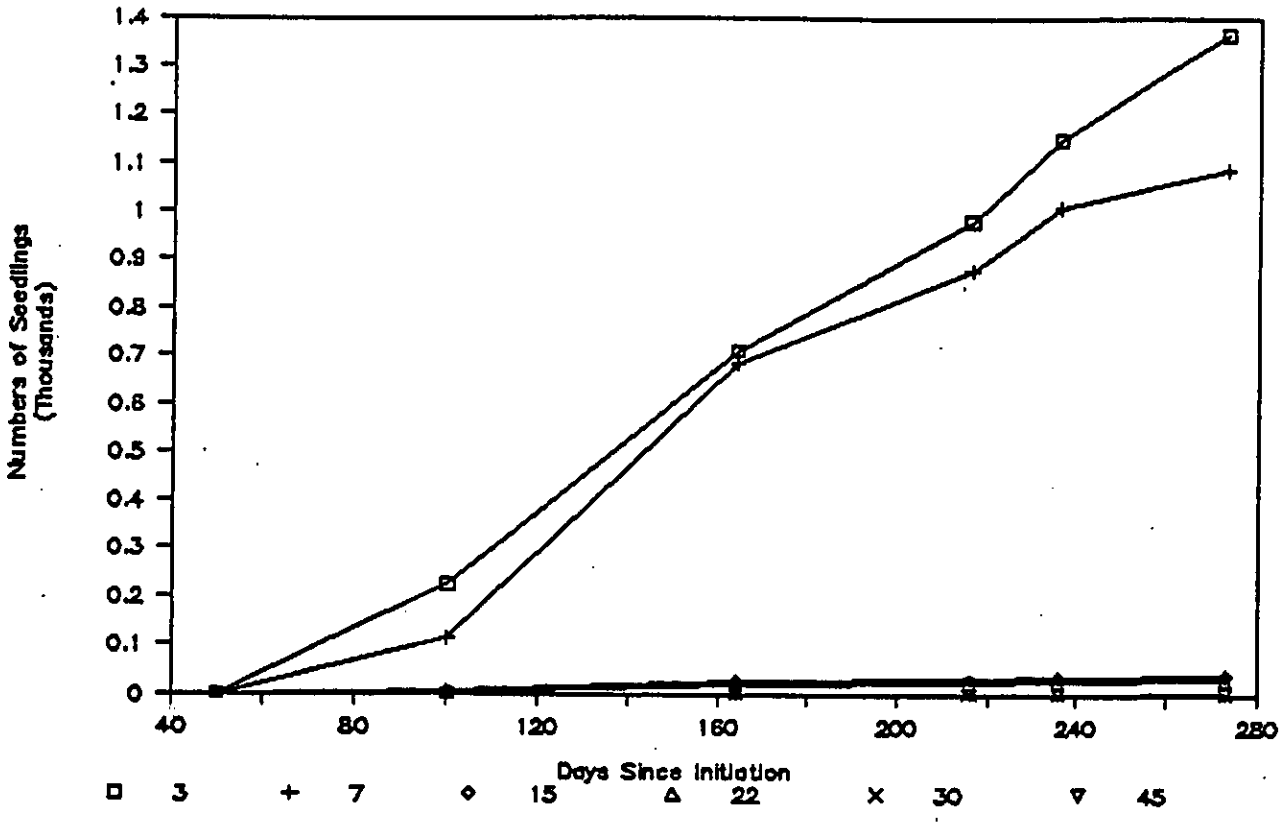

Figure 11. Cumulative germination of chamise seeds from soils receiving 30 minute heat treatment (duration of the experiment 9 months). The different lines indicate different soil moisture conditions one week prior to placing soils in trays in the greenhouse, symbols of these moisture levels are indicated below the x-axis.

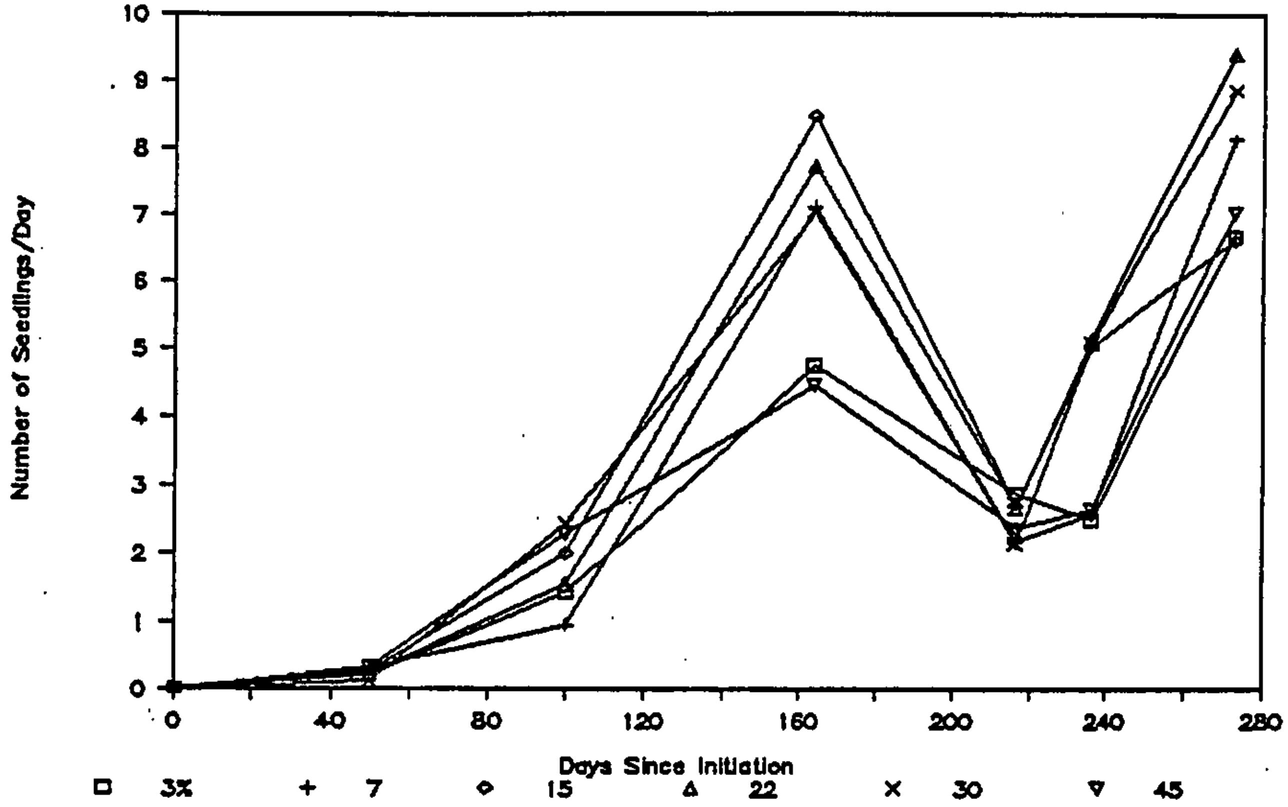

Figure 12. Germination rate (# seeds per day) from soils receiving no heat treatment. The different lines indicate different soil moisture conditions one week prior to placing soils in trays in the greenhouse, symbols of these moisture levels are indicated below the x-axis.

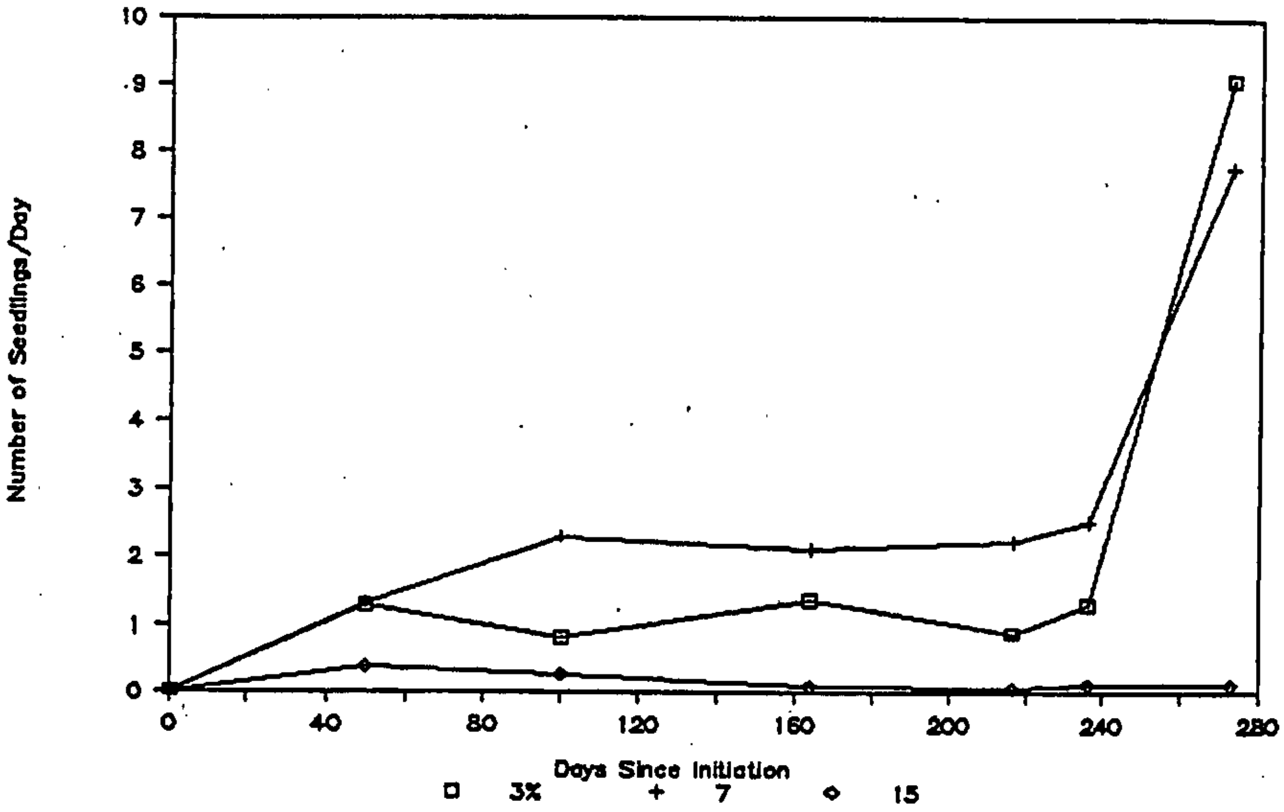

Figure 13. Germination rate (# seeds per day) from soils receiving 10 minute heat treatment. The different lines indicate different soil moisture conditions one week prior to placing soils in trays in the greenhouse, symbols of these moisture levels are indicated below the x-axis.

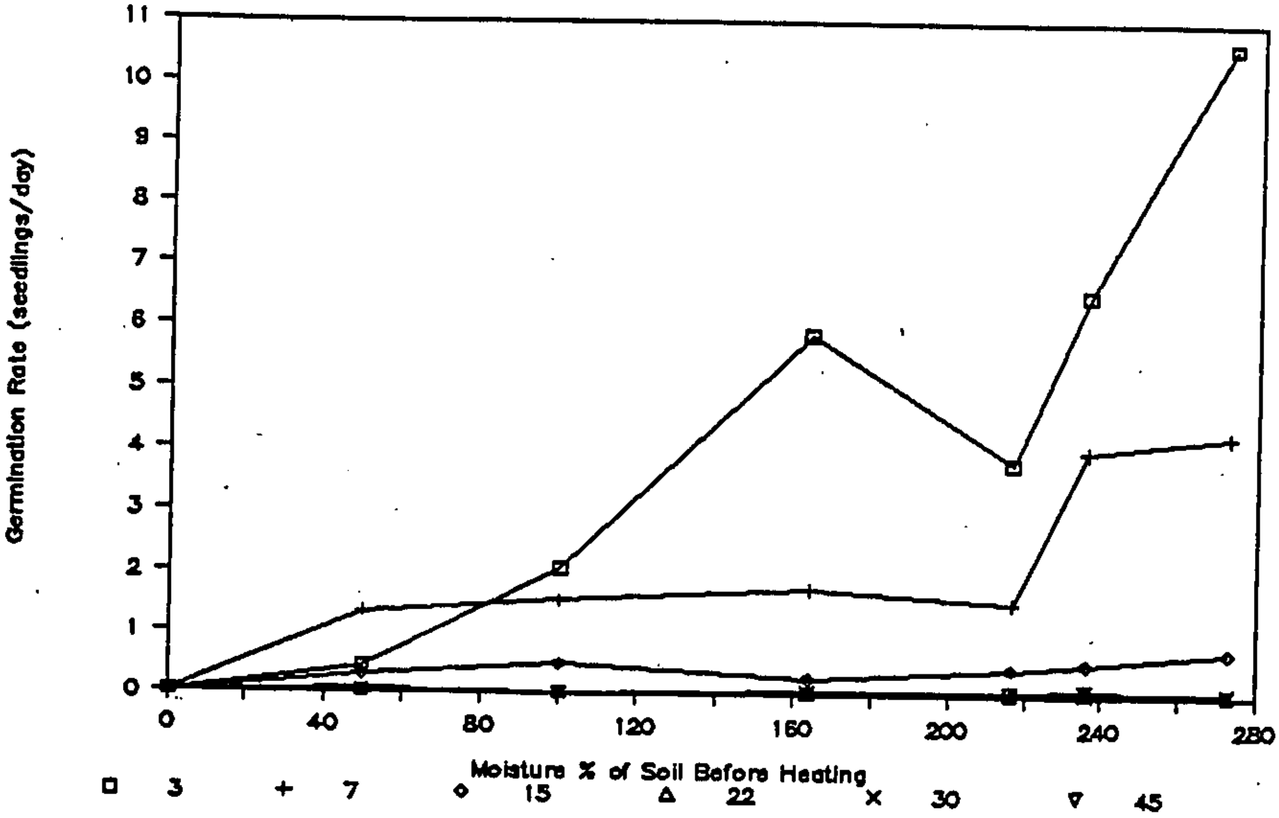

Figure 14. Germination rate (# seeds per day) from soils receiving 20 minute heat treatment. The different lines indicate different soil moisture conditions one week prior to placing soils in trays in the greenhouse, symbols of these moisture levels are indicated below the x-axis.

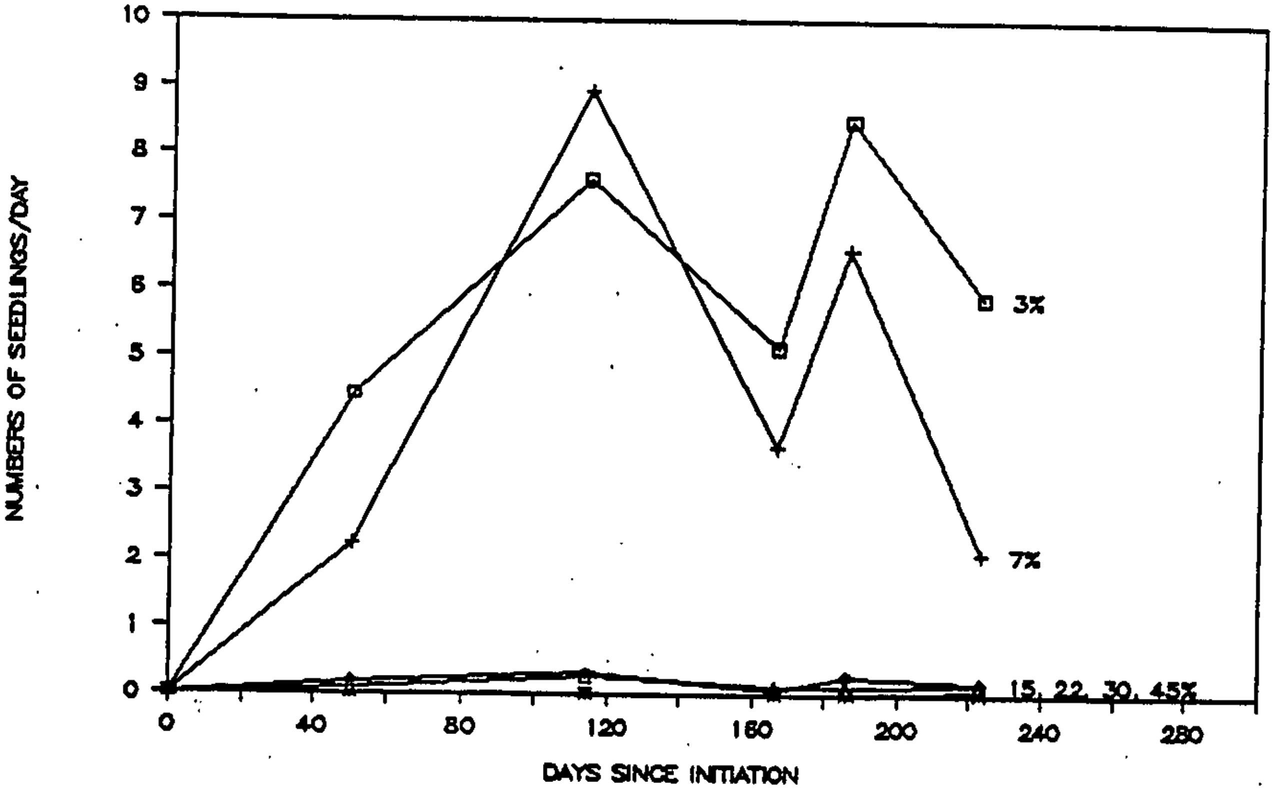

Figure 15. Germination rate (# seeds per day) from soils receiving 30 minute heat treatment. The different lines indicate different soil moisture conditions one week prior to placing soils in trays in the greenhouse, symbols of these moisture levels are indicated below the x-axis.