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ASSESSING THE POTENTIAL FOR VEGETATIVE COVER IN HARSH, TROPICAL ENVIRONMENTS: A CASE STUDY FROM THE DOMINICAN REPUBLIC

By

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ABSTRACT

ASSESSING THE POTENTIAL FOR VEGETATIVE COVER IN HARSH, TROPICAL ENVIRONMENTS: A CASE STUDY FROM THE DOMINICAN REPUBLIC

By

Charlotte Gaye Burpee

Vegetative cover is a key to protecting soil from degradation, but is not used extensively in tropical agricultural systems, due in part to socio-economic and technical constraints. This research addressed physiological (weather and soil), ecological and socio-economic constraints to the use of vegetative cover for food production and erosion control in a rural village in the tropics. Specifically, there were four phases: 1) characterizing boundary conditions of temperature and water for germination of eight tropical species and two temperate benchmark species in growth chambers, 2) evaluating reliability of laboratory germination tests as a rapid screening technique for soil surface germination at a semi-arid field site, 3) investigating socio-economic factors with potential to affect dry-season cover crop adoption and use and 4) reviewing patterns of land use and marine ecosystem change and their relationship to human activity systems to address possible constraints and advantages to the use of vegetative cover.

Boundary condition experiments clearly identified species with potential for harsh surface soil environments like those found in the village of Buen Hombre (vegetable amaranth, jack bean, tropical kudzu, lablab bean, sunnhemp, tepary bean, and tropical velvet bean). Two species, vegetable amaranth and tepary bean, germinated well under a wide range of temperatures and water potentials, and sunnhemp performed well at all but the driest water potentials. Jack bean, lablab bean and tropical velvet bean were only able to germinate within a narrow window

of near-saturation water potentials, but tolerated a wide range of temperatures.

Field germination was reduced 19 to 44% compared to lab germination and was severely limited by biological interference from birds and insects. Biotic factors were equally or more important to germination success and early survival than soil or weather factors.

In combination with key informant and group interviews, traditional socio-economic survey instruments yielded valuable data. Villagers barely subsist in a non-cash farming-fishing economy, which is based on intricately related, fragile marine and terrestrial ecosystems. Vegetative cover, if introduced at no cost to farmers and evaluated in collaboration with them, has great potential to diversify agricultural production activities, extend the growing season and protect marine ecosystems from potentially damaging erosion.

To my husband and children,

John A. Siebs, Jr., Cameron Burpee Siebs and Alexis Burpee Siebs;

to my mother and father,

Charlotte Bates Burpee and W. Atlee Burpee III;

and to the people of Buen Hombre.

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CHAPTER 1

INTRODUCTION

Much of the cultivated land in the world is subjected to varying degrees of physical, chemical and biological degradation in the forms of erosion, acidification, salinization, compaction, nutrient and organic matter depletion (Lal and Stewart, 1990; Postel, 1989). The control of these processes and amelioration of their effects is critical to long-term sustainability of agricultural ecosystems globally. Key among the technical solutions to problems of land degradation is the maintenance of vegetative cover on the soil, particularly during non-crop periods when rates of degradation are high. Though conceptually simple, vegetative covers are not used extensively in agricultural management systems. While the reasons for this are often related to socio-cultural factors, a major technical limitation is correlated with poor germination of vegetative cover species when seeded on the soil surface, rather than sown in traditional ways. Aerial, or broadcast, seeding of cover crops is critical, since it is often necessary to seed into an existing crop and/or the economics do not favor sowing cover crops by traditional methods. In developing regions, for example, lack of available labor and the mechanics of shifting agriculture may require cover crops to be seeded on the soil surface.

Another problem in the utilization of cover crops is that plant species currently being used for vegetative cover may be inappropriate, particularly if surface seeding is the primary method of establishment. Though cover crops have long been used in crop rotations in the tropics, until recently most research on cover crops has been conducted in temperate regions with temperate species (Kretschmer, 1989).

Research methodology developed for temperate species "generally has not been successful" with tropical species due to "lack of knowledge of the diversity, adaptability and reasons for persistence in tropical species" (Kretschmer, 1989).

An additional concern is that of the research conducted in developing countries, "far too much has been done on fertile experimental stations, or with chemical fertilizers, thereby making it virtually useless to small farmers" (Bunch, 1987). Most green revolution innovations depend on high external inputs applied in low-risk environments. The resulting technology has been inappropriate for subsistence farmers tilling small-scale, complex, diverse farms in risk-prone environments (Chambers et al., 1989).

Two major technical problems limit the use of vegetative covers in controlling land degradation and restoring productivity to degraded lands. The first is identification of plant species for use as cover crops, and the second is improved germination of seeds sown on the soil surface. The ideal plant species must be able to germinate under harsh environmental conditions, particularly since water is often limiting at the soil surface, and availability of water is one of the most important factors affecting seed germination (Berkat and Briske, 1982). Though optimum conditions for germination are known for many species (AOSA, 1988; ISTA, 1985), boundary conditions are known for only a few (J. A. Zeevart, personal communication).

The purpose of this research was fourfold. One objective was to determine boundary conditions for germination in a controlled laboratory environment. Species selected for testing were under-researched, tropical species with potential for harsh, limiting environments. Because subsistence villagers often lack food at the end of the dry season and because erosion can be severe with the first intense rains of the rainy season, when the ground is bare and unprotected, species selected for testing as part of the first objective also had to have potential for providing ground cover during the dry season and for producing human food, stock forage or income.

Since germination and early growth are critical to the establishment of vegetative cover in degraded environments, the investigation was limited to those two growth stages as a rapid screening technique. Therefore, the second objective was to develop a rapid screening method of species selection for full-scale testing in the field. This addressed the question as to whether surface germination experiments in the lab could be used to establish minimum threshold levels for species establishment and subsequently be used as a general predictor of surface germination and early growth in the field.

Because of the multidisciplinary nature of problems of soil degradation, the third objective was to ascertain whether local problems of marginal land use and subsistence farming in the vicinity of the field test site (village of Buen Hombre, Dominican Republic), could be alleviated by dry season cover crops and whether socio-economic factors would lead to acceptance or rejection of cover crop technology. Finally, the fourth objective was to characterize ecological and human environments at the tropical field site to determine whether use of vegetative cover was appropriate at a macro-level.

This dissertation addresses each of the four objectives in a chapter, with boundary conditions for germination of selected species, based on controlled laboratory experiments, summarized in Chapter 1, field germination response and a comparison of field and laboratory data in Chapter 2, the socio-economic context into which vegetative cover crops would be introduced, described in Chapter 3 and key ecosystems and their related human activity systems characterized in Chapter 4. An overall summary and conclusions ties the four objectives and their corresponding research projects together in a brief final discussion.

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CHAPTER 1

BOUNDARY CONDITIONS OF GERMINATION FOR EIGHT SPECIES OF VEGETATIVE COVER WITH POTENTIAL FOR THE TROPICS

INTRODUCTION

Traditional, applied agronomic research generally includes four phases: defining an agricultural problem, developing hypotheses related to potential solutions, testing those hypotheses in laboratories, greenhouses or field plots and then evaluating their effectiveness at increasing yield, reducing erosion, reducing economic, labor or energy costs, etc. In this chapter, several constraints to the use of vegetative cover crops in the tropics are investigated using the traditional approach. There are a number of under-researched cover crop species with great potential for use by subsistence farmers in the tropics for erosion control and dry season food production. However, use of vegetative cover is restricted, partly due to a lack of data on suitability of specific crops for specific environments.

The objective of this study was to develop a screening procedure for species selection for harsh environments. Species chosen for use as aerial-seeded cover crops had to be able to withstand harsh conditions at the soil surface. Thus, the screening procedure involved determining boundary conditions for germination of a minimum parameter set (temperature and water), under light conditions approximating those at a tropical field site. Laboratory data were later compared to field data (Chapter 2), and the laboratory procedure was evaluated for effectiveness as a rapid screening technique. A brief review of seed germination is presented below as background context for a discussion of experimental data that follows. Germination response to temperature and water potential under controlled laboratory conditions will then be discussed.

OVERVIEW OF SEED GERMINATION

Seed Dormancy

Seed dormancy, the state in which mature imbibed seeds fail to germinate, is an evolutionary safeguard against unpredictable natural environments (Hillel, 1972; Mayer and Poljakoff-Mayber, 1975). As a survival mechanism, dormancy allows seeds to avoid potentially destructive environmental stresses. Under natural conditions, the breaking of dormancy generally results in a range of germination times for the population of individual seeds of a species (Hillel, 1972). This strategy of non-uniform germination prevents local extinction of a species due to severely detrimental conditions (Mayer, 1980/81). Before dormancy is broken and germination begins, the environment must provide a set of physical and chemical cues, indicating that optimal conditions for germination exist. These conditions are specific to each species. In addition, water must be imbibed and the physiological blocks of dormancy must be removed by certain metabolic events (Heydecker, 1977; Hillel, 1972).

Germination and Water Uptake

Germination is quantifiable, begins with imbibition of water by the seed and ends with protrusion of part of the embryo, usually the radicle, through the seed coat (Mayer, 1980/81). Water uptake is essential to germination and involves three distinct phases: an initial phase of rapid water uptake, which then decreases and plateaus into a transition or lag phase of negligible uptake, followed by a third phase of rapid, increased water uptake (Bradford, 1986; Hadas, 1982; Haigh and Barlow, 1987; Hegarty, 1977). This last phase, the growth phase, ends with radicle emergence, occurs only in viable, non-dormant seeds and occurs only when the seed has reached a threshold water content, as opposed to a specific seed water potential, that is specific to the species (Bradford, 1986; Hunter and Erickson, 1952; Prokof'ev et al, 1983). However, individual seeds within a seed lot vary somewhat both in the substrate water potential and in the moisture percent at which germination occurs, and low vigor seeds may require higher seed moisture contents for germination (Hegarty, 1978).

In the initial phase, viable and non-viable seeds with very low water potentials (down to about -100 MPa) imbibe water equally well (Berrie, 1984; Hegarty, 1978; Villiers, 1972). The process is purely physical and results from a large gradient for water uptake (Bradford, 1986; Mayer and Poljakoff-Mayber, 1975; Villiers, 1972). During the second, or transition, phase of steady water content, there is metabolic activity, respiration begins and new cells are formed (Hegarty, 1977). During the third phase, water uptake depends more on osmotic and pressure potential. In order for germination to occur at the end of this phase, the seed's matric potential must be greater than about -1.5 to -2.0 MPa in most species, though seed water content is the critical variable for radicle emergence (Bradford, 1986; Kaufman and Ross, 1970).

Germination and Temperature

Non-dormant seeds germinate over a wide range of temperatures. The relationship during germination between rate of germination and temperature is not the Q_{10} of a simple chemical reaction (Heydecker, 1977). The relationship is linear between a minimum "base" temperature and an optimum temperature, at which the highest percent of seeds germinate in the shortest time (Garcia-Huidobro et al, 1982; Heydecker, 1977; Hillel, 1972; Mayer and Poljakoff-Mayber, 1975). Beyond the optimum up to maximum temperatures, percent germination decreases. Below the base temperature and above a maximum temperature, germination simply does not occur.

Base temperature may vary for seed lots of the same variety, depending on conditions under which the parent plant produced seed (Hardwick (1972), Harrington (1972) and Hegarty (1972) in Heydecker, 1977). Some data suggest that the base temperature for germination is genotypic, that all seeds of a species have a common base temperature and that the difference lies in the amount of thermal time, or the accumulated temperature, required for germination (Ellis and Butcher, 1988; Garcia-Huidobro et al., 1982). Seed physiological age also affects temperature requirements for germination, with optimum temperature becoming broader and higher with age of seed (Langridge and McWilliam, 1967). Additionally, some seeds germinate at a specific temperature, while others require diurnal fluctuations in temperature (Garcia-Huidobro et al, 1982; Mayer and

Poljakoff-Mayber, 1975).

Germination and Light

The environmental conditions under which a parent plant produces seeds affects light sensitivity within a seed lot. Thus, germination response to light varies greatly both by and within species (Vidaver, 1977). As a prerequisite to germination, some species require long exposures to light. Others require darkness, intermittent light exposure or different length photoperiods. Other species germinate regardless of light conditions (Mayer and Poljakoff-Mayber, 1975; Vidaver, 1977). When red light exposure is required to break dormancy and initiate germination, the light effect depends on both light intensity and duration (Mayer and Poljakoff-Mayber, 1975).

Temperature-Water-Light Interactions and Germination

Stress to seeds due to temperature or water alone can trigger a dark or light requirement for germination, as can interactions between light and water stress, temperature and water stress or between temperature and light (Heydecker, 1977). Certain light conditions can also permit germination at unfavorably high temperatures for some species (Mayer and Poljakoff-Mayber, 1975). And interactions between water and temperature are such that a seed's threshold water potential is lowest at the seed's optimum temperature (El-Sharkawi and Springuel, 1977; Fyfield and Gregory, 1988).

Laboratory Data as a Predictor of Field Germination

When laboratory data is used as a predictor of seed germination response in the field, it can serve only as a general indicator of possible germination success or failure in specific environments. The laboratory conditions under which seeds are usually studied do not exist in fields, and constantly changing field conditions in the seed-soil-water-atmosphere micro-environment cannot be duplicated in laboratories (Koller, 1972). In lab experiments, constant temperatures and unnatural water cycles varying from near total water immersion to no water, accompanied by complete aeration, are standard. In nature, interactions between environmental factors control germination in a number of ways. For example, diurnally alternating temperatures, the time factor involved in amplitude of temperature cycles and the damping of amplitude with soil depth provide seeds with complex temperature information and conditions, compared to that provided by one constant lab temperature (Koller, 1972). "The temperature relations of germination observed under laboratory conditions are not simple, straightforward indicators of the degree to which germination is temperature-regulated under natural conditions. In fact, they can at times be quite misleading" (Koller, 1972). In addition, environmental stresses do not occur singly in nature, but as a complex, and seed response to environmental stress varies, even for seed lots of the same genus (Pollock and Roos, 1972).

Hadas (1982) describes the environment of a seed in terms of seed-soil water relations. As soil matric potential (ψ_m) decreases, there is a substantially greater decrease in seed germination, because a decrease in soil ψ_m in the seed's micro-environment causes a decrease in water conductance to the seed. On the other hand, seed swelling during imbibition may increase seed-soil contact to some extent, because Hadas (1977) found good correspondence between similar osmotic solution potentials in laboratory experiments and soil matric potentials in the field.

MATERIALS AND METHODS

Several sets of germination experiments were conducted in a growth chamber to characterize germination response of selected species to temperature, water potential and pre-chilling treatments.

Species Selection

Plant species (Table 1) were selected for inclusion in this study based on specific criteria and information gathered from five different sources (Martin and Ruberte, 1980; McLeod, 1982; National Academy of Science, 1979; Price, 1981-1989; Ritchie, 1979). Each tropical species was selected because it was under-utilized and under-researched, had low management requirements, made efficient use of water, was adapted to either marginal lands or dry lands and had high nutritional value if it was a food/ forage-producing species. In addition, a number of species were selected for their nitrogen-fixing ability and production of multiple, edible plant parts. One species (sunnhemp) was inedible, but had many of the above traits and was selected for its income-producing potential. Two temperate species, Grand Rapids lettuce and wheat, were also selected for testing because they were well-researched cultivars in germination work (Berrie, 1985; Mayer and Poljakoff-Mayber, 1975). They were used as benchmark species to test the validity of the experimental methods used. Seeds of seven indigenous species were collected at the field site for testing and comparison to introduced species.

Seeds were ordered from the U.S. Department of Agriculture, Ferry-Morse Seed Company, Native Seeds/Search (Tucson, Arizona), Setropa Limited (Bussum, Holland), M/S Inland and Foreign Trading Company (Singapore) and the College of Tropical Agriculture (University of Hawaii).

Germination test procedures

All germination experiments were conducted in a Conviron[1] growth chamber with a Conviron CMP 3244 Controller (Conviron Products of America, Pembina, North Dakota 58271), programmed for a constant relative humidity of 65% and 12-hour night/day periods of 10-20°C, 20-30°C, 30-40°C, or 35-45°C, with low temperatures in darkness and high temperatures accompanied by a photoperiod of 1,270 nM sec^{-1} of light. Because relative humidity may influence relative growth rates, and because relative growth rates characterize competitiveness (K. A. Renner, personal communication), percent relative humidity, as well as photoperiod length, were maintained at levels approximating conditions at the Dominican Republic field site as much as possible.

Seeds selected for germination experiments were not visibly damaged and were selected without regard to size or color. Seeds were germinated in either 150 mm- or 100 mm-diameter Petri dishes, or in 30.5 x 30.5 x 2.5 cm plexiglass trays, on one thickness of standard blue germination blotter paper moistened with distilled

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1 Mention of the trade name, proprietary product or vendor does not constitute a guarantee or warranty for the product by Michigan State University or the author, and does not imply its approval to the exclusion of other products or vendors that may be suitable.

water. At twice daily intervals for the first five days and daily intervals afterwards, lids and sealed plastic wrap covering germination containers were removed to aerate, count and remove germinated seeds. Moldy seeds were removed as they occurred. Seeds were considered germinated upon radicle protrusion from the seed coat.

In most cases, experiments lasted until no germination had occurred for five successive days. Germinated seeds were counted, rinsed, air-dried for one hour (amaranth, hierba mora, lettuce) or dried with a vacuum funnel, weighed, re-dried and re-weighed in a 70°C oven for 48 hours to obtain seed water content at germination as a percent of seed dry weight. Initial seed water content prior to the beginning of germination experiments was also determined for each species. Initial seed moisture percent was determined only once on seed samples of 50 (jack bean, lablab bean, tropical velvet bean), 200 (tropical kudzu, sunnhemp, tepary bean, wheat) and approximately 1,000 (amaranth, lettuce) seeds.

Temperature experiments

An experiment of germination response to four temperature regimes was conducted at the alternating temperatures listed above. Distilled water was added daily to germination containers to maintain water content at near-saturation throughout the experiment. Each temperature treatment consisted of four replications of varying numbers of seeds by species, depending on availability (Table 2).

Water potential experiments

An experiment investigating germination response to four different water potentials was conducted at 20-30°C (approximate field site night-day temperatures) with daily additions of distilled water to approximate near-saturation and at -0.5, -1.0 and -1.5 MPa of water potential with high molecular weight solutions. Four replications of each species of seeds for each treatment (Table 4) were germinated at 20-30°C in 150 mm Petri dishes on blotter paper, or in 30.5 x 30.5 x 2.5 cm plexiglass trays, on 64 mm-thick styrofoam board wrapped in 2 layers of cheesecloth with a hole and cotton wick inserted in the center of the board and cheesecloth, with two rectangular pieces of blotter paper resting on top. The styrofoam board floated on a reservoir of polyethylene glycol $[H(OCH_2CH_2)_nOH]$, or PEG, solution. Initially, blotter paper at the surface was wet thoroughly with PEG solution and then rewet in sections where the wick system failed to keep blotter paper sufficiently wet.

One of the major successes in germination research involves simulation of seed-soil water conditions. Very high molecular weight osmotic solutions have been used as a laboratory substrate to apply moisture stress to germinating seeds and simulate soil matric potentials in the field (Hadas, 1977; Hadas, 1982; Pollock and Roos, 1972). It is assumed that because osmotic potential in most agricultural soils is negligible, the osmotic stress of non-reactive, high molecular weight solutions can be used to simulate matric potential. This is, in fact, the case. Hadas (1977) germinated three large- and small-seeded species in PEG solutions of different water potentials and found good agreement between final germination percent in the field and that predicted by performance in the lab.

In the water potential experiments conducted for this study, PEG, with an average molecular weight of 8,000 (Aldrich Chemical Company, Milwaukee, Wisconsin 53201), was mixed with distilled water, according to the following formula, to produce solutions at -0.5, -1.0 and -1.5 MPa of water potential:

$$\psi = 0.130\,[PEG]^2\,T - 13.7\,[PEG]^2$$

where ψ is solution water potential in MPa, [PEG] is PEG concentration in g PEG g^{-1} or ml^{-1} of water and T is temperature in °C (Hardegree and Emmerich, 1990). Because growth temperatures alternated between equal 12-hour periods at 20 and 30°C, calculations were made for each temperature and the mean of the two calculated g PEG ml^{-1} H_2O for each temperature was taken. These calculations resulted in 0.2122 g PEG ml^{-1} water for -0.5 MPa, 0.3098 g PEG ml^{-1} water for -1.0 MPa and 0.3794 g PEG ml^{-1} water for -1.5 MPa.

When used as a germination substrate, filter or blotter paper may concentrate PEG solution and decrease water potential in the solution-paper matrix (Hardegree and Emmerich, 1990). The magnitude of this effect depends both on original PEG solution concentration and the ratio of solution volume to paper dry weight. However, if the ratio of PEG solution volume to dry substrate paper weight is greater than 12 and if measures are taken to prevent evaporation from Petri dishes, the concentration effect of the paper substrate can be minimized (Emmerich and Hardegree, 1990; Hardegree and Emmerich, 1990). Accordingly, the ratio of PEG solution volume to dry substrate paper weight in these experiments was maintained at or above 14.

In addition, to inhibit evaporation of water from the PEG solution, germination trays/dishes were tightly covered with polystyrene lids (in the case of Petri dishes) or commercial household plastic wrap (in the case of plexiglass trays). Germination trays/dishes were replenished with PEG solution as needed to dampen the blotter paper and prevent zones of solute accumulation with lower water potential near germinating seeds and to simulate daily watering of field plots. Lids and plastic sealing wrap were removed daily for aeration.

Pre-treatment experiment

In the temperature experiment discussed earlier, lettuce, amaranth and wheat seeds (Table 2) were pre-treated to break dormancy, according to AOSA procedures (Association of Official Seed Analysts, 1988). This was done for comparison to previous germination research, in which standard practice involved the pre-treatment of certain species. Wheat pre-treatment involved pre-chilling for 3 days at 4°C on dampened blotter paper. Amaranth pre-treatment also involved pre-chilling, however blotter paper was dampened with a 0.2% KNO_3 solution, rather than distilled water (Association of Official Seed Analysts, 1988).

A separate pre-treatment study was completed to compare response of amaranth and wheat with and without pre-treatments at 12-hour periods of 20-30°C and 30-40°C under 1,270 nM sec^{-1} of light during the high temperature period. Lettuce was not included in the pre-treatment studies, as it responded poorly at these temperatures. Four replications of each species were germinated in Petri dishes with one layer of blotter paper at each temperature regime.

Substrate experiment

All germination experiments described above were completed on blotter paper.

A substrate experiment was conducted to ascertain whether a soil substrate, using soil taken from the Dominican Republic field site, would affect germination response in the growth chamber. A plastic box 48 x 36 x 5 cm was filled to a depth of 3 cm with surface (0-7.6 cm) soil taken from a composite of 30 soil samples collected at the perimeter of experimental plots in the village of Buen Hombre (Chapter 3). The box was sectioned into 4 quadrants, each representing one replication. A specific number of seeds (Table 5) from each species was placed at the surface and grown at 20-30°C. Data from this experiment were compared to germination data for seeds germinated on blotter paper in Petri dishes at near-saturation under identical growth chamber conditions.

Dormancy-breaking experiment

Seeds from six of seven species collected at the field site did not germinate under laboratory conditions. Therefore, in a final experiment to investigate dormancy of indigenous species, a series of pre-treatment tests were conducted on one of the six species, cardo santo (*Argemone mexicana*), in order to break dormancy. Pre-treatments included treatment with 0.2% KNO_3, mechanical scarification, acid treatment (a two minute soaking in concentrated sulfuric acid, rinsed in tap water and pre-chilled at 4°C for 12 hours), pre-heating at 104°C for 45 minutes and pre-treatment with gibberellic acid (concentration of 1,000 mg l^{-1}). None of these pre-treatments succeeded in breaking dormancy, so only experiments with the indigenous species hierba mora were successful in terms of the occurrence of germination.

Use of thermal time

Germination data in this chapter are reported in thermal time, or accumulated temperature. Between the base and optimum temperatures for a species, the relationship between germination rate, or the time to 50% of final germination, (t^{-1}) and temperature is linear (Angus et al., 1980/81a; Garcia-Huidobro et al., 1982; Kanemasu et al., 1975; del Pozo et al., 1987). In most cases, time to 50% germination is directly proportional to temperature. Since the seed's time scale is strongly related to its thermal environment, thermal time can be defined as a seed's view of time (Ritchie and NeSmith, 1991). Thermal time is useful for comparing germination within and between species in different regions and climates. The mathematical formula for thermal time, "growing degree days," or °Cd (Ritchie and NeSmith, 1991), is based on the sum of the mean daily temperature minus the base temperature of a particular species for the total number of days to germination:

$$°Cd = \sum (T_{mean} - T_{base})$$

Base temperature was calculated for each species in the study, using a mathematical relationship described by Monteith (1977), in which rate of germination (or inverse of time in days to germination of a percentage of the germinating population) was plotted against mean temperature at which germination occurred (Covell et al., 1986; del Pozo et al., 1987; Lawlor et al., 1990; Ong and Monteith, 1985). Linear regressions fitted to the data points produced base temperature as the x-intercept. Normally, this calculation is based on multiple points of data obtained from germinating seeds on a thermogradient plate having small increments of temperature over a wide range of constant temperatures. However, one of the objectives of this study was to develop general indicators of germination response based on a minimum dataset of variables. Therefore, temperature data were obtained in most cases for only three or four points, and base temperature determinations were considered to be no more than rough estimates. Base temperatures were based on values reported in the literature or data determined from this study (Table 5). As an example, Figure 1 illustrates the determination of the base temperature of 14°C used for jack bean thermal time calculations in this study.

Statistical design and analyses

In the experiments above, there were four replications of each species in a factorial design with species, time, temperature or water potential and pre-treatment or substrate as factors in the analyses of variance. The data in the temperature, water potential, substrate and pre-treatment experiments showed highly significant differences between species, times and substrate or pre-treatment and between time by species.

RESULTS AND DISCUSSION

Temperature and water potential experiments: benchmark species

In this study, wheat and lettuce have been designated as model species for characterization of germination in stressful environments. The entire lettuce population, in the top graph of Figure 2a, germinates immediately at optimum temperatures for lettuce (10-20°C). These data agree with previous research (Khan et al., 1978). At higher temperatures (20-30°C), rate of germination is slowed, and final cumulative germination percent is reduced. Inability of lettuce to germinate at temperatures above 25-35°C, with threshold temperature depending on cultivar, variety and seed lot (Hegarty and Ross, 1979; Saini et al., 1986), is characteristic (Berrie, 1984; Heydecker, 1977; Khan, 1977). The percent standard deviation plotted at the bottom of Figure 2a, with one standard deviation point corresponding to each data point in the plot above shows that as lettuce seeds experience temperature stress at temperatures above 25°C, variance increases. At even higher temperatures of 30-40°C and 35-45°C, lettuce fails to germinate entirely. For this reason, lettuce serves as an inadequate benchmark species for germination research in the tropics. At temperatures of 20-30°C, with decreasing water potential, lettuce germination rates and amounts drop and variance increases dramatically (Figure 2b).

The second baseline species is wheat. Figure 3 shows that wheat performance is better at lower temperatures and higher water potentials, with decreases in rate, decreases in final amounts and increases in variance under stress due to temperature or water. These wheat data correspond well to previous research (Ashraf and Abu-Sharka, 1978; Hanson, 1973; Kaufman and Ross, 1970). Because germination occurs at all but the highest temperatures and lowest water potentials, wheat is a good benchmark species for germination research of tropical species.

Analysis of the data in these two graphs suggests that variance provides information about a seed under stress and the stability of its response that may be just as important to characterization of a seed's response as germination variables are. For that reason, graphs in this chapter were designed to display both means and standard deviations clearly.

Temperature and water potential experiments: eight tropical species

Germination rates for amaranth (Figure 4a) at all temperatures between 10 and 45°C are high, but variance is highest at low temperatures, indicating the seed is under more stress at these temperatures. Though decreases in ψ (Figure 4b) result in decreases in both cumulative germination percent and rate of germination, amaranth germinates at even the most severe water deprivation of -1.5 MPa of ψ.

An indigenous species harvested from the tropical field site, hierba mora (Figure 5), germinates most quickly at lower temperatures, has highest cumulative germination percent at moderate temperatures (approximating those of its native environment) and fails to germinate at temperature regimes above 30°C. In addition, hierba mora does not germinate unless saturated conditions are present and have persisted for more than 50°Cd of thermal time (Figure 5b). Then it germinates quickly.

These data show that hierba mora possesses a survival mechanism appropriate to its native, semi-arid environment of irregular, infrequent rainfall. If one combines the water requirement with hierba mora's temperature restriction, it is possible to predict that hierba mora will germinate in its native environment only in years when there is persistent rain during the rainy season.

Rainy season at the Buen Hombre field site begins in November or December and lasts until February or March, which is also the only time of the year that daily air temperatures do not exceed 29 or 30°C. Surface soil temperatures would be slightly higher, but would follow air temperatures. This may also indicate that only buried seeds, where soil temperatures are cooler, will germinate.

Jack bean (Figure 6a) germinates well at all temperatures, but has a much faster rate at 10-20°C, which would be important in a highly competitive environment, for example, one with many indigenous weed species. As temperature and stress to the seed increase, variance increases. And at all temperatures, there is increased variance as germination percentage first increases. This is followed by a decrease to minimal variance as final germination percentage is approached, except at 30-40°C temperatures, which have high final variance. Jack bean tolerates only mild water stress during germination (Figure 6b). Jack beans resisted mold growth under experimental conditions much longer than any other species.

Tropical kudzu (Figure 7) demonstrates a common survival mechanism, in which there is great variability in the germination times of individual seeds, so that germination of the population as a whole occurs over an extended period of time. Rate and final cumulative germination percent are highest at 30-40°C and saturated water conditions. Maximum final germination percentage occurs at near-saturation and 30-40°C, with 49.5% ± 3.0%. It should be noted that maximum germination percentage did not occur at 20-30°C until accumulated thermal time reached 612°Cd, or 68 days. This time-spread of germination is much longer than any of the other species tested. At 35-45°C temperature regime, only seeds that germinated quickly escaped mold growth and rotting.

Highest germination rates and final percentages for lablab bean occur at temperatures of 10-20°C and 30-40°C (Figure 8a) and at higher water potentials (Figure 8b). Thirty-six percent of the seeds in the 20-30°C experiment (Figure 8a) and the near-saturation experiment (Figure 8b) succumbed to a fungal pathogen, resulting in unusually low germination rates and percentages for the near-saturation

ψ seeds and those in the middle temperature range. Had those 36% of seeds germinated, germination rates would presumably have been similar to rates at 10-20°C and 30-40°C, and final germination percent would have been about 88%. Again, variance is initially high in the temperature experiments and later drops, with the exception of the 20-30°C seeds, which are under fungal pathogen stress. Variance at all ψs except -1.5 MPa, where minimal germination occurs, is high, with greatest variance at the most stressful ψ of -1.0 MPa.

Sunnhemp reaches maximum germination percentage at all but the highest temperatures, with only rate and standard deviation varying by temperature (Figure 9a). Fastest initial rate occurs at lowest and highest temperatures, with a lag in rate at about 50% germination for the lowest temperatures. Variance is initially high at 10-20°C and 30-40°C, with final standard deviation being lowest for the lower temperatures and higher for the high temperatures. Each increase in water stress results in substantial decreases in cumulative germination percent with variance highest at higher matric potentials (Figure 9b). This increase in variance under the least stressful water conditions is atypical for the species studied. In some sunnhemp seeds, cotyledons emerged before radicles. Therefore, for sunnhemp, as is true for some species, germination needs to be defined more broadly as radicle or cotyledon emergence, whichever occurs first.

Tepary bean responds well to higher temperatures, and has decreased germination at 10-20°C, with a corresponding increase in variance at the coolest temperature regime, indicating more stress and a less stable germination response (Figure 10a). This species germinates well at all but the very driest conditions, and variance shows the pattern of initial higher values that decrease upon reaching final germination percentage and small increases in standard deviation with increasing water stress (Figure 10b). At 35-45°C, approximately 90% of tepary seeds were covered with mold by the third day of the study.

Unlike tepary, velvet bean does poorly under even minimal (-0.5 MPa) water stress and germinates best at the coolest temperatures tested. There is an unexplained delay in germination rate and increase in variance at 20-30°C, compared to temperatures just above and below 20-30°C (Figure 11). Velvet bean was susceptible to fungi at 30-40°C and only those seeds quick to germinate escaped senescence due to rotting. Variance was generally high for all treatments and may be due to small sample size.

In summary, based on these experiments, amaranth and tepary are highly adaptable species in terms of germination and are able to germinate at a wide range of temperatures and water levels, from 10 to 45°C and 0.0 to -1.5 MPa. Sunnhemp germinates at all temperatures tested and at all but the driest water potentials. One would expect amaranth, sunnhemp and tepary to do well in tropical, water-limited environments during the germination phase of growth.

Jack bean, velvet bean and lablab all require wet conditions for germination, though all germinate in tropical temperatures. These three bean species are large-seeded and once they have imbibed sufficient water and have germinated, are able to put down roots rapidly and survive in very dry environments (Bunch, 1987; Fenner, 1985; National Academy of Sciences, 1979). In fact, in a pilot experiment (data not reported) at the tropical field site, a jack bean seedling that received rain at Day 1, 3 and 5 after planting, produced a bush and 5 filled seed pods 3 months later with no further precipitation.

Seed moisture percent at germination

Bradford (1986) and Hunter and Erickson (1952) report that seed moisture percent, not seed water potential, is the trigger for germination and that each species has a unique threshold level. Most germination literature reporting seed moisture percent, reports the change in seed moisture percent from its initial, pre-experiment value to its final moisture percent at germination (Bradford, 1986; Hegarty, 1978), rather than just final germination moisture percent. Tables 6 and 7 report two values -- initial moisture percent on a dry weight basis and moisture percent at germination, also calculated on a dry weight basis, for both the temperature experiments (Table 6) and the water potential experiments (Table 7).

The smallest seeds tend to have high variation in weights. The nature of germination studies often results in only a few seeds germinating on a particular day, and when the seeds are very small, it is difficult to obtain accurate weights. A possible solution to the problem would be to have large numbers of seeds per replication for the smallest-seeded species. All the small-seeded species in this study (amaranth, hierba mora, lettuce, wheat), except tropical kudzu, tend to have lower moisture percents at germination, all less than 80% on a dry weight basis. Large-seeded species and kudzu all have seed moisture percents above 88%. These figures are lower than that reported by McDonough (1975), who found that water content of tested grass seeds at germination ranged from 77 to 97% and that water content of legume seeds ranged from 162 to 168%. Also, there is a tendency for some species (lablab, sunnhemp, tepary and velvet bean) to show a trend toward increased seed moisture percent with increased environmental stress. Wheat tends toward decreased moisture percent with stress, though variance tends to be high for these data.

Pre-treatment experiment

Prior to the temperature studies, wheat, lettuce and amaranth were pre-treated (Table 2) to break dormancy and provide comparability to previous germination research. In the pre-treatment study to examine the effects of pre-treatment on germination rate and percent germination of amaranth and wheat, lettuce was excluded because of poor germination response at study temperatures. These data show that at 20-30°C, suboptimal germination temperatures for amaranth, germination of untreated amaranth decreases 14% from pre-treated, and untreated wheat has a slower germination rate, but similar final germination percentage, to that of pre-treated wheat (Figure 12). At 30-40°C, an optimum temperature for amaranth, untreated and pre-treated amaranth have similar germination rates and percentages; while untreated wheat, under supraoptimal wheat temperatures, shows reduced rates and germination percentages compared to pre-treated wheat. The point is that pre-treatment tends to increase germination rate and/or final germination percentage only when the seed is subjected to stressful germination conditions. For comparison of laboratory data to other laboratory experiments, pre-treatment should be done for comparability of results. But for comparison of lab to field data, pre-treatment should be done only if it is possible and practical to treat seeds in both laboratory and field studies. (It should be noted that while wheat, lettuce and amaranth were pre-treated in laboratory temperature studies, they were not pre-treated in the water potential experiments, because the data were to be compared to field data and pre-treatment was not possible at the field site).

Substrate experiment

Figure 13 compares growth chamber germination of lablab on blotter paper to germination on soil from the Dominican Republic field site. Lablab response is typical of that of all but one of the other species tested -- faster germination rate, but lower final germination percentage on the soil medium. What varies from species to species is the magnitude of reduction in final germination percentage and rate of germination.

Lettuce was the only exception to this trend, with a 59% increase in final germination percent on the soil medium. This may be a result of lettuce seeds falling into surface soil cracks and a reduction in seed temperature over that of seeds on the blotter paper medium. These substrate data can be used as a species-specific rate reduction factor in predicting field response from laboratory data (Table 8). Although not investigated in this study, possible reasons for the reduction of germination on soil are the activity of soil pathogens, fungi or microbes; high soil pH; variation in pore size; hydraulic conductivity or soil matric potential.

CONCLUSION

Using a traditional research approach to the use of vegetative cover in tropical environments, the studies discussed above focused on one key constraint -- the lack of basic data characterizing germination of tropical species at different temperatures and water potentials. Though laboratory data collected in these experiments are not exhaustive or extensive, they provide initial insight into species characterization of selected under-researched tropical species for two of the three key variables controlling germination response. Data demonstrate that under either temperature or water stress, germination rate slows and/or final germination percentage decreases for each of the eight species studied. These changes in germination response are usually accompanied by increases in variance, which generally occur before and during a large shift in the mean, and treatment variance comparisons indicate when conditions for the germinating seed.

To summarize, these data successfully and rapidly characterize the eight tropical species studied, over a wide range of temperatures and water potentials, defining harsh to optimum conditions for each. So the method proved effective as an initial characterization tool. The question remains, given prior knowledge of macro-level temperature and water conditions at a field site, will it serve as an effective screening procedure for field testing?

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Table 1. Selected species with potential as cover crops in harsh environments, characterized in laboratory germination studies

Common Name (Variety)	Latin Name
Vegetable amaranth (Hijau)	*Amaranthus cruentes* L.
Hierba mora*	*Solanum americanum* Miller
Jack bean	*Canavalia ensiformis* (L.) DC
Tropical kudzu	*Pueraria phaseoloides*
Lablab bean	*Lablab purpureus* (L.) Sweet; *Dolichos lablab*
Lettuce (Grand Rapids)	*Lactuca sativa*
Sunnhemp	*Crotolaria ochroleuca*
Tepary bean	*Phaseolus acutifolus* A. Gray
Tropical velvet bean	*Mucuna deeringia*
Wheat (Frankenmuth)	*Triticum aestivum*

* Indigenous species collected from Dominican Republic field site

Table 2. Experimental conditions for germination <u>temperature</u> experiments, water not limiting (ψ=near-saturation)

Species	10°-20°C		20°-30°C		30°-40°C		35°-45°C	
	S/R[1]	C[2]	S/R	C	S/R	C	S/R	C
Amaranth	50[3]	P[7]	50[3]	P	50[3]	P	50[3]	P
Hierba mora	50	T[8]	50	T	50	T	--[9]	--[9]
Jack bean	20	T	10	T	20	T	20	T
Tropical kudzu	--[4]	--[4]	100	P	50	T	50	T
Lablab bean	50	P	50	T	50	T	50	T
Lettuce	50[5]	P	50[5]	P	50[5]	P	--[9]	--[9]
Sunnhemp	50	T	50	T	50	T	50	T
Tepary bean	50	T	50	T	50	T	50	T
Velvet bean	20[6]	P	15[6]	T	20[6]	T	20[6]	T
Wheat	50[5]	P	50[5]	P	50[5]	P	50[5]	P

1 Number of seeds per replication
2 Container in which germination experiment conducted; see notes 7 and 8
3 Seeds pre-chilled 3 days at 4°C on blotter paper moistened with 0.2% KNO_3 solution to break dormancy
4 Seeds not available for this experiment
5 Seeds pre-chilled on damp blotter paper 3 days at 4°C to break dormancy
6 Seed coats knicked opposite hilum and micropyle to promote germination
7 P= sterile Petri dish
8 T= plexiglass tray
9 Not included in this experiment (failure to germinate at 30°-40°C temperatures)

Table 3. Experimental conditions for germination water potential experiments, temperature not limiting (20°-30°C)

Species	0.0 MPa		-0.5 MPa		-1.0 MPa		-1.5 MPa	
	S/R[1]	C[2]	S/R	C	S/R	C	S/R	C
Amaranth	50	P[3]	100	P	100	P	50	T
Hierba mora	50	T[4]	100	T	50	P	50	T
Jack bean	10	T	40	T	40	T	20	T
Tropical kudzu	100	P	50	T	50	T	50	T
Lablab bean	50	T	40	T	50	P	50	T
Lettuce	50	P	50	T	50	T	50	T
Sunnhemp	50	T	50	T	50	T	50	T
Tepary bean	50[5]	T	50	T	50	T	50	T
Velvet bean	15[5]	T	50	T	20	T	50	T
Wheat	50	P	50	P	100	P	50	T

1 Seeds per replication
2 Container in which germination experiment conducted; see notes 3 and 4
3 P= sterile Petri dish
4 T= plexiglass tray
5 Seed coats knicked opposite hilum and micropyle to promote germination

Table 4. Seeds per replication by species for substrate experiment

Species	Number of seeds per replication
Amaranth	50
Hierba mora	50
Jack bean	15
Tropical kudzu	50
Lablab bean	25
Lettuce	50
Sunnhemp	50
Tepary bean	50
Tropical velvet bean	10
Wheat	50

Table 5. Reported and experimentally determined base temperatures for selected species

Species	Reported base temperature (°C)	Reference	Base temperatures assigned in this study (°C)
Amaranth	8	National Research Council, 1984	10
	8	Putnam, 1990	
	11.9	Angus et al., 1980/81a	
Hierba mora	--	-----------------	10*
Jack bean	--	Kay, 1979: "does not tolerate frost"	14**
Tropical kudzu	12.5	Skerman, 1977	16
Lablab bean	3	Murtagh and Dougherty, 1968	7
	9.6	Angus et al., 1980/81a	
Lettuce	2	Thompson et al., 19769	2
	7,10	Thomas and Miller, 1979, in Lawlor et al., 1990	
Sorghum	10	Kanemasu et al., 1980/81a	10
		Angus et al., 1980/81a	
	>10	Singh and Dhaliwal, 1972	
Sunnhemp	--	--------------------	10**
Tepary bean	>8	Kay, 1979	8
	8	Scully and Waines, 1988	
Tropical velvet bean	>5	Kay, 1979	10
	>10	Skerman, 1977	
Wheat	0	Gallagher, 1979	3
	2	Del Pozo et al., 1987	
	2.6	Angus et al., 1980/81a	
	3.3-5.6	Nuttonson, 1955	
	5	Cudney et al., 1989	
	>5	Singh and Dhaliwal, 1972	

* Base temperature assigned arbitrarily, no existing data
** Base temperature assigned based on data collected in this study

Table 6. Seed moisture %: initial and final in temperature experiments (near-saturation)

Species	Initial Moisture % Mean	Moisture % at germination 10°-20°C Mean	10°-20°C Std. Dev.	20°-30°C Mean	20°-30°C Std. Dev.	30°-40°C Mean	30°-40°C Std. Dev.
	----------	----------	----------	%	----------	----------	----------
Amaranth	9.5	35.1	15.9	24.5	8.5	76.5	29.2
Hierba mora	--[1]	16.5[1]	7.9[1]	49.9[1]	27.8[1]	---[3]	---[3]
Jack bean	18.2	129.4	7.1	117.4	13.3	141.6	11.8
Tropical kudzu	11.3	---[2]	---[2]	128.9	5.7	143.2	12.2
Lablab bean	12.4	96.5	10.9	88.5	10.0	116.7	14.8
Lettuce	2.8	61.3	18.3	70.1	40.3	---[3]	---[3]
Sunnhemp	11.6	129.4	18.1	98.7	23.4	127.1	9.9
Tepary bean	11.8	100.6	5.9	95.9	5.3	111.2	7.9
Velvet bean	10.0	107.0	13.7	99.2	9.6	120.7	13.0
Wheat	10.1	58.3	4.7	77.9	12.9	55.7	19.4

1 Sample size too small for reliable results
2 No seeds available for this experiment
3 No germination at this temperature

Table 7. Seed moisture %: initial and final in water potential experiments (20°-30°C night-day temperatures)

Species	Initial Moisture % Mean	0.0 MPa Mean	0.0 MPa Std. Dev.	-0.5 MPa Mean	-0.5 MPa Std. Dev.	-1.0 MPa Mean	-1.0 MPa Std. Dev.
	Moisture % at germination						
	%						
Amaranth	9.5	30.6	14.2	34.9	14.9	18.2	9.5
Hierba mora	--[1]	49.9	27.8[1]	62.2	17.3[1]	---[2]	---[2]
Jack bean	18.2	117.4	13.3	104.0	5.0	97.7	1.8
Tropical kudzu	11.3	128.9	5.7	102.0	21.5	98.3	17.6
Lablab bean	12.4	88.5	10.0	110.2	11.4	103.6	5.7
Lettuce	2.8	70.1	40.3	47.6	28.3	---[2]	---[2]
Sunnhemp	11.6	98.7	23.4	133.3	23.8	122.6	17.0
Tepary bean	11.8	95.9	5.3	118.0	9.7	113.6	4.8
Velvet bean	10.0	99.2	9.6	105.3	7.7	---[2]	---[2]
Wheat	10.1	51.5	16.9	39.4	6.6	46.3	8.0

1 Sample size too small for reliable results
2 No germination at this water potential

Table 8. Maximum germination percent as affected by substrate medium in growth chamber experiments (20°-30°C, near-saturation water potential)

Species	Maximum germination percent		LSD
	Blotter Paper	Soil	
Vegetable amaranth	98.0	86.5	NS[1]
Hierba mora	97.0	59.5	NS
Jack bean	95.0	92.0	NS
Tropical kudzu	49.5	23.0	9.9**
Lablab bean	57.5	45.0	NS
Lettuce	33.0	92.0	23.0**
Sunnhemp	89.0	81.5	NS
Tepary bean	93.5	68.5	19.6*
Tropical velvet bean	71.5	65.0	NS
Wheat	99.0	89.5	NS

1 Not significant at LSD = 0.05
* Significant at LSD = 0.05
** Significant at LSD = 0.01

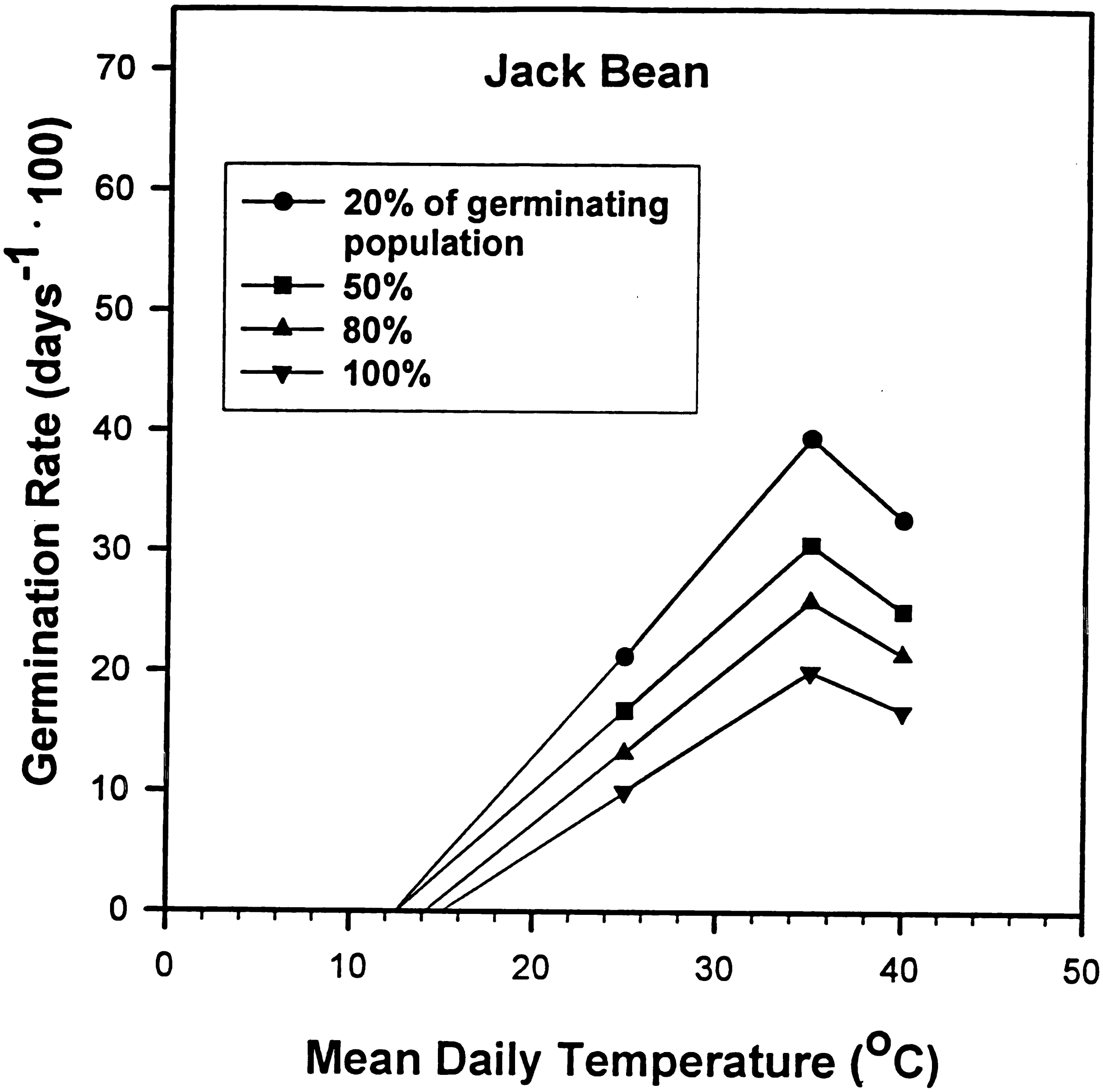

Figure 1. Germination rate by temperature for jack bean with base temperature estimated from x-intercept

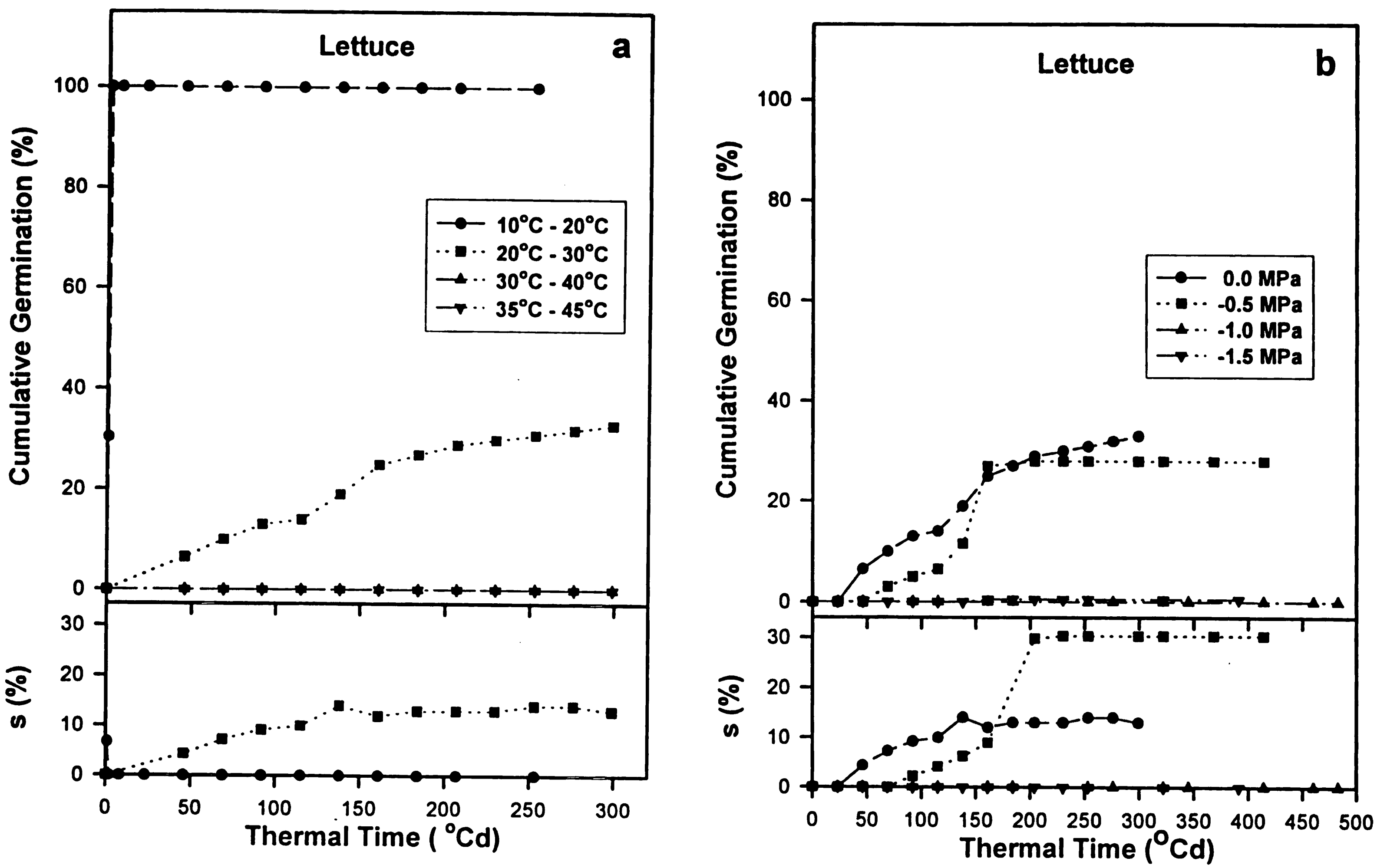

Figure 2. Mean cumulative germination percent and standard deviation (s) of <u>lettuce</u> in response to a) temperature b) water potential

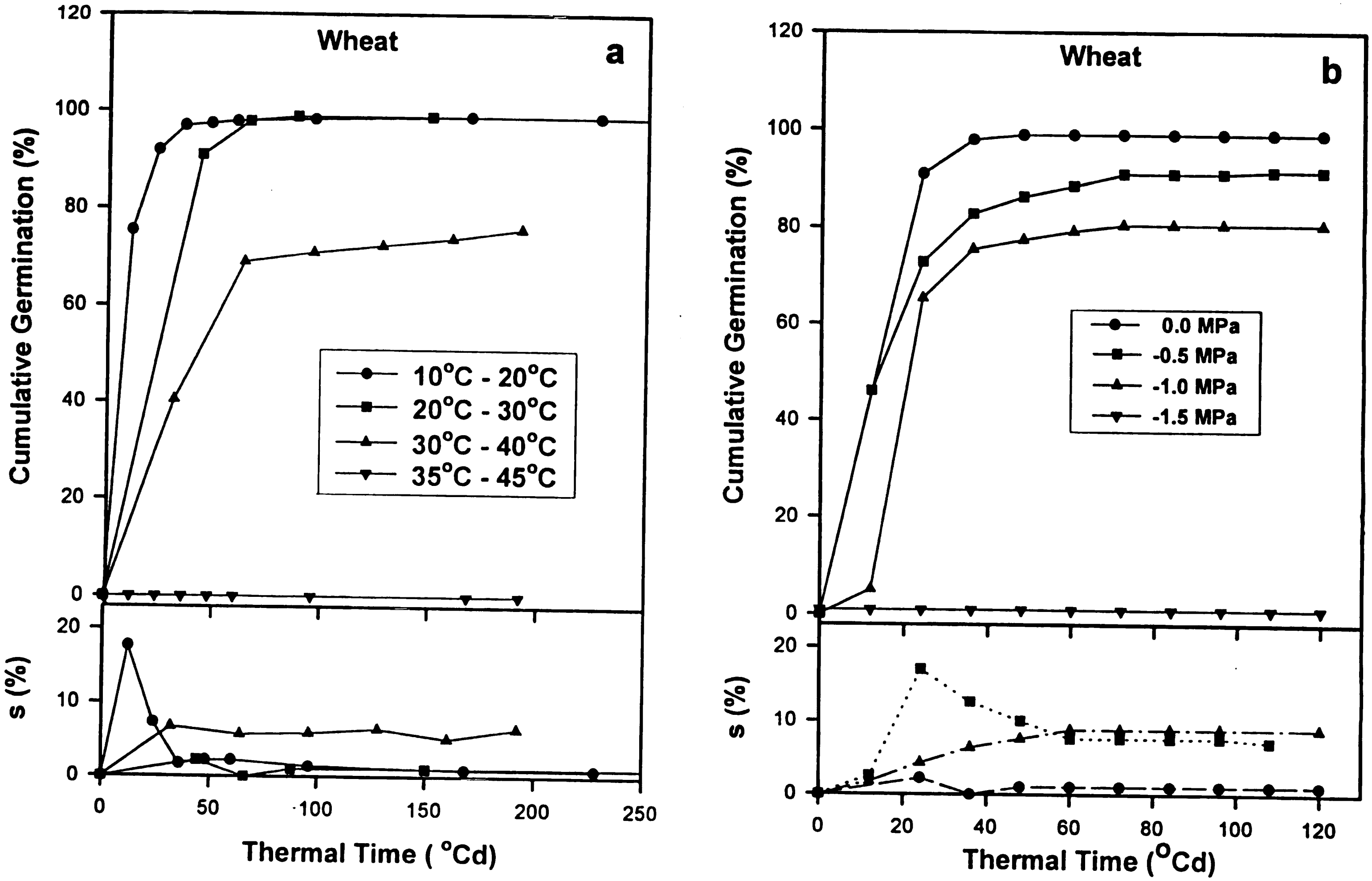

Figure 3. Mean cumulative germination percent and standard deviation (s) of <u>wheat</u> in response to a) temperature b) water potential

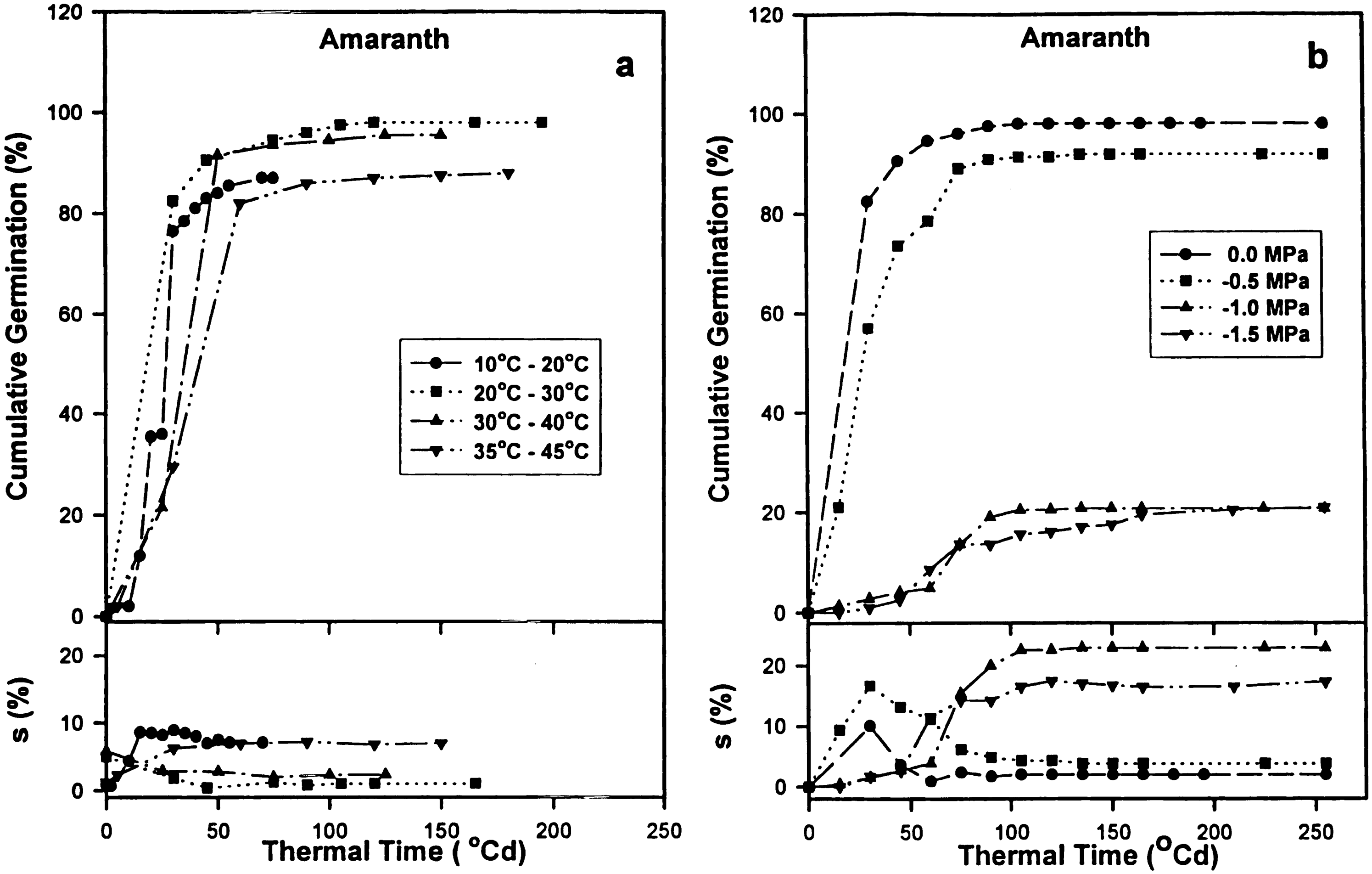

Figure 4. Mean cumulative germination percent and standard deviation (s) of vegetable amaranth in response to a) temperature b) water potential

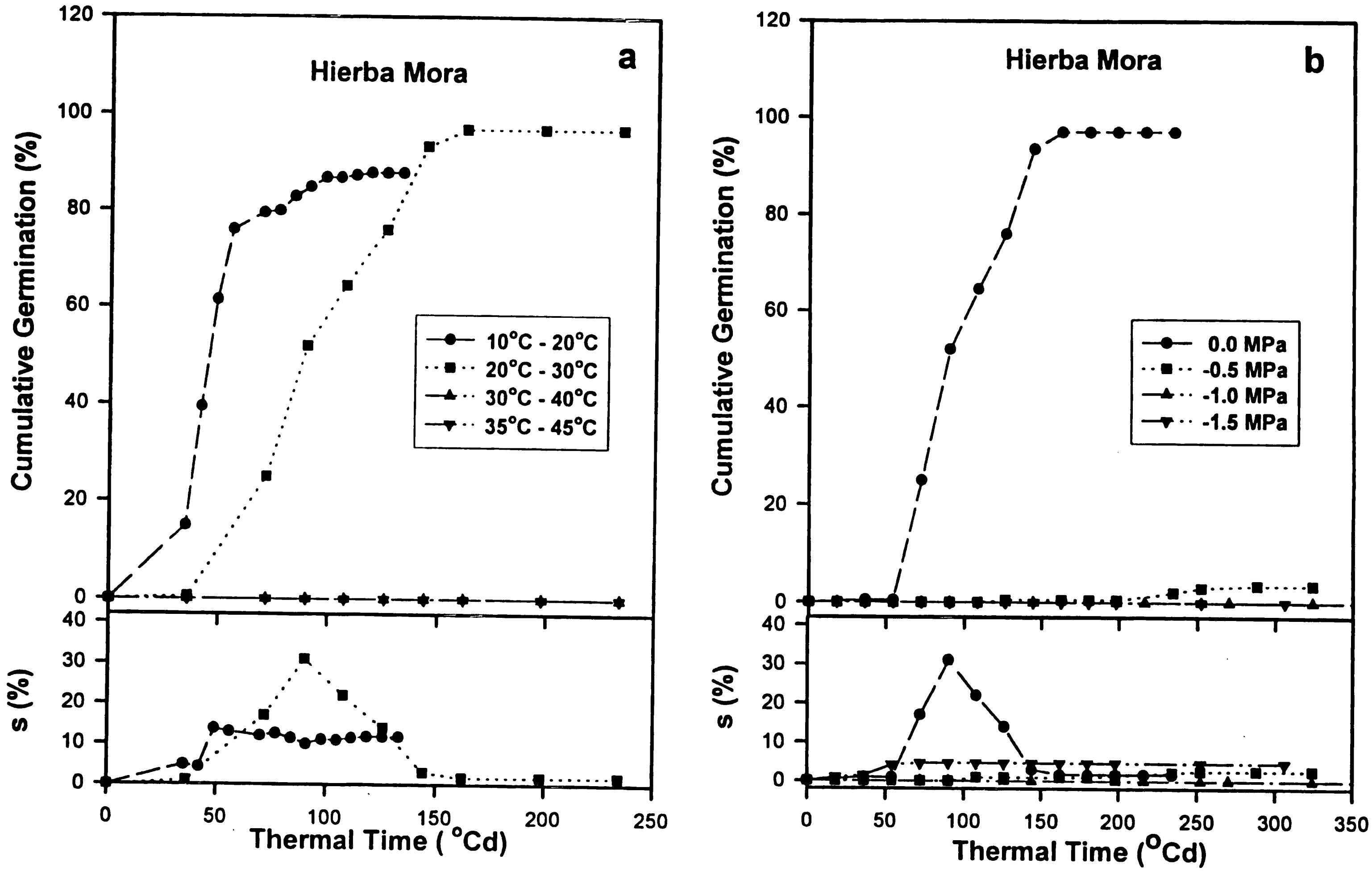

Figure 5. Mean cumulative germination percent and standard deviation (s) of <u>hierba mora</u> in response to a) temperature b) water potential

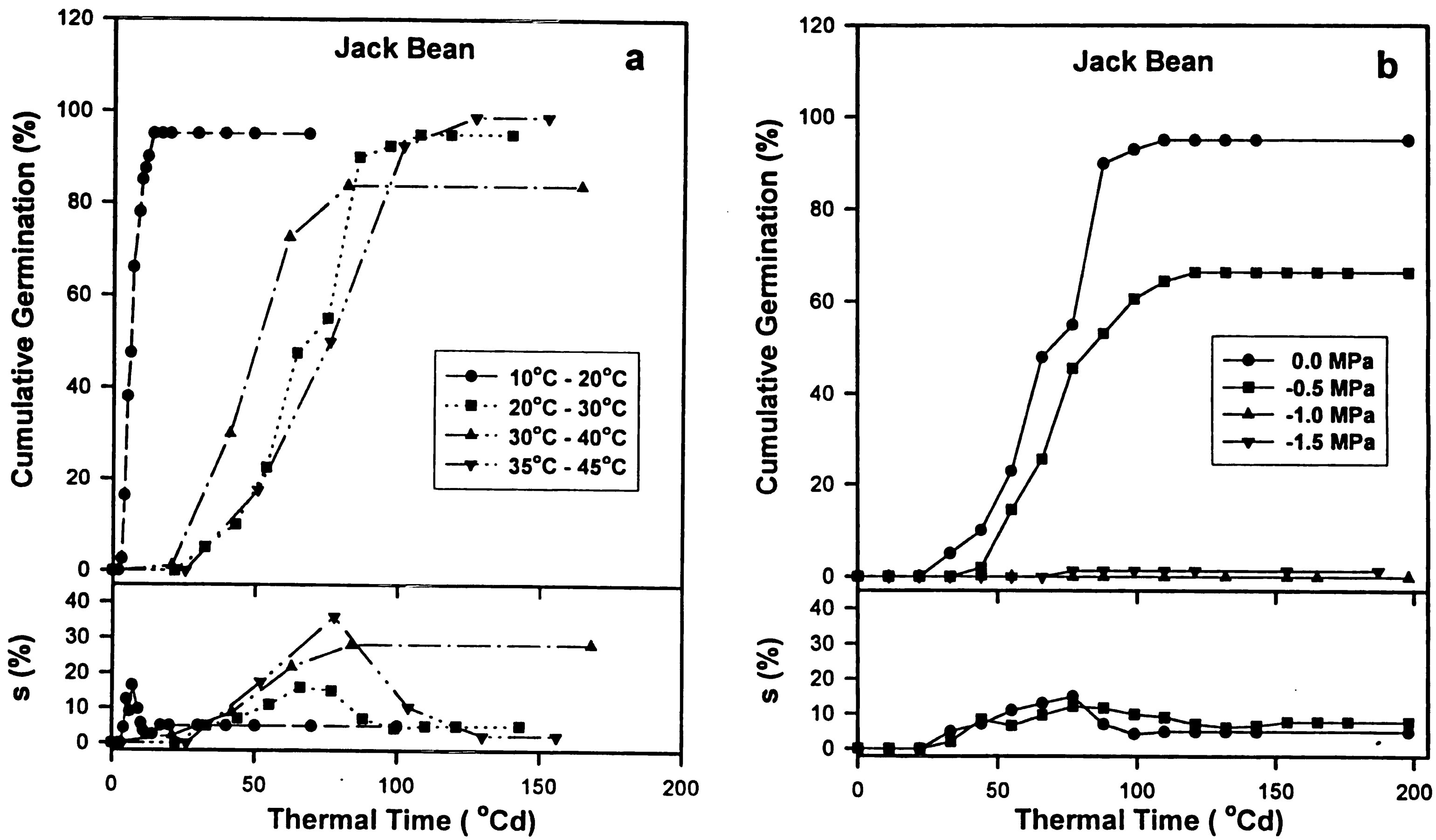

Figure 6. Mean cumulative germination percent and standard deviation (s) of jack bean in response to a) temperature b) water potential

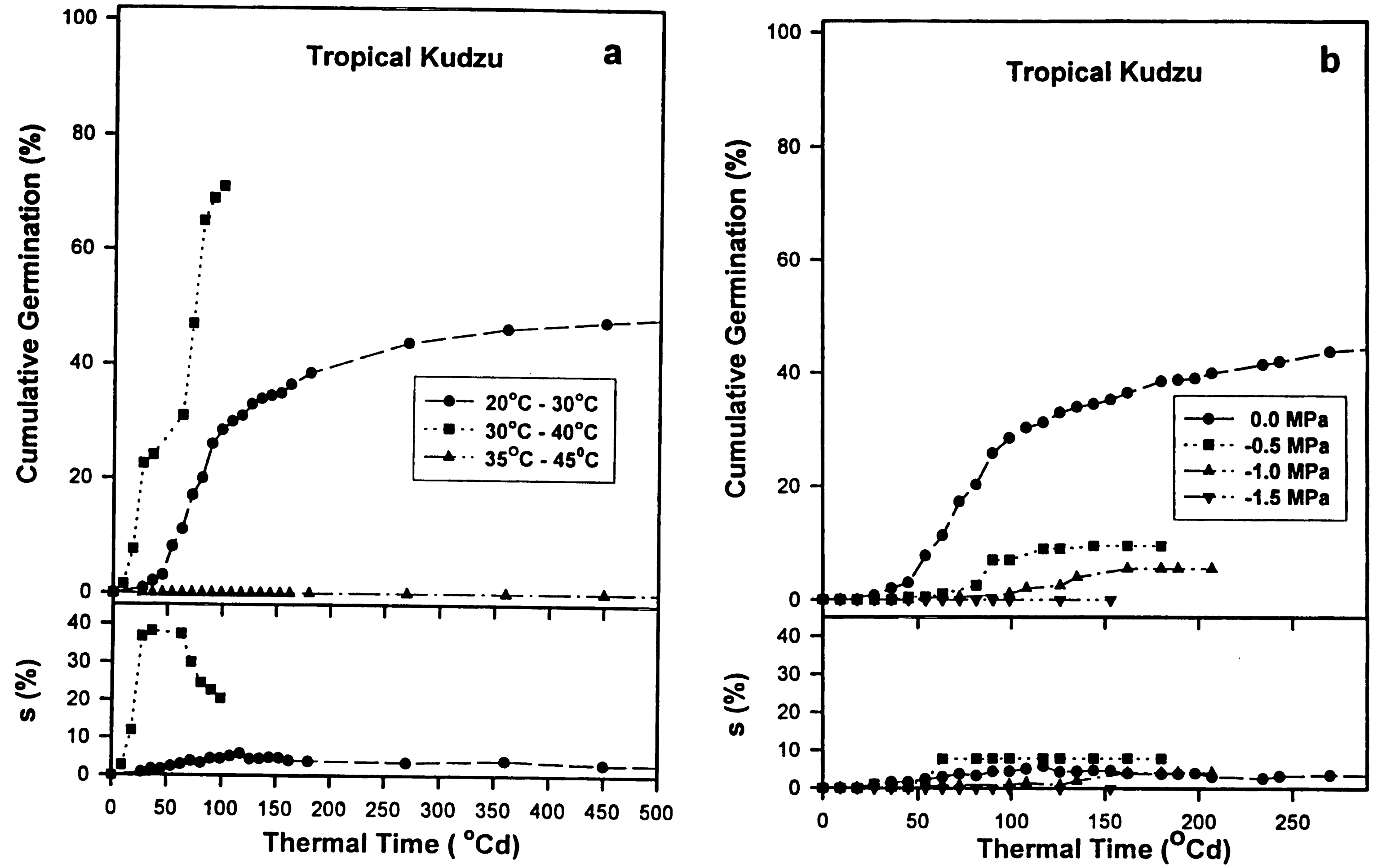

Figure 7. Mean cumulative germination percent and standard deviation (s) of <u>tropical kudzu</u> in response to a) temperature b) water potential

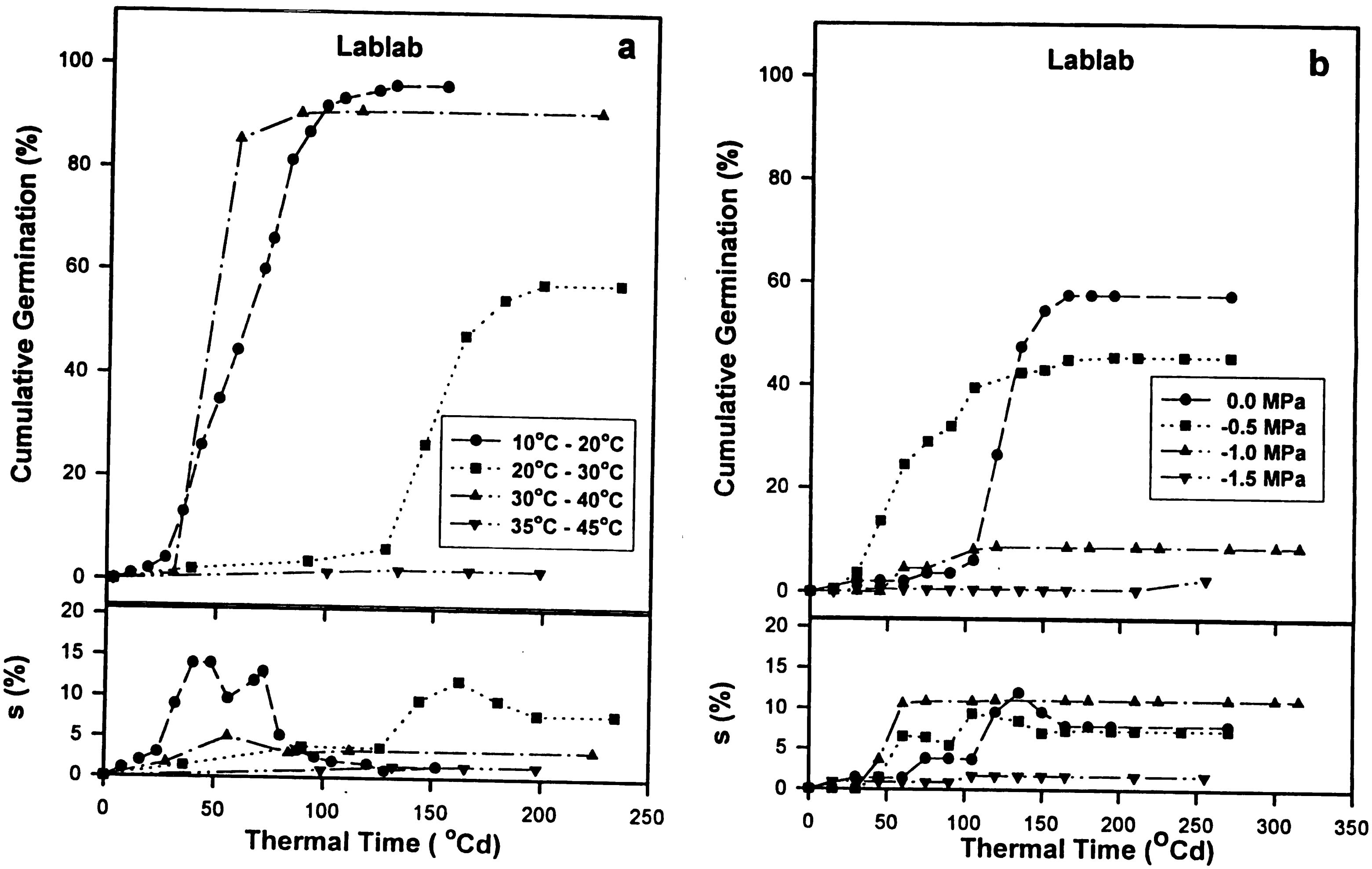

Figure 8. Mean cumulative germination percent and standard deviation (s) of lablab bean in response to a) temperature b) water potential

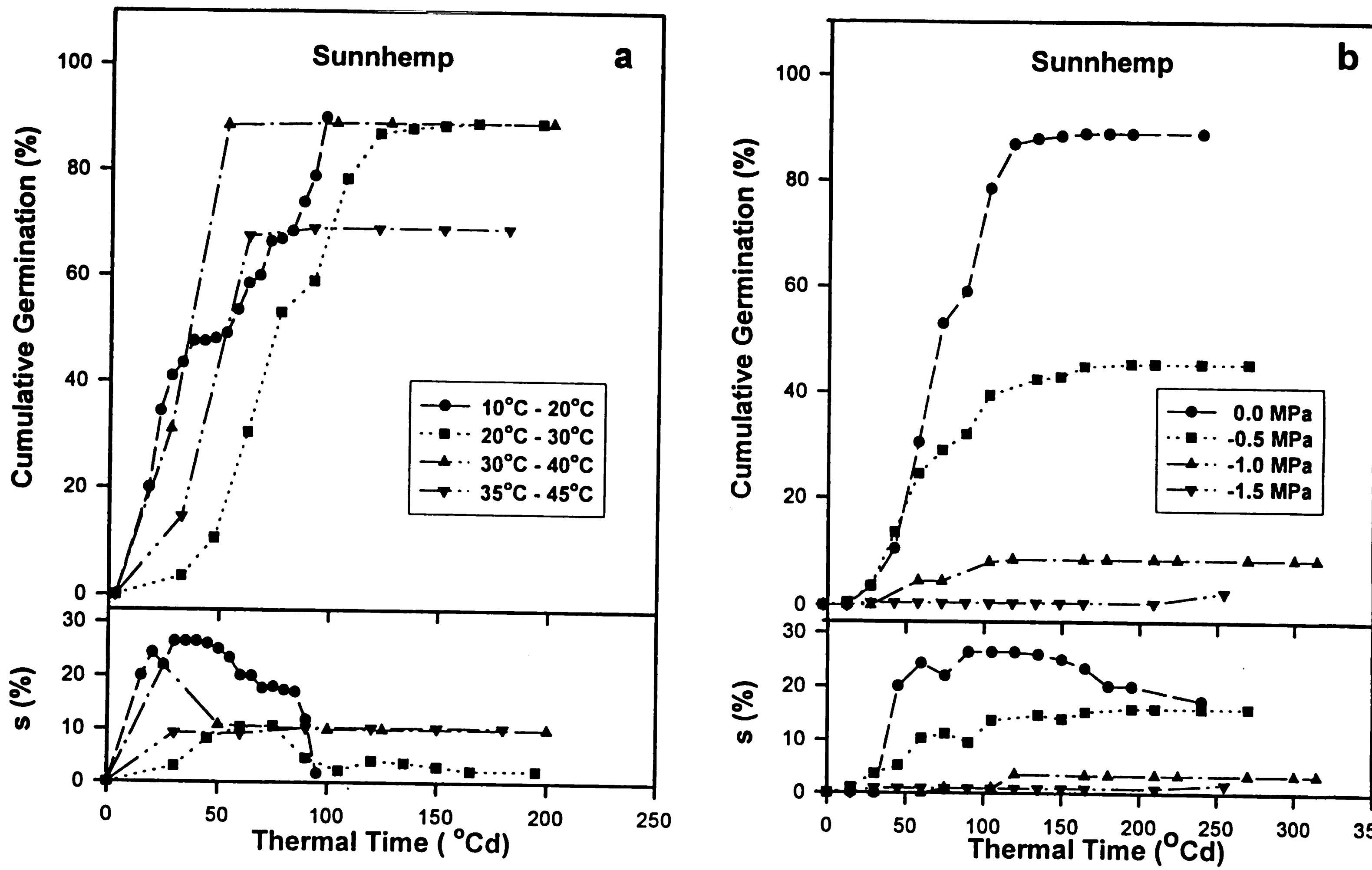

Figure 9. Mean cumulative germination percent and standard deviation (s) of sunnhemp in response to a) temperature b) water potential

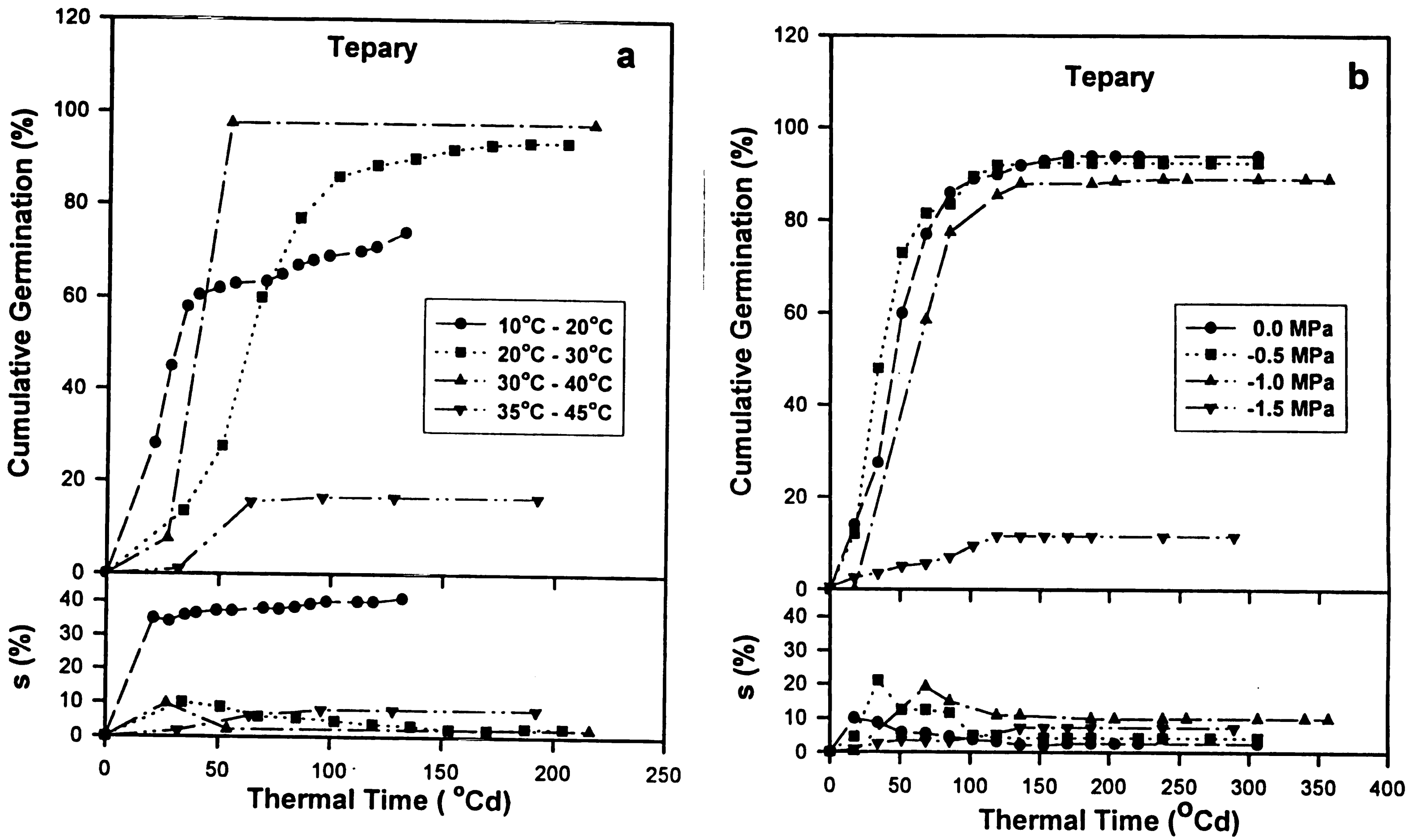

Figure 10. Mean cumulative germination percent and standard deviation (s) of <u>tepary bean</u> in response to a) temperature b) water potential

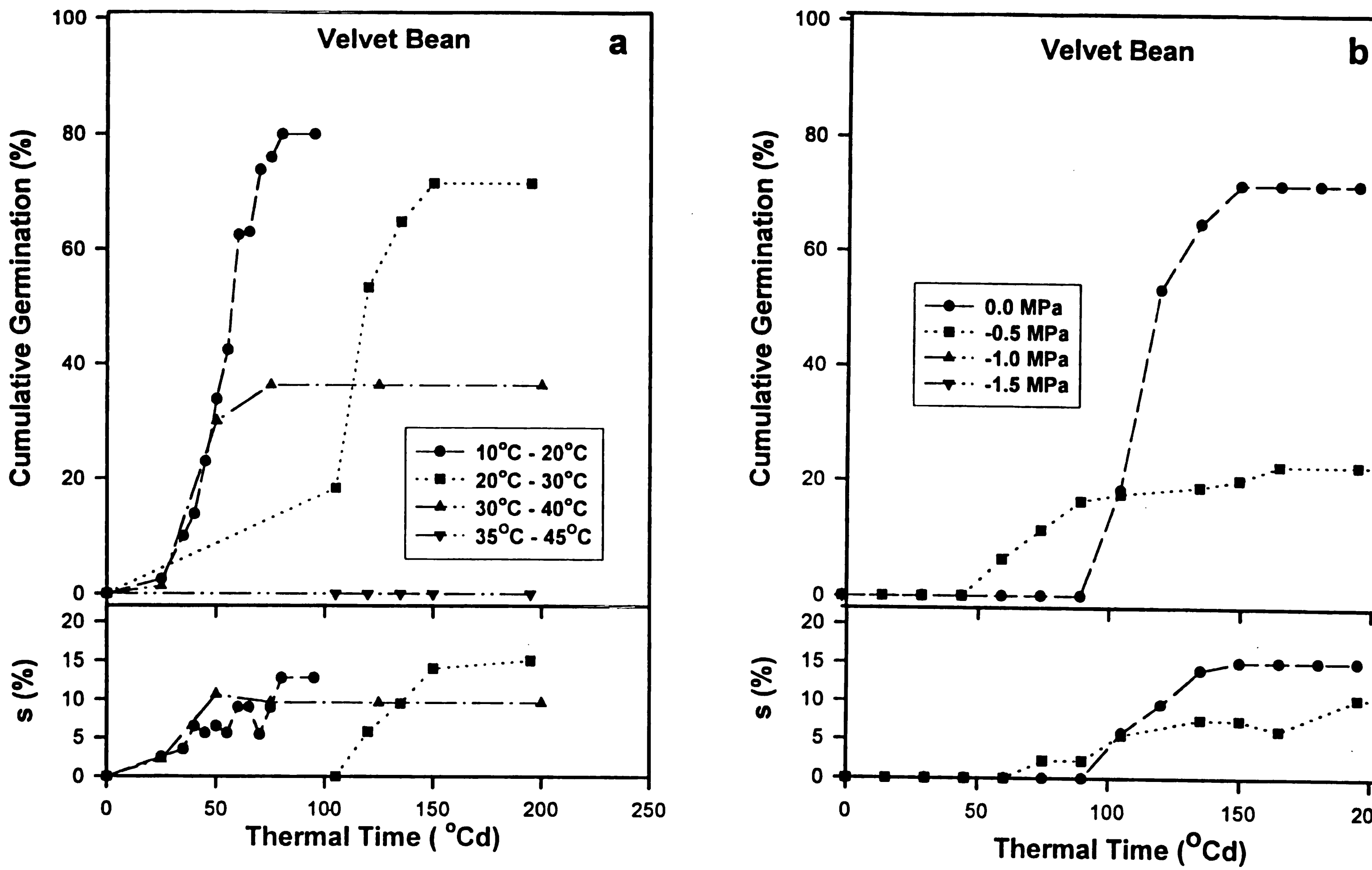

Figure 11. Mean cumulative germination percent and standard deviation (s) of <u>tropical velvet bean</u> in response to a) temperature b) water potential

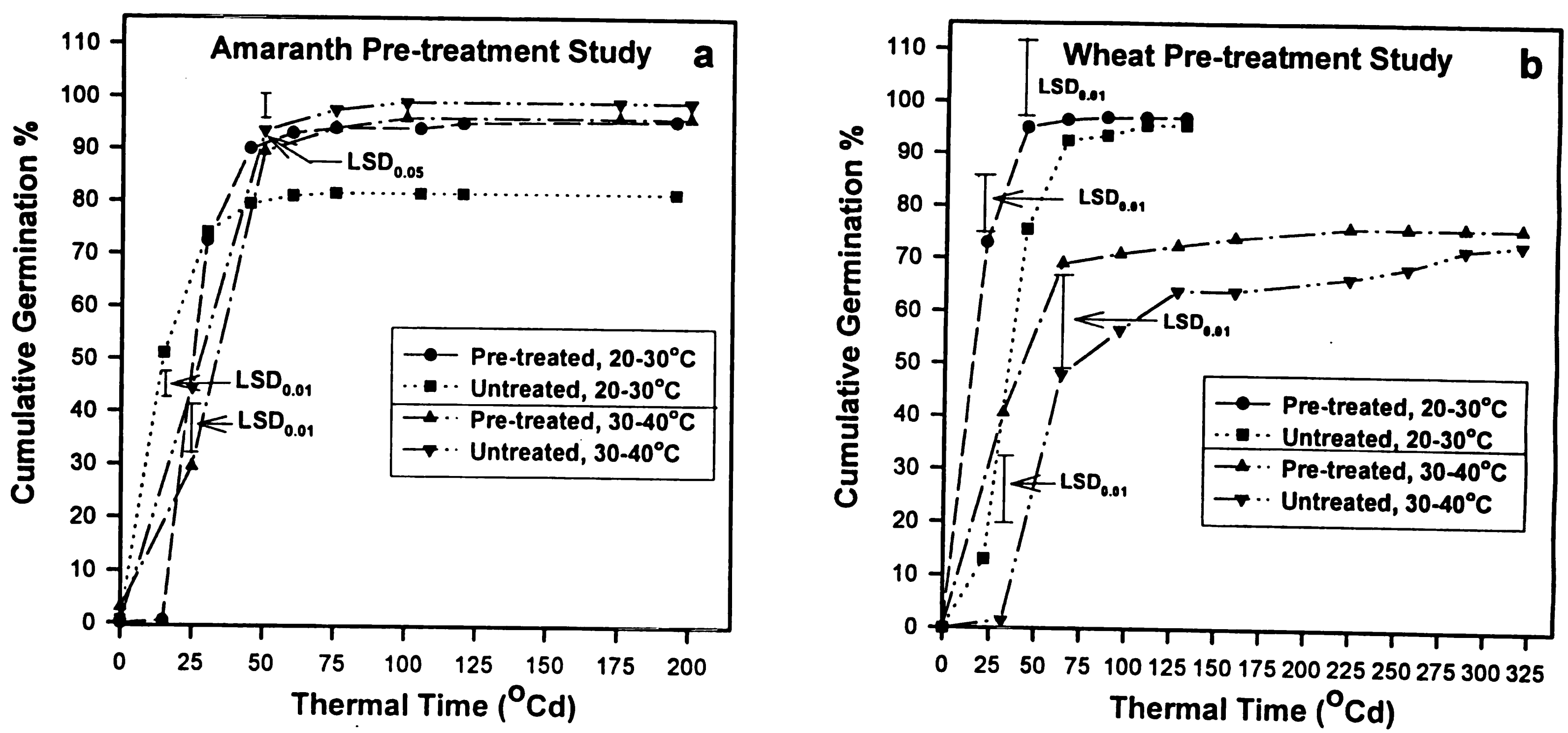

Figure 12a. Mean cumulative germination percent of <u>vegetable amaranth</u> as affected by pre-treatment at 20-30°C and 30-40°C

Figure 12b. Mean cumulative germination percent of <u>wheat</u> as affected by pre-treatment at 20-30°C and 30-40°C

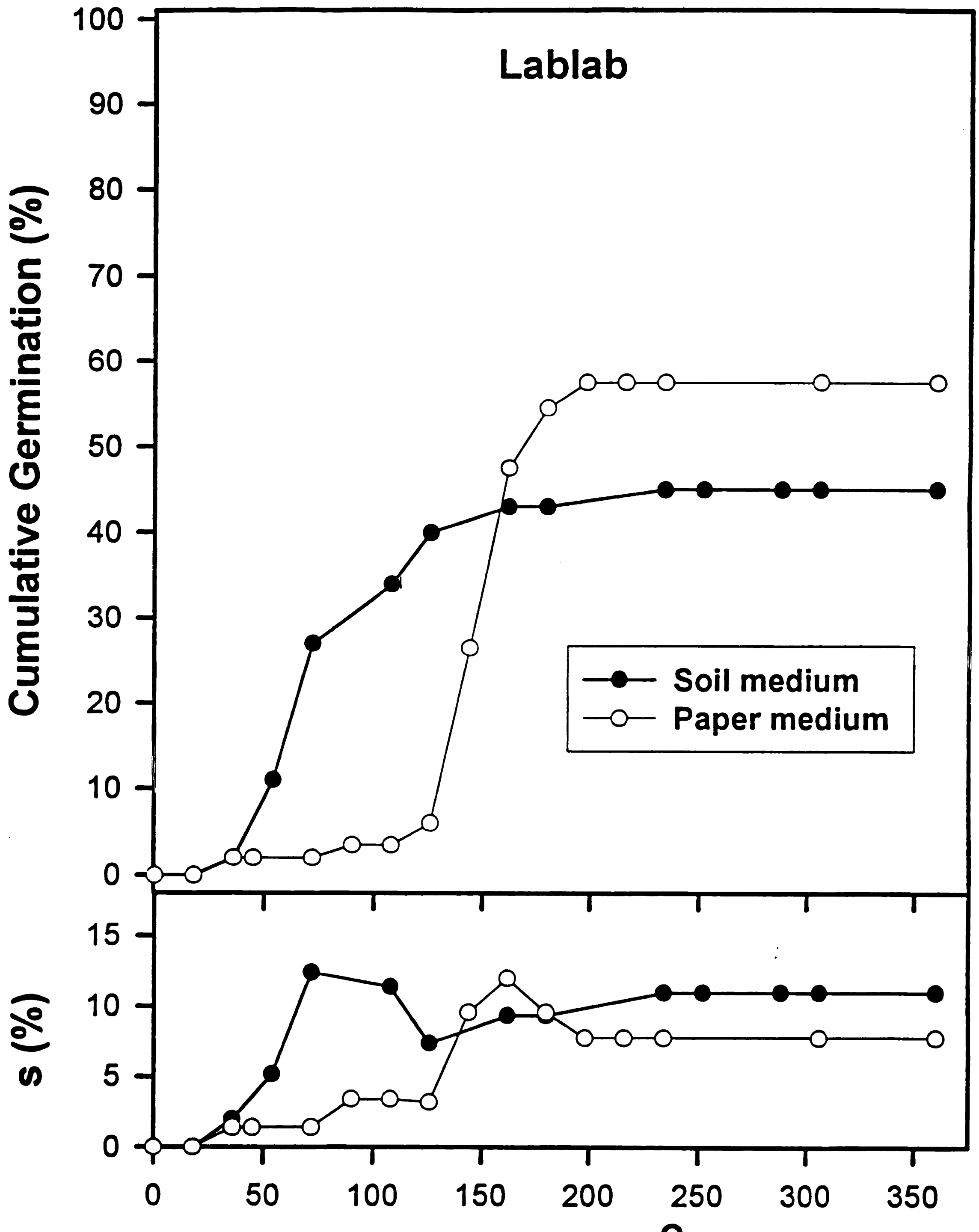

Figure 13. Cumulative germination of lablab bean as affected by blotter paper substrate and soil substrate

CHAPTER 2

FIELD GERMINATION RESPONSE OF SEVEN TROPICAL SPECIES OF VEGETATIVE COVER

INTRODUCTION

The majority of seed germination studies have been conducted in laboratories with temperate species under highly controlled, and often moderate, conditions of light, temperature and water (Khan, 1977). Many fewer studies have been conducted under field conditions where multiple detrimental environmental factors decrease rates and final germination percentages. These factors include too little or too much light/water, suboptimal or supraoptimal temperatures, limiting soil fertility or soil physical structure, pathogens, harmful microbial activity, and predacious birds, insects and rodents (Khan, 1977; Roundy et al., 1985).

Low water potential alone directly inhibits seed germination in the field. Indirectly, low soil matric potential decreases soil hydraulic conductivity and water movement to the seed, decreasing seed imbibition (Hadas, 1982; Hadas and Russo, 1974a; Hadas and Russo, 1974b). This can cause lower field germination rates for some species under identical field and laboratory matric potentials (Roundy et al., 1985); though Hadas (1977) found good germination correspondence from lab to field matric potentials for chickpea, sorghum and vetch.

The relationship between germination and soil matric potential is not simple, especially when seeds are placed at the soil surface. Seed size, rate and amount of seed swelling during imbibition, nature of seed surface and seed mucilage content all influence seed-soil-water contact area and eventual germination in the field and Black, 1983). In an early study, Swanson and Hunter (1936) compared lab and field germination of 17 sorghum varieties. Mean lab germination was 95%, and mean field germination was 50%, with a range of 30 to 50% reduction in field germination.

Still remaining within the confines of the traditional approach to agronomic research (Chapter 1), this study goes one step beyond laboratory germination research and addresses an important hypothesis regarding seed germination in the field -- that boundary conditions for germination established in growth chamber experiments are useful in predicting performance in high stess environments occurring in the field. Therefore, the objective of this study was to field test surface germination and early growth of seven tropical species with potential for use as vegetative cover crops at a specific tropical field site. Field data are compared to previously collected laboratory data (Chapter 1) to ascertain the effectiveness of lab data in predicting field germination response.

MATERIALS AND METHODS

Introduction

Between 1990 and 1993, a series of initial exploratory (data not reported) and then full-scale field seed germination experiments were conducted in the village of Buen Hombre in the Dominican Republic, which shares the Caribbean island of Hispaniola with Haiti to its west. Hispaniola lies east of Cuba and west of Puerto

Rico. Buen Hombre is located on the northwest coast of the Dominican Republic, near the Haitian border at approximately 19° 51′ N latitude and 71° 24′ W longitude.

Characterization of Soil Resources and Weather

Soil resources and weather conditions were characterized prior to the initiation of field experiments. Soil resources in Buen Hombre were characterized in a non-traditional way, based on methods suggested by Pawluk et al. (1992). No detailed information exists for soils of Buen Hombre, or in fact for many soils in the Dominican Republic. Local research institutions generally have not existed long enough, or lack the time and money, to collect and interpret soil data. However, Pawluk et al. (1992) recommend that in developing countries where little previous data exist, soil scientists should work with farmers to identify general soil types of importance to local agriculture and then locate typical examples of each type. Data collection efforts are then focused only on soils of local importance. This technique seemed appropriate and was used in Buen Hombre. Farmers described three general soil types, "black," "yellow," and "mixed."

Accordingly, soil profile pits were dug in the black and yellow soils at valley and hill slope locations, respectively, designated as being representative locations for these two soils by the current president of the farmer's association. Horizon depths were measured and characterized as to soil color, soil structure and soil texture, which was determined from soil samples taken from each horizon, using the Bouyoucos hydrometer method (Gee and Bauder, 1986). Soils were classified into taxonomic subgroups using standard criteria (Soil Survey Staff, 1990).

Soil fertility tests were performed on what villagers defined as the three main soil types of Buen Hombre -- "black," "yellow," and "mixed" -- to verify villagers' descriptions of relative soil fertility. Composite surface (0 to 7.6 cm) soil samples were collected from forty locations in each of three fields, designated as having soil that was representative of one of the three soil types by the president of the farmer's association. Samples were thoroughly mixed, subsampled, air-dried in the village (relative humidity of 65 to 75%), air-dried again under laboratory conditions (27% relative humidity) and sieved through a 6.25 mm screen. Soil fertility tests were performed at the Michigan State University soil testing laboratory, using Olsen's sodium bicarbonate extraction for available phosphorus, ammonium acetate extraction for potassium, calcium and magnesium and ammonium bicarbonate-DTPA extractable for manganese, zinc, copper and iron (Council on Soil Testing and Plant Analysis, 1980).

Bulk densities were determined on intact soil cores (7.6 cm in diameter, 7.6 cm in length) sampled in quadruplicate at depths of 0-7.6 cm and 7.6-15.2 cm for the black soil only. Bulk density was determined on a mass per volume basis after oven-drying cores for 48 hours at 105°C in a forced air oven (Blake and Hartge, 1986).

Weather data were obtained from a centrally located LICOR data logger, which operated between 1990 and 1993 for separate 3- or 4- week periods in January, 1991; February, 1991; March, 1991; March, 1992; April, 1991; April, 1992 and a 15-week period from July to October, 1991. The data logger recorded mean hourly temperature at one meter above the soil surface, mean hourly surface soil temperature at 2.5 cm beneath the soil surface and mean solar radiation every 15 minutes in Watts m^2. Precipitation was measured manually with a rain gauge at the center of the village. Relative humidity was measured twice daily with a sling psychrometer at 7:00 a.m. and 4:00 p.m.

Seed germination experiments

Experimental field plots were centrally located in the valley on the black soil designated by villagers as being representative of other black soils in the village. Plots were prepared by clearing weeds and plant debris from the surface with machetes, clearing rocks away, manually cultivating the top 5 cm of soil and constructing small bordered plots 50.8 x 101.6 cm with a 7.6 cm embankment on all four sides to concentrate and control water applications. The entire plot area was fenced and gated with posts and barbed wire to provide further control and protection against intrusions by cattle, goats and curious children (Figure 1).

Full-scale germination field experiments were conducted in March and April, 1992, to investigate germination response at the end of the rainy season, and in September and October, 1991, to follow germination response at the end of the dry season. Seeds were planted at the soil surface in evenly spaced rows, and a colored plastic toothpick was inserted in the soil adjacent to each seed to mark its location. Seeds selected for planting were not visibly damaged and were selected without regard to size or color. Species planted and number of seeds per replication for both the March-April and September-October studies are listed in Table 2. Plots were hand-watered daily with 4 L per plot, using water transported by burro from the Buen Hombre well (Figure 1).

Visible, ungerminated seeds remaining at the surface were counted daily, as were germinated seeds. Seeds were not removed upon germination, and seedlings were monitored for height, leaf number and extent of insect damage throughout the experiment. Weed seedlings were counted daily in the September-October, 1991, experiment. The duration of the March-April experiment was 19 days. The September-October experiment lasted 24 days.

Species Selection

Plant species (Table 1) selected for inclusion in the field experiments did not overlap entirely with those tested in laboratory experiments (Chapter 1). Seed propagation plots at a research institute in Santiago failed due to irrigation pump failure. Therefore, some species used in the laboratory experiments were not available for field testing. An indigenous species, Hierba Amarga (*Parthenium hysterophorus* L.), did not germinate in lab or field experiments. Also, a bird-resistant sorghum variety was field tested, but was unavailable for laboratory experiments.

Use of thermal time

Germination data are reported in thermal time (Ritchie and NeSmith, 1991), or accumulated temperature, for ease of comparison to laboratory data, using the formula for thermal time in growing degree days, or °Cd (Ritchie and NeSmith, 1991):

$$°Cd = \Sigma (T_{mean} - T_{base}) \qquad [1]$$

Base temperatures used were those defined in Chapter 1.

Statistical design and analyses

Field experiments were conducted as a randomized complete block design with four replications of each species separated in time. Analyses of variance were performed on all data. There were highly significant differences between species and between times in all these experiments and oftten between time by species, as well.

RESULTS AND DISCUSSION

I. Agricultural Context: Soil Resources and Weather

Buen Hombre soils ("black," "yellow" and "mixed") are all reported to be productive for a wide variety of crops, when there is rain. Black soils tend to be clustered in the valley, while yellow soils are generally located on mountain and hill slopes. Table 3 shows soil profile characterization for both soils, and Table 4 lists taxonomic descriptions. Buen Hombre soils are calcareous mollisols (developed soils with high pH) or entisols (soils with an ochric epipedon and little development of subsurface horizons). The semi-arid climate greatly slows soil development. Soil texture is coarse at the lower horizons of all three black profiles (gravelly sand, sandy gravel). The upper horizons are fine- and moderate-textured (sandy loam, loam, silt loam and clay loam), but tend to be rocky at the surface. There is some surface crusting and cracking under repeated high intensity watering.

Soil fertility tests validate farmers' reports of productive soils. Soils are moderately fertile and high in pH (Table 5). Both black and yellow soils have high potassium levels and soil phosphorus levels above 24 kg ha^{-1}, which is the level at which there is no crop response to additions of fertilizer phosphorus (Council on Soil

Testing and Plant Analysis, 1980). Manganese and copper levels are adequate. Cation exchange capacity is high, indicating the soil's ability to retain nutrients for plant growth. However, soils with free calcium carbonate in the top 50 cm and pH values above 7.3, like those in Buen Hombre, "are often deficient in micro-nutrients, particularly Fe and Zn" (Sanchez and Logan, 1992). Zinc levels are low in these Buen Hombre soils, though iron levels are adequate. Mean bulk densities for the black soil are 1.04 Mg m^{-3} at a depth of 0-7.6 cm and 1.06 Mg m^{-3} at 7.6-15.2 cm. These are relatively low bulk density values, indicating the likelihood of ample pore space for aeration and root growth near the surface. In conclusion, soil fertility and soil physical properties for the soils tested do not appear to be limiting for agriculture.

Historical accounts (Halmo et al., 1991) and records (Portman et al., 1991) report average rainfall between 600 and 700 mm annually. Temperatures in the village range from 19 to 33°C, with relative humidity generally between 60 and 70%. Figure 1a shows mean daily soil and air temperatures for a 4-week period from mid-March to mid-April, 1992. March and April are at the end of the rainy season, when vegetative cover of drought tolerant species would be planted so that germination and initial root growth could take place while there was still rainfall. Species planted in March and April could provide food during the dry season and could provide ground cover for erosion protection at the beginning of the rainy season.

Figure 2b shows temperature data for a 4-week period from mid-September to mid-October, 1991, at the end of the dry season. Mean daily air temperature for March and April is 26.1°C ± 1.6°C, and mean daily soil temperature is 28.3°C ±

1.8°C. Mean daily air temperature for September and October is 29.0°C ± 1.7°C; mean daily soil temperature is 28.1 °C ± 0.9°C. For thermal time calculations, a mean daily temperature of 27°C was used for March-April data and 28.5°C was used for September-October data. Mean solar radiation for both experiments, calculated every 15 minutes over a 4-week period from mid-month to mid-month, resulted in similar diurnal solar radiation cycles and variance in data for March-April and September-October (Figure 3).

II. Field Germination Response and Comparison to Laboratory Data

Field germination response of benchmark species: lettuce and wheat

Lettuce did not germinate in field experiments, as temperatures were too high for this cold-season species. Field germination data of wheat on a surface area basis shows the number of visible, but as yet ungerminated seeds per square meter of soil surface, as well as the number of visible, germinated seeds at the surface for March-April (Figure 4a) and for September-October (Figure 4b). Figures 4a and 4b each have a variance graph beneath, showing standard error values corresponding to each data point in the corresponding graph above. In Figure 4a, the number of ungerminated seeds at 0°Cd thermal time reflects seed density at planting, which decreases prior to germination as seeds fall into cracks, subside into soil with watering, are eaten by birds and insects, etc. The lines in Figure 4a representing germinated and ungerminated seeds cross when ungerminated seeds below the surface disappear from view and later germinate.

Wheat reached 90 germinated seeds m^{-2} in March-April, with almost no germination in September-October. Wheat plots were attractive to ants, and many seeds were lost to ant predation. The first insect damage to seedlings was noted on day 11. Seedlings that survived insect damage in March-April grew to 16.0 cm and appeared robust. September-October seedlings were spindly and weak by the close of the experiment. Although it will be discussed more thoroughly later in this chapter, March-April wheat germination in the field in the tropics is reduced 57.5% from growth chamber germination, though rates are similar when germination is carried out on the field site soil in a growth chamber.

Field germination response of tropical species

Hierba amarga, the species indigenous to Buen Hombre, and tropical kudzu did not germinate in the field in either March-April or September-October. In the March-April study, a rapid initial decrease in visible lablab seeds at the surface was the result of seeds falling into cracks and subsiding into the soil with watering (Figure 5a). Germination was much lower at the end of the dry season (Figure 5b), never reaching 20 seeds m^{-2}, than it was at the end of the rainy season (Figure 5a), when maximum levels reached 50 germinated seeds m^{-2}. Figure 5b includes number of weeds per square meter as a simple indicator of competition from indigenous species. As in Figures 6b to 9b, weed growth increases with time in all the September-October experiments. Germinated lablab seeds were not affected by insect damage until seedlings reached a mean height of 5.8 cm. As seedlings increased in size, insect damage also increased.

Bird-resistant sorghum plots had high weed populations, and sorghum germinated poorly in both field experiments (Figure 6). Original planting density was 297 seeds m^{-2} in March-April and 77 seeds m^{-2} in September-October.

Ungerminated seeds were too small for easy visibility at the surface and thus were not plotted in the figures. Sorghum plots were the subject of much ant activity, and many sorghum seeds were eaten shortly after planting. Of the sorghum that did germinate, insect damage was not noted until nine days after planting.

Sunnhemp also germinated better in March-April, reaching a maximum density of 124 germinated seeds m^{-2}, compared to 43.5 seeds m^{-2} in September-October (Figure 7). Visible seeds at the surface decreased rapidly, and the earliest germinators germinated from surface cracks. Ants ate sunnhemp seeds, but not to the same extent as sorghum. As early as day 5 post-planting, insect damage to seedlings had begun. Seedlings were subjected to several kinds of insect damage, including decapitation of main stem and top leaves, deformity and yellowing of leaves and "excavation" of the top palisade leaf layer. Goats also dug under barbed wire fencing to eat sunnhemp seedlings.

Velvet bean reached maximum germination of 96 seeds m^{-2} in March-April, with almost no germination at the end of the dry season (Figure 8). Seeds rapidly subsided into the surface with watering, but remained visible, and seed coats turned black. The earliest germinators were those that had fallen into small crevices at the soil surface. Some seeds were eaten at the soil surface prior to germination. Earliest insect damage occurred at day 8, ultimately killing all seedlings through decapitation of stem and leaves, leaf curling, leaf holes and leaf blackening. Also, local goats were fond of young velvet bean plants.

Weed competition and insect damage in field experiments

It is interesting to note that indigenous weed species growing in microplots were also damaged by insects. It is clear from these experiments that once water is no longer limiting, biological activity in the form of bird, insect and goat predation is the single greatest limitation to success of surface germination and seedling survival at this tropical field site at this time of year (September-October), when there is very little else growing. Though insecticides could have been applied in the experiments, it is not realistic to expect villagers to buy insecticides for cover crops during large-scale field implementation. Therefore, they were not used here.

Hand broadcast seeds that remain at the surface until germination are those shunned by ants and birds, or those that subside quickly, such as velvet bean (Figure 10). In harsh subsistence environments like Buen Hombre, broadcasting at the surface appears to put seeds at too great a risk for successful establishment. Hand broadcast seeds may need to be selected based on their ability to germinate quickly, subside or fall into cracks quickly, or seeds may need to be trampled into the soil at planting. In March-April, several species originally planted at a rate of 50 per microplot were replanted at a rate of 100 per plot in order to get successful germination. Thus, another management strategy to deal with tropical biological activity is overseeding. Dark seeds, such as sunnhemp, may have an advantage in surface seeding, if dark soil acts as camouflage protecting them from birds and goats. Hand broadcasting may be an inappropriate management technique for tropical environments, but insect damage to seedlings after germination can be just as severe as seed loss at the surface from predation prior to germination.

Reporting of laboratory vs field germination data

Laboratory germination data were reported in Chapter 1 as cumulative germination percent. Figure 11 shows field data for tropical velvet bean, reported both as cumulative germination percent and the actual germination percent of still visible seedlings recorded in the field each day. A key issue in field germination, where water, temperature and light are not limiting, is post-germination senescence due to insect, pathogen or predatory damage. It is clear from Figure 11 that reporting field data as cumulative germination percent obscures information about day-to-day attrition of seedlings. For this reason, actual germination percent is the format used to present field data in Figures 12 to 17.

Field data as actual germination percent

Wheat has low germination in March-April (Figure 12a) and lower germination in September-October (Figure 12b), but seedlings persist. Lablab (Figure 13) has low germination, but ungerminated seeds persist relatively well at the surface. On a density basis, more lablab seeds germinated in March-April (Figure 5a) than September-October (Figure 5b). But as a proportion of initial seeds planted, lablab germinates at a maximum 26% in September-October, compared to 20% in March-April. Sorghum (Figure 14) germinates poorly in both experiments. All other species perform better at the end of the rainy season (Figures 15 to 17), and tepary has a slower rate of seed loss in September-October.

Comparison of field and laboratory data

Maximum cumulative germination percent in the laboratory on blotter paper at mean daily temperatures of 25°C under near-saturation water conditions is compared to cumulative germination percent of field data at mean daily temperatures of 27°C, with daily watering (Table 6). These data show similar thermal times to maximum germination for lablab. Though thermal time at maximum cumulative germination percent is greater for sunnhemp and tepary in laboratory experiments, these species first reach near-maximum germination percents of 87.0% (sunnhemp) and 88.5% (tepary) at 120°Cd (sunnhemp) and 119°Cd (tepary) (data not shown), which is very similar to field thermal time data for maximum cumulative germination percent in Table 6. Velvet bean and wheat show greatly delayed germination rates in the field, compared to laboratory results. And all species show reduced maximum germination percent in the field.

However, soil taken from the field test site and used to replace blotter paper as a substrate, reduces laboratory germination. Therefore a more realistic comparison between field and laboratory data is one in which laboratory experiments are conducted on field site soil as the germination medium. When such a comparison is made (using soil substrate), maximum germination percent is reduced 19 to 57.5% from laboratory to field, depending on the species (Table 7), as compared to reductions ranging from 31.5 to 63.5% from laboratory (using blotter paper substrate) to field (Table 6). Though further testing is needed to ascertain whether the species-specific reduction factor (rightmost column, Table 7) is relatively consistent from year to year, lab data in this study provides useful information about field germination and early growth response under limiting conditions.

For the benchmark species, laboratory data predicted lettuce would probably not germinate under field conditions unless mean daily temperatures remained at or below 25°C, but that wheat would germinate. Also from laboratory data, one would have expected amaranth and tropical kudzu to do well in the field under Buen

Hombre weather conditions. Yet they did not germinate at all, due perhaps to harsh physical conditions at the surface or surface exposure to birds and insects. For jack bean, lablab, sunnhemp, tepary and velvet bean, laboratory data accurately predicted success in the field, though jack bean could not be included in full-scale testing, due to lack of seed availability.

CONCLUSIONS

Boundary conditions for germination, established in growth chamber experiments, can in fact be used to predict germination in high stress field environments. Whether the specific reductions in final germination percent from lab to field (in this case, reductions of 19% for lablab, 44% for sunnhemp, 24% for tepary and 32% for tropical velvet bean) are relatively consistent from year to year remains to be tested. What is clear is that based on laboratory characterization studies (Chpater 1), successful germination performance was predicted for the field for all but two species. Based on these data and data for jack bean from a preliminary field study, the next step would be field trials of jack bean, lablab bean, bird-resistant sorghum, sunnhemp, tepary bean and tropical velvet bean for an entire dry season. Objectives would be to monitor crop response to physical conditions at the site beginning in May, ascertain whether biotic interactions are reduced with large plots or are confined to edges and monitor labor and economic factors, as well as villager reponse to cover crops at several levels (adoption, use, management, incorporation into diets, etc.).

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Table 1. Selected species with potential as cover crops in harsh environments, characterized in field germination studies

Common Name (Variety)	Latin Name
Vegetable amaranth (Hijau)	*Amaranthus cruentes* L.
Hierba amarga*	*Parthenium hysterophorus* L.
Tropical kudzu	*Pueraria phaseoloides*
Lablab bean	*Lablab purpureus* (L.) Sweet; *Dolichos lablab*
Lettuce (Grand Rapids)	*Lactuca sativa*
Bird-resistant sorghum	*Sorghum bicolor*
Sunnhemp	*Crotolaria ochroleuca*
Tepary bean	*Phaseolus acutifolus* A. Gray
Tropical velvet bean	*Mucuna deeringia*
Wheat (Frankenmuth)	*Triticum aestivum*

* Indigenous species collected from Dominican Republic field site

Table 2. Buen Hombre field experiments: species and number of seeds per replication

Species	March - April Number of seeds per replication	September - October Number of seeds per replication
Hierba amarga	25	50
Tropical kudzu	25	--[1]
Lablab bean	25	40
Lettuce	50	50
Sorghum	25	100
Sunnhemp	50	100
Tepary bean	50	100
Velvet bean	25	100
Wheat	50	100

1 Species not tested in this experiment

Table 3. Soil profiles of "black" and "yellow" soils, Buen Hombre

Buen Hombre "black" valley soil

Horizon	Depth (cm)	Texture	Color	Structure: Shape	Structure: Grade
Ap	0-18	Clay Loam	10YR 3/3	SAB	Mod
A	18-36	Clay Loam	10YR 5/3	AB	Mod
E	36-53	Loam	10YR 6/2	SAB	Mod
B	53-70	Clay Loam	10YR 4/3	SAB	Mod
C	70-99	Extremely cobbly sand and gravel	-------- ---	---	
2Cbk	99-132	Clay Loam	10YR 4/3	SAB	Mod

<u>Notes</u>: Haploxeroll; 0% slope; solum = 53 cm; 8.0 pH for Ap horizon; effervescence for all horizons with 1.0 N HCl, no effervescence with 0.1 N HCl

Buen Hombre "yellow" hill soil

Horizon	Depth (cm)	Texture	Color	Structure: Shape	Structure: Grade
A1	0-9	Loam	2.5Y 4/4	SAB	Mod
A2	9-20	Loam	2.5Y 3/2	SAB	Mod
Bw	20-44	Silt Loam	2.5Y 4/3	SAB	Mod
C	44+	Silty Clay Loam	2.5Y 5/4	Platy	Mod

<u>Notes</u>: Torriorthent; 7% slope; solum = 44 cm; 7.8 pH for A1 horizon; effervescence for all horizons with 1.0 N HCl, no effervescence with 0.1 N HCl

Table 4. Classification of black and yellow soils, Buen Hombre

Soil	Key characteristics	Family name
Soil 1: Higher elevation (southernmost), black valley soil	• Mollisol • Horizon development • Warm temperatures • High base status	Loamy, mixed (calcareous), isohyperthermic Haploxeroll
Soil 2: Mid-elevation, black valley soil	• Mollisol • Horizon development • Warm temperatures • High base status	Fine-loamy over fragmental, mixed (calcareous), isohyperthermic Haploxeroll
Soil 3: Lower elevation (northernmost), black valley soil	• Entisol • Very young soil, little horizon development • Warm temperatures • Aridic soil moisture	Coarse-loamy over fragmental, mixed (calcareous), isohyperthermic Torriorthent
Soil 4: Yellow hillslope soil	• Entisol • Very young soil, little horizon development • Warm temperatures • Aridic soil moisture	Fine-loamy over fragmental, mixed (calcareous), isohyperthermic Torriorthent

Table 5. Soil fertility of the three major Buen Hombre soil types, as designated by farmers

Soil test	"Black" Soil	"Yellow" Soil	"Mixed" Soil
Soil pH	7.6	8.1	8.0
Cation exchange capacity (cmols (NH_4^+) kg^{-1} soil)	39	32	41
MACRONUTRIENTS			
Olsen phosphorus (kg ha^{-1})	30	25	20
Potassium (kg ha^{-1})	1,664	1,375	637
Calcium (kg ha^{-1})	15,279	12,167	15,845
Magnesium (kg ha^{-1})	780	1,295	1,344
MICRONUTRIENTS			
Zinc (mg kg^{-1})	0.7	0.7	0.5
Manganese (mg kg^{-1})	46.4	14.4	12
Copper (mg kg^{-1})	1.7	0.6	7.4
Iron (mg kg^{-1})	7.5	6.5	7
Nitrate-N (mg kg^{-1})	12.9	3.5	8.2

Table 6. Maximum cumulative germination, a comparison of field and laboratory data

Species	Laboratory[1]			Field[2]		
	Thermal time	Maximum cumulative germination	Standard deviation	Thermal time	Maximum cumulative germination	Standard deviation
	--°Cd--	--%--	--%--	--°Cd--	--%--	--%--
Lablab bean	198	57.5	7.9	194	26.0	3.0
Sunnhemp	165	89.0	2.2	119	38.0	3.0
Tepary bean	187	93.5	2.6	123	45.0	6.8
Tropical Velvet bean	150	71.5	15.0	272	33.0	2.3
Wheat[3]	110	95.5	4.6	216	32.0	6.4

1 Laboratory data are for 20-30°C night-day experiments at near-saturation water potential
2 Field data are reported in maximum cumulative germination percent
3 Data are for un-pretreated wheat (no pre-chilling prior to laboratory or field experiments)

Table 7. Maximum cumulative germination, a comparison of laboratory experiments using Buen Hombre soil medium to field experiments in Buen Hombre

	Maximum cumulative germination				
Species	Laboratory, Buen Hombre soil	Standard deviation	Field, Buen Hombre	Standard deviation	Lab minus field
	---------- % ----------				
Lablab bean	45.0	11.1	26.0	3.0	19.0
Sunnhemp	81.5	13.7	38.0	3.0	43.5
Tepary bean	68.5	11.3	45.0	6.8	23.5
Tropical velvet bean	65.0	11.2	33.0	2.3	32.0
Wheat	89.5	9.6	32.0	6.4	57.5

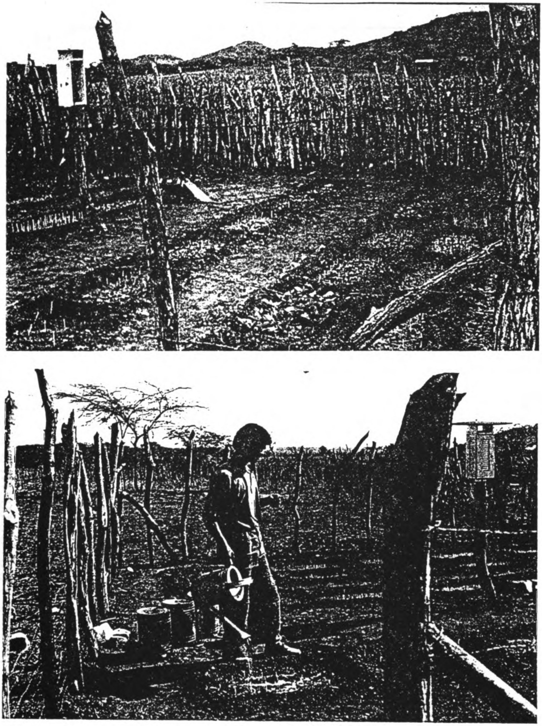

Figure 1. Photographs of: (top) experimental field plots, Buen Hombre, Dominican Republic, and (bottom) M. Perez, watering one microplot

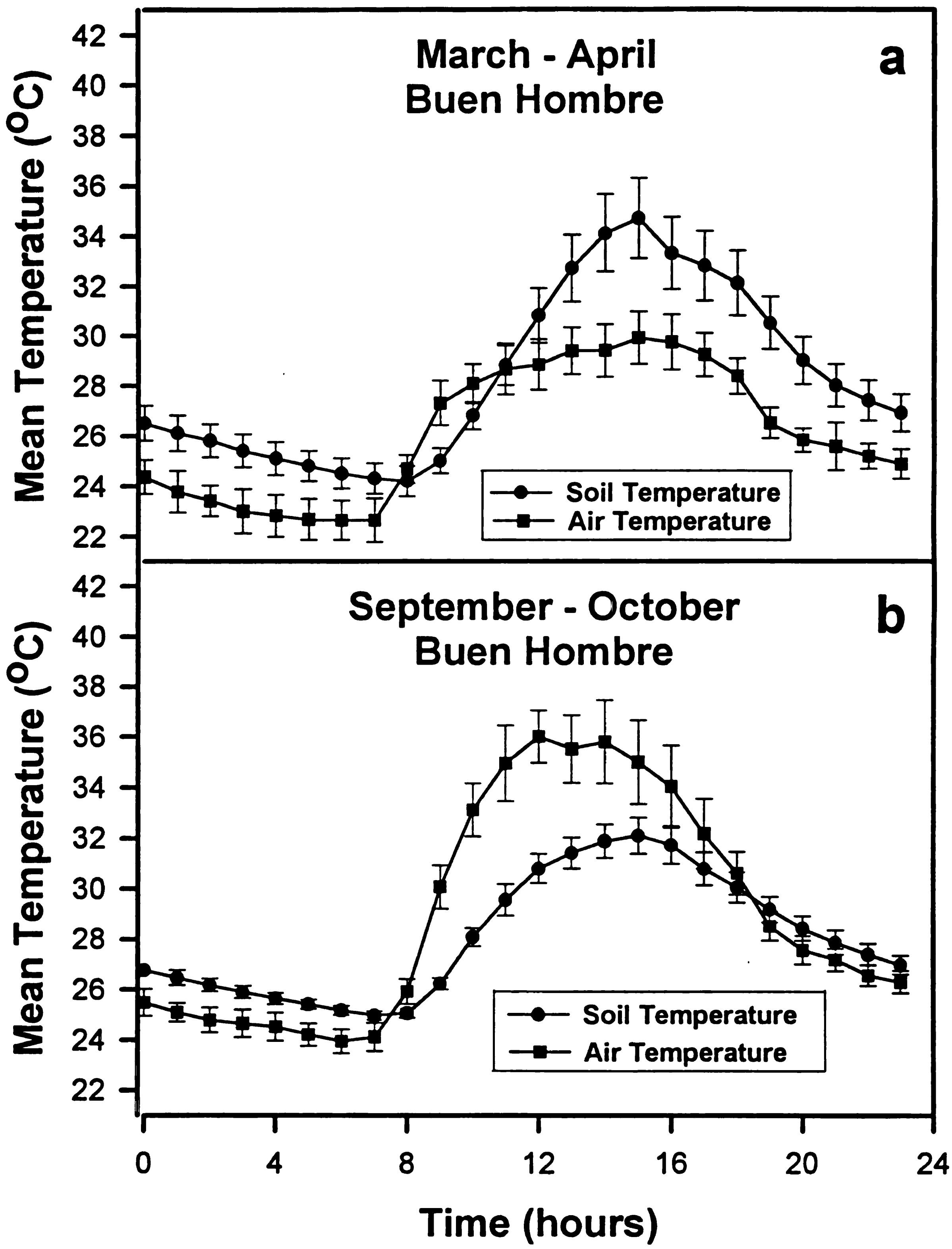

Figure 2. Average daily surface soil and air temperatures, Buen Hombre: a) March-April, 1992 b) September-October, 1991

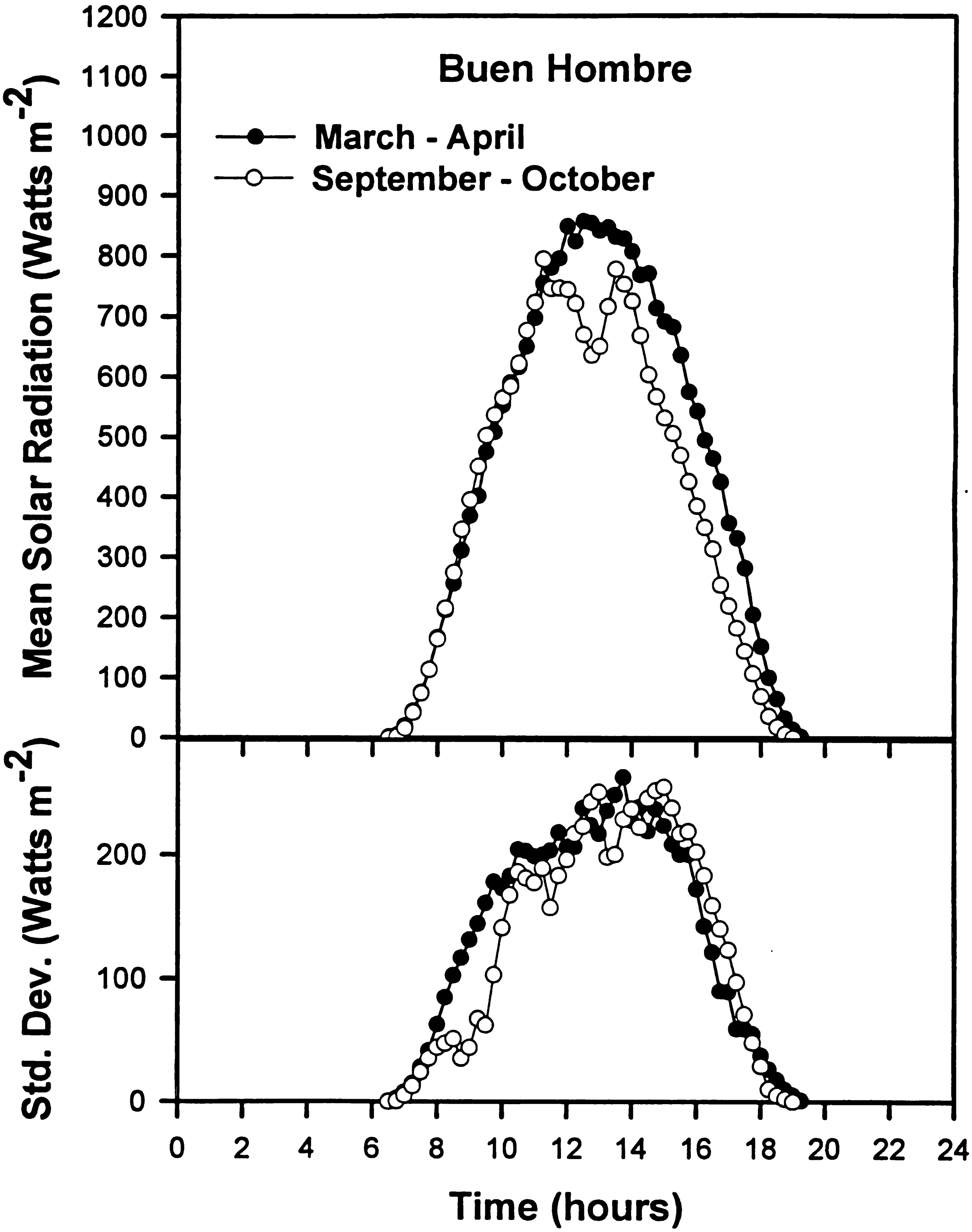

Figure 3. Mean solar radiation, Buen Hombre: March-April, 1992, and September-October, 1991

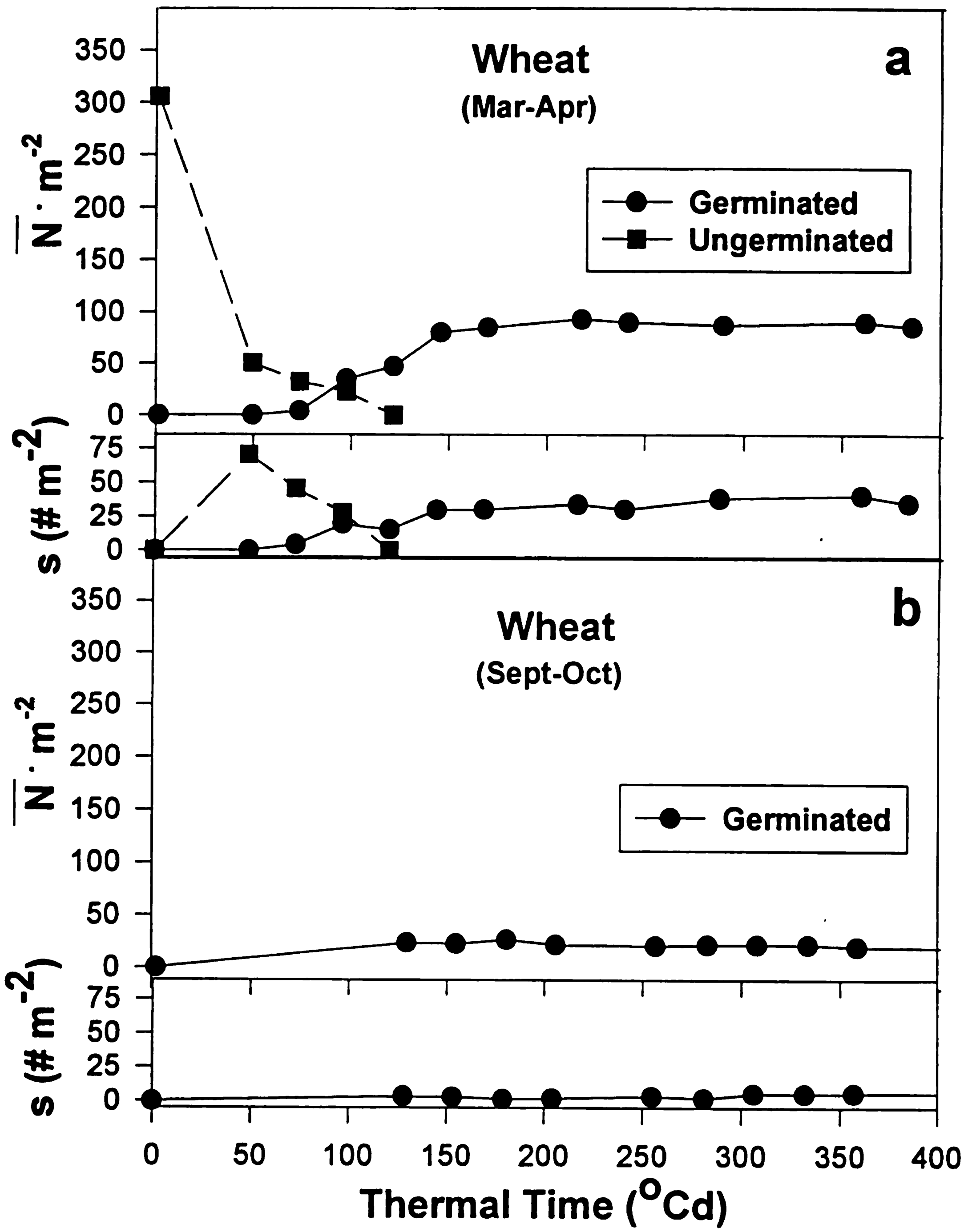

Figure 4. Mean density (N) and standard deviation (s) of germinated and ungerminated <u>wheat</u> seeds in the field: a) March-April and b) September-October

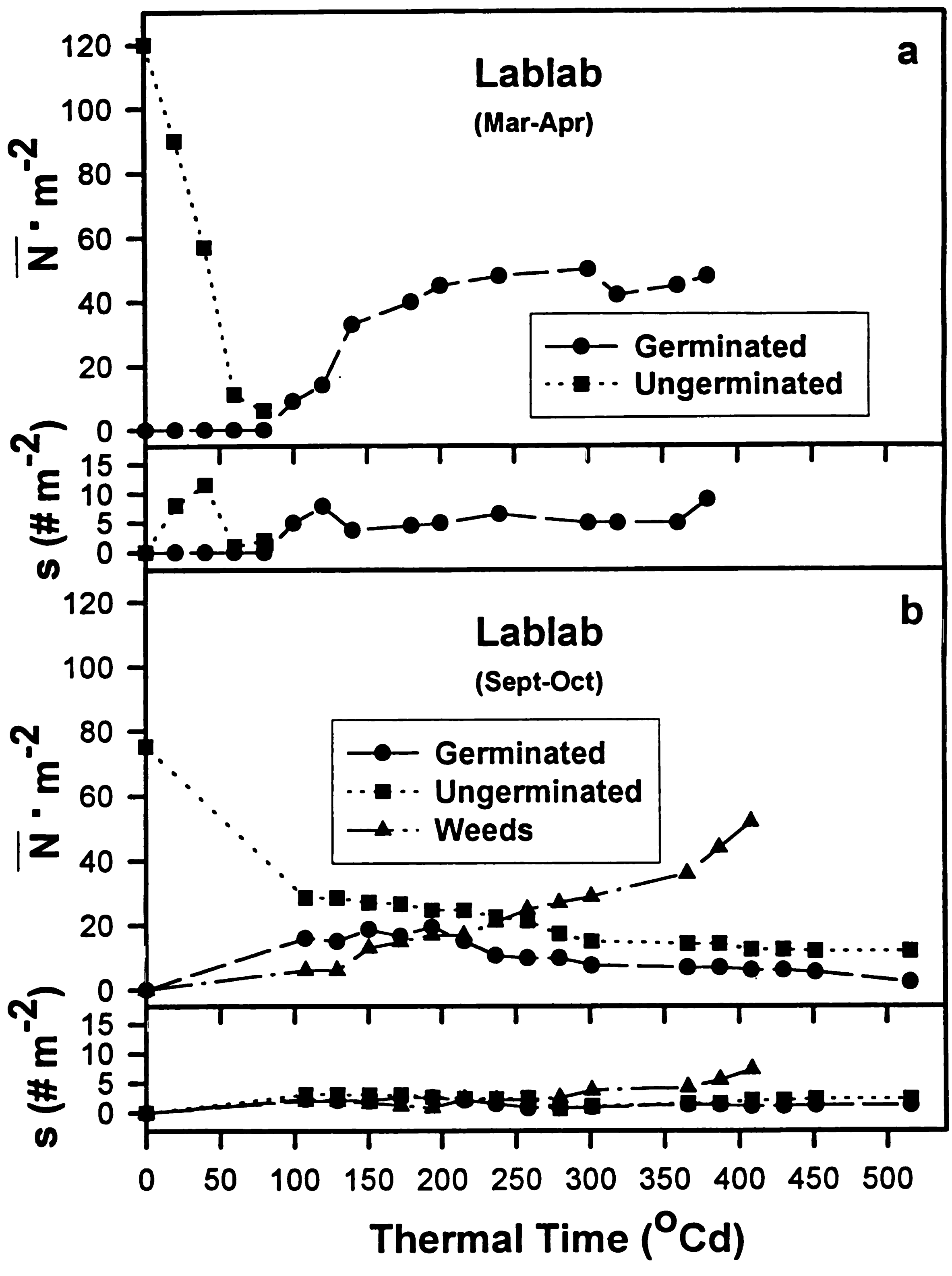

Figure 5. Mean density (N) and standard deviation (s) of weeds and germinated and ungerminated lablab seeds in the field: a) March-April and b) September-October

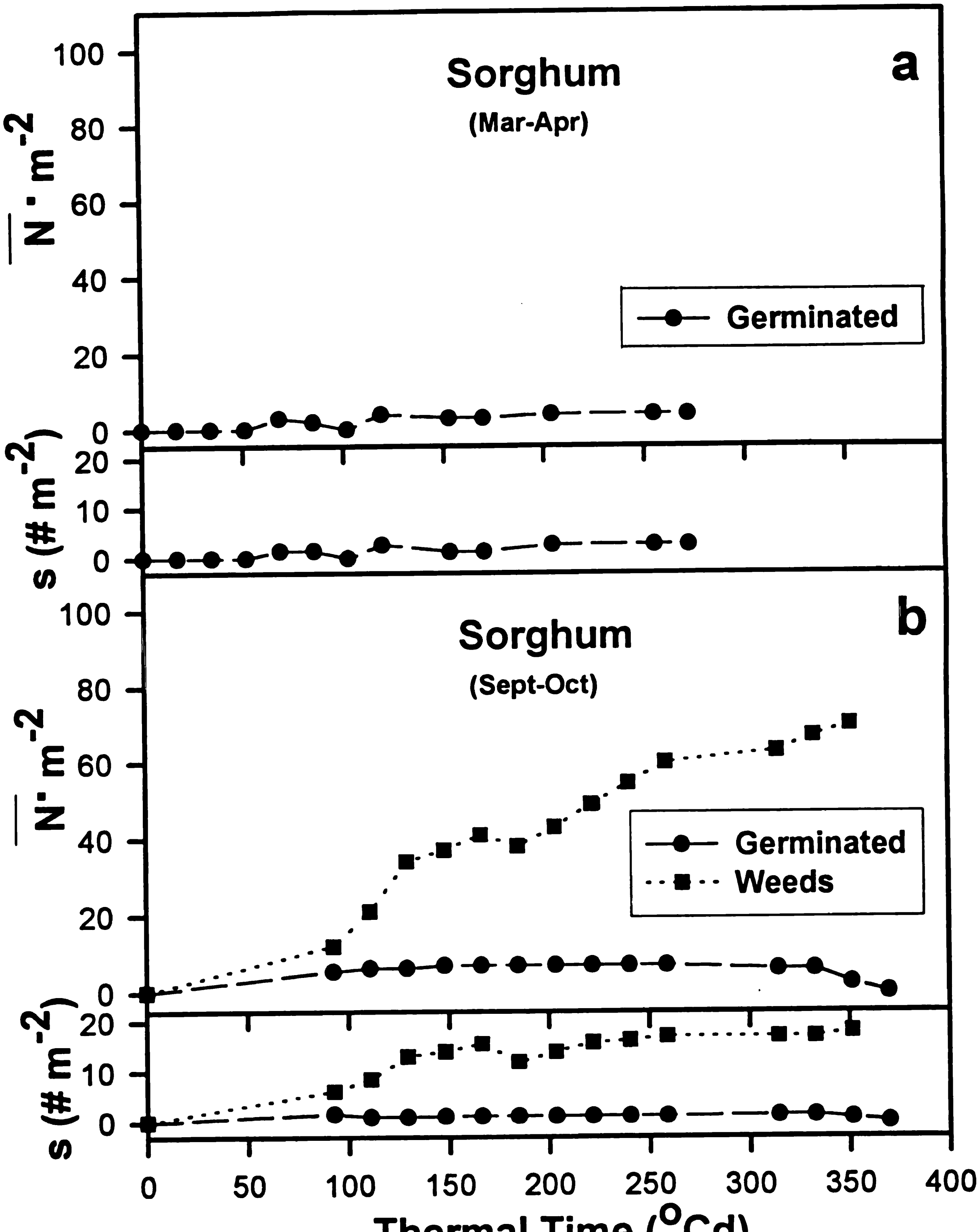

Figure 6. Mean density (N) and standard deviation (s) of weeds and germinated and ungerminated bird-resistant sorghum seeds in the field: a) March-April and b) September-October

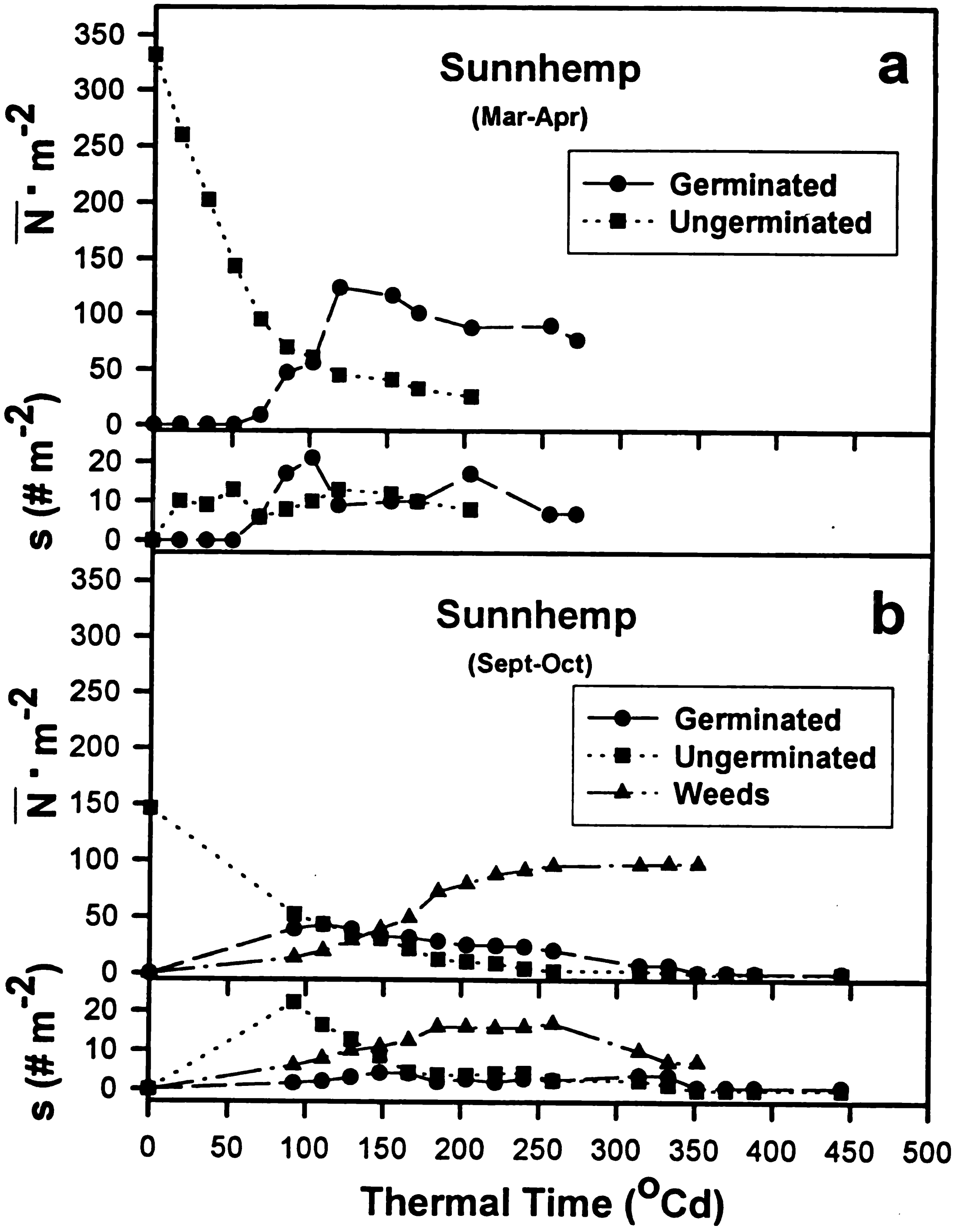

Figure 7. Mean density (N) and standard deviation (s) of weeds and germinated and ungerminated sunnhemp seeds in the field: a) March-April and b) September-October

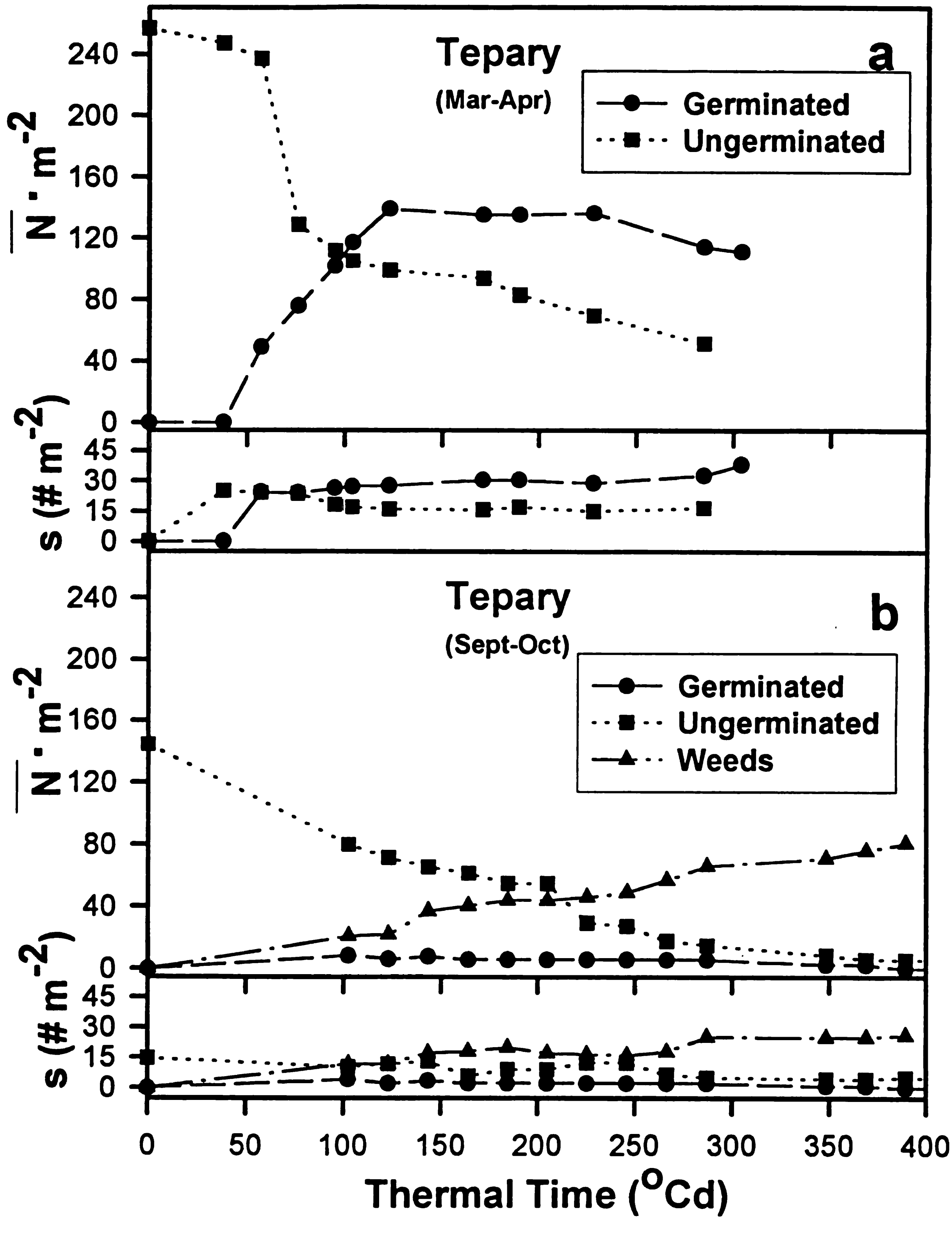

Figure 8. Mean density (N) and standard deviation (s) of weeds and germinated and ungerminated tepary seeds in the field: a) March-April and b) September-October

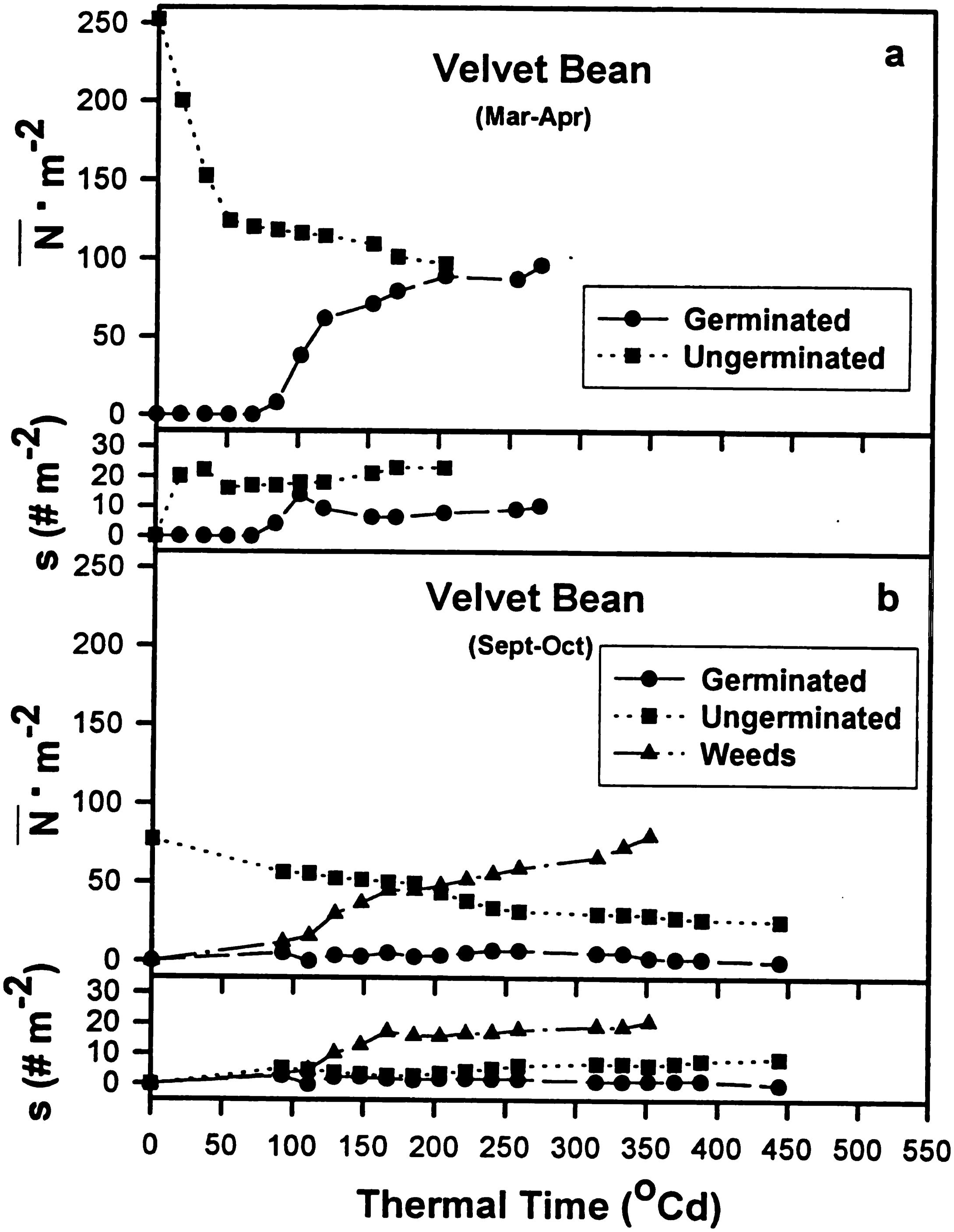

Figure 9. Mean density (N) and standard deviation (s) of weeds and germinated and ungerminated tropical velvet bean seeds in the field: a) March-April and b) September-October

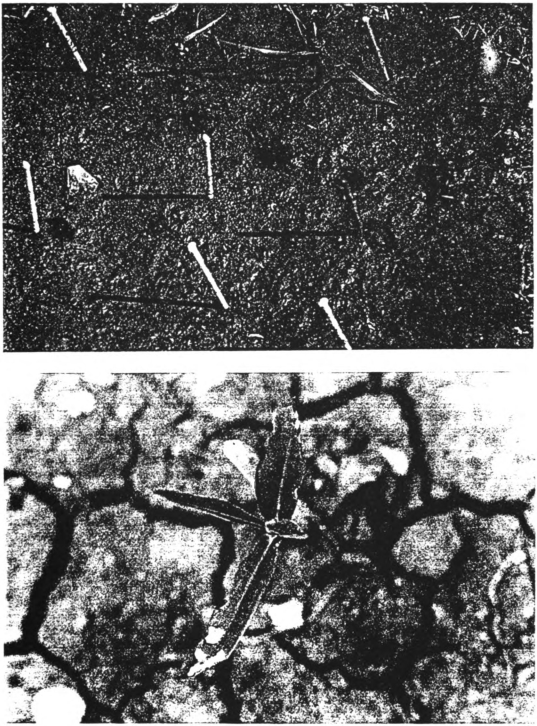

Figure 10. Photographs of: (top) white velvet bean seeds that have turned black and subsided into the soil, and (bottom) sunnhemp seedlings with insect damage

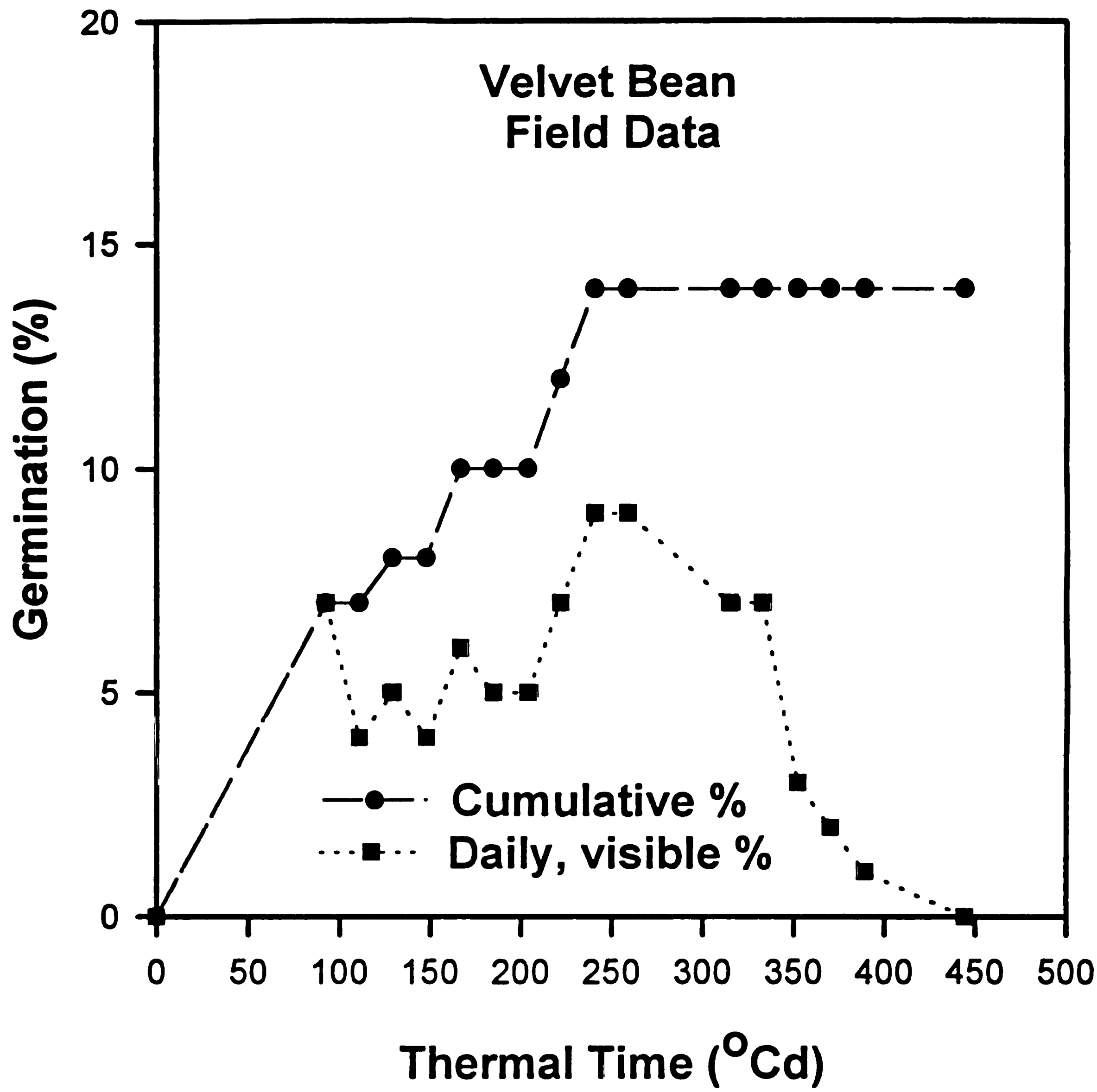

Figure 11. Actual vs. cumulative germination percent of tropical velvet bean in the field

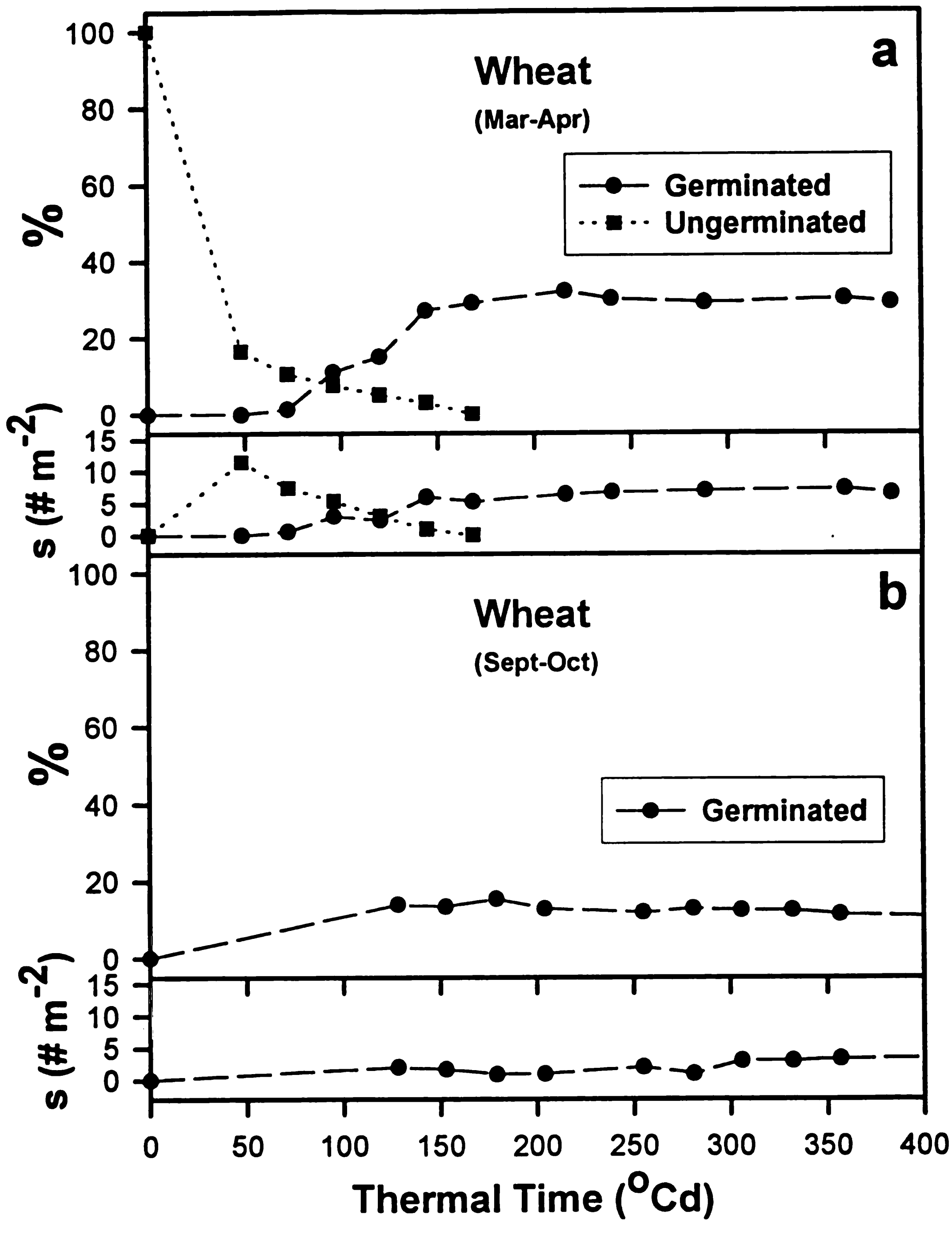

Figure 12. Mean percent (%) and standard deviation (s) of germinated and ungerminated wheat seeds in the field: a) March-April and b) September-October

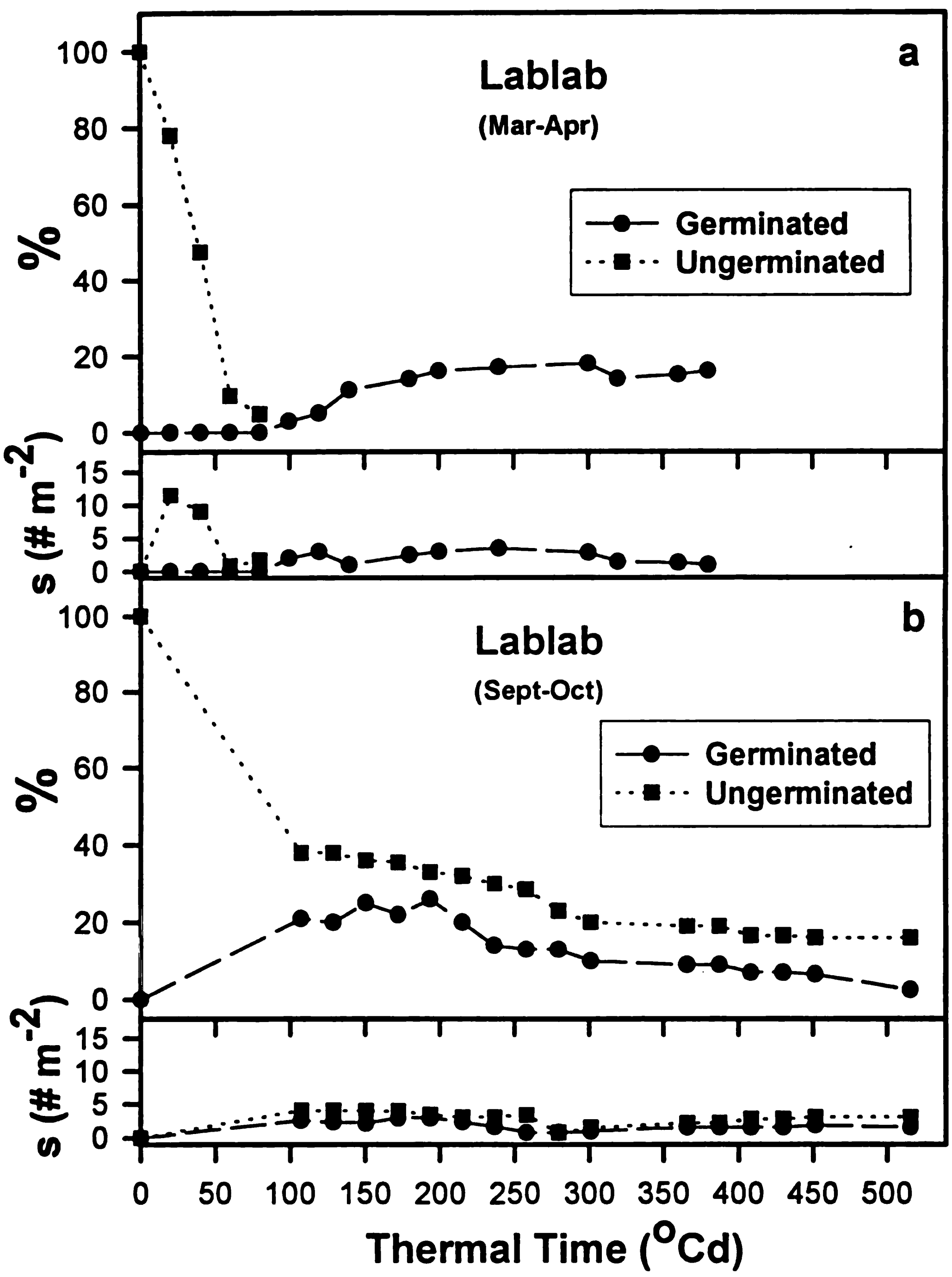

Figure 13. Mean percent (%) and standard deviation (s) of germinated and ungerminated lablab seeds in the field: a) March-April and b) September-October

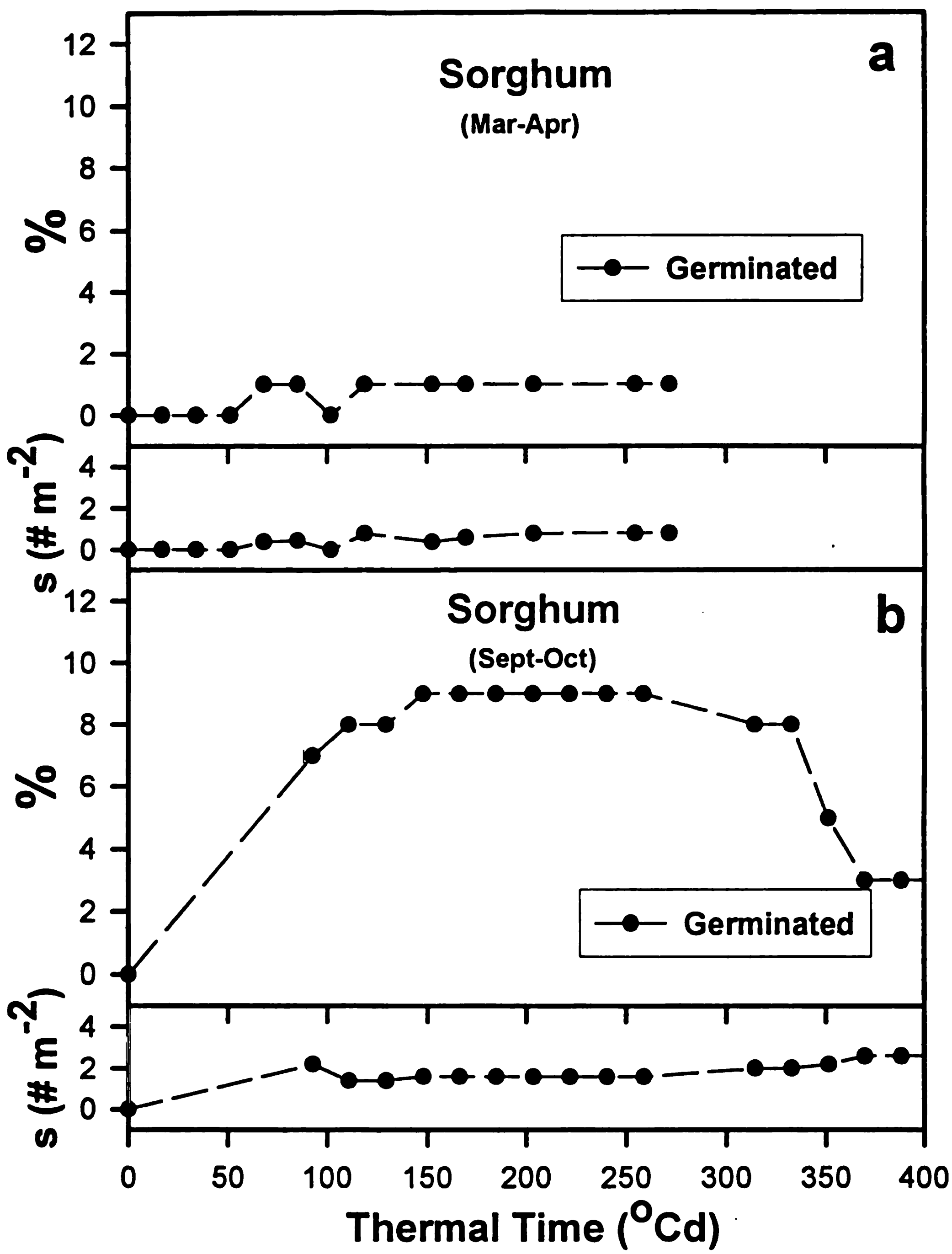

Figure 14. Mean percent (%) and standard deviation (s) of germinated and ungerminated bird-resistant sorghum seeds in the field: a) March-April and b) September-October

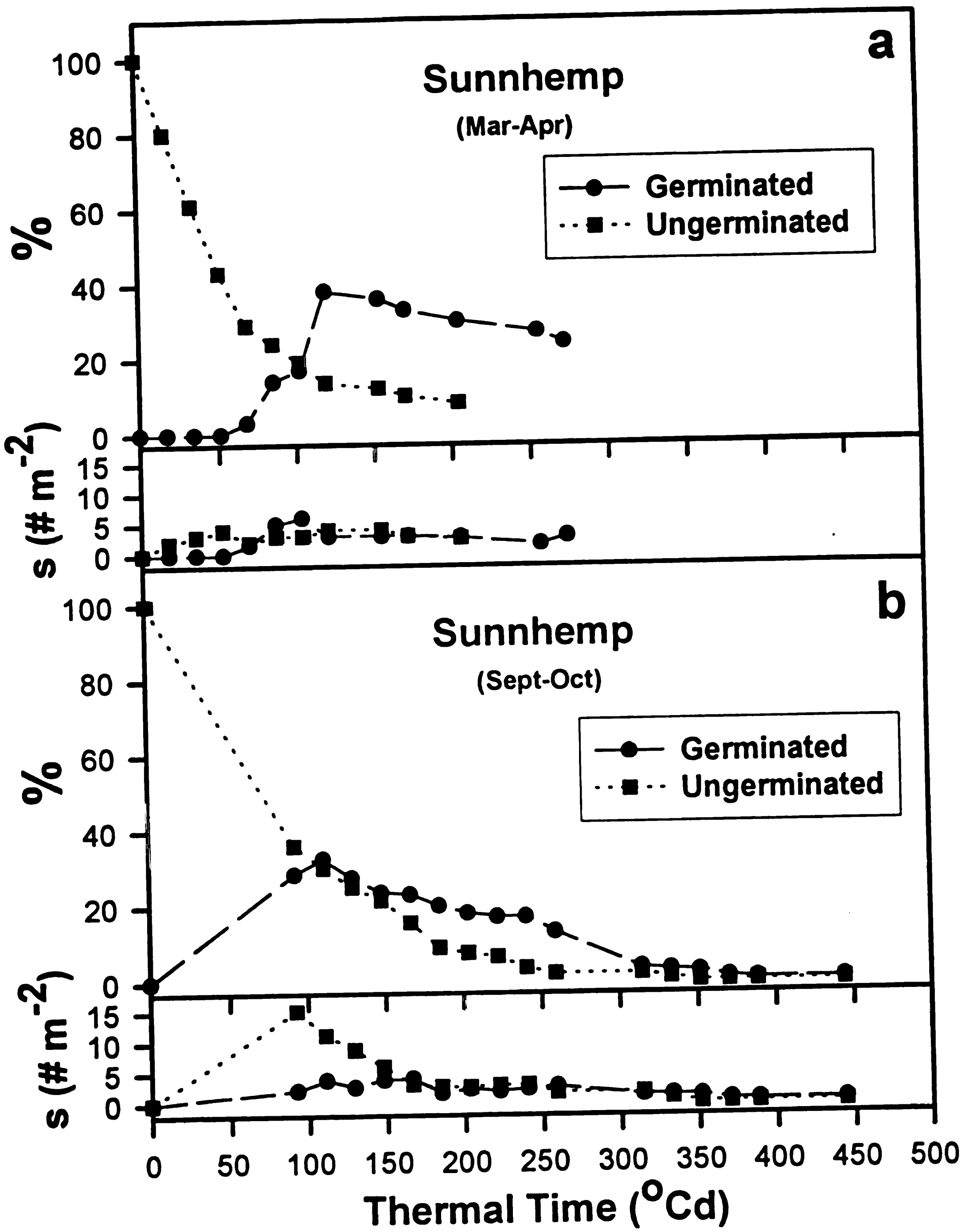

Figure 15. Mean percent (%) and standard deviation (s) of germinated and ungerminated sunnhemp seeds in the field: a) March-April and b) September-October

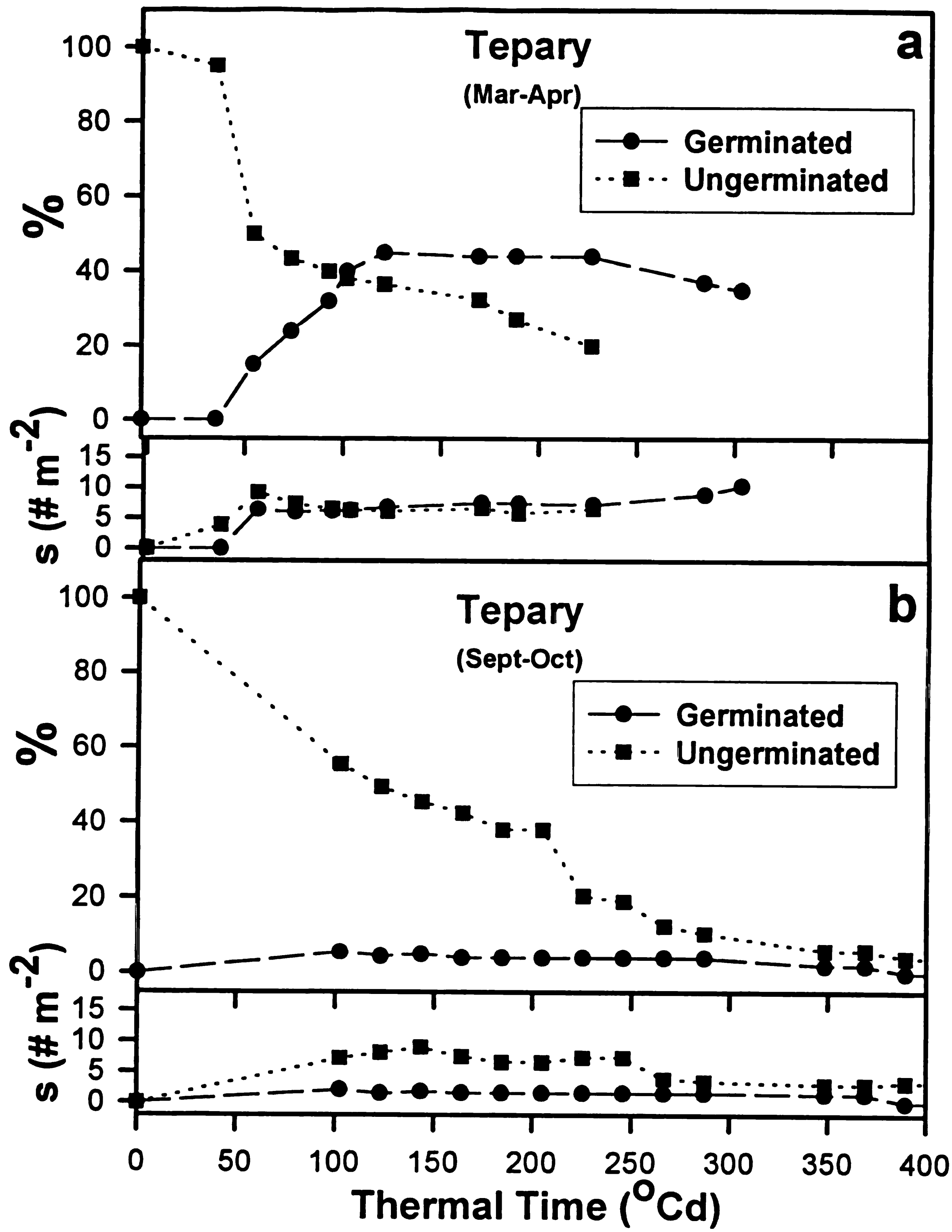

Figure 16: Mean percent (%) and standard deviation (s) of germianted and ungerminated tepary seeds in the field: a) March-April and b) September-October

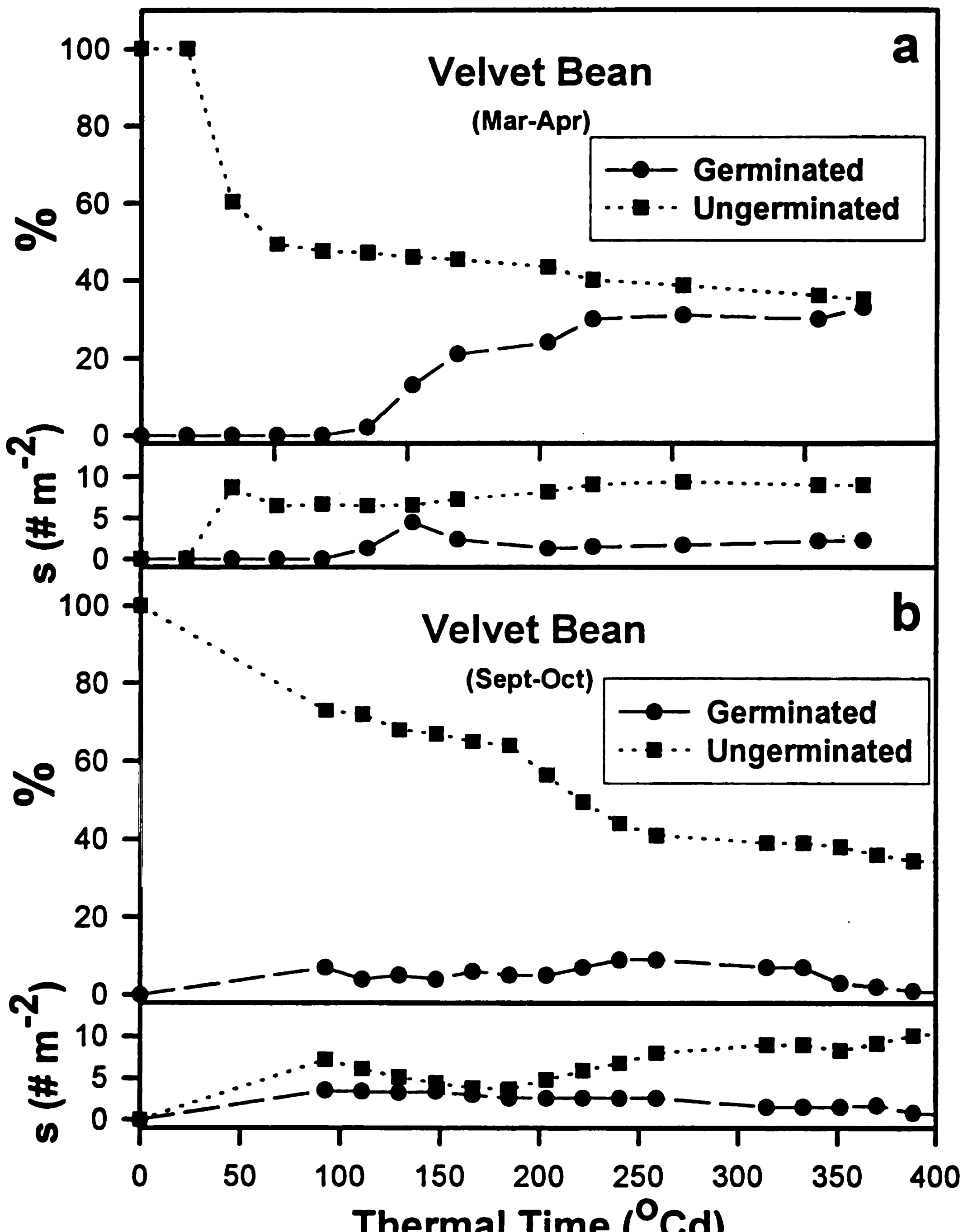

Figure 17. Mean percent (%) and standard deviation (s) of germinated and ungerminated <u>tropical velvet bean</u> seeds in the field: a) March-April and b) September-October

CHAPTER 3

SOCIO-ECONOMIC FACTORS RELATED TO USE OF VEGETATIVE COVER AT A TROPICAL FIELD SITE

INTRODUCTION

Socio-economic factors influencing adoption of technology in small-scale agriculture of the tropics have been ignored in the past in the search for solutions to land degradation (Conway, 1986). The result has been that often technology with great potential has not been adopted by subsistence farmers, because agricultural professionals have made inaccurate assumptions about what farmers want or need, or they have concentrated on the wrong problems (Chambers et al., 1989). Therefore, research summarized in this chapter moves one step beyond the traditional scientific approach to agronomic problems. The research presented here makes use of survey research techniques (Alreck and Settle, 1985; Casley and Lury, 1987) to gather information both about what is happening in the aggregate in farmers' fields at the Dominican Republic field site and about what is hapening outside their fields that may affect what happens within their fields.

The hypothesis of this study is that quantitative and qualitative analyses of agronomic practices and socio-economic factors at the tropical field site will provide an understanding of both that will aid in making cover crop technology site-appropriate. Thus, the objective of the research was to identify local agronomic practices and problems and identify socio-economic factors with potential impact on adoption or use of vegetative cover.

MATERIALS AND METHODS

A sample of farming households was interviewed in April, 1992, with two sets of survey questions (Appendix I), one for the head of the household dealing with farming and one for the spouse dealing with gardening, family health and nutrition. The study population for the survey included all those families living in housing units within the village of Buen Hombre, whose head of household was a member of the local farmer's association. Each farming household had an equal probability of being selected for participation in the survey. The overall sampling rate for a farming household family unit was .67 or 1 in 1.50.

The list of farming association members prepared by the secretary of the association included 30 names. Twenty households were randomly selected for interviewing. Final response rate for the study was r = 20/20 = 1.00.

Questionnaires were edited, open-ended questions were grouped into like categories and responses were recorded on coding sheets. Data were entered into a computer analysis package in a rectangular format, sorted, checked for "illegal," or incorrect, codes and inconsistencies. Since there was a uniform sampling fraction, taking 1/1.5 of farming households in the village, a weight of 1.5 could be used to estimate the entire population of farming families.

RESULTS AND DISCUSSION

Introduction

Although survey questionnaires are used successfully in many developed countries to elicit a wide range of socio-economic and political data, this technique posed some problems for people in Buen Hombre. People in this village do not normally view the world or interact with it in terms of quantifiable data and information. Questions about how often and how many were difficult for villagers, especially with retrospective questions that referred to an entire year. In spite of this, villagers appeared to enjoy the extra attention and gave meaningful answers to many questions. Data from formal interviews were supplemented with key informant interviews on specific topics, informal walks through the village with small groups of villagers to survey agriculture, trees or plants and group meetings with relevant adults to construct a seasonal calendar and draw a village map.

Demographic information

The survey questionnaire provides a useful perspective on villagers and village life. Farming families range in size from small to large, with approximately four children and two adults per family (Table 1). Only 45% of household heads were able to respond to a question about annual income. Mean agricultural income for the 35% of respondents with incomes below $715 U.S. was $284. Ten percent of respondents had annual farm incomes above $2,860, with a mean of $4,100.

To a question about total family income over the past year, a year of drought, 45% responded, "Don't know;" 25% said none or very little and the mean for those responding with an amount was $381. Key informant interviews elicited the information that during the month of December and sometimes January, when crops had just been planted and the sea was too turbulent for spear-fishing, many villagers simply slept. They were not taking in enough calories to do anything else (T. Perez, personal communication).

Agriculture and farming

Fifty percent of household heads never attended school, 30% attended for two or three years and none completed more than 6 years of schooling. Nineteen percent of the remaining adults sampled had no schooling, 27% attended one or two years of school and 14% finished seventh or eighth grade.

Fifty percent of farmers farm one plot, 35% farm two and 15% farm three. Thirty-three percent inherited their land, 43% obtained it from the state by cultivating the land over a number of years, 5% bought their land and 10% received it through some combination of the above. Ten percent rented the land they work. The mean size of land owned was 69.4 tareas, or 4.37 hectares. Sixty percent farm flat land, 10% farm slopes and 30% farm both. Slopes are 6-12% (farmed by 10% of respondents), 12-18% (5% of farmers), 18-25% (10% of farmers) and 5% of farmers work slopes greater than 25%. Fifty-five percent farm more than one soil type. Eighty-five percent farm black soil, 40% farm yellow, 10% farm red, 15% work sandy soils and 15% stony. Only 15% use soil amendments (manure, ashes and undecomposed organic matter), but 85% use insecticides, provided by the tobacco company, for tobacco. Ninety-five percent save seeds from one year to the next, and 35% exchange seeds or cuttings with other farmers.

All farmers surveyed grow tobacco for cash, as well as beans; 95% grow corn, 70% pigeon peas, 65% a tropical sweet potato variety and 60% grow cassava. Farmers also mentioned eggplant, tomatoes, broad beans, onions, watermelon, carrots, and cucumber.

Seventy-five percent of farmers sow the same crops each year, and 80% sow more than one crop per field. By their own account, only 10% of farmers do any experimentation and that is to test which crops do better on different soils. Ninety-five percent save seeds from one year to the next, and 35% exchange seeds or cuttings with other farmers.

Because rainy season onset varies annually, the timing of field clearing with machetes, hoes, a government tractor or the tobacco company tractor also varies and is often completed over a period of several months. Fifty-five percent of respondents clear fields in November, 35% also work in October and 25% in December. Tilling and planting generally occur between October and December, with some harvesting as early as February. Sixty percent of farmers harvesting some crops in March and 40% in April. Seasonal labor requirements, in a calendar based on information gathered during group meetings with 90% of adult villagers, shows average monthly precipitation and gives a rough indication of time use in the village by gender (Figure 1). Months of greatest rainfall are accompanied by high farming activity. Low rainfall tends to be paired with increased fishing activity, as heavy rainfall causes coastal turbulence and impedes fishing.

Ninety-five percent of families give some of their harvest to others. Eighty percent were unable to attach a monetary value to those gifts, but $104 was the mean value given by those who responded. Eighty percent own farm animals, chickens, goats, pigs or cows; seventy percent give farm animals or farm animal products to others and 25% sell to others. Sixty percent gather wild plants for use as medicine, spices or in the home.

Gardening

A separate set of questions was asked of the spouse of the head of household. Fifty-three percent of the 19 sampled wives responded that they had had a garden the previous year. Ninety-five percent said they plant a garden when it rains. Seventy-five percent of these gardens are flower gardens, and 20% are a mix of flowers and vegetables. Thirty-seven percent of the women amend their soils with manure, ashes and fertilizer; and 37% add insecticides. Twenty-six percent buy seeds, 68% save seeds from year to year and 95% exchange seeds or cuttings.

Health and nutrition

When there is sufficient food, 79% prepare three meals a day. When food is insufficient, 53% prepare two meals and 42% prepare only one. Village women cook white rice, beans and sometimes fish, when there is little food. Vegetables, bread and milk are added to meals in good times. Forty-two percent of women supplement their family's diet with wild plants, such as leafy greens and chicory.

Women report their children are ill anywhere from several times a month (37%) to several times a year (37%) with flu, diarrhea, fever and anemia. Adults are ill less often, generally two to four times a year with flu, headaches and various infections. The responses from both men and women verified by observations during field work, portray a harsh subsistence existence with malnutrition, ill-health and infectious diseases for many villagers much of the year. Because their parents can no longer support them, children are often sent out of the village to work by age 12.

Quality of life

One way of ascertaining quality of life indirectly is to ask respondents how they would improve their lives. Responses to this type of question vary somewhat by gender, as Table 2 shows. For improving family life, men mention employment most frequently and women mention education. Both men and women agree that water and roads are the most important factors in improving conditions for the village as a whole. Agriculture projects are mentioned by only 10%, either because of a failed tobacco project in 1984, with a resulting lack of hope by villagers for agriculture, or because agricutlural projects will need to be tied to other projects (R. Stoffle, personal communication).

Vegetative cover

In the survey, no direct questions were asked of villagers about the use of vegetative cover crops in the dry season. Because of interpersonal ties that had developed between villagers and the interviewer, there was a strong possibility that answers would be biased toward what villagers perceived the interviewer would want to hear. Instead, key informants (two different presidents of the farmer's association) were asked if they thought villagers would be interested in or willing to grow drought-tolerant crops during the dry season, providing the crops produced food or animal feed. Both men responded with a definite yes (R. Cabrera and A. Burgos, personal communication).

In another indirect approach to assess village attitudes to specific cover crops, seedlings were left to survive on their own when field experiments were completed. Jack bean, from an early hillslope experiment (data not reported), grew to maturity and produced seed with no rain beyond that which fell in the first week after planting. Farmers called the plant "the miracle bean." Tepary bean also grew to maturity with whatever rain fell during the dry season at the end of the March-April experiment. Beans were subsequently harvested and cooked by the landowner's wife in a dish that the entire family was said to have enjoyed (T. Perez, personal communication). This farmer requested that every villager be given access to tepary seeds for dry season planting.

The situation in the village late in the dry season and early in the rainy season is so severe, that even though villagers generally do not experiment with ways to improve agriculture, there is great potential for crops like tepary and jack bean. If such crops are introduced carefully, and villagers are shown when to plant, the necessity of overseeding and protecting plots from goats, etc., the species tested in this study could make a positive difference in villagers lives' and ecosystems.

CONCLUSIONS

Survey responses indicate there would be great demand for off-season, food- or income-producing species in Buen Hombre. Also, vegetative cover would be likely to prevent at least some erosion, as 30% of farmers cultivate land with a 6% or greater slope.

Most farmers in the village fish, as families who depend entirely on farming migrated out of the village by late 1993, due to an extended drought and persistently low tobacco prices (A. Burgos, personal communication). Yet wives' responses indicate that combined fishing and farming activities do not provide enough food for three meals a day throughout the entire year, even when taking into account villagers' proclivity to share what they have with others. In addition, responses of household heads indicate minimal cash income each year. The two leading responses of sampled adults on how to improve fmily life are employment and education. Presumably education is perceived as a path to employment.

These socio-economic, diet and health variables indicate the need for additional food and income in the village. The findings of this study suggest that villagers would be eager to plant off-season crops and would willingly incorporate at least one of the tested species into their diet. A seasonal labor calendar (Figure 1) indicates that March and April are already very demanding in terms of male labor, with heavy commitments to harvesting and spear fishing. May appears to be the best month for planting of vegetative cover, both in terms of labor commitments and precipitation. Additionally, there are lower labor commitments for males in the months right after May, when weeding and harvesting would occur.

Thus, a traditional survey, has provided initial information about local agronomic practices and problems and socio-economic factors. These data indicate that certain species of off-season vegetative cover would be likely to be adopted and used by villagers, especially with more extensive field testing in collaboration with villagers and professionals. The process of change needs to include research and development, in which change is evaluated as it occurs.

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Table 1. Household composition of farming families, Buen Hombre

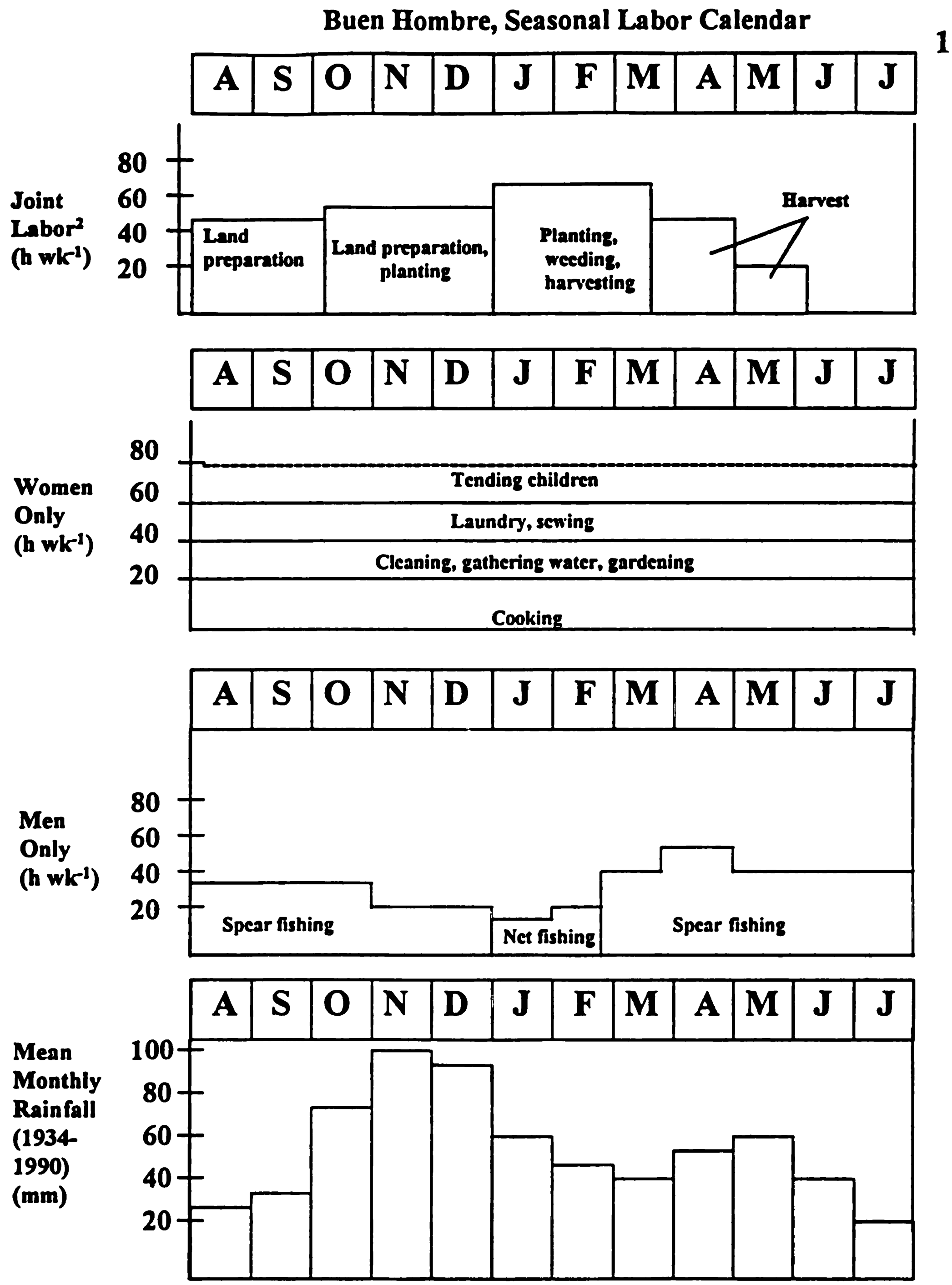
People per household	Mean	Range
	--#--	--#--
Total	5.9	1-13
Males	3.1	1-7
Females	2.8	0-9
Age 21 or over	2.0	1-3
Under age 21	3.9	0-11

Table 2. Factors that would improve life for families and village as a whole, opinions of farmers and wives, first five mentions

Factor	Factors that would improve life for respondents family[1]		Factors that would improve life for village[2]	
	Males	Females	Males	Females
	% mentioning factor			
Employment	60	16		11
Education	35	53	10	11
Water		16	85	79
Food and health	20	11		
Roads		11	75	79
Electricity	10		45	68
Agriculture project			10	

1 Question respondents were asked: If anything were possible, what would you like to see for the future of your family?

2 Question respondents were asked: If anything were possible, what would you like to see for the future of Buen Hombre?



1 Months of the year starting with August

2 75-85% contribution from men; 15-25% contribution from women

Figure 1. Seasonal labor and precipitation calendar, Buen Hombre

CHAPTER 4

ECOLOGICAL AND REMOTE SENSING ANALYSES OF A CARIBBEAN VILLAGE: A CASE STUDY FROM THE DOMINICAN REPUBLIC

OVERVIEW OF INTERNATIONAL DEVELOPMENT AND ARGUMENT FOR A NEW APPROACH

For many years, the approach to international development has involved the imposition of solutions and technologies of the northern hemisphere on countries of the South (Korten, 1990; Reintjes et al, 1992). Traditional development efforts have generally involved importing technologies to deal with specific, individual development problems, ignoring environmental and socio-economic heterogeneity of indigenous systems (Conway, 1986). Attempts to simplify complex, local subsistence management systems by introducing costly, non-renewable, external inputs have failed to improve subsistence life in the tropics (National Research Council, 1993).

As an example, technological change introduced to agriculture has usually involved mechanization, improved seeds and the use of pesticides and fertilizers, and has emphasized large-scale production by large landowners. Specifically, in

Latin America, it has resulted in countries becoming net importers of agricultural chemicals and machinery, with increases in production of export/commercial crops (Altieri, 1992). For many subsistence farmers who have converted to cash crops, the conversion has been accompanied by "loss of food self-sufficiency, genetic erosion, loss of traditional farming knowledge, [and] permanence of rural poverty" (Altieri, 1992).

High-input development approaches have fostered dependency and instability, while increasing risks, rather than reducing them (Lightfoot and Noble, 1993). Again in Latin America, there has been a trend toward diminished government involvement in technological change and increasing private sector involvement. The private sector's focus has been on technology that increases profits (fertilizers, pesticides, biotechnology), rather than on technology that promotes sustainability and stability (mixed cropping systems, biological insect control, green manure) (Altieri, 1992).

Increasingly today, however, traditional development perspectives are being replaced by more sustainable approaches that are participatory and multi-disciplinary and based on indigenous tropical cultures and environments. The reasons for this shift are well-documented (Chambers et al, 1989; Conway, 1986; Eswaran et al, 1993; Lal and Ragland, 1993; Senanayake, 1984).

Senanayake (1984) gives an example of substituting tractors for buffaloes in Sri Lanka in order to save time and labor. Direct losses to villagers, due to the replacement of buffaloes, included loss of milk and manure. Indirect losses stemmed from the disappearance of buffalo wallows, which provided, among other things, refuge for fish in the dry season, when rice paddies were dry. The fish were a protein source for landless villagers and were predators of the larvae of malaria-carrying mosquitoes.

In order to shift successfully from traditional development approaches to more sustainable approaches, scientists, development professionals and government officials need a basic understanding and knowledge of local human systems and ecosystems. The key to understanding complex, local systems and to developing management systems that increase ecosystem production, while conserving and sustainably exploiting them, is indigenous participation and knowledge. By involving local communities in assessing their natural resource environments and in developing more productive systems, fragile socio-economic and environmental conditions can be strengthened and enhanced (Lightfoot and Noble, 1993). Change based on indigenous systems can ensure cultural and ecological compatibility.

Critical to the development and introduction of new technology that is also sustainable is an emphasis on innovations that are ecologically appropriate, such as dryland agronomic management techniques and xerophytic cultivars for arid regions (Lightfoot and Noble, 1993), rather than high-cost irrigation, chemical and machinery inputs. The advantage of particpatory approaches is that they can contribute to sustainable development by adapting external technologies to local conditions through collaboration with local people, or through simple refinement and improvement of already existing local technologies. The disadvantage of the use of participatory methods alone (to the exclusion of technological methods) is that the result may be too simplistic for the situation.

Throughout the world, natural resource problems are frequently intensified by population pressure on the environment, increasing the rate and severity of degradation. Problems are further complicated by diverse human groups with widely divergent opinions about what the problems are, what the causes are and how to solve them. For difficult, multiple-issue problems, technological solutions alone can also be insufficient to deal with complex, dynamic interactions between people and their environments.

Wilson and Morren (1990) describe a comprehensive, practical procedure for dealing with complex agriculture and natural resource problems. It combines participatory methods used in international development in countries of the South (Chambers et al., 1989; Haverkort et al., 1991) with soft systems methods used in industry and government in countries of the North (Checkland and Scholes, 1990). Wilson and Morren present a strong case in favor of what might be called a "participatory-systems" approach to "messy," multi-faceted population-environment problems. Briefly and very simply, this approach requires participation of all relevant parties to a specific situation. Through examining the situation from different perspectives and by using a systems approach, the goal is to reach agreement on what the problem is, what would constitute improvement and what methods and technologies would achieve agreed-upon goals. This technique is participatory, holistic and multidisciplinary. The method combines basic and applied science with "hard" and "soft" systems science, using participatory methods.

The first step in the participatory-systems process involves conducting quantitative and qualitative inventories of relevant ecosystems and related human systems (Wilson and Morren, 1990). These inventories form the basis of subsequent steps in the process. They are used to define specific human-environment problems in a region, design appropriate research; propose and put into practice feasible, sustainable and equitable solutions; monitor change and evaluate alternative solutions prior to field testing. If done properly, initial inventories and resulting analyses can explain a few critical relationships in both ecosystems and human activity systems, focusing limited research and development resources on a few key areas where significant improvements can be made. The careful use of existing resources is particularly important in developing countries where institutional and professional human resources are often inadequate.

BUEN HOMBRE: A TROPICAL CASE STUDY

In 1985, Stoffle (1986) conducted research in an isolated farming-fishing village on the northwest coast of the Dominican Republic. There were two key findings in that initial and subsequent research:

- first, a development project that was highly successful from a technological standpoint and was appropriate from a socio-cultural perspective, but failed because of competition between the development agencies involved (Stoffle et al., 1991)
- and second, villagers modified and improved introduced technology based on expertise with and knowledge of local species and ecosystems.

Subsequent to that research and the project failure, village leaders stated that they would not agree to any further development projects in the village unless they were actively involved, had veto power and strong leadership roles (N. Gomez and T. Perez, personal communication).

Another study (Stoffle and Halmo, 1991), that overlapped with the initial stages of research conducted by this author and involved collaborative research efforts, found that along the northwest Dominican coast, local ecosystem change and the human dimensions of that change could be monitored and predicted through interdisciplinary applications of remote sensing research. Further, such research could be used in planning and protection of coastal ecosystems.

These two studies indicated that the village of Buen Hombre (Figure 1) and the situation occurring there would provide an excellent example of the dynamic and complex natural resource crises for which a participatory-systems approach to problem-solving is appropriate. A potential crisis is developing in Buen Hombre, involving people and their natural resources. Decisions being made over the next few years may have irreversible consequences for the future of this region. The situation is complex and constantly changing. It involves subsistence villagers who depend on fragile marine and terrestrial ecosystems for survival, outsiders who are encroaching on the resources in these ecosystems illegally and destructively, a potentially harmful government edict declaring the region a tourist zone (J. Serulle, personal communication), and apathetic, corrupt local government officials.

This paper presents a case study of Buen Hombre within the framework of the participatory-systems model described by Wilson and Morren (1990). More specifically, it presents summaries of collaborative research and of previous research in the village (Stoffle and Halmo, 1991) and analyses of preliminary inventory data collected as a first step in the participatory-systems process. To that end, using quantitative and qualitative tools from several academic disciplines, data were collected between 1990 and 1993 during six research trips to this coastal village to assess critical human and ecosystem resources.

Central issues of the situation in Buen Hombre will be presented from a multidisciplinary perspective. The expectation is that this background information will be used by relevant groups of people to test and evaluate the participatory-systems approach in developing a comprehensive ecosystem management system for the region. Buen Hombre would serve as an excellent pilot project for the Caribbean, because it is representative of a situation common to the islands, in which human groups are engaged in intricate, survival-based interactions with closely linked, stressed ecosystems that serve as a buffer between land and sea.

MARINE AND TERRESTRIAL ECOSYSTEMS

Coastal marine and terrestrial ecosystems along the northwest coast of the Dominican Republic are intricately related ecologically and to human subsistence activity. Both ecosystems and related human activity systems are discussed.

I. Reef and Coastal Mangrove Ecosystems: General Background

Mangroves are tropical, forested, coastal wetlands that "thrive in the shelter of coral reefs" and provide a spawning ground for fish, as well as a home for crabs, shrimp and mussels among the mangrove roots (Weber, 1993). Mangroves serve to stabilize coastlines from weather damage, protect coral reefs from silt due to erosion and are in turn buffered from the ocean by coral reefs. In coastal areas where mangroves have been cut, fish populations have dropped, due to the key role mangroves play in the life cycle of fish (Weber, 1993).

Coral reefs support algae and grasses, which in turn support diverse populations of marine animal life. Reefs are considered second only to tropical rainforests in biological diversity, with considerable potential to contribute to science and medicine (Weber, 1993b). However, coral reefs are easily stressed (or "bleached") and can be killed by overfishing, abnormal temperatures, excessive fresh water, excessive human activity or high rates of sedimentation due to erosion. Because humans "disrupt and destroy reefs too often for the corals to recuperate fully" (Weber, 1993b), human disturbances are more difficult for reefs to recover from than natural disasters.

When reefs are stressed, coral polyps expel zooxanthellae, the red, yellow or orange algae which live symbiotically in the translucent coral tissue, providing food and oxygen from photosynthesis to the coral and receiving structural protection from the coral in return (Weber, 1993b). When zooxanthellae are expelled, reefs appear white, as the white calcium carbonate coral skeletons become exposed. Because of this change in color, the process of reef degradation, or "reef bleaching," can be monitored, using satellite images (Figure 2).

The worldwide trend for reef systems, documented by reef scientists over the last two decades, is that generally only remote reefs with little human activity have remained healthy (Weber, 1993b). The Dominican Republic is one of 18 countries, including neighboring Haiti, Cuba, and Jamaica, with seriously devastated reef systems, due to dense coastal populations and heavy coastal development (Weber, 1993b). Sediments resulting from deforestation, especially from mangrove clearing, wash into the sea and block the sunlight needed by zooxanthellae to complete photosynthesis. The sedimentation begins a chain reaction that leaves coral weakened and more vulnerable to disease and other stresses.

Coastal development, often for tourism, drives mangrove destruction. The destruction results not only in increased siltation in coastal waters, but the destruction of shellfish habitats and fish spawning grounds. Sewage and urban runoff are introduced, which degrades coastal water quality, fostering eutrophication (influx of nutrients from soils and sewage), which in turn overfertilizes zooxanthellae, which multiply to toxic amounts inside coral polyps (Weber, 1993b).

II. Reef and Coastal Mangrove Ecosystems of Buen Hombre

The village of Buen Hombre, "Good Man," lies 44 km northeast of the Haitian border (between 19°51'0" and 19°52'10" N latitude, 71°23'10" and 71°25'30" W longitude), offshore from a triple reef system in the middle of one of the longest stretches of coastal mangrove growth in the Caribbean (Figure 3). The isolated Buen Hombre reef system is one of the most vital, biologically diverse and ecologically complex systems remaining in the Caribbean (Luczkovich, 1991). It has been fished sustainably for a hundred years by Dominicans descended from Cuban immigrants, and four hundred years before that by pre-Colombian Indians. The northwest coast's triple reef system has an inner, middle and outer reef, with a break in the long reef system just offshore from Buen Hombre, permitting boat passage to and from the village.

Through ground-truthing and interpretation of time series Landsat satellite data (1975, 1985, 1989) for the northwest coast, Wagner et al. (1991) and ERIM (1994) reported "early indications of environmental stress due to human factors [fishing and tourism]" in neighboring reef systems east of Buen Hombre. These reefs, approximately 40 km to the east of Buen Hombre, at Punta Rusia, have substantial tourist activity and very few mangroves. Reefs to the west, approximately 40-45 km away, near the larger Dominican city of Monte Cristi, are "fished out." Reefs just across the Haitian border to the west are dead.

The obvious question is: what is different about Buen Hombre? Why are its reefs healthier than those of its neighbors? There seem to be three related reasons:

A. Population

1. Low population:

The 1981 census reports 397 people in 82 occupied dwellings in Buen Hombre (Castillo, 1991). Eleven years later, in the middle of a 4-year drought, an unofficial census completed under the direction of the author showed population had fallen to 329 occupants (188 males, 141 females) in 83 dwellings. Population in the village traditionally fluctuates with rain, or anything that affects subsistence activity. In periods of contracted drought, there is permanent and temporary migration to cities and towns inland. Migration is the traditional method of relieving population pressure on limited natural resources. Women tend to emigrate in greater numbers, perhaps due to the ease with which they can find domestic employment.

2. Low population density:

The census mapping area that includes Buen Hombre is the Buen Hombre District and includes three other villages with a total 1981 population of 929 (Table 8) over a total of 4,091 hectares, resulting in a population density of 32.4 people per km^2, or approximately one person for every 3 hectares (7.4 acres). This figure is relatively low, compared to 277.6 people per km^2 in El Salvador, the most densely populated Central American country, or 65.1 people per km^2 in Costa Rica, with the second lowest population density in Central America.

B. Physical environment:

Buen Hombre is isolated and separated from the rest of the island to the south by the Cordillera Septentrional mountains (Figure 1). The topography is mountainous and hilly, with a gradual descent to the sea. The rugged, dirt road north from the main highway (Highway 1, *Carretera Duarte*) is a one-hour drive to Buen Hombre. The climate is semi-arid, as the village lies in the rain shadow of the mountains. Annual rainfall is 600 to 700 mm, with an unpredictable rainy season between October and January to March, with the driest months falling between July and September (Portman et al, 1991). Droughts are common.

"Potable" water must be brought in by burro or motor during most of the year. A few houses have *aljibes*, simple roof water catchment systems with cement block cisterns. The lagoon also catches and stores rainwater, for a few months after the rainy season. The Buen Hombre well, with *agua salada*, saline water, is used for watering stock and kitchen gardens, and for laundry and bathing. The closest drinking water source, when filled by government water trucks, is the government cistern (3 km away). Most villagers pay local moped owners to transport water from at least 4 km away in Las Canas.

Water samples from three of the four fresh ("sweet") water sources used by villagers were sampled by the author according to standard Michigan Department of Health (MDPH) procedures in 500ml containers provided for that purpose and were later analyzed by the MDPH Water Supply Division. Test results validate villagers' perceptions of local well water as being *muy mal*, very bad (Table 1). It is highly mineralized, with unacceptable levels of nitrates and sulfates. Lead levels are somewhat high, but could be naturally occurring (Williams, personal communication). Water from district lagoons falls within acceptable limits for tested characteristics, though bacteriological tests for coliform bacteria were impossible to perform within the required time frame from source to testing laboratory. Intestinal problems are common among villagers. Farm animals use the lagoons freely as their water source and siesta spot.

C. Conservation ethic:

Village fishermen know their survival depends on reef health and conservation of marine flora and fauna. Villagers display a strong conservation ethic, which results from a long-term relationship between villagers and their ecosystems, involves a sense of ownership toward local ecosystems and involves sophisticated knowledge of the ecosystem (Stoffle et al., 1994). Informally, fishermen avoid fishing species with low populations for a year or two and ban the use of diving equipment, because of the advantage it provides humans over fish.

To illustrate anecdotally, a fisherman from the neighboring village of Las Canas was told he could not fish in Buen Hombre with his diving tank. He was then told, "If you are willing to fish with fins and a spear, as we do, you can swim beside us, and we'll welcome you as a brother" (T. Perez, personal communication).

In summary, isolation, low rainfall and lack of potable water all control population and tourism, which are also responsible for keeping human activity on the coral reefs low. Currently, low rainfall is the main factor preventing erosion and reef degradation due to siltation, and local norms prevent unsustainable fishing practices. City fishermen from Monte Cristi to the west do not have the direct survival link to the health of their reefs, as village fishermen do. Based on the behavior of these city fishermen in Buen Hombre, cultural norms in favor of sustainable practices are weak or absent among outsiders.

III. Terrestrial Ecosystems of Buen Hombre

Inland from the reef and coastal mangrove ecosystems is the valley of Buen Hombre (Figure 3), flanked to the south, east and west by mountains and hills. The main north-south road cuts through the horseshoe valley on the east edge, with houses, shops and bars clustered along the road. There is farmland up hillsides to the east of the road, and in the valley west of the houses. Before the road drops to the sea at the north edge of town, branches of the road split east and west, running parallel to the coast, with more houses and farmland adjacent to the road.

As in much of the rainfed tropics, the small-scale, low resource agriculture of Buen Hombre occurs in a complex, diverse environment and depends on the whim of weather, or more precisely, whether or not, when and how much it rains. Temperatures are tropical, moderated by near constant ocean breezes, and are not limiting for agriculture. Weather data obtained from historical accounts (Halmo et al, 1991), historical records (Portman et al, 1991) and field research (Chapter 2) indicate that lowest annual temperatures are approximately 19°C. Highest temperatures reach 33°C in July and August, with mean daily temperatures of 25 to 28°C. Relative humidity generally ranges from 60 to 70%. As villagers report, the most limiting agronomic factor in this region is low rainfall.

The goal of village agriculture, past and present, has been to reduce risk and maintain subsistence production. Of necessity and like most subsistence farmers worldwide, the approach of village farmers to management of their agroecosystems has been multidisciplinary and holistic.

Agriculture (data collected through ethnographic interviews with two farming association presidents) is a combination of a tobacco (*Nicotiana tabacum*) cash crop grown in monoculture, with a mixed cropping system of subsistence root vegetables, including cassava/*yuca* (*Manihot esculenta*), sweet potatoes/*batatas* (*Ipomea batatas*), yams/*ñame* (*Dioscorea* spp.), potatoes/*papas* (*Solanum tuberosum*) and tannia/*yautía* (*Xanthosoma mafaffa*), as well as dry beans (*Phaseolus vulgaris*), broad beans/*haba* (*Vicia faba*), corn (*Zea mays*), pigeon peas (*Cajanus cajan*) and an assortment of vegetables and fruits. Crops are rarely chemically treated or fertilized, though some pesticides are applied to tobacco. Labor is generally manual, involving all but the youngest family members. Village livestock include pigs, goats, sheep, cattle, burros, chickens and turkeys. Every family owns a few chickens.

A. Land Use

Satellite image data analyzed by Wagner et al. (1991) delineate two types of mangroves, permanently and intermittently submerged. These analyses also show that the most common terrestrial ecosystem surrounding Buen Hombre farmland is forest, ranging from light to dense, varying between degraded, cactus and dry forests. Rangelands and savannahs are the next most common land use category, with some bare soils west of the village on mountaintops and hilltops.

In a second unpublished remote sensing project by CEUR-CARTEL (Centro de Estudios Urbanos y Regionales - Centre d'Applications et de Recherches en Télédétection), aerial photos taken in 1958, 1966, and 1984 were used to generate land use maps, land use intensity and erosion risk maps (St.-Pierre, personal communication).[1] PAMAP-GIS maps of unpublished data were provided by St.-Pierre in machine-readable disk format and then translated to ERDAS, reformatted and redrawn in ATLAS-GIS by the author (Figures 5, 6, 7).

Table 2, based on information provided by St.-Pierre, was modified and translated from Spanish by the author and lists different land use categories used in Figure 5. Categories in Figure 6 were based on subjective ranking of land use categories in Figure 5, with forests ranked as low intensity land use and rainfed agriculture as high intensity (St.-Pierre, personal communication). Categories in Figure 7 for erosion risk potential were based on relative risk factors of slope, vegetative cover and land use type (Figure 4).

Detailed land use distribution (Table 3) and total land area for each major land use type (Table 4) between 1958 and 1984 for the Buen Hombre census district, which is 7.6 km south, 3.0 km west and 5.0 km east of the bay, were quantified based on CEUR-CARTEL data. Over the 26-year period beginning in 1958, there was a decrease in farmland and a corresponding increase in grazing lands, with a constant 25 to 26 km^2 of forested area, or 62% of total district land. Temporal differences occurred not so much in total land area per category, but in the spatial distribution of different land use categories (Figure 5).

The classification system (Table 2) used in Figure 5 highlights the different types of agriculture practiced in the Dominican Republic. In Buen Hombre, for example, no land is allocated to irrigated agriculture (Category 2.2 in Table 2),

[1]The author is collaborating with St.-Pierre on a paper for publication. References to St.-Pierre's portion of that collaborative effort are cited here as unpublished data.

indicating that district producers are small-scale, agriculture is low input and there is no water source. Nationwide, increased population between 1958 and 1984 corresponded to decreases of land area in forested land and increases in agriculture and pastureland (St.-Pierre, unpublished data). In Buen Hombre, where district population increased 87% between 1960 and 1981 (Table 5), the total forested area remained constant from 1958 to 1984 (Table 3), but there was a 304 hectare increase in land allocated to moderate intensity land use, with a 270 hectare decrease in land under high intensity use (Table 6). Figure 6 illustrates the spatial distribution of these data, showing substantial change over the 26-year period.

The CEUR-CARTEL data for erosion risk potential show 40% and 55% decreases in land area at moderate and high risk of erosion, respectively, between 1966 and 1984, and a 36% increase in land at very high risk of erosion (Table 7). Due to the permanency of slope locations, Figure 6 shows less change in the location of susceptible areas, compared to the figure for land use intensity, but substantial spatial change back and forth between the four risk categories over time. Land area at very high risk for erosion decreased from 508.5 hectares in 1958 to 421.0 hectares in 1966, increasing again to 570.5 hectares in 1984. These data show clearly that erosion risk potential in this region fluctuates with changing environmental conditions and human activity.

B. Soil Resources

Buen Hombre has three general soil types of agronomic importance to villagers -- "black," "yellow" and "mixed." Generally, black soils are located in the valley and yellow soils on slopes. All are moderately fertile, calcareous and productive for a wide variety of crops when there is rain. None appear to have physical or structural limitations for agriculture (Chapter 2).

C. Transects

Two parallel North-South transects of developed and undeveloped lands were completed on walks with key informant villagers for comparison of indigenous ecosystems to local agroecosystems. Each transect was approximately 1,250 meters in length. Land use and vegetation changes were noted as elevation increased with distance from the sea, and composite soil samples made up of 15 samples from a 10 m^2 area from the surface 0 to 0.05 m were taken at the approximate midpoint of each major elevation/vegetation change. Soil samples were analyzed for pH, texture and color.

The agricultural, or developed land transect, followed the main N-S road and was surrounded by village houses and farm plots. The transect of undeveloped land was to the west of the main road, beginning at the sea, approximately 500 m west of the north tip of the road, and followed an alternating SW-NW pattern of four 250-meter segments to the base of and then up the village mountain, bordering the valley farmland on the west. (See Figure 3 for transect path.) The mountaintop (lat. 19°51′58.4″ N, long. 71°25′4.3″ W) had an elevation of 144 m, lay 1,250 m due west of the village road and 650 m due south of the sea.

As part of the transect data, a collection of indigenous botanical specimens was started, using standard plant collection procedures (Jones and Luchsinger, 1986), in February, 1991, during the last month of the rainy season. A few specimens were collected at each of the major elevation changes from beach to foothills. A total of 23 specimens were collected initially, with the intent of increasing the collection on a subsequent trip. However, an extended drought prevented collection of additional specimens. Specimens were identified by the Michigan State University Herbarium and by Dr. Thomas Zanoni, National Botanical Gardens, Santo Domingo, Dominican Republic.

In addition, ethnobotanical interviews, using methods described by Stoffle et al. (1990), were conducted in Buen Hombre with key informants, selected for their knowledge of indigenous species. Data were collected on walks with key informants, from sea level to an elevation of 140 meters. Plants and trees were photographed; interviews were recorded. Six sets of on-site ethnobotanical interviews were conducted on dates representing the end of the rainy season, a few months after the rainy season, and the dry season. Interview topics included common name, specimen location, micro-ecological zone, general soil type, growth habit, striking botanical features, height of specimen, maximum possible height, seasonal color variations and medicinal and non-medicinal uses. Species were identified using two Dominican botanical dictionaries (Geilfus, 1989; Liogier, 1974), and tolerance/adaptation to environmental limitations was noted for each.

Briefly, the results of those interviews indicated that villagers use terrestrial vegetation (plants, cacti, scrub, bushes and trees) in multiple ways, and utilitarian knowledge of approximately 95% of local species is comprehensive, sophisticated and passed on orally between generations. Indigenous plant species are many and varied (Table 8), with 38 species belonging to 26 families identified in initial inventories as being important to villagers for stock forage, spices, human or bird food, fence posts, medicine, lumber, etc. Adaptive strategies exhibited by these species are rich and varied (Geilfus, 1989; Liogier, 1974), implying that to compete effectively, introduced species need to possess tolerance and avoidance/resistance mechanisms for dealing with the specific ecosystem limitations of this region (herbivorous insects, low rainfall, high pH soils).

In tree inventory walks, key informants identified 55 species from 33 botanical families (Table 9). Most, if not all, of the most common tree species (including bushy plants and cacti) are also adapted in one or more ways to harsh environments (Geilfus, 1989; Liogier, 1974). Many are leguminous. Many tolerate drought, insects or high temperature; infertile, alkaline, calcareous or saline soils; and rocky soils or sandy soils.

The mix of native vegetation (Tables 8 and 9) in undeveloped lands (Figure 9) suggests a more ecologically appropriate agricultural management system for developed lands (Figure 8) of the region -- multi-story mixing of diverse, high pH-tolerant, drought-tolerant/resistant grass, plant and tree species. Concerted management efforts along these lines have potential to increase agroecosystem diversity and stability, production and income.

IV. Human Factors

The human factors discussed here are potentially critical factors in the success or failure of sustainable ecosystem management in the region. Human activity systems in Buen Hombre are based on productive (farming and fishing) aspects of the two main ecosystems. Listed below are six cultural elements observed in the village that appear to be both a response by villagers to their human and natural environments, and an explanation of or motivation behind villagers' behavior in interactions with both environments:

- sovereignty - Sovereignty is highly valued throughout the Caribbean because of the colonial history of European domination in the region. Freedom from external control and an intense interest in and involvement with politics are pan-Caribbean cultural elements (Stoffle, 1986).
- dependency - There is also a conflicting tendency by many islanders to look externally for solutions to local problems (while simultaneously resenting foreign intervention or assistance). This is due partly to the colonial history of enforced dependence and partly to the nature of high populations on small islands, in which all the resources needed by inhabitants cannot be provided locally.
- occupational multiplicity - There is a need among islanders to be engaged in a variety of activities to reduce risk and ensure survival under severe constraints (Burpee and Morgan, 1986; Comitas, 1973).
- subsistence production - This strategy maintains some production every year, compared to the strategy of cash crop production, which is generally characterized by instability, with high production in some years and none in others.
- social networks - Multiple, complex kinship/community networks are maintained to reduce risk, by sharing individual good fortune with a maximum number of family/community members (Rubenstein, 1987).
- migration - This is the traditional, ultimate response to extremely limiting environments. Caribbean emigrants are usually the healthiest, best educated and most highly motivated citizens, causing "brain drain" and slowed economic

development at home (Pastor, 1985).

To summarize, the significance of these human cultural factors is that any changes proposed as solutions to people-environment problems in Buen Hombre must foster sovereignty, but provide appropriate support, maintain occupational multiplicity, increase production through increasing diversity and protecting stability, foster equitable distribution of production to avoid community divisiveness, and generate local or regional income-producing activities to prevent migration abroad or to already overburdened cities.

V. Relationships between ecosystems and human activity systems

In Buen Hombre, human survival is tied to interdependent relationships and complex balances between terrestrial, marine and human ecosystems. As an example, fishing adds stability to village subsistence systems by increasing diversity of food and income sources. However, when rough weather, overfishing by outsiders, failure of boat motors or turbulent sea conditions curtail fishing, villagers depend on agricultural produce or agricultural "savings accounts" in the form of farm animals. On the other hand, when crops fail, villagers increase fishing activities, hunt forest fowl, take advantage of external social support networks, etc.

Another example of the complex human-ecosystem balance in coastal areas like Buen Hombre concerns the mangrove ecosystem. During droughts, the absence of terrestrial runoff to the mangroves results in higher proportions of salt to fresh water in mangrove swamps, slowing mangrove growth, and causing extremely low mangrove water levels that restrict mangrove use as fish breeding and spawning grounds. Alternately, excessive fresh water runoff into new-growth mangrove swamps takes away the competitive advantage of slower growing salt-tolerant, mangrove species over faster-growing non-salt tolerant tree seedling species. However, once established, mangrove trees grow faster in greater fresh water concentrations. And without periodic additions of organic matter and nutrient-carrying clay sediments, nutrient-poor coastal sands slow mangrove growth. Yet an excess of clay sediments impedes mangrove root aeration and soil drainage and causes coral reef damage (Hutchings and Saenger, 1987).

Thus, mangroves serve as a checkpoint between marine and terrestrial ecosystems, regulating coastal physical and biological interactions, providing biological habitat for birds and insects, fish and shellfish, and adding stability to human subsistence activity by supporting marine and terrestrial fauna, and by providing lumber. Changes occurring in either the human activity systems, the marine or terrestrial ecosystems can affect the mangrove interface and ultimately the whole system.

VI. The natural resource situation in Buen Hombre

During the last fifty years, two major changes in Buen Hombre have jeopardized village subsistence activity -- one affecting the terrestrial ecosystem and one, the marine ecosystem. Village reports, verified by regional rainfall records, indicate that since the 1940's, agricultural production has changed both in terms of the species planted and in decreasing overall production. Elder villagers tell of "sufficient" rain prior to the 1940's. Many crops were grown, including bananas and upland (dryland) rice. Both these crops require an annual minimum of approximately 1,000 mm of evenly distributed precipitation for moderate yields (Da Mota, 1980; Stansel, 1980; Soto, 1985). These crop rainfall requirements coincide with available climatic records for the region, which report average annual rainfall amounts of 1,200 mm for an unspecified 7-year period, sometime between 1900 and 1926, as well as separate estimates of average annual amounts of 1,000 to 1,500 mm prior to 1941 (Portman et al., 1991).

But since the 1940's, precipitation has decreased to an average of 600 to 700 mm per year (Portman et al, 1991), making cultivation of bananas and rice, as well as many other crops, impossible under rainfed conditions. During the period of this study, the region underwent a four-year drought. Whether or not the higher annual rainfall of the early 1900's will return, is debatable. According to Huke (1976), the period between 1890 and 1945 was the most benign period for world climate in the last thousand years. It encouraged humans to extend cultivation into areas that were previously beyond the outer limits of production.

Cuban immigrants settled the village of Buen Hombre at the beginning of the benign period in 1897. By 1950, when precipitation levels in Buen Hombre had gone from marginal to unacceptable for rice and bananas, villagers began cultivating species requiring less water, such as tobacco, pigeon peas and cotton. Many villagers expect an increase in precipitation at some point, but the past, not the present, may be the meteorological aberration.

Thanks in part to possibly erroneous expectations of future climate trends, village response to recent droughts has been decreased reliance on terrestrial ecosystems and increased reliance on marine ecosystems. There is no evidence of a conscious shift among villagers to dryland agriculture as a viable, permanent mode of production, with the exception of the selection of some drought-tolerant species.

Under such circumstances, maintenance of healthy reefs as productive fisheries has become vital to village well-being. Unfortunately, a shift to increased fishing is problematic from several perspectives.

Fishermen from towns and cities east and west of Buen Hombre have been encroaching on local fishing grounds since before 1985, using large nets with illegally small netting to catch relatively profitable shrimp. Though Buen Hombre reef systems are healthier than reefs directly to the east and west, the *chinchorro* nets have damaged marine vegetation and decreased fish and shellfish populations by entrapping the youngest and smallest of many fish and shellfish species. By 1987, populations of certain species were severely diminished or had disappeared entirely. Although the degradation was reversed, at least temporarily, through an intervention effort in 1993, the productive capacity of these reef and mangrove ecosystems appears to be easily overstressed.

The second major factor that may jeopardize village subsistence activity, specifically village fishing activity, is related to a 1990 government edict declaring the northwest coast between Puerto Plata and Monte Cristi a tourist zone (Dr. J. Serulle, personal communication). Local sources predict construction of a coastal access highway within approximately ten years (Ing. R. Serulle, personal communication). Beyond the possible negative short-term impacts of mangrove destruction and increased human activity resulting from this declaration, there is an additional long-term factor with potential to affect local coastal ecosystems adversely. Global warming has been predicted, and its effects include rising sea levels, differential ocean warming, stronger storms, and increased, harmful ultraviolet radiation in equatorial regions (Weber, 1993b). These changes are expected to threaten existing tropical reef systems worldwide.

CONCLUSIONS

Significant findings of this initial analysis of the Dominican coastal district of Buen Hombre include the following:

- Due to the combined factors of isolation, low rainfall, low population, lack of potable water, and conservation-conscious villagers, local reef and mangrove ecosystems are currently biologically diverse and productive, unlike degraded and deteriorating coastal ecosystems in the remainder of the island of Hispaniola.

- Local terrestrial ecosystems include a diverse mix of trees and plants (adapted to local climate and soils) within diverse landscapes.

- Diversity in subsistence production depends on vitality and diversity in a continuum of near-shore marine to near-shore terrestrial ecosystems.

- Stability of village subsistence production depends on some measure of success in both fishing and farming activities. Neither activity alone is sufficient for survival under significant perturbations to either relevant productive ecosystem.

- Districtwide, population has doubled over the two decade period beginning about 1960 and was accompanied by shifts in land under moderate and high intensity land use.

- Village agricultural production of moderately fertile entisols and inceptisols has recently been constrained by recent droughts and has resulted in out-migration of non-fishing, farming-only families.

- Illegal net fishing by "outside" fishermen has caused visible harm to coastal reef flora and fauna populations in Buen Hombre.

- Socio-cultural, anthropological, economic, historical and political factors, as well as eloquently-stated opinions by village leaders, indicate the necessity of village involvement and/or leadership in any further research and development efforts.

These findings indicate that in Buen Hombre key relationships between humans and their most economically productive ecosystems are threatened by increased population, increased human activity, the vagaries of local weather and most likely global climate change, as well. These findings also suggest two areas where a few key changes have the potential to make a significant positive impact on the productivity, stability, equitability and sustainability of human-ecosystem interactions:

- With training provided by local agricultural scientists in simple techniques of experimental design, theory and statistics (as has been done successfully in Bolivia and Ecuador by Ruddell and Beingolea (1995)), villagers could evaluate and test low-input, sustainable dryland agronomic techniques for local use.

- A mariculture project involving "farming" of non-aggressive shellfish and algal food supplies in sea cages could provide subsistence and market production. Villagers have expertise in this technology (Stoffle, 1986), readily available markets, and an operating fishermen's association for oversight and leadership, but lack loans/funding for initial costs.

These improvements are recommended in response to specific local conditions: previous and potential climate change, increased human pressure on coastal ecosystems and difficulty of villagers in meeting basic survival requirements. Taken into account are issues of sovereignty, dependency, occupational multiplicity, diversity and stability of production, sustainability of ecosystems, equitability, income generation and empowerment.

In the final analysis, though, successful improvement of the situation in Buen Hombre will depend on the ability of villagers, scientists and policy makers to agree on both the nature of the problem and on what constitutes improvement, as well as their ability to evaluate and test the solutions they propose. The National Research Council (1993) has stated that worldwide, any unmanaged ecosystems will be lost through overuse. In cases like Buen Hombre, where human activity systems are extensively and intricately involved in complex, dynamic local ecosystems, the participatory-systems model has potential as an effective vehicle for improvement and change.

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Table 1. Quality of drinking water in Buen Hombre district, sampled April 15, 1992

Chemical Element or Compound	Buen Hombre well (mg L^{-1})	Las Canas lagoon (mg L^{-1})	Las Huberas lagoon (mg L^{-1})	Unacceptable levels for drinking water (mg L^{-1})
NO_3 (nitrate)	12.3	ND[1]	ND	>10
Cl (chloride)	1908	10	13	>250
Fl (flouride)	1.1	0.1	0.1	>4.0
Hardness as $CaCO_3$	1945	132	95	>250
Fe (iron)	ND	ND	ND	>0.5
SO_3 (sulfate)	916	ND	ND	>500[2]
Na (sodium)	1043	ND	ND	>250
Ca (calcium)	194.5	40.6	28.3	---[3]
Mg (magnesium)	277.0	7.5	5.7	---
Pb (lead)	0.024[4]	0.004	ND	
pH	7.0	7.1	7.2	

[1]Not detectable. [2]The EPA (Environmental Protection Agency) is considering a sulfate limit of 400 to 500 mg L^{-1}. [3]Non-toxic element, water softening may be appropriate. [4]Unacceptable Pb level for municipal well.

Table 2. Land use classification system for Buen Hombre (based on CEUR-CARTEL system) (Source: St.-Pierre, personal communication)

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1. HUMAN SETTLEMENTS

1.1 Urban Dwellings

1.2 Rural Dwellings: Villages, towns, etc.

2. AGRICULTURE

2.1 Non-irrigated mixed cultivation: Typical subsistence cultivation on small landholdings, generally intercropped; minimum of 50% land area in production. No irrigation equipment identified.

2.2 Irrigated mixed cultivation: Crops in constant production. Irrigation equipment identified.

2.3.1 Non-permanent agroforestry: Small cultivated parcels surrounded by forest. At least 75% of area is forested.

2.3.2 Non-permanent agriculture in bushland/degraded forest: Intensified use of soils, the fallow cycle has been shortened and does not allow re-establishment of forest. At least 75% of area is covered with bushy vegetation.

2.3.3 Non-permanent agriculture in grazing lands: Cultivation cycles are shortened, fallow is reduced to less than 5 years, and bushy vegetation cannot re-establish. At least 75% of total area is covered with pasture/grazing lands.

2.4 Traditional perennial crops: Coffee, cocoa, coconut are found in forested patches, often interspersed with human settlements. Also found are lengthwise gullies of running water.

2.5 Plantations (e.g., citrus, pineapple, melons): Export crops, managed with industrialized technology.

2.6 Tobacco: All types of terrain are in production, landholdings greater than 8 hectares.

2.7 Rice: Predominantly monoculture, different field sizes and forms of production.

Table 2. (Cont'd.)

2.8 Sugar cane: These fields are used only for sugar cane production; large-scale production.

3. PASTURELANDS

3.1 Improved grazing lands: Areas that have been cleaned, developed, maintained for grazing, normally fenced.

3.2 Natural grazing lands: Areas that have not been cleaned for cultivation or grazing and show no evidence of being maintained. Usually unfenced and found within areas that contain patches of bushland and/or forests. Used extensively by cattle ranchers in the mountains, with an initial fallow period. Less than 25% covered by bushy vegetation.

3.3 Pasture with trees: Generally natural, permanent pasture with approximately 25% scattered trees (e.g., palm trees).

4. FORESTS

4.1 Forested terrain: Canopy cover of 50% or more, does not include cultivated perennials. Includes coniferous, mixed and dry forests.

4.2 Mangroves: Coastal woodlands.

4.3 Bushy vegetation ("matorrales"): Land with a wide variety of bushes and small trees. Normally this type of tree has little or no commercial value. Generally used for household consumption, such as for firewood. Usually natural vegetation in the process of recuperation. Canopy cover greater than 50%.

5. WATER

5.1 Water masses: Includes rivers, lakes, lagoons, dams. Natural or man-made.

6. WETLANDS, LAND SUBJECT TO FLOODING: (Swampland, marshes) Can be connected to the sea. Frequently associated with lowlands. Aquatic, water-tolerant vegetation as a result of flat, lowlands.

7. BARREN LANDS: (Includes saline soils, highly eroded areas, etc.) Areas barren of vegetation, not including land devastated by mines.

8. QUARRIES, MINES: Includes rock/mineral deposits, areas where vegetative cover and soils removed to expose rocks, limestone, bauxite.

Table 3. Land use distribution, Buen Hombre District: 1958, 1966, 1984 (Source: St.-Pierre, unpublished data)

TYPE OF LAND USE	1958 km²	1958 %	1966 km²	1966 %	1984 km²	1984 %
Non-irrig. agriculture*	13.2	32.4	11.9	29.0	9.3	22.6
Temp. agric./scrubland			0.1	0.3		
Temp. agric./pasture	0.8	1.9	1.2	2.9	3.7	9.0
Perennial tree crops					0.3	0.6
Natural pastureland					1.2	3.0
Pastureland with trees			0.9	2.2	0.1	0.2
Forest	25.6	62.6	24.7	60.4	25.3	61.8
Mangroves	0.9	2.3	0.9	2.3	0.9	2.2
Bushy vegetation	0.2	0.6	1.0	2.5		
Wetlands	0.2	0.4	0.2	0.4	0.2	0.5

*See Table 2 for complete descriptions of land use categories.

Table 4. Type of land use by general category, Buen Hombre District (Source: St.-Pierre, unpublished data)

Type of land use	1958 (km²)	1966 (km²)	1984 (km²)
Farmland, non-irrigated	13	12	9
Forest	26	25	25
Pastureland, grazing lands	1	1	5
Grassland with trees	0	1	0
Mangroves	1	1	1

Table 5. Population for Buen Hombre District*, 1935-1981 (Source: Castillo, National Census, Dominican Republic, 1936,1951,1961, 1971, 1982)

Population	1935	1950	1960	1970	1981
Males	141	155	390	No data	739
Females	125	123	320	No data	587
TOTAL	266	278	710	1,053	1,326

*Buen Hombre Census District includes Buen Hombre, Los Conucos, Las Canas and Las Brigidas (Figure 3).

Table 6. Degree of intensity of land use, Buen Hombre District: 1958, 1966, 1984 (Source: St.-Pierre, unpublished data)

Degree	1958 (hectares)	1966 (hectares)	1984 (hectares)
Low	2,713.76	2,677.29	2,642.68
Moderate	78.37	213.24	517.60
High	1,299.47	1,201.06	931.33

Table 7. Degree of erosion risk potential, Buen Hombre District: 1958, 1966, 1984 (Source: St.-Pierre, unpublished data)

DEGREE	1958 (hectares)	1966 (hectares)	1984 (hectares)
Low	3,282.39	3,360.75	3,360.76
Moderate	147.63	140.34	83.84
High	153.09	169.50	76.55
Very High	508.49	421.02	570.46

Table 8. Plant species** identified by villagers, Buen Hombre

Family***	Botanical Name	Common Name
Acanthaceae	*Justicia sessilis* Jacq.[49]	Carpintera
	Ruellia tuberosa L.[6]	Guaucí
Amaranthaceae	*Philoxerus vermicularis* (L.) R. Br.[6]	Verdolaga del Mar
Amaryllidaceae	*Frucraea hexapetala* (Jacq.) Urb.[6]	Cabuya
Apocynaceae	*Echites umbellata* Jacq.[*4]	Curamaguey
Asclepiadaceae	*Matelea maritima* (Jacq.) Woodson[*6]	Guanabanita
Asteraceae	*Artemisia domingensis* Urb.[49]	Altamisa
	Mikania papillosa Klatt[6]	Bejuco Blanco
	Parthenium hysterophorus L.[*136]	Hierba Amarga
Boraginaceae	*Heliotropium angiospermum* Murray[*46]	Alacrancillo
Brassicaceae	*Lepidium virginicum* L.[*2]	Matuerso
Chenopodiaceae	*Chenopodium ambroisioides* L.[*458]	Celedonia
Euphoribiaceae	*Jatropha gossypifolia* L.[478]	Tuatua
	Chamaesyce hirta L.[4]	Malcasá
Lamiaceae	*Leucas martinicensis* (Jacq.) R. Br.[*2]	Molenillo
Leguminosae-Caesalpinioideae	*Senna angustisiliqua* (Lam.) Woodson & Barneby[*69]	Carga Agua
	Cassia occidentalis L.[78]	Bruca
Liliaceae	*Aloe vera* (L.) Burm. f.[68]	Sábila

Table 8. (Cont'd.)

Malpighiaceae	*Stigmaphyllon periplocifolium* (Desf.) Juss.[6]	Bejuco de Cascarita
Malvaceae	*Abutilon abutiloides* (Jacq.) Garcke[*1]	Escoba Blanca
	Gaya occidentalis (L.) HBK.[9]	Escoba Dulce
Nyctaginaceae	*Boerhaavia scandens* L.[*1]	--
Orchidaceae	*Vanilla barbellata* Rchb. F.[4]	Bejuco de Lombriz
Papaveraceae	*Argemone mexicana* L.[*1]	Cardo Santo
Plumbaginaceae	*Plumbago scandens* L.[*1]	Pega Pollo
Poaceae	*Cenchrus* spp.[9]	Cadillo
	Digitara decumbens Stent[6]	Pangola
	Eragrostis spp.[*2]	Grama
	Panicum maximum Jacq.[3]	Hierba de Guinea
Rubiaceae	*Spermacoce assurgens* Ruiz & Pavon[*4]	Juana La Blanca
Scrophulariaceae	*Capraria biflora* L.[*45]	Feregosa
	Scoparia dulcis L.[4]	Cancharagua
Solanaceae	*Datura inoxia* Miller[*1]	Cornicopio
	Lycium americanum Jacq.[*4]	Gri Gri
	Solanum americanum Miller[*3]	Hierba Mora
	Solanum polyacanthum Lam.[4]	Doncella
Verbenaceae	*Lanata* sp.[*146]	Oreganillo
	Lanata camara L.[6]	Doña Sanica
	Stachytarpheta jamaicensis L.[4]	Verbena

*Plant species collected in Buen Hombre, and subsequently identified by Dr. Thomas Zanoni, National Botannical Gardens, Santo Domingo

**Botanical references: Geilfus, 1989; Liogier, 1974; Weniger and Robineau, 1988.

Table 8. (Cont'd.)

*** The Code of Botanical Nomenclature was adhered to for family names (those with -*aceae* suffixes) of plants in this table, except in the case of the Fabaceae family. For this family, the traditional name of Leguminosae was used to emphasize the nitrogen-fixing capabilities of certain species.

Numeric superscripts indicate ecozones where specimens were encountered (species may occur in other ecozones):

^{1}Cleared agricultural field ^{2}Edge of agricultural field
^{3}Fallow field ^{4}Sandy coastal, or beach, zone ^{5}Coastal salt flats
^{6}Foothills, scrub vegetation ^{7}Roadside ^{8}Household yard/garden
^{9}Mountain

Table 9. Tree species* identified by villagers, Buen Hombre

Family	Botanical Name	Common Name
Anacardiaceae	*Anacardium occidentale* L.[9]	Cajuil
Annonaceae	*Annona muricata* L.[89]	Guanábana
	Annona squamosa L.	Anón
Boraginaceae	*Cordia curassavica* (Jacq.) R. & S.	Juan Prieto
	Cordia laevigata Lam. = *Cordia nitida* Vahl[9]	Muñeco
Burseraceae	*Bursera simaruba = Bursera gummifera = Elaphrium simaruba*[9]	El Almácigo
Cactaceae	*Cereus jamacaru* DC.[267]	Cayuco
	Harrisia divaricata (Lam.)[6]	Yaso
	Nopalea cochenillifera (L.) Salm-Dick[68]	Tuna de España
Capparaceae	*Capparis flexuosa* L.[4]	Mostazo
Combretaceae	*Conocarpus erectus* (Vahl) R. & S.[45]	Mangle Prieto
	Laguncularia racemosa (L.) Gaerth. f.[5]	Mangle Blanco
Euphorbiaceae	*Jatropha Curcas* L.	Piñon de Leche
	Jatropha multifida L.[8]	Piñon Extranjero
Leguminosae	*Diphysa robinoides*[5]	Palo Amarillo
Leguminosae-Caesalpinoideae	*Parkinsonia aculeata* L.[269]	Cambron
	Peltophorum berteroanum Urb.[2]	Guatapanal
	Tamarindus indica L.[48]	Tamarindo
Leguminosae-Mimosoideae	*Acacia farnesiana* (L.) Willd.[249]	Aroma
	Prosopsis juliflora (Sw.) DC	Bayahonda
	Samanea saman (Willd.) Merrill[8]	Samán

Table 9. (Cont'd.)

Leguminosae-Papilionoideae	*Adenanthera pavonia* L.[9]	Coralillo
	Rhynchosia pyramidalis (Lam.) Urb.[9]	Pega Palo
	Sesbania grandiflora (L.) Pers.[8]	Gallito
Liliaceae	*Yucca aloifolia* L.[8]	Jericó
Malpighiaceae	*Bunchosia glandulosa* (Cav.) L. C. Rich[26]	Cabra
	Malpighia domingensis Small[6]	Cereza Cimarrona
Malvaceae	*Abutilon american* L.[46]	Yerba Blanca
Meliaceae	*Trichilia pallida* Sw.	Palo Amargo
	Azadirachta indica = *Melia azadirachta*[8]	Nim
Moringaceae	*Moringa oleifera* Lam.[8]	Libertad
Myrtaceae	*Cryptorrhiza haitiensis* Urb.[4]	Canelillo
	Eucalyptus deglupta[49]	Bagras
	Eugenia foetida Pers.[9]	Escobón
	Eugenia glabrata (Sw.) DC.[9]	Arraiján
Oxalidaceae	*Oxalis barrelieri* L.	Vinagrillo
Palmaceae	*Coccothrinax argentea* (Lodd.) Sarg.[9]	Guano
Phytolaccaceae	*Petiveria alliacea* L.	Anamú
Polygonaceae	*Coccoloba diversifolia* Jacq.[49]	Uvero
	Coccoloba uvifera (L.) L.[4]	Uva de la Playa
Punicaceae	*Punica granatum* L.[8]	Granada
Rhamnaceae	*Krugiodendron ferreum* (Vahl) Urb.[89]	Ciguamo
	Ziziphus reticulata (Vahl)[4]	Sopaipo
Rhizophoraceae	*Cassipourea obtusa* Urb.[9]	Parrilla

Table 9. (Cont'd.)

Rosaceae	*Crataegus mexicana*[4]	Manzanilla
Rubiaceae	*Antirhea lucida* (Sw.) Benth. & Hook.[4]	Aguacatillo
	Chiococca alba (L.) Hitchc.[9]	Timaque
	Exostema caribaeum (Jacq.) R. & S.[9]	Quina
	Stevensia buxifolia Poit.[4]	Cuabilla
Rutaceae	*Amyris elemifera* L.[9]	Guaconejo
Sapindaceae	*Melicoccus bijugatis* Jacq.[8]	Limoncillo
Solanaceae	*Solanum umbellatum* Mill.[4]	Friega Platos
Staphyleaceae	*Turpinia paniculata* Vent.[8]	Violeta
Ulmaceae	*Phyllostylon brasiliensis* Capanema[69]	Baitoa
Zygophyllaceae	*Guaiacum officinale* L.[48]	Guayacán

*Botanical references used: Geilfus, 1989; Liogier, 1974; Weniger and Robineau, 1988.
Numeric superscripts indicate ecozones where specimens were encountered (species may occur in other ecozones):
[1]Cleared agricultural field [2]Edge of agricultural field [3]Fallow field [4]Sandy coastal, or beach, zone
[5]Coastal salt flats [6]Foothills, scrub vegetation [7]Roadside [8]Household yard/garden [9]Mountain

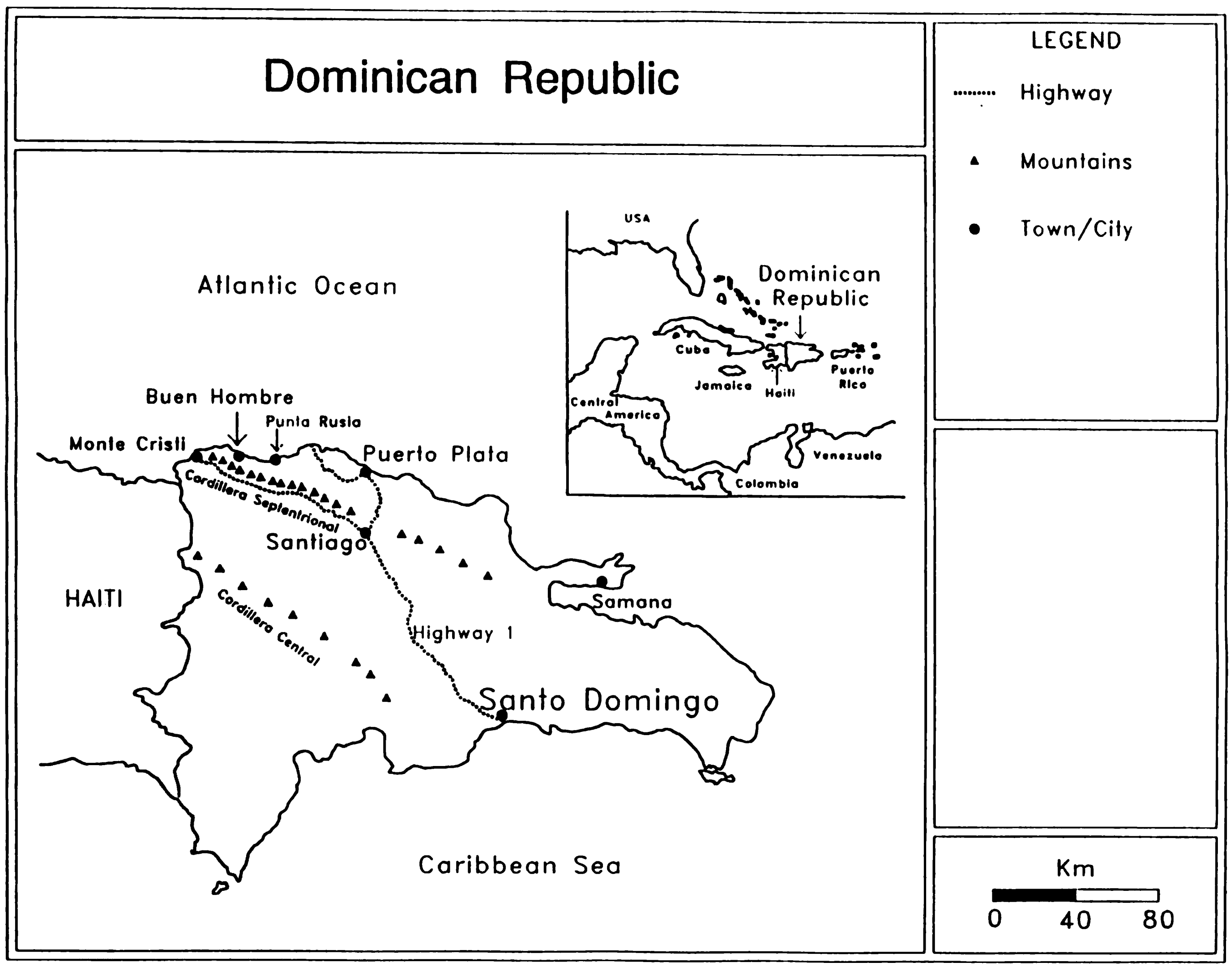


Figure 1. Map of Dominican Republic with study site of Buen Hombre on northwest coast (redrawn from tourist brochure)

Figure 2. 1985 Landsat satellite image of northwest coast of Dominican Republic, showing bleached off-shore reefs (Photo provided by T. Wagner, Environmental Research Institute of Michigan)

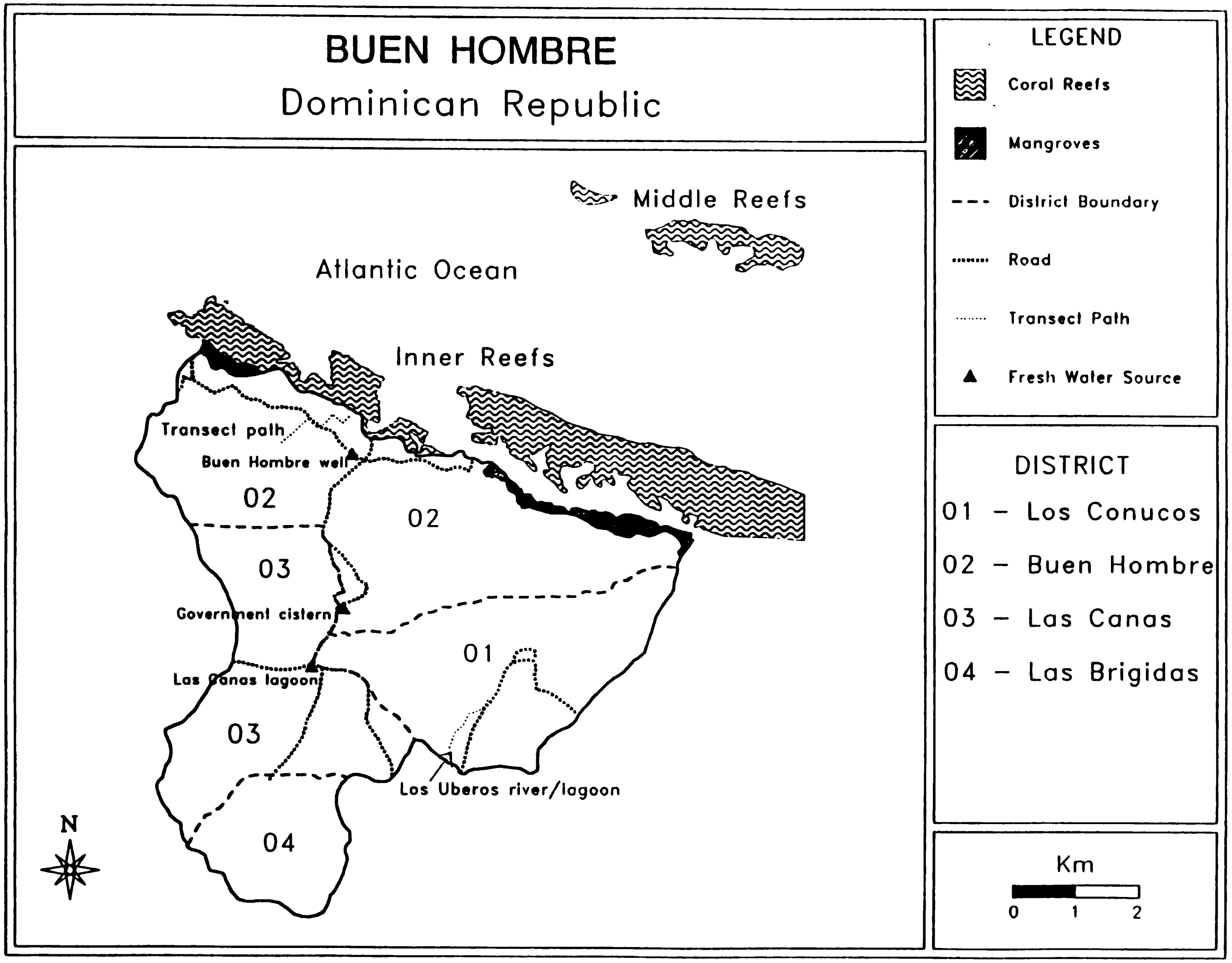


Figure 3. Map of Buen Hombre Census District, showing fresh water sources, mangrove and coral reef systems (boundaries based on census map boundaries)

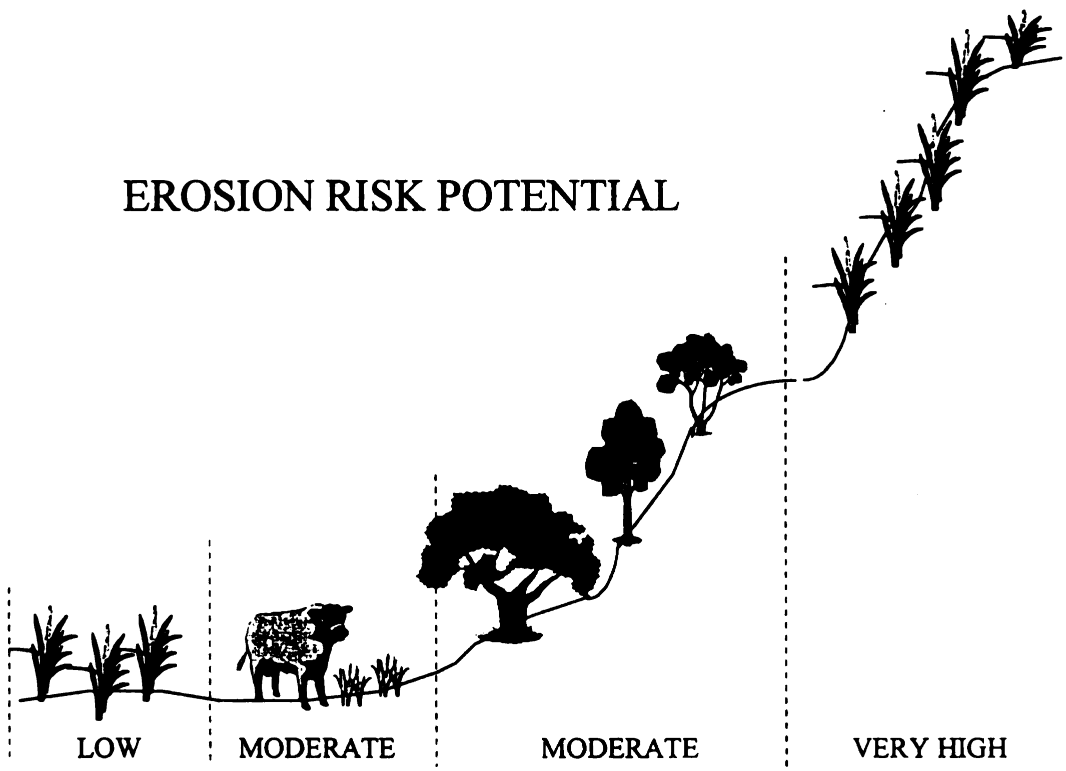


Figure 4. Graphic representation of combined factors of slope, land use and vegetative cover, used to determine erosion risk potential

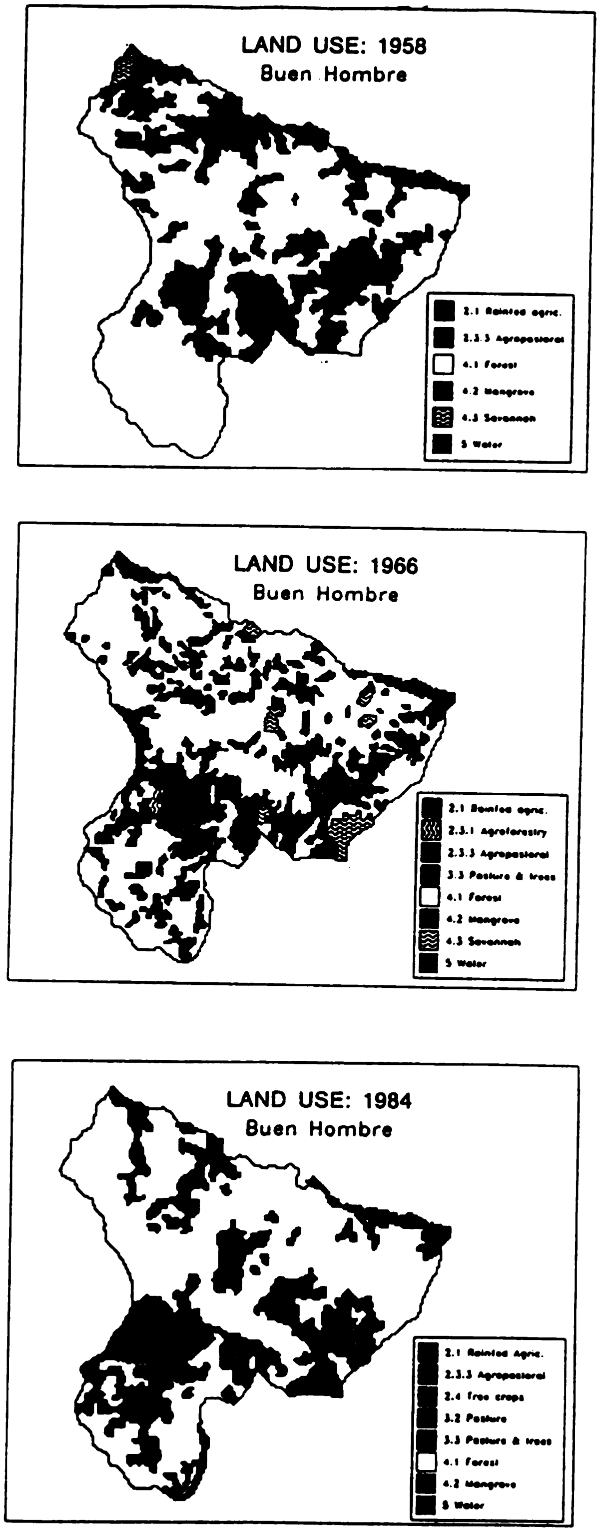


Figure 5. Buen Hombre land use: 1958, 1966 and 1984. (Modified and redrawn from unpublished CEUR-CARTEL data provided by St.-Pierre)

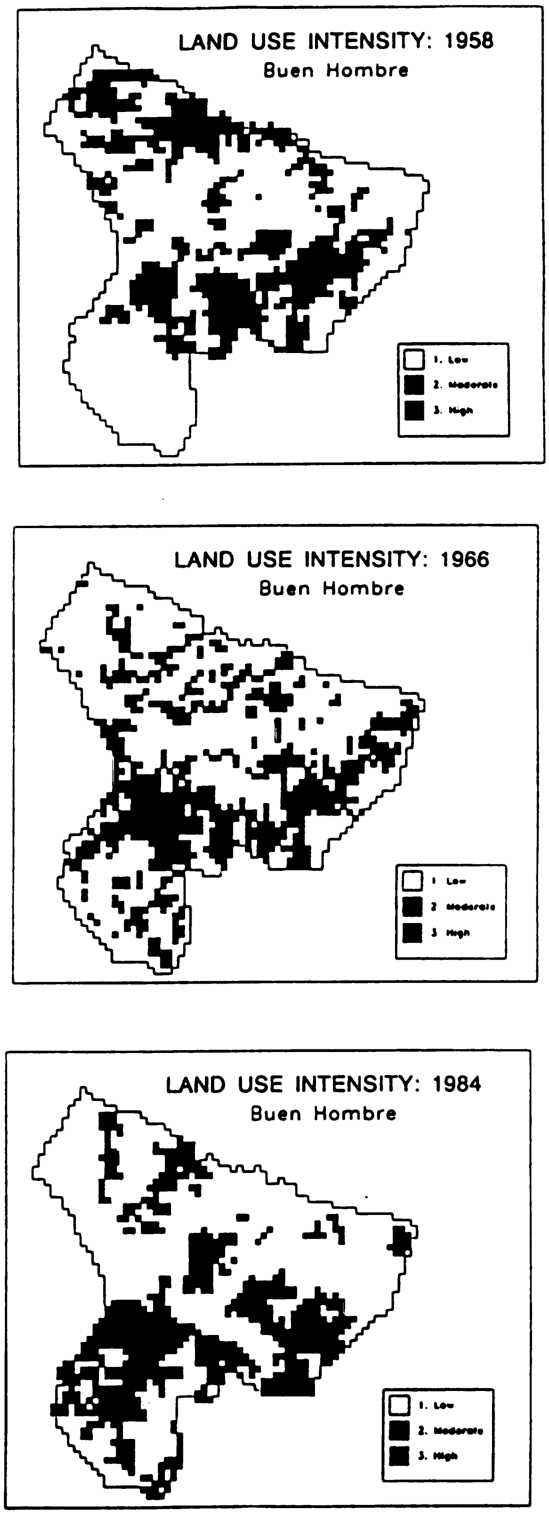


Figure 6. Buen Hombre land use intensity: 1958, 1966 and 1984. (Modified and redrawn from unpublished CEUR-CARTEL data provided by St.-Pierre)

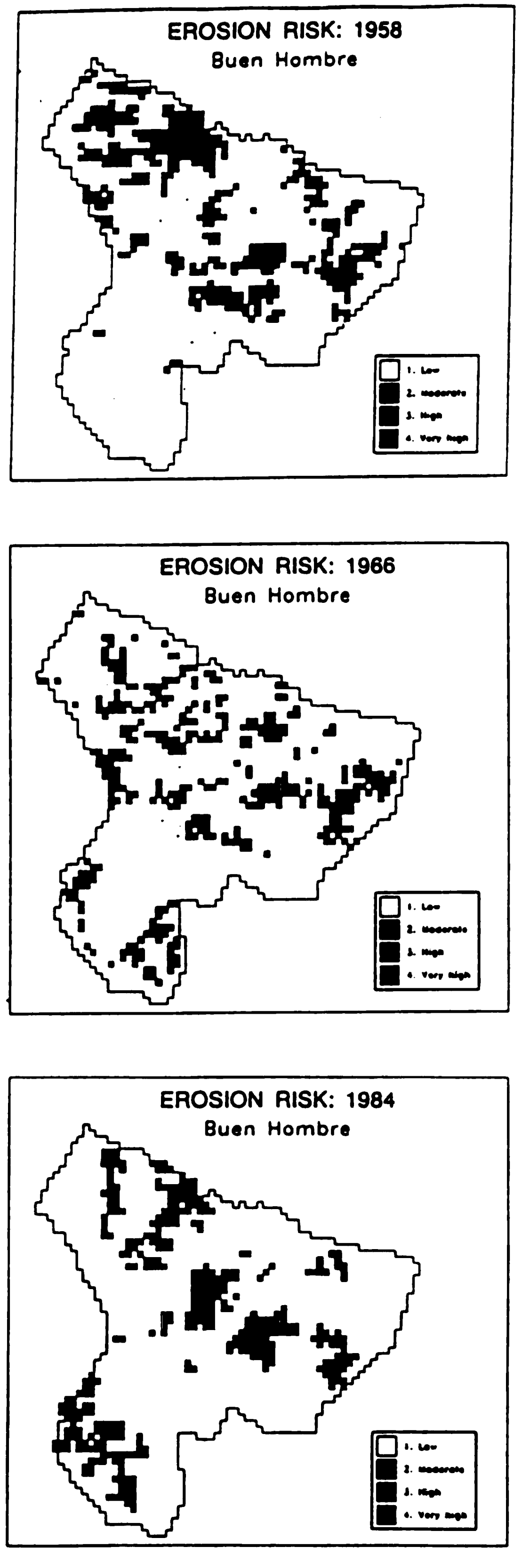
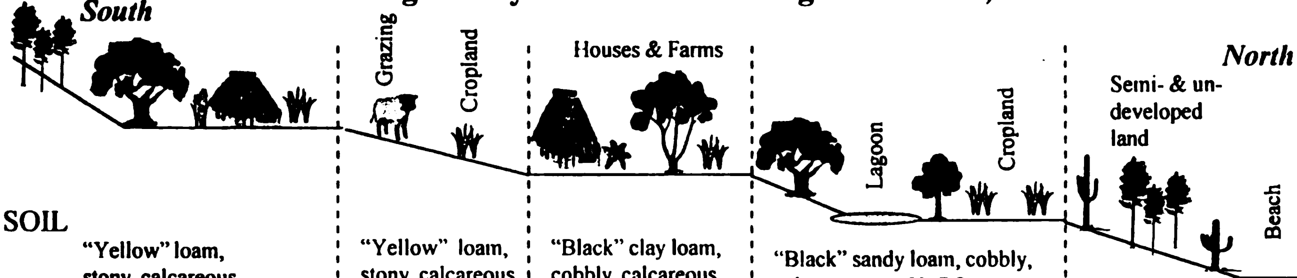


Figure 7. Buen Hombre erosion risk potential: 1958, 1966 and 1984. (See Figure 3 for factors used in category designations.) (Modified and redrawn from unpublished CEUR-CARTEL data provided by St.-Pierre)

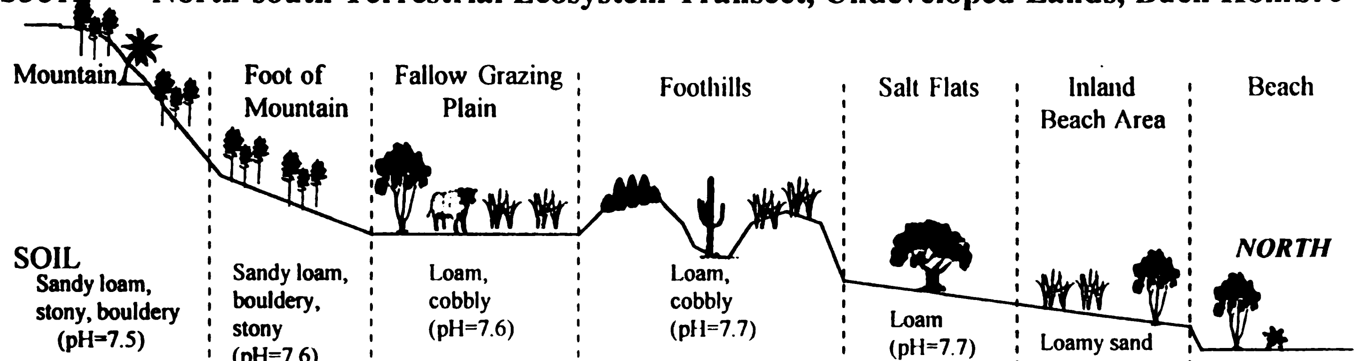
North-south Agroecosystem Transect along Main Road, Buen Hombre



SOIL	"Yellow" loam, stony, calcareous (pH=8.1)	"Yellow" loam, stony, calcareous (pH=7.8)	"Black" clay loam, cobbly, calcareous (pH=7.9)	"Black" sandy loam, cobbly, calcareous (pH=7.9)	Loamy sand pH=7.6-7.7; Sand
CROPS	Tobacco Mixed cultivation - maize, beans, fruit, vegetables	Tobacco, mixed cultivation	Tobacco, mixed cultivation	Tobacco, mixed cultivation, cotton, watermelon, papaya	Indigenous plant/tree species
LIVESTOCK	Ruminants, poultry, pigs	Grazing	Free grazing	Ruminants, poultry, pigs, free grazing	Free grazing
PROBLEMS	Poor tobacco market, water shortages, crop pests	Water shortages, erosion	Water shortages, crop pests, livestock damage to crops	Water shortages, crop pests, livestock damage to crops	Infertile soil, poor water retention, erosion
SOLUTIONS	New cash crop (cotton, tropical lettuce), dryland agriculture, drought tolerant species, IPM (integrated pest management)	Drought-tolerant trees, cover crops, contour shrubs (perennial forage between vetiver grass on contour)	Control grazing; see solutions for Column 1	See solutions for Column 3	Drought-resistant cover crops and forages, contour shrubs/grasses

Figure 8. Transect of developed agricultural land, village of Buen Hombre

North-south Terrestrial Ecosystem Transect, Undeveloped Lands, Buen Hombre



	Mountain	Foot of Mountain	Fallow Grazing Plain	Foothills	Salt Flats	Inland Beach Area	Beach
SOIL	Sandy loam, stony, bouldery (pH=7.5)	Sandy loam, bouldery, stony (pH=7.6)	Loam, cobbly (pH=7.6)	Loam, cobbly (pH=7.7)	Loam (pH=7.7)	Loamy sand (pH=7.6-7.7)	Sand
VEGETATION	Tropical deciduos, dry forest: trees, grass, bushes		Fallow: grass, bushes, trees	Semi-desert scrub: cacti, grass, bushes, scattered trees	Sparse vegetation: plants, trees	Mixed: scrub, bushes, trees, mangrove trees	Succulents, grass, trees, bushes
PLANT/TREE FAMILIES	Acanthaceae Anacardiaceae Annonaceae Asteraceae Boraginaceae Burseraceae Leguminosae-Caesalpinoideae Leguminosae-Mimosoideae Leguminosae-Papilionoideae Malvaceae Myrtaceae Palmaceae	Poaceae Polygonaceae Rhamnaceae Rhizophoraceae Rubiaceae Rutaceae Ulmaceae Verbenaceae	Cactaceae Liliaceae Poaceae	Acanthaceae Amaryllidaceae Asclepiadaceae Asteraceae Cactaceae Leguminosae-Caesalpinoideae Malpighiaceae Malvaceae Poaceae Verbenaceae	Amaranthaceae Boraginaceae Leguminosae-Caesalpinoideae	Capparaceae Chenopodiaceae Combretaceae Euphoribaceae Leguminosae-Mimosoideae Meliaceae Myrtaceae Orchidaceae Poaceae Rhamnaceae Rubiaceae Scrophulariaceae Solanaceae Zygophyllaceae	Acanthaceae Apocynaceae Asteraceae Combretaceae Euphoribiaceae Leguminosae-Caesalpinoideae Malvaceae Myrtaceae Poaceae Polygonaceae Rosaceae Verbenaceae

Figure 9. Transect of undeveloped agricultural land, village of Buen Hombre

SUMMARY AND CONCLUSIONS

This research addresses the use of vegetative cover in harsh tropical environments, similar to those found in the semi-arid farming-fishing village of Buen Hombre in the Dominican Republic. Three major constraints to the introduction and use of vegetative cover in tropical subsistence agriculture are -- technical agronomic constraints, socio-economic constraints and ecological constraints. A key technical constraint for aerial broadcast seeds is species selection for limiting conditions of high temperature and insufficient water at the soil surface. Therefore, the first goal of this research was to develop a rapid screening technique in the laboratory to identify species that would be suitable for such environments. The second goal was to conduct field tests of species showing promise in growth chambers and evaluate the effectiveness of the rapid screening procedure as a selection tool.

Laboratory germination experiments, which were conducted over a wide range of temperatures and water potentials, characterized boundary conditions of germination for eight tropical species and were reasonably good at predicting germination response in the field. Subsequent field tests identified six species with potential for the Dominican Republic field site -- jack bean, lablab bean, sorghum, sunnhemp, tepary bean and tropical velvet bean.

The laboratory technique worked well, and with some modifications, the rapid screening technique could be adapted for use as an on-location screening procedure at small research institutes in the tropics. (Large, costly growth chambers would be replaced by small, inexpensive, simply designed ones for germination studies.) In another modification, the negative effects of biotic interactions in field studies could be avoided or decreased by overplanting, insecticide applications or by conducting large-scale field studies (relegating biotic interference to edges).

Assuming that the technical constraints above are surmountable, the next level of constraints to the use of vegetative cover in subsistence agriculture include sociological, cultural and economic factors. Initial survey research indicated that in this village, mean annual income of responding farmers was $381 or less, subsistence conditions for families in terms of food, health and nutrition were severely limiting and villagers were very open to the possibility of change. Current constraints to the use of vegetative cover include lack of knowledge and expertise on use and management within the village, lack of previous experimentation by village farmers, lack of access to seeds and possible labor constraints during certain months of the year. There appear to be no cultural norms against the use of beans of different colors in the diet, though incorporation of leafy greens might be problematic, as they are considered a condiment, rather than a crucial part of the diet. Food-producing vegetative cover planted in the off-season has great potential to alleviate food shortages and malnutrition. It also has potential to diversify and increase subsistence production, increase villagers' self-sufficiency and reduce emigration. Villagers appear eager to adopt this technology. If given some assistance, in my opinion, villagers are capable of conducting both simple selection studies and larger field-scale experiments, evaluating results and fine-tuning this technology for their environment. Ultimately, the effects of increased use of vegetative cover in this village would be better land management, modest increases in productivity and greatly increased ecological stability.

From an ecological perspective, constraints to the use of this technology are related to the interdependence and delicate balance that exists between land-based and marine-based ecosystems. Pressure applied to one ecosystem (e.g., through drought or unsustainable fishing by outsiders) results in excessive strain to the productive capacity of the other. This causes negative consequences within the ecosystems and for villagers who cannot survive on one ecosystem alone. The fragile balance between subsistence agriculture, an undependable water supply and subsistence fishing can be strengthened and stabilized by drought-tolerant vegetative cover, which would prevent excessive, damaging erosion to mangrove and reef ecosystems and would relieve some fishing pressure on reefs by providing an additional food source for villagers. Because change, possibly dramatic change, is imminent in this region, villagers must improve their ability to manage local ecosystems.

Strategic directions for the future include combined research and development in the village, possibly using the participatory-systems model to define problems, design research, propose solutions and evaluate resulting projects. A combined project involving the two key ecosystems and their related human activity systems is recommended: a fish mariculture project (to relieve marine ecosystem pressure, provide dry season sustenance and increase cash income) with vegetative cover and mixed-system dryland agriculture project (to provide stable, increased yields over a longer time period).

This recommendation would meet the implicit objectives of the author to strengthen subsistence production and stabilize the local environment. It would also be consistent with the high priority placed by villagers on income generation. Future research needs to address rates of change, ecosystem management by villagers, indicators villagers could use to monitor ecosystem change, issues of adoption of sustainable technology and use by villagers, as well as agronomic issues (surface and below-surface germination, monocropping versus intercropping with species of introduced and indigenous vegetative cover, planting times and labor requirements). Critical to the success of future intervention in this village is development combined with research and strong village involvement.

APPENDIX I:

BUEN HOMBRE SURVEY QUESTIONNAIRE

ENTREVISTAS EN BUEN HOMBRE
BUEN HOMBRE INTERVIEWS

BUENOS DIAS/BUENAS TARDES:

ME GUSTARIA HACERLE ALGUNAS PREGUNTAS SOBRE AGRICULTURA, LAS PLANTAS, LOS ANIMALES Y SU VIDA AQUI EN BUEN HOMBRE. ¿TIENE USTED TIEMPO DE HABLAR CONMIGO Y RESPONDER ALGUNAS PREGUNTAS?

NO NECESITA DARME SU APELLIDO, ASI SUS RESPUESTAS SERAN CONFIDENCIALES. LAS RESPUESTAS SERAN COMBINADAS CON LAS RESPUESTAS DE OTRAS FAMILIAS, LO QUE HACE DIFICIL IDENTIFICAR EL ORIGEN.

(GOOD MORNING/GOOD AFTERNOON: I WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT AGRICULTURE, PLANTS, ANIMALS AND YOUR LIFE HERE IN BUEN HOMBRE. DO YOU HAVE A LITTLE TIME TO TALK TO ME AND ANSWER SOME QUESTIONS? I WILL NOT ASK FOR YOUR LAST NAME, SO YOUR REPLIES WILL BE KEPT CONFIDENTIAL. YOUR ANSWERS WILL BE COMBINED WITH ALL THE OTHER FAMILIES AND WILL NOT IDENTIFIED.)

IDENTIFICACION DE LA ENTREVISTA (INTERVIEW IDENTIFICATION)

Numero de la entrevista (Interview #) ________________________

Nombre del entrevistador (I'vwr's name) ________________________

Fecha de la entrevista (Date of i'vw) ________________________

C1. ¿Cual es su nombre? (What is your name?) ______________________

C2. ¿Cuantos años tiene Ud.? (Age?) _________

C3. Sexo (Sex) ______________

¿Quien mas vive aqui? Solamente tiene que decirme sus nombres tienen, sus edades, su sexo y que relacion con usted. (Who else lives here? Just tell me their first names, ages, sex and how they are related to you.) **(LLENE LAS RESPUESTAS EN LA CAJA ABAJO.)**

C3. ¿Nombre? (First name)

C4. ¿Cuantos años tiene (en que año nacio)? (Age)

C5. Sexo (Sex)

C6. ¿Que relacion tiene el/ella con Usted? (How is he/she related to you?)

C7. ¿Alguien mas? (Anyone else?) **NO SI (REPITA C3 - C7)**

C8. ¿Hay otras personas temporalmente ausente, pero que regresaran a vivir aqui pronto, personas que no tienen casa en otro lugar? (Are there others who are away for awhile, but will return to live here soon, people who do not have a main home anywhere else?)

NO **SI**

CONTINUE A C9

¿Es el/ella un miembro de la familia, tambien? (Then he/she is really a part of your family, too.)

(REPITA C3 - C7 Y ENTRE EN LA CAJA ABAJO.)

Nombre Primero	Año Nacio o Edad	Sexo	Relacion con Informante	¿Agricultor?	¿Esposa?

BUEN HOMBRE INTERVIEW

ANONYMOUS COVER SHEET
(To replace original cover sheet after interviewing)

Interview Number ____________________

Name of Interviewer __________________

Date of Interview ____________________

Anyone listed, but temporarily away?

1. No
2. Yes

Relisting of this family only, with farmer first and relation to farmer. (Put youngest children last.)

Line Number	Age	Sex	Relation to farmer	Check in row if: Informant	Farmer	Spouse
1			Farmer			
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

ENTREVISTA DE AGRICULTOR
(FARMER'S INTERVIEW)

Q.1. ¿Es Ud. un miembro de la asociacion de agricultores? (Are you a member of the agricultural association?)

1. NO | **5. SI**

Q.2. ¿Tiene Ud. su propia finca o cultiva una parcela de tierra? (Do you have your own farm or do you cultivate a parcel of land?)

1. NO | **5. SI**

VAYA AL FIN

Q.2a. ¿Cuantas parcelas tiene Ud.? (How many plots do you have?)

1. UNO | **2. DOS** | **3. TRES** | **4. CUATRO** | **5. CINCO O MAS**

Q.3. ¿Como obtuvo la tierra que cultiva? (How did you obtain your farmland?)

____

____

____

Q.4. ¿En tareas, cual es el tamaño total de sus parcelas? (In tareas, what is the total size of all your plots together?)

____

Q.5. ¿Son suyas todas las parcelas que cultivo este año? (Do you own all the plots you farmed this year?)

1. NO | **5. SI**

Q.5a. (SI ES TERRATENIENTE) ¿Alquila algunas parcelas a otras personas? (IF A LANDOWNER: Do you rent any of your other land to other people?)

1. NO | **5. SI**

Q.5b. ¿Cuantas tareas alquila Ud.?

____

Q.5c. ¿Paga el alquiler en pesos, parte de su cosecha, animales o algo mas?

____

VAYA A Q.6

VAYA A Q.7

Q.6. (SI CULTIVA PARCELAS QUE PERTENECEN A OTRA PERSONA) Da Ud. algo al dueño en intercambio por cultivar la tierra? (IF RESPONDENT CULTIVATES LAND BELONGING TO SOMEONE ELSE: Do you give anything to the landowner in exchange for farming the land?)

1. NO **5. SI**

Q.6a. Paga en pesos, da parte de la cosecha, animales o algo mas? (Do you pay cash, give part of your harvest, animals or something else?)

1. PESOS **2. COSECHA** **3. ANIMALES** **8. ALGO MAS**

Q.7. Son sus tierras, o las tierras que Ud. cultiva, planas o cuestas o ambos? (Is your land flat, sloped or both?)

1. PLANAS **2. CUESTAS** **3. AMBOS**

Q.7a. Aqui hay cuatro cuadros de cuestas con diferente cantidades de inclinacion. ¿Puede mostrarme cual se parece mas a la mayoria de las cuestas en su tierra? (Here are 4 pictures of slopes with different amounts of steepness. Can you tell me which is like most of the slopes on your land.)

1. 0-6%   2. 6-12%   3. 12-18%   4. 18-25%

5. MAS QUE 25%

8. OTRO (Explique):______________________________
____
____
____

Ahora voy a hacerle algunas preguntas acerca de los cultivos que usted siembra.
Q.8. ¿Cuando hay lluvia, cuales cultivos siembra Ud. usualmente? (When there is rain, which crops do you plant?)

# del cultivo	Nombre del cultivo	# del cultivo	Nombre del cultivo
1		9	
2		10	
3		11	
4		12	
5		13	
6		14	
7		15	
8		16	

Q.8a. ¿Alguna mas? (are there more?)

Q.8b. ¿Cuando no hay mucha lluvia, cuales cultivos siembra Ud.? (When there's not much rain, what crops do you plant?)

Q.9. ¿Cuales cultivos parecen crecer mejor aqui en Buen Hombre cuando hay lluvia? (Which crops seem to grow better here in Buen Hombre when there is rain?)

Q.9a. (SI HAY CULTIVOS ESCRITO EN Q.9 ARRIBA) ¿Porque piensa que estos cultivos crecen mejor que otros en Buen Hombre? (Why do you think these crops grow better than other crops in Buen Hombre?)

Q.9b. ¿Y cuando no hay mucha lluvia, cuales cultivos parecen crecer mejor en Buen Hombre? (And when there isn't much rain, which crops grow better in Buen Hombre?)

Q.9c. (SI HAY CULTIVOS ESCRITO EN Q.9b ARRIBA) ¿Y porque piensa que estos cultivos crecen mejor cuando no hay mucha lluvia en Buen Hombre?

Q.10. ¿Siempre siembra Ud. sus cultivos al mismo tiempo del año o cambia el tiempo de siembra? (Do you always plant your crops at the same time of year, or do you change the time of planting?)

1. EL MISMO TIEMPO	5. DIFERENTE TIEMPO	8. OTRO

Q.10a. ¿Porque?

Q.11. ¿Siembra los mismos cultivos en las mismas parcelas cada año, o cambia los cultivos que siembra en cada parcela? (Do you plant the same crops in the same fields each year, or do you change the crops that you plant in each field?)

1. LOS MISMOS CULTIVOS | **5. DIFERENTES CULTIVOS** | **8. OTRO**

Q.11A. ¿Puede decirme porque siembra sus cultivos asi? (Can you tell me why you plant your crops this way?)

Q.12. ¿Siembra Ud. solamente un cultivo por parcela o siembra mas de un cultivo por parcela? (Do you plant only one crop in a field or more than one crop in the same field?)

1. UN CULTIVO | **5. MAS QUE UN CULTIVO** | **7. OTRO**

Q.12a. ¿Porque siembra un solo cultivo?

Q.12b. ¿Porque los siembra juntos?

Q.12c. ¿Cambia algunas veces la combinacion de cultivos? (Do you change the combination of crops sometimes?)

1. NO | **5. SI**

Q.12d. ¿Porque?

Q.12e. ¿Cuales cultivos siembra juntos? (Which crops do you plant together?)

Q.13. ¿Siembra todas sus parcelas cada año o permite la tierra a quedar eriaza algunos años? (Do you plant each field every year or do you let the land lie fallow some years?)

1. SIEMBRA CADA AÑO | **5. ERIAZO ALGUNOS AÑOS** | **8. OTRO**

Q.13a. ¿Con que frecuencia es la tierra eriaza? (How often is the land fallow?)

____

Q.13b. ¿Como decide Ud. cuando cultivar y cuando no cultivar? (How do you decide when to cultivate and when not to cultivate?)

____

____

____

Q.14. ¿Generalmente, en cuales meses del año hace estas tareas -- (Generally, in what months of the year do you do these tasks --)

Q.14a. limpia los campos? (clear the fields?)

____

Q.14b. labra el suelo? (till the soil?)

____

Q.14c. deshierba? (weed?)

____

Q.14d. cosecha? (harvest?)

____

Q.15. ¿Que metodos usa Ud. para limpiar los campos antes de sembrar los cultivos? (What ways do you use to clear land before planting crops?)

____

____

____

Q.15a. ¿Porque usa estos metodos para limpiar? (Why do you clear the land this way?)

____

____

____

Q.15b. ¿Normalmente quien limpia sus campos? (Usually, who clears your plots?)

____

Q.16. ¿Como cultiva el suelo antes de sembrar semillas? (How do you cultivate the soil before planting seeds?)

Q.16a. ¿Porque prepara los suelos asi? (Why do you prepare the soil this way?)

Q.16b. Normalmente, quien labra la tierra antes de sembrar? (Usually, who tills the land before planting?)

Q.16c. ¿Hay alguien mas? (Is there anyone else?)

Q.17. ¿Como siembra sus semillas? (How do you plant your seeds?)

Q.17a. ¿Cuando siembra sus semillas, que distancia hay entre las semillas? ¿Hay un diseño regular o no? ¿Hay surcos? (When you plant your seeds, what distance is there between seeds? Is there a regular pattern or not? Are there rows?)

Q.17b. ¿Normalmente, quien siembra las semillas? (Usually, who plants the seeds?)

Q.17c. ¿Hay alguien mas que ayuda? (Is there anyone else who helps?)

Q.18. ¿Como deshierba sus cultivos -- a mano, con una azada o de que otra manera? (How do you weed your crops -- by hand, with a hoe or what?)

Q.18a. ¿Porque deshierba en esta manera? (Why do you weed in this way?)

Q.18b. ¿Cuantas veces durante la estacion de creciendo deshierba Ud. sus cultivos?

1. UNA VEZ	2. 2 VECES	3. 3 VECES	4. 4 VECES
5. MAS QUE 5 VECES	7. NUNCA		

Q.18c. ¿Usualmente, quien deshierba los cultivos? ¿Alguien mas?

____

Q.19. ¿Como cosecha sus cultivos?

____

____

____

____

Q.19a. ¿Usualmente, quien ayuda con la cosecha?

____

Q.20. ¿Que tipos de tratamiento hace a sus cultivos despues de la cosecha? (How do you process your crops after harvest?)

____

____

____

Q.20. ¿Quien hace el tratamiento de los cultivos? ______

____

Q.21. ¿Como almacena sus cultivos? (How do you store your crops?)

____

____

Q.21a. ¿Por cuanto tiempo duran?____________________

____

Q.21b. ¿Que problemas tiene con almacenaje? (What problems do you have with storage?)

____

____

____

____

____

____

Q.22. ¿Vende algo de su cosecha?

1. NO	5. SI

Q.22a. ¿Mas o menos, cuanto dinero gana de la cosecha tipicamente en un año?

____

Q.22b. ¿Da algo de la cosecha a otras personas?

1. NO **5. SI**

Q.22c. ¿Cuanto piensa es el valor de la parte de la cosecha que da a otras personas?____________________

Q.23. ¿Hay tipos diferentes de suelos de tierra en el campo que labra Ud.? (Are there different types of soils in the fields you work?)

1. NO **5.SI**

Q.23a. ¿Puede describir los tipos diferentes?

Suelo #1 ____________________

Suelo #2 ____________________

Suelo #3 ____________________

Suelo #4 ____________________

Q.23b. ¿Cambia sus metodos de labrar o los cultivos que siembra de acuerdo al tipo de suelo?

1. NO **5. SI**

Q.23c. ¿Como?____________________

Q.24. ¿Añade algo al suelo a mejorarlo, como estiercol, hojas, cenizas, plantas muertas o abono? (Do you add anything to improve the soil, like manure, leaves, ashes, dead plants or fertilizer?)

1. NO **5. SI**

Q.24a. ¿Que añade?

1. ESTIERCOL **2. HOJAS** **3. CENIZAS** **4. PLANTAS MUERTAS**

5. ABONO **8. OTRA COSA** **(Especifique:)**____________________

Q.24b. (SI USA ABONO) ¿Cuanto cuesta el abono y donde le compra? ____________________

Q.24c. ¿Hace algo mas para proteger o mejorar el suelo en sus parcelas? ____________________

Q.25. ¿Usa Ud. algunos pesticidas/quimicos para matar insectos of deshierbas?

1. NO | **5. SI**

Q.25a. ¿Cuales quimicos usa, y los usa contra los insectos o para deshierbar o que?____________________

____

Q.25b. ¿Cuanto cuestan?______________________________

Q.26. ¿Que tipo de equipo usa para labrar el suelo?

____

Q.26a. ¿De donde viene estos equipos -- de vecinos, de familia o ya los tenia o que? __________

____

Q.27. ¿Ensaya Ud. algunas veces metodos nuevos de cultivo, como diferentes metodos de sembrar o desherbar o nuevos cultivos? (Do you ever try out new methods of farming, like different ways of planting or weeding or new crops?)

1. NO | **5.SI**

Q.27a. ¿Puede pensar de un ejemplo de un metodo nuevo que uso?

____

Q.28. ¿Conoce algunos agricultores quienes ensayan metodos nuevos de hacer sus tareas en la finca, o que prueban metodos diferentes de labrar? (Do you know any farmers who try out new ways of doing their farm tasks, who test different methods of farming?)

1. NO | **5. SI**

Q.28a. ¿Quien? ______________________________

Q.29. ¿Tiene animales, como vacas, ovejas, chivos o pollos?

1. NO | **5. SI**

Q.29a. Que tipos, y cuantos de cada tipo?

____

Q.29b. ¿Que comen, sus animales, durante el tiempo de lluvia? ________________________

Q.29c. ¿Que comen durante los meses cuando no hay lluvia? ________________________

Q.29d. ¿Siembra Ud. algo que los animales pueden comer?

Q.29e. ¿Cuando compra alimentos para los animales, cuanto cuestan?

Q.29f. ¿Vende los animales o cosas que los animales producen, como huevos o leche?

1. NO | 5. SI

Q.29g. ¿Mas o menos, cuanto dinero gana Ud. en un año tipico por sus animales?

Q.29g. ¿Da algunos animales, o cosas producido por los animales, a otras personas?

1. NO | 5. SI

Q.29h. ¿Cuanto piensa es el valor en pesos de estas cosas en un año?

Q.30. ¿Quien o quienes en la familia hace las decisiones para la finca -- cuando hacer las tareas agricolas, cuantas semillas se siembran, cuando sembrarlos, etc.?

Q.31. ¿Recoge Ud. plantas silvestres, utiles, que crecen en otros lugares?

1. NO | 5. SI

Q.31a. ¿Con que frecuencia recoge plantas - cada dia, una vez por semana, una vez por mes, durante estaciones especiales o que? ________________________

Q.31b. ¿Que tan lejos de Buen Hombre va a recogerlas?

Q.31c. ¿Hay algunas plantas silvestres que Ud. considera utiles para sembrar cerca de la casa?

1. NO **5. SI**

Q.31d. ¿Cuales, y porque son importantes?

Q.31e. ¿Ha sembrado Ud. algunas cerca de su casa? ¿Cuales?

Q.31f. ¿Hay plantas silvestres que son mas importantes durante ciertos periodos del año?

1. NO **5. SI**

Q.31g. ¿Cuales, y cuando?

Q.31h. ¿Porque son importantes, estas plantas?

Q.32. ¿Si podria Ud. pudiera sembrar un cultivo que fuera perfecto para Buen Hombre, perfecto para el clima, los suelos y los problemas de Buen Hombre, que caracteristicas tendria esta planta? Por ejemplo, podria crecer con muy poco agua, podria producir alimentos para personas, animales o que piensa?

Q.33. ¿Podria decirme de donde o de quien obtiene sus semillas?

Q.33a. ¿Tiene que pagar las semillas?

1. NO → Q.34

5. SI → Q.33b

14

Q.33b. ¿Cuanto cuestan?

Q.34. ¿Intercambia algunas semillas o recortes con otros agricultores?

1. NO **5. SI**

Q.34a. ¿Que tipos de semillas o recortes?

Q.35. ¿Guarda algunas semillas de un año para otro?

1. NO **5. SI**

Q.35a. ¿Cuales?

Ahora, quisiera hablar un poco de la educacion de las personas en la familia y del ingreso familiar.

Q.36. ¿Hasta que grado asistio a la escuela?

Q.36a. ¿Cual que el ultimo grado de las otras personas en la familia con 16 o mayores de 16 años?

Nombre **Grado final de escuela**

Q.37. ¿Mas o menos, cual fue su ingreso total en el año pasado?

Q.37a. ¿Cuales fueron las mayores fuentes de este dinero?

Q.38. ¿Si cualquiera cosa fuera posible, que quisiera Ud. ver para el futuro de su familia?

Q.39. ¿Y si cualquiera cosa fuera posible, que quisiera ver para el futuro de Buen Hombre?

No hay mas preguntas por ahora. Muchas gracias para su tiempo y su colaboracion repondiendo a las preguntas.

Q.40. ¿Tiene Ud. o tuvo un jardin este año?

1. NO

Q.40a. Tiene un jardin en años cuando hay lluvia?

1. NO

5. SI

Q.40b. ¿Cuales plantas siembra Ud. en su jardin?

Q.40c. ¿Cuando hay bastante lluvia, siembra plantas diferentes que cuando no hay mucha lluvia?

1. NO

5. SI

Q.40d. ¿Cuales plantas siembra cuando hay lluvia, y cuales plantas siembra cuando no hay mucha lluvia?

5. SI

Q.41. ¿Durante que meses tiene un jardin?

Q.42. ¿Como prepara el suelo en su jardin antes de sembrar?

Q.43. ¿Quien trabaja en el jardin? ¿Alguien mas?

Q.44. ¿Añade algo al suelo a mejorarlo, como estiercol, hojas, cenizas, plantas muertas o abono? (Do you add anything to improve the soil, like manure, leaves, ashes, dead plants or fertilizer?)

1. NO

5. SI

Q.44a. ¿Que añade?

1. ESTIERCOL 2. HOJAS 3. CENIZAS 4. PLANTAS MUERTAS

5. ABONO 8. OTRA COSA (Especifique:)

Q.44b. (SI USA ABONO) ¿Cuanto cuesta el abono y donde le compra? ______

Q.44c. ¿Hace algo mas para proteger o mejorar el suelo en su jardin? ______

Q.45. ¿Usa Ud. algunos quimicos o pesticidas para matar insectos o deshierbar?

1. NO | 5. SI

Q.45a. ¿Cuales quimicos usa, y los usa contra los insectos o para deshierbar o que? ______

Q.45b. ¿Cuanto cuestan? ______

Q.46. ¿Que tipo de tratamiento hace a sus plantas despues de la cosecha? (How do you process your crops after harvest?)

Q.46a. ¿Quien hace el tratamiento de las plantas?

Q.47. ¿Como almacena sus cultivos? (How do you store your crops?)

Q.47a. ¿Por cuanto tiempo duran? ______

Q.47b. ¿Que problemas tiene con almacenaje? (What problems do you have with storage?)

Q.48. ¿Vende algo de su cosecha?

1. NO | 5. SI

Q.48a. ¿Mas o menos, cuanto dinero gana de la cosecha tipicamente en un año?

Q.48b. ¿Da algo de la cosecha a otras personas?

1. NO

5. SI

Q.48c. ¿Cuanto piensa es el valor de la parte de la cosecha que da a otras personas? ____________________

Q.49. ¿Con que frequencia trabaja en su jardin?____________________

Q.50. ¿Que es el problema mas grande que tiene creciendo plantas en su jardin?____________________

Q.50a. ¿Como trata este problema?____________________

Q.51. ¿Cuales otros problemas tiene creciendo cosas en su jardin?_

Q.51a. ¿Como trata estos problemas?____________________

Q.52. ¿Si Ud. pudiera sembrar una planta que era perfecta para Buen Hombre, perfecto para el clima, los suelos y los problemas de Buen Hombre, que caracteristicas tendria esta planta? Por ejemplo, podria crecer con muy poco agua, podria producir alimentos para personas, animales o que piensa?

Q.53. ¿Podria decirme de donde o de quien obtiene sus semillas?

Q.53a. ¿Tiene que pagar las semillas?

1. NO | 5. SI

Q.53b. ¿Cuanto cuestan?______________________________

Q.54. ¿Intercambia algunas semillas o recortes con otras personas?

1. NO | 5. SI

Q.54a. ¿Que tipos de semillas o recortes?

Q.55. ¿Guarda algunas semillas de un año para otro?

1. NO | 5. SI

Q.55a. ¿Cuales?______________________________

Q.56. ¿Hay algo mas respecto a su jardin que quisiera decirme?

Q.57. ¿Cuando hay bastante alimento, cuantas comidas prepara Ud. cada dia?______________________________

Q.58. ¿Y normalmente, para estas comidas, que cosas prepara?

Q.59. ¿Y cuando no hay mucho alimento, cuantas comidas prepara para cada dia?______________________________

Q.60. ¿Que cosas prepara para comer cuando no hay mucho alimento?

Q.61. ¿Prepara alimentos diferentes para los muchachos? (SI SI) ¿Que prepara?

Q.62. ¿Algunas veces prepara plantas silvestres que colegio Ud. para comer? (SI SI) ¿Cuales?

Q.63. ¿Con que frecuencia tienen enfermedades los muchachos en la familia?

Q.64. ¿Y los adultos, con que frecuencia tienen enfermedades?

Q.65. ¿Que tipo de enfermedades tienen los muchachos?

Q.66. ¿Que tipo de enfermedades tienen los adultos?

Q.67. ¿Quien o quienes en la familia hacen las decisiones para la familia -- cosas como donde gastar el dinero, como cuidar los niños enfermos, cuando arreglarla la casa, cuando visiatar al medico, etc.?

Q.68. ¿Si cualquiera cosa fuera posible, que quisiera Ud. ver para el futuro de su familia?

Q.69. ¿Y si cualquiera cosa fuera posible, que quisiera ver para el futuro de Buen Hombre?

Muchas gracias para su tiempo y su colaboracion repondiendo a las preguntas.