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Title: The Use of Remote Sensing in an Integrated Approach for Stress Detection on the Cultivated Cranberry

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Remote sensing is an attractive method for the detection and monitoring of crop stress. The feasibility of using remote sensing for the detection and monitoring of fungal diseases, insects, weeds, and non-infectious diseases affecting the cultivated cranberry (Vaccinium macrocarpon Ait.) is evaluated. A study on the fungal disease twig blight (Lophodermium spp.) was undertaken to illustrate the potential of using remote sensing. The important symptoms for remote sensing detection include leaf discoloration, reduced vigor, and biomass loss. Biomass loss and reduced vigor are the most important symptoms for cranberry stress detection, while leaf discolorations are usually inconspicuous and not widespread. Weeds, areas of dehydration, and general bog conditions can be easily detected at image scales of 1:12,000 and smaller. Fungus and insect damage can be monitored at smaller scales (1:6,000 and smaller); however, this information is more useful for

regional or higher levels of management rather than for the individual grower. This is due to the likelihood of damage symptoms being the result of inefficient control practices rather than from the early establishment of stress. Many of the stresses have similar symptoms, making the identification of the stress agents difficult. Thus the timing of imagery acquisition is important and additional sources of information are necessary. Currently, remote sensing is best suited for inclusion in an integrated approach for a working stress detection and monitoring system.

Study plots for the fungal disease twig blight (Lophodermium spp.) were selected in Long Beach, Washington. Aerial missions were conducted using color and color IR film with a 9" x 9" format (1:12000) and a 70mm format (1:3800). The progression of twig blight was monitored in study plots located in a commercial cranberry bog with ground photography employing 35mm color and color IR film. Comparisons of 11 different filters were made (5 IR filters, 3 red filters, and one green, yellow, and blue filter) with the best film/filter combination being a Wratten no. 12 (yellow) and color IR film. Aerial photograph interpretations were made from differences in image tone rather than leaf color changes. However, color differences are useful for identifying certain stress agents. Darker image tones had a positive correlation to Lophodermium spp. incidence, were independent of upright density, and had a negative correlation to upright density-revised. Upright density-revised is the total number of uprights minus the number of infected uprights. Healthy uprights grow above and cast a shadow over damaged uprights; therefore, upright density-revised is a better predictor of ground conditions important for remote sensing. Interpretation differences between filters could be attributed more to exposure differences than to anything else.

The Use of Remote Sensing in an Integrated Approach for Stress Detection on the Cultivated Cranberry

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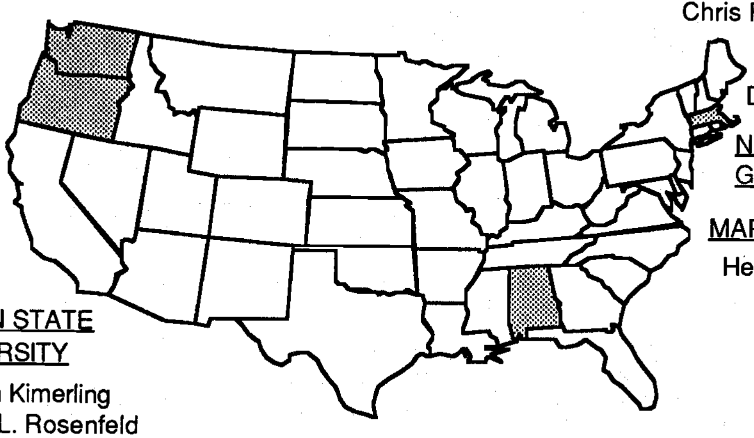

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CHAPTER I

INTRODUCTION

Despite recent heavy marketing programs that have produced an increased consumption of cranberry products, cranberry culture remains somewhat obscure, known only to the local communities where they are grown. Presently, the industry is in a welcomed state of calm steady growth. However, the past has not shown great stability and the cranberry industry is now facing problems similar to those affecting general agriculture.

With environmental legislation and the increasing complexity of ecological, economic, and social interactions, there is a need for greater and better resource data that provide the grower with a more efficient means for keeping productivity high while meeting public concerns. Methods for collecting, recording, and interpreting and transferring data to decisionmakers are needed. Planning for the future is underway and remote sensing has the potential to be a part of that future.

The purpose of this study is to evaluate the feasibility of using remote sensing for the detection and monitoring of stress affecting the cultivated cranberry plant, Vaccinium macrocarpon Ait. Data were collected from a water-harvested commercial cranberry bog in Long Beach, WA where the McFarlin variety of cranberry is grown. The stress, Lophodermium spp. twig blight, a fungal disease, was selected to illustrate this potential.

Cranberry plants need much care and attention for continued successful cultivation. New cranberry plantings become full bearing in 6 to 8 years. Some plantings have produced for over a century. Cranberry growers do not have the luxury of rotating crops and replantings are expensive (thus, resistant varieties are slowly put into production). The long term trend of increasing yields has meant increased water usage (for irrigation, frost protection, and the changeover from dry to wet harvesting methods) and increased nutrition (producing heavier vines). This trend has caused a decline in berry quality and has possibly produced a more favorable environment for stress. To insure the protection of a crop, there is a tendency to over-apply chemical treatments. This tendency, together with the need for great quantities of water and the close proximity of bogs to population centers, is causing considerable concern.

The needs of the cranberry grower are to identify the location of stress, identify the causal agent, realize the extent of the stress, and employ any control measures accordingly. The most common method for crop evaluation is simply to walk through the bog making visual inspections. The problems with this are the effect of bog traffic (the trampling of vines), the difficulty of identifying and documenting at ground level the location and extent of stress, and the cost of labor. Remote sensing can solve some of these problems and be a welcomed addition to an overall management program.

Remote sensing is seen as a relatively quick, cost effective method for collecting data that can be repeated. Once a scene is recorded, the image becomes a permanent historical record whose data remain accurate for that particular point in time. Usually benefits are stated in terms of increased productivity, greater efficiency for combating stress, and assessing damage. Also, the bird's eye perspective provides with relative ease the location and position of objects. Currently, remote sensing is being recognized as a cost effective measure when compared to not doing anything or to using alternative methods and the associated personnel needed to carry them out. In addition, remote sensing provides a useful communications tool and is recognized for its public relations potential.

Occasionally, there has been confusion over the potential applications versus the immediate applications of remote sensing. Decisionmakers can be supplied with the needed data when remote sensing is combined with other techniques such as field measurements and statistics. It is this integrated approach that makes for the best results. A working remote sensing system should include physical, economic, and cultural practice information, thereby increasing accuracy.

In light of the above introduction, this paper first considers the object of the study, the cranberry plant and secondly, cranberry plant stress. These are reviewed with an emphasis on the important characteristics for remote sensing. Thirdly, remote sensing of vegetation is reviewed including the spectral regions of the electromagnetic spectrum and how vegetation and vegetation stress interacts with electromagnetic energy. In addition, atmospheric effects, sensors, and imagery are covered. Fourthly, a remote sensing vegetation stress study on twig blight of the cultivated cranberry was undertaken and shows some of the prospects and problems for a working remote sensing system. Lastly, how remote sensing might be best applied to a cranberry stress detection and monitoring system is discussed.

CHAPTER II

THE CRANBERRY

The cultivated cranberry is a prostrate, woody broadleaf evergreen vine producing stems or runners and vertical branches called uprights. Runners grow from 1 to 6 feet and have 1/3 to 1/2 inch long oblong or oval leaves with margins rolling downward and are opposite along the vine. Uprights originate from the axillary buds on the runners, produce 2-3 inches of growth per year, and grow for several years. Eventually uprights develop a lean in the basal area so that an upright several feet long may extend only 6-8 inches high depending on the variety and upright density. Leaves on the uprights have a whorled arrangement (Shawa et al., 1984; Shoemaker, 1978).

Uprights normally bloom starting in the second year. Mixed buds are formed terminally on uprights and set prior to dormancy. Fruit buds which are larger than the vegetative buds contain flowers, leaves, and a growing point. Two to seven flowers may appear at the base of the current year's growth beginning in late spring. The flowering period lasts from 3 to 6 weeks (Figure II.1). It normally takes 3 to 4 years from the time cuttings are planted to when the bog is

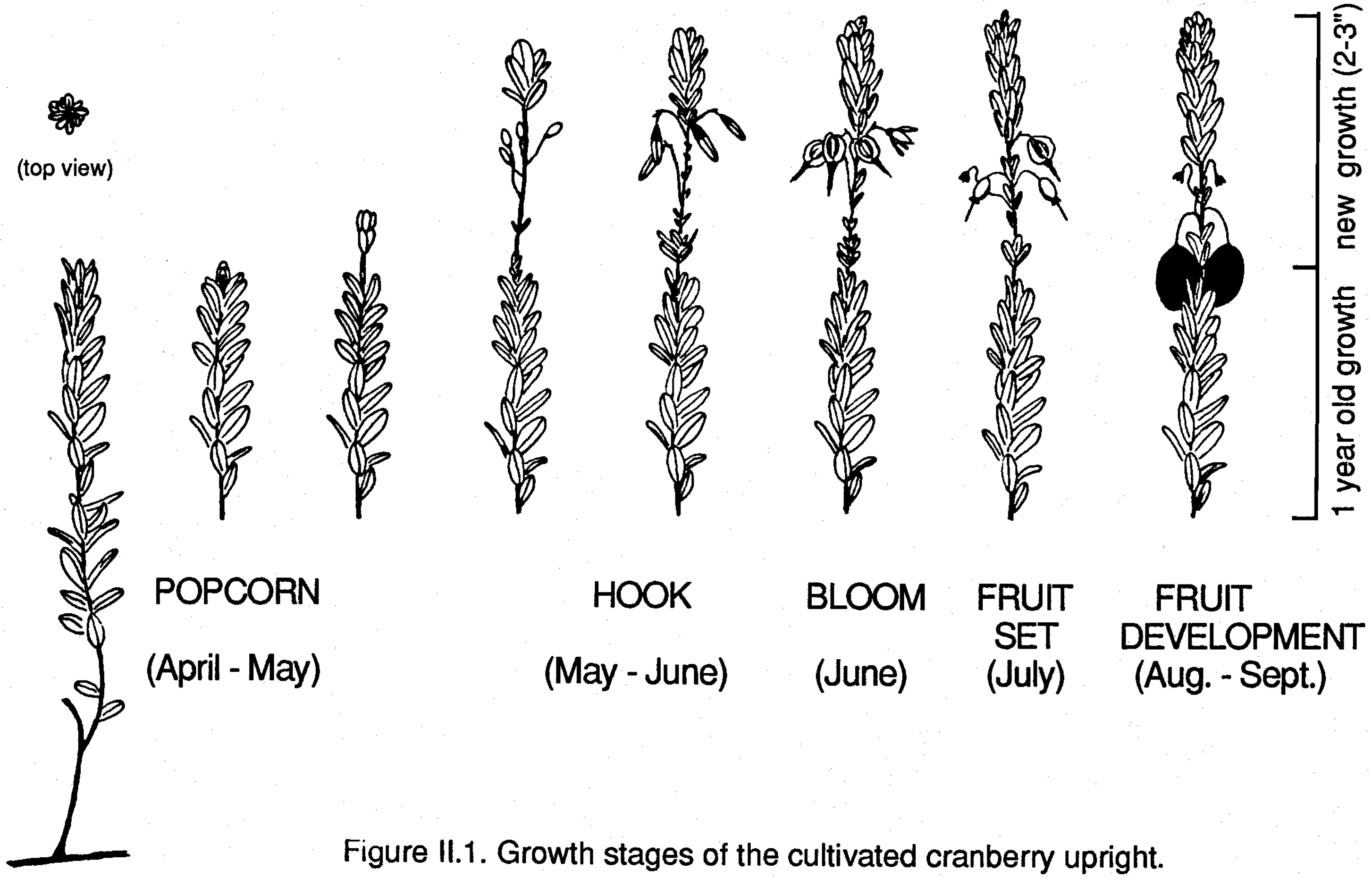


Figure II.1. Growth stages of the cultivated cranberry upright.

completely covered and a profitable crop is produced. In another 3 to 4 years, the bog will become full bearing. Well maintained bogs have produced crops for over a century. Cranberry yield is based on the upright density, the percentage of fruiting uprights, the number of flowers on the fruiting upright, the percent fruit set, and finally the weight of the berries (Shawa et al., 1984; Shoemaker, 1978).

Leaves on the vine are dark glossy green during the growing season and turn to a reddish-brown during the dormant season. They remain on the plant for up to three years before dropping. Leaf color varies with age and variety and may vary considerably within a bog.

The cranberry root system is not extensive, developing in the upper four inches of soil. The roots are very fine and fibrous with no root hairs. Instead, nutrients are absorbed through a symbiotic relationship with ericoid endomycorrhizal fungi. The roots may develop at practically any point along the runner, thus propagation is easily achieved by simply inserting cranberry cuttings in the soil (Shawa et al., 1984; Stribley & Read, 1976).

The natural habitat for cranberries is one that has continually wet conditions such as bogs containing peat and muck soils, along streams, swamps, and lakes- all with certain general requirements. These requirements include an acid soil (a pH of 4.5-5.5 is best), plenty of water, and good drainage. Although much water is needed, a high water table or floods of six days or more during the growing season will cause injury (Shawa et al., 1984). The optimal water table depth is 12-15 inches (Eck, 1976).

Cranberry cultivation can be successful outside of its natural habitat in man-made bogs. Bogs have been constructed in sandy soils on terraced hillsides or in swales (Shawa et al., 1984). In Massachusetts an experimental bog has been constructed consisting of four inches of sand covering twelve inches of silt in an old gravel pit. Results show that water retention properties of the silt work well in drought conditions; however, drainage is impeded in water surplus conditions, causing vine injury (Caldwell, 1982).

On the West Coast cranberries are grown on various soils. In Washington, cranberries are grown on various types of peat, much of which is a brown sphagnum peat found parallel to the coast between the sand bars and sand dunes. Bogs in the Grayland area are mainly in one peat swamp eight miles long and one mile wide. There is also a black peat covered with sphagnum moss west of Grays Harbor.

In Clatsop County, Oregon, cranberries are grown on Spalding peat (sphagnum moss with woody material). In Coos and Curry Counties most of the cranberries are grown on Blacklock soils containing no peat; rather they contain an acid dark grey fine sandy loam over a layer containing illuvial humus and further, illuvial iron forming a hardpan.

The cultivated cranberry (Vaccinium macrocarpon Ait.) is native to North America and can be found in peat bogs extending north to Newfoundland, west to Minnesota, and south to Illinois, Indiana, Ohio, West Virginia, and North Carolina. The cultivated cranberry is also known as the American or large cranberry. All but 12 of the approximately 135 known varieties have been propagated from native plants in Massachusetts, New Jersey, and Wisconsin. Of the 12 varieties, two originated in Michigan (Early Ohio and Prolific), one in Oregon (Stankavich), and two in Canada (Beaver or Beaver River and Cumberland Point). Three were introduced by a USDA breeding program in 1950: Beckwith (McFarlin X Early Black), Stevens (McFarlin X Potter), and Wilcox (Howes X Searles). Three more were introduced by the USDA in 1961: Bergman (Early Black X Searles), Franklin (Early Black X Howes), and Pilgrim (Prolific X McFarlin). The twelfth variety, Crowley (McFarlin X Prolific), was introduced in 1961 by Washington State University (Dana, 1983; Chandler & Demoranville, 1958).

Approximately 50 varieties are currently used for cultivation with one variety (Early Black) accounting for 31% of the total North American acreage. Five varieties (adding Howes, McFarlin, Searles, and Stevens) account for 87% and 8 varieties (adding Ben Lear, Crowley, and Bergman) account for 96% of the total acreage. The importance of certain varieties vary from one region to another. For example, the McFarlin variety accounts for 97% of the total acreage in Washington. Identifying different varieties is difficult. Differences are found in berry size, shape, color, and time to maturity; also vine texture, upright length, and leaf size and color are used.

The wild cranberry (Vaccinium oxycoccus L.), also known as the small, swamp, spice, moss, English, and European cranberry, is not cultivated primarily due to its small berries. It is native to Arctic and cool regions of the Northern hemisphere and is historically important in Europe where it is still harvested for local consumption.

Related to the cranberry is the lingonberry (Vaccinium vitis-idaea). Common names include the mountain cranberry in Maine, cowberry in Massachusetts, foxberry, lingberry, and Preissellberren in Germany. Again, cultivation in North America is negated by small berries. However, in Europe and the Soviet Union it is historically important and in much of Europe is still preferred over the cultivated cranberry.

Less related and unimportant species include the bog bilberry (Vaccinium uliginosum) and the bearberry (Arctostaphylos uva-ursi). The bearberry is also commonly known as the hog cranberry in Massachusetts, the upland cranberry in New Jersey, foxberry, sandberry, crowberry, grouse berry, and kinnikinnick.

CHAPTER III

CRANBERRY PLANT STRESS

Stress detection starts with knowledge of what the possible stresses and syndromes are. This not only includes strain (any physical or chemical change in a plant), injury (a detrimental strain), and/or damage (any loss) caused by the stress, but also temporal and spatial (horizontal extent and vertical profile) characteristics. Tables III.1 through III.5 are a summary of stresses found on the West Coast.

It is important to also understand conditions that exist within a cranberry bog. In Washington, cranberries are grown on peat bogs near sea level. As these bogs are drained, the peat settles. Drainage also causes the exposed peat to decompose creating muck soils. Although settling is constant, peat generally does not settle uniformly nor is the bog uniformly fertile. This creates depressions within a bog and leads to areas or pockets of vegetation showing deficiency symptoms, excessive growth or both. In addition, cultural practices both in general and for stress control measures in particular should be known and understood including water management, sanding, pruning, nutrition, and chemical usage.

TABLE III.1a DISEASE INFECTION, SYMPTOMS, AND TREATMENT TIMINGS

	CROP CALENDAR							
DISEASE	DORMANCY	LATE DORMANCY	BUD BREAK	POPCORN-HOOK	HOOK-BLOOM	FRUIT SET	FRUIT DEVELOPMENT	HARVEST
	NOV DEC JAN	FEB MAR	APR	MAY	JUN	JUL	AUG SEPT	OCT
FUNGI								
TWIG BLIGHT (*Lophodermium* spp.)		Infected uprights die, turning brown then tan (only one year old growth is killed).			Infection occurs on new growth ■■■■	■■■■	■■■■	
COTTONBALL (*Sclerotinia oxycocci*)			Infection occurs on new plant growth (usually uprights) ■■■■		Vine tips wilt and die, becoming brown and shriveled			
RED LEAF SPOT (*Exobasidium vaccinii*)			Infection to young leaves and stems Red spots on the upper side of leaves, paler on the underside ■■■■	■■■■	Premature leaf drop Stems are red and swollen New growth on uprights die	Symptoms may appear during periods of rainy and cloudy conditions after dormancy		
ROSE BLOOM (*Exobasidium oxycocci*)			Infection to axillary (side) buds Pink or rose colored leaves on short lateral branches ■■■■	■■■■	Fleshy growth dries up, turns black, and dies			
STORAGE ROTS								
END ROT (*Godronia cassandrae*) (*Fusicoccum putrefaciens*)		Fungus is present year-round on stems and leaves and may be wound invading			Symptoms include stem blight and leaf cast ■■■■	■■■■	■■■■	Some infection occurs

■■■■ Fungicide treatments

TABLE III.1b DISEASE INFECTION, SYMPTOMS, AND TREATMENT TIMINGS

DISEASE	CROP CALENDAR DORMANCY NOV DEC JAN	LATE DORMANCY FEB MAR	BUD BREAK APR	POPCORN-HOOK MAY	HOOK-BLOOM JUN	FRUIT SET JUL	FRUIT DEVELOPMENT AUG SEPT	HARVEST OCT
BLACK ROT (*Ceuthospora lunata*) (*Strassaria oxycocci*)	Inoculum on stems and leaaves is carried over from the previous season		Primarily a wound-invading organism of leaves, stems, and fruit throughout the growing season			■■■■■■■■■■■■■■■■	Most infection of the fruit is thought to be late in the growing season or at harvest	
VISCID ROT and UPRIGHT DIEBACK (*Diaporthe vaccinii*)					Leaves may first show a mottling Diseased uprights exhibit a yellowish cast, which may progress to an orange or bronze, then brown and dies. Blossoms are also affected.		Diseased uprights can be differentiated from healthy ones late in the growing season	
		Control: provide adequate moisture,control rank vine growth, and cool vines during hot spells.						
BOTRYSOPHAERIA FRUIT ROT and LEAF DROP (*Phyllosticta elongata*)	Circular black pin hole-sized fruiting bodies occur all year long on the underside of senescent leaves and latent on live leaves.	■■■■■■■■■■	■■■■■■■■■■	■■■■■■■■■■		Symptoms occur on new leaves ■■■■■■■■	■■■■■■ Reddening of leaves Defoliation of runners and uprights Latent infection	
RIPE ROT (*Sporonema oxycocci*)			Infection occurs? ■■■■■■■■■■■■■	Hooks and blossoms turn brown and die (blossom blight) ■■■■■■■■■■■■■				
VIRUS DISEASE								
FALSE BLOSSOM (*Chlorogenus vaccinii* Holmes)	Infection of the disease is from the feeding activity of the blunt-nosed leafhopper (*Scleroracus vaccinii* Van D.) (*Euscelis striatulus* Fallen).			The insect hatches in late May or early June and matures in a month.	Flowers are erect or absent. Leaves are smaller and closer to the stem (uprights appear slender). A number of uprights are close together (witches' broom effect) and eventually dies (may be years).		Premature reddening of leaves from infection.	

TABLE III.2a INSECT SYMPTOMS AND TREATMENT TIMINGS

INSECT	CROP CALENDAR							
	DORMANCY	LATE DORMANCY	BUD BREAK	POPCORN-HOOK	HOOK-BLOOM	FRUIT SET	FRUIT DEVELOPMENT	HARVEST
	NOV DEC JAN	FEB MAR	APR	MAY	JUN	JUL	AUG SEPT	OCT
BLACK-HEADED FIREWORM (<u>Rhopobota naevena naevena</u>)			<u>First Brood</u> Larvae feed on the underside of the leaf and are hidden by producing a cover of frass and webbing. Some larvae move to the growing tips or unopened buds. All larvae eventually move to the top where leaves or blossoms are webbed together. Feeding continues until fully grown.			<u>Second Brood</u> As the larvae matures fruit becomes infested. This brood feeds heavily and grows more rapidly than the first. Damage occurs to current crop and fruit buds for next years crop. Severe injury is indicated by brown vines as if scortched by fire.	(Third brood) feeding takes place on new growth which is webbed or tied together.	
				■■■■	■■■■		■■■■	
BLACK VINE WEEVIL (<u>Otiorhynchus sulcatus</u>)				The beginning of damage symptoms. Plants are girdled from the root to the crown. Plants weaken, wilt, turn brown and die.		Larvae descend to feed on the roots and the bark of roots from the time they leave the egg until pupation, the following spring.		
	□□□□ (flooding)				■■■■ (for dry harvested bogs)	■■■■		
CRANBERRY GIRDLER (<u>Chrysoteuchia topiaria</u>)					Egg laying begins	Larvae feed on the bark of vines which are partialy or completely girdled or severed. These vines turn orange and then brown. Peak feeding is in September.		
						■■■■		
TIPWORM (<u>Dasyneura vaccinii</u>)				Damage occurs from the first brood-cupped tips and resembles frost injury.		Damage from the second brood is more severe. This is due to tip injury not being able to recover in time for the following year.		
				■■■■	■■■■		■■■■	

■■■■ Insecticide treatments

TABLE III.2b INSECTS AND OTHER PEST SYMPTOMS AND TREATMENT TIMINGS

INSECT	CROP CALENDAR DORMANCY NOV DEC JAN	LATE DORMANCY FEB MAR	BUD BREAK APR	POPCORN-HOOK MAY	HOOK-BLOOM JUN	FRUIT SET JUL	FRUIT DEVELOPMENT AUG SEPT	HARVEST OCT
CRANBERRY FRUITWORM (*Acrobasis vaccinii*)				■■■■■■■■■■	■■■■■■■■■■	■■■	Larvae feed only on the berries, eating all of the pulp and seeds before moving on (only by close inspection). ■■■■■■■■	
CUTWORMS (*Agrotis ipsilon*) (*A. niger*)			Larvae feed on new growth or girdle young plants. ■■■■■■■■■■■■■■ (if not flooded)					
OYSTERSHELL SCALE (*Lepidosaphes ulmi*)				Eggs hatch (hook stage) ■■■■■■■■■■■■■■	When heavily infested vines turn red due to the feeding of the growing scales.			
LECANIUM SCALE (*Lecanium corni*)				■■■■■■■■■■■■■■	Egg laying begins	Insects attach themselves to either side of the leaves (resemble yellow mites). ■■■■■■■■■■■■■■■■	Migration to the vine stems forming a brown scale covering for the winter.	
NEMATODES Stubby root (*Trichodorus christiei*) Sheath (*Hemicycliophora* spp.) Spiral (*Helicotylenchus* spp.)			Plant-parasitic nematodes feed on living plant roots and may reduce the root system by 50-75%. Symptoms are similar to drought and nutrient deficiencies.			Nematode populations tend to decrease with hot and dry conditions.		

TABLE III.3a COMMON WEEDS AND TREATMENT TIMINGS

CROP CALENDAR

WEEDS	DORMANCY			LATE DORMANCY		BUD BREAK	POPCORN-HOOK	HOOK-BLOOM	FRUIT SET	FRUIT DEVELOPMENT		HARVEST
	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT
GRASSES-Annual												
Bluegrass (*Poa*)	■	■	■	■	■	■	□	□	□	□		
Bentgrass (*Agrostis*) (& perenn.)	■	■	■	■	■	■	□	□	□	□		
Sicklegrass (*Parapholis*)			■	■	■	■	□	□	□	□		
Barnyard grass (*Echinochloa*)			■	■	■	■	□	□	□	□		
GRASSES-Perennial												
Velvetgrass (*Holcus*)	■	■			■	■	□	□	□	□		
Oniongrass (*Melica*)	■	■			■	■	□	□	□	□		
Salt grass (*Distichlis*)			■	■	■	■	□	□	□	□		
Rice cutgrass (*Leersia*)					■	■	□	□	□	□		
Needle grass (*Stipa*)					■	■	□	□	□	□		
LILIES & IRISES-Perennial												
Lily-of-the-valley (*Maianthemum dilatatum*)					■	■				□		
Golden-eyed grass (*Sisyrinchium californicum*)					■	■				□		
RUSHES & SEDGES-Annual												
Louse grass (*Juncus bufoneous*)	■	■			■	■	□	□	□	□		
Rush (*Juncus*) (& perennials)	■	■			■	■	□	□	□	□		
RUSHES & SEDGES-Perennial												
Spikerush (*Eleocharis*)	■	■			■	■				□		
Sedge (*Scirpus*)	■	■			■	■	□	□	□	□		
Tussocks (*Scirpus validus*)	■	■			■	■	□	□	□	□		
Inflated sedge (*Carex vesicaria*)	■	■			■	■	□	□	□	□		
Cottontop (*Eriophorum chamissonis*)	■	■			■	■	□	□	□	□		

■■■■ Herbicides applied to the bog   □□□□ Swab treatments

TABLE III.3b COMMON WEEDS AND TREATMENT TIMINGS

WEEDS	CROP CALENDAR											
	DORMANCY			LATE DORMANCY		BUD BREAK	POPCORN-HOOK	HOOK-BLOOM	FRUIT SET	FRUIT DEVELOPMENT		HARVEST
	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT
BROADLEAF·Annuals												
Tearthumb (Polygonum sagittatum)	■	■	■	■	■	■				□		
Chickweed (Cerastium) (& perenn.)	■	■	■	■	■	■				□		
Clover (Trifolium) (& perennials)	■	■	■	■	■	■				□		
Smartweed (Polygonum)	■	■	■	■	■	■				□		
Sand spurry (Spergularia)	■	■	■	■	■	■				□		
Fireweed (Erechtites hiercifolia)	■	■	■	■	■	■	□	□	□	□		
BROADLEAF·Perennials												
Sorrel, sheep sorrel (Rumex)	■	■	■	■						□		
False dandelion (Agoseris)	■	■	■	■						□		
Asters (Aster)	■	■	■	■	■	■	□	□	□	□		
Dogwood (Cornus canadensis)			■	■						□		
Alders (Alnus)			■	■						□		
Lotus (Lotus corniculatus)			■	■						□		
Tideland clover (Trifolium wormskioidie)			■	■						□		
Silverleaf (Potentilla)			■	■						□		
Buttercup (Ranunculus repens)			■	■	■					□		
Buckbrush (Spiraea douglasii)			■	■	□	□	□	□	□	□		
Willow (Salix)			■	■	□	□	□	□	□	□		
Birdsfoot trefoil (Lotus)			■	■	■	□	□	□	□	□		
Loosestrife (Lysimachia terrestris)			■	■	■	■	□	□	□	□		
Equisetum ·Annual												
Field horsetail (Equisetum arvense)			■	■	■	■	□	□	□	□		
Equisetum ·Perennial												
Scouring rush (Equisetum hyemale)			■	■	■	■	□	□	□	□		

TABLE III.4a NUTRIENT DEFICIENCY SYMPTOMS AND TREATMENT TIMINGS

	CROP CALENDAR							
NUTRIENT	DORMANCY	LATE DORMANCY	BUD BREAK	POPCORN-HOOK	HOOK-BLOOM	FRUIT SET	FRUIT DEVELOPMENT	HARVEST
	NOV DEC JAN	FEB MAR	APR	MAY	JUN	JUL	AUG SEPT	OCT
NITROGEN (N)			reduction of growth and vigor; yellowish green leaves with reddish bronze cast; older leaves affected first; defoliation occurs leaving only the tip leaves	■■■■	■■■■	■■■■	■■■■	
PHOSPHORUS (P)			all upright leaves turn red progressing to purplish red ■■■■	■■■■				
POTASSIUM (K)			reduction of growth and vigor; leaves turn dark bronze-red; older leaves affected first; defoliation occurs leaving only the tip leaves ■■■■	■■■■				
MAGNESIUM (Mg)			older leaves on runners and uprights progrssively turn red, necrosis, and leaf drop ■■■■	■■■■				
CALCIUM (Ca)	■■■■		new leaves on runner gradually turn red, brown, and then dies (in a few days); shoot tip dies back					
MANGANESE (Mn)			young leaves are light yellow-green; tip leaves turn yellow, light brown, then dies	▨▨▨▨	▨▨▨▨	▨▨▨▨		

■■■■ Fertilizer treatments ▨▨▨▨ Foliar feeding

TABLE III.4b NUTRIENT DEFICIENCY SYMPTOMS AND TREATMENT TIMINGS

<table>
<tr><th></th><th colspan="8">CROP CALENDAR</th></tr>
<tr><th>NUTRIENT</th><th>DORMANCY</th><th>LATE DORMANCY</th><th>BUD BREAK</th><th>POPCORN-HOOK</th><th>HOOK-BLOOM</th><th>FRUIT SET</th><th>FRUIT DEVELOPMENT</th><th>HARVEST</th></tr>
<tr><th></th><th>NOV DEC JAN</th><th>FEB MAR</th><th>APR</th><th>MAY</th><th>JUN</th><th>JUL</th><th>AUG SEPT</th><th>OCT</th></tr>
<tr><td>IRON (Fe)</td><td></td><td></td><td colspan="5">uprights turn chlorotic; yellowish-green leaves turn rusty yellow from the tip downward; symptoms may appear during the fall and dormancy period</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭</td><td></td><td></td></tr>
<tr><td>ZINC (Zn)</td><td></td><td></td><td colspan="5">youngest leaves of an upright are affected; leaves are a lemon yellow color; symptoms may appear during the fall and dormancy period</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭</td><td></td><td></td></tr>
<tr><td>BORON (B)</td><td></td><td></td><td colspan="5">youngest leaves are affected; bluish color followed by a mottled chlorotic spotting; stunted vines; reduced growth; deformed berries</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭</td><td></td><td></td></tr>
<tr><td>COPPER (Cu)</td><td></td><td></td><td colspan="5">youngest leaves are affected; leaves are distorted, turn brown, and die; defoliation takes place from the top down</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭▭</td><td></td><td></td></tr>
<tr><td>SULFUR (S)</td><td></td><td></td><td colspan="5">youngest leaves are affected; leaves turn light yellowish-green</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="5">■■■■■■■■■■■■■■■■■■■■■■■■■■■■■■
(sulfur is supplied from N and K treatments)</td><td></td></tr>
</table>

TABLE III.5 WATER MANAGEMENT AND CULTURAL PRACTICES

ACTIVITY		CROP CALENDAR											
		DORMANCY			LATE DORMANCY		BUD BREAK	POPCORN-HOOK	HOOK-BLOOM	FRUIT SET	FRUIT DEVELOPMENT		HARVES
		NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT
WATER MANAGEMENT													
FROST PROTECTION													
	thermostat setting for sprinklers (°F)	30	29	28	30	32	32	34	34	34	34	32	32
	most sensitive periods				■	■	■	■	■	■			
HEAT PROTECTION													
	thermostat setting for sprinklers (°F)								80	80	80		
IRRIGATION	(3/4 inch per week)								■	■	■	■	
FLOODING	wet harvest												■
	pest control		■	(variable)	■	■							
PRUNING	wet harvest	■	■	■	■								
	dry harvest (usually)												■
SOIL TESTING		■	■	■									
SANDING	wet harvest (seldom)	■	■	■	■	■	■	(used to level low areas and rejuvenate bogs					
	dry harvest (3-5 yrs.)	■	■	■	■	■	■	and may be applied to parts or all of bog)					
NEW PLANTINGS						■	■	■					
LEAF ANALYSIS											■		

The biochemistry and physiology of a plant can be affected by diseases in many different ways. These changes can be grouped into three main areas: decreased photosynthesis, increased respiration, and altered translocation patterns. Pathogens can affect chloroplasts, chlorophyll content, or enzymes important for photosynthesis, thus reducing the rate of photosynthesis, often altering starch metabolism, and is observed as chlorosis of the leaves. By using enzymes, pathogens can break down cell walls and alter metabolism resulting in deficiency symptoms (reduced growth vigor and chlorosis). Enhanced polyphenoloxidase activity (hypersensitivity) can result from diseases involved in necrosis of plant tissues. Also, diseases can cause increased auxin levels altering the growth regulator balance. Diseases affecting root and vascular systems can affect water and salt uptake and translocation observed as wilting or desiccation (Russell, 1981).

Important infectious disease symptoms for remote sensing are characterized by leaf discoloration, reduced growth vigor, and/or a loss of biomass. However, changes in leaf color are usually inconspicuous among healthy uprights, not widespread, and involve close visual inspection. This is true for red leaf spot disease and some storage rots. Fruit and storage rots (end rot, black rot, viscid rot, ripe rot etc.) not only attack fruit but also cause some leaf spotting and blight. Leaf color changes are often the precursor to reduced growth vigor and eventually to biomass loss. Typically, the primary symptoms will be the reduction of plant vigor and biomass loss. This is certainly true for cottonball, which causes upright tips to wilt and die, and twig blight, which causes one year old growth to die. However, all diseases from Table 1 show symptoms to some degree of blight, premature leaf drop, or necrosis.

Diseases can affect growth by reducing vigor the first year and biomass loss the following year. Also, injury or damage to an upright can result in the growth of side shoots. Disease detection is possible after disease symptoms occur (mid-summer to harvest and the following season) and before the vines appear to recover (without further infection about two seasons). The recovery of vegetation refers to remote sensing detection and not necessarily to the health of individual infected or damaged plants. Thus, a significant number of uprights have to be affected for remote sensing detection, considering that the optimum upright density is between 200 and 300 uprights per square foot and could be 2 to 3 times greater. Thus, the timing of imagery acquisition becomes increasingly important.

Symptoms of twig blight appear the season following infection. The infected uprights can be differentiated from healthy uprights beginning in late dormancy. The infected leaves turn brown, eventually assuming a faded brown or tan color, and remain attached to the uprights. Only the previous year's growth dies. The disease is often noticed developing first on the margins of bogs and may occur in small areas or take over the entire bog (Shawa et al., 1984; Bristow, 1986a). Before new growth is initiated within a bog, twig blight symptoms would be interpreted on an image as reduced vigor, unless damage is severe and would be interpreted as biomass loss. During the growing season only very severe symptoms would be interpreted as biomass loss.

Infection of the fungal disease cottonball occurs on new growth during spring. Symptoms first appear during bloom when vine tips wilt and die (tip blight). Usually the symptoms are inconspicuous among healthy uprights but may become severe. Often the disease appears in young bogs that are not harvested; harvesting removes the source of inoculumn-cranberries (Boone, 1982c). The symptoms would be interpreted on an image as reduced vigor if the disease becomes severe.

Infection of the fungal disease red leaf spot occurs on new growth with symptoms of leaf spotting appearing soon afterward. A few weeks later, symptoms of premature leaf drop and the death of new growth appear. Young bogs and areas of luxuriant growth are susceptible (Boone and Tontyaporn, 1986; Shawa et al., 1984). When the disease is severe, symptoms (leaf drop and necrosis) would be interpreted on an image as reduced vigor (leaf spotting is negligible).

Infection of the fungal disease rosebloom occurs during the spring usually to just the axillary buds. Conspicuous hypertrophied pink leaves develop (appearing similar to a rose). New growth is less vigorous and yield is thought to be reduced by only 1 to 2 percent (Shawa et al., 1984). Damage is slight and not widespread. If rosebloom becomes severe, symptoms would be interpreted on an image as reduced vigor.

The fruiting bodies of Botrysophaeria fruit rot occur in a bog all year long with new ones appearing during July-August. Symptoms of leaf reddening and defoliation of runner and uprights appear late in the season with damage evident the following spring. Typically, patches of damage would be interpreted on an image as biomass loss.

The extent of diseases is highly variable and climatic events or conditions may induce or determine the severity of occurrence. For example, a disease may be of consequence one year in a bog and not the next year and may occur in very small pockets, depressions, wet spots, or cover the entire bog. This may be due to changing climatic conditions (moisture, humidity, and/or temperature) or cultural practices (irrigation, pruning, sanding, weed removal, fungicides etc.). Fungal diseases are generally not a problem in well-managed bogs. However, in poorly managed bogs or adverse conditions, red leaf spot, rose bloom, and especially fruit and storage rots may develop (fungi causing fruit and storage rots are present in bogs).

It is evident that conditions favoring one disease also favor certain others and often appear together or in combinations with other stresses. For example, red leaf spot is not usually severe enough for control measures; however, the fungus black spot (<u>Mycosphaerella</u> <u>nigro-maculans</u> Shear) may enter the plant through the red leaf spot lesions (Boone & Tontyaporn, 1986). Also, black rot is primarily a wound invading organism. Thus, symptoms of fungi in total may appear severe. However, initial infections produce symptoms that are inconspicuous among healthy vegetation. Symptoms on new growth may be surrounded by apparently healthy uprights and old growth on the same infected upright making interpretations difficult. Remote sensing is currently best suited for the detection and monitoring of chronic stress.

Many diseases have been transported on vines brought from one region to another with variable effects. Also, diseases over time have been of variable importance. For example, all bogs on the West Coast planted with Wisconsin vines had the viral disease false blossom. However, without the presence of the insect vector in the Pacific Northwest, the disease ran its course. Twig blight is currently only a problem in West Coast bogs. Black rot, rose bloom, and various rots were first realized in Pacific County, Washington during the mid-1920's when expansion of the cranberry industry commenced. In 1924 red leaf spot was believed to be the most important disease in Pacific County, Washington (Giddings & Wood, 1925). Cottonball has been a problem in the past; however, the McFarlin variety is now predominantly cultivated in Washington (97%) and Oregon and is quite resistant (as is Crowley). The McFarlin variety is also somewhat resistant to end rot, but is susceptible to twig blight. The varieties Crowley and Stevens are both susceptible to twig blight and Stevens to red leaf spot. Recently, red shoot disease (Exobasidium perenne) was found in Bandon, Oregon. This disease was previously reported in Nova Scotia and is a first for the Pacific Northwest (Bristow, 1987).

Control measures involve the protection of susceptible tissue and currently have a 80-90% success rate. Growers control diseases by bog sanitation and other bog improvements in addition to a yearly fungicide program. Without a yearly fungicide program, growers would need to apply fungicides immediately after climatic events or certain adverse conditions; this may be what the future holds, but is not feasible at this time. Remote sensing can show bog conditions that favor diseases and shortcomings of control programs in terms of injury or damage to vegetation.

It is difficult to assess the economic loss caused by diseases. Assessment accuracy is reduced by various factors including the duration and severity of disease infection, the stage of plant growth when infection occurs, the incidence of disease which may not be related to disease effects, varietal tolerance, and the interactions between variety, fertility, and disease (Russell, 1981). Therefore, it is easier to determine control measure costs. Economic thresholds are then developed and refer to levels of stress in which control costs equal the returns from productivity gains. Recently, economic thresholds have been developed for insect pests under Massachusetts conditions, but they have not yet been developed for diseases and weeds.

Unlike the highly variable levels of fungal disease incidence, insects tend to build up population levels. Insect populations are determined by the ratio of births to deaths in a given time period. This ratio is affected by climate and weather, the availability or accessibility of food and shelter, natural enemies, and cultural practices (resistant varieties, nutrition and growth conditions of the cranberry plant, bog sanitation, cropping systems, and insecticide usage).

Insect symptoms result primarily from larvae feeding. This may include defoliation of complete areas within a bog, as with the cranberry girdler and black vine weevil, or be interpreted as reduced crop vigor (unless feeding is very severe) as with the black-headed fireworm, the tipworm, and various cutworms. The cranberry fruitworm larvae feed only on the berries and involve close inspection. Various scales are a problem only when bogs are heavily infested producing a discoloration of foliage resembling drought and with dead vines appearing later. Plant parasitic nematodes found in the upper soil horizons provide symptoms similar to drought and nutrient deficiencies as they feed only on living plant roots and can reduce the root system by 50-75% (Haglund, 1987).

Currently, the three most important insect pests on the West Coast are the cranberry girdler, the black-headed fireworm, and the black vine weevil. The larvae from the cranberry girdler begin to feed about mid-July on the bark of vines, girdling or severing roots. Peak feeding is reached in September and ends in early or mid-October. Vines may be completely girdled with dying or dead patches usually noticed in September (Roberts & Mahr, 1982). Large areas may become damaged if the insect is not kept in check.

The black-headed fireworm occurs in most or all cranberry bogs. They exhibit an uneven distribution within a bog, often noticed on bog margins, as they are thought to thrive on plants surrounding bogs. Feeding from the first brood is on the underside of leaves, peaking about mid-May (April through mid-June), and affects the growing tips and buds (Shawa et al., 1984). The first brood is light and injury or damage would be interpreted on an image (if at all) as reduced growth vigor. However, if the first brood is not controlled, the second brood can cause considerable damage. The second brood begins in July and peaks about mid to late July. Feeding is heavier and takes place directly on new growth (runners and uprights) and berries. The vines become brown when feeding is severe and would be interpreted as biomass loss on an image.

The black vine weevil is a root weevil that feeds on roots. However, the black vine weevil may completely girdle a plant from root to crown. Feeding begins in May or June and continues until the following spring. Symptoms include wilting and plant death and begin to appear in May or June (Shawa et al., 1984). Often symptoms appear on bog margins and very large irregular areas of dead vines are evident when feeding is severe.

In some growing areas the cranberry fruitworm is a serious pest. However, larvae feed only on the berries. Therefore, detection of the cranberry fruitworm involves close inspection. The tipworm larvae feed on the tips of plants and produce symptoms similar to the black-headed fireworm. There are two broods with damage occurring in May or June from the first brood and damage from the second brood occurring in July. Cutworms include various species whose larvae can affect or consume leaves, buds, flowers, and berries. Infestations are erratic, but they can do considerable damage when present in a bog.

Insect control measures before World War II consisted of bog sanitation and the application of various substances and concoctions. After World War II, broad spectrum organic insecticides were extensively used (organochlorines and organophosphates) believing that insect control meant killing insects. However, greater numbers of natural enemies tend to be killed and the availability of food and shelter for pests increases. Thus, the population recovery for pests may be exponential.

In general agriculture, environmental considerations and insecticide resistance lessened the usage of some broad spectrum insecticides and some were banned. Currently, selective insecticides and other control measures (flooding, sanding, insect-parasitic nematodes, etc.) used together in integrated pest management (IPM) schemes have been slowly developing and gaining favor. For the cranberry industry, organophosphates (diazinon, malathion, and parathion) are extensively used with some selective insecticides, and in the 1980's IPM schemes have been expanding.

The common sampling methods for the cranberry IPM schemes are visual inspection, visual scanning, sweeping with a net and sex pheromone traps (Brodel, 1985). For example, sex pheromone traps are placed in a bog for the cranberry girdler (2 traps/5 acre bog). When the economic threshold of 25 moths per trap is reached, control measures are undertaken no more than 2 to 3 days later. Therefore, remote sensing would be useful for monitoring injury or damage because detection is based on symptoms caused by larvae (not the moths or adults that produce the larvae).

Weeds are a constant problem, reducing yields and the quality of cranberries. Weeds compete for sunlight, soil moisture, and nutrients. They also shade and crowd out cranberry plants, thus helping to maintain an environment that favors disease development, harbors some insects and nematodes, and impedes harvest operations. Shade conditions may also produce longer and fewer uprights (Roberts & Struckmeyer, 1942; Hicks et al., 1968). In addition, the leaf to stem angle increases (leaves become horizontal). Uprights have fewer flowers and weed bloom may compete for pollinating insects (Hicks et al., 1968). The detection of weeds on an image is by the relative differences of leaf color and structure from the cranberry plant and by the typical increased vigor of weeds.

Weed control is by both application of herbicides and sanitation practices. Before the development of herbicides, growers pulled weeds by hand and by 1940 were applying various petroleum products: solvents, paint thinner, kerosene, and distillate (Crowley, 1954). Problems with herbicide applications include acidic organic matter absorbing chemicals at low rates (high rates may cause injury to the cranberry plant), injury to the cranberry root system (due to its shallow nature), weed resistance, and herbicide drift or run-off (Shawa et al., 1984).

Nutrient deficiencies are non-infectious diseases that show symptoms primarily in terms of leaf discoloration and secondly, reduced crop vigor. Macronutrients consist of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and sulfur (S). Of these nutrients, N, K, and Mg deficiency symptoms appear first on older leaves. All other nutrients have deficiency symptoms that affect younger leaves first or all leaves on an upright. Excessive nitrogen treatments promote luxuriant vine growth which creates a favorable environment for fungi and has been linked to fruit rots. Excessive nitrogen also contributes to a biennial bearing condition (Shawa, 1987). Nutrition diagnoses are made by leaf analysis towards the end of the growing season (July-August) and by a post harvest soil analysis (November-January).

Nutrient deficiencies are somewhat difficult to identify. Generally in a problem area, all other possible stresses are ruled out before a nutrient deficiency is considered to be the cause. This is also a problem for remote sensing. Leaf discoloration is not widespread and deficiencies are rarely severe; thus prospects for detection on an image is based on reduced growth vigor characteristics.

Frost injury is another non-infectious occurrence that is a major problem appearing in depressions or over entire sections of bogs. Either the blossom buds, growing point, or the entire bud is killed. When the entire bud is killed, excessive vegetation may be stimulated, producing side shoots. However, when the growing point is injured a condition called umbrella bloom develops (the vegetative bud does not elongate and bloom becomes terminal) and may be interpreted as reduced vigor. Injury to the blossom buds affects yield (no fruit), but vegetative growth does occur.

Frost injury also allows the infection of wound invading fungi. Thus, practically all of the West Coast bogs contain sprinklers for frost protection and also for cooling vines during periods of excessive heat. Drought conditions may show chlorosis, anthocyanescence, or wilting and produce premature leaf drop and perhaps dieback the following year.

Cultural practices vary between regions and from one bog to another within a region. Generally sand is applied to bogs for new plantings, to rejuvenate part or all of a bog, to level depressions, and for some pest control. Clean light-colored sand is usually applied and is easily interpreted on an image. However, the high reflectance of sand masks new plantings and the beginnings of weed infestations. Pruning is usually heavier in dry harvested bogs and more care is given to vine growth then in wet harvested bogs. Also, pruning may be uneven within a bog.

Raking can have desirable results (removing litter, training vines, and creating a more uniform looking bog) or undesirable results ("filling in" stressed or bare spots creating a different looking bog from the previous season). Nutrition, chemical and water management varies with kind, rate, timing, and method of application. Growers may operate several bogs and treat them differently.

We now know that reduced vigor may be due to insects, fungal diseases, non-infectious diseases, nematodes, severe pruning, and other agents and cultural practices. Also, necrotic areas within a bog not only are caused by fungi and insects, but can be due to excessive applications of fertilizers and herbicides. What we need to know now is, what can be detected on an image and what is the causal agent or agents.

Pertinent References

There are several collective works on cranberry diseases (Bain, 1926; Crowley, 1954; Hall et al., 1981; Shawa et al., 1984; Shear, 1920; Shear et al., 1931; Stevens, 1917; 1924; Stevens & Bain, 1929). Specifically, there are studies on end rot (Boone, 1982a; Shear, 1917; Shear & Bain, 1929; Stevens & Morse, 1919), dieback (Boone, 1982b), cottonball (Boone, 1982c), black rot (Boone & Schwarz, 1982), red leaf spot (Boone & Tontyaporn, 1986), Botryosphaeria (Boone & Weidemann, 1986; Weidemann & Boone, 1984; 1983; 1981; Weidemann et al., 1982), rose bloom (Bristow, 1978; Pelluet, 1928), and false blossom (Chen, 1971; Dobroscky, 1929; Kunkel, 1945; Spaeth & Kraybill, 1927; Stevens, 1931; 1944; Stevens & Sawyer, 1926; Wilcox, 1951; Wilcox & Beckwith, 1935; 1933). Usually studies on diseases cover control practices. In addition, there is the annually updated Pacific Northwest Plant Disease Control Handbook and disease control programs (Shawa et al., 1987).

There are collective works on cranberry insects (Crowley, 1954; Franklin, 1950; 1952; 1948; Marucci, 1977; Shawa et al., 1984; Smith, 1903). There are also specific studies on the girdler (Kamm & McDonough, 1982; 1979; McDonough & Kamm, 1979; Roberts & Mahr, 1982; Scammell, 1917), black vine weevil (Shanks, 1979), tipworm (Marucci & Boyd, 1984), black-headed fireworm (Plank, 1922), cutworms (Franklin & Lacroix, 1924), fruitworm (Tomlinson, 1966; 1960), and insect control (Henry, 1986; Marucci & Moulter, 1971a; 1971b; Miller, 1966; Roberts, 1986; Shawa et al., 1987). There are a few articles on plant parasitic nematodes on the cranberry (Bird & Jenkins, 1964; Boone & Barker, 1966; Zuckerman et al., 1964).

There are general works on weeds (Beckwith & Fiske, 1925; Cross, 1952; Hall, 1969; Hall et al., 1981; Hicks et al., 1968; Skroch & Dana, 1965; Yas & Eaton, 1982; Shawa et al., 1984) and on control (Crowley, 1939; Dana, 1975; 1965a;

1965b; Dana et al., 1965; Demoranville & Cross, 1964; 1958; Miller et al., 1966; Shawa, 1980; Shawa et al., 1985).

There are collective works on nutrients (Eaton, 1971a; 1971b; Eaton & Meeham, 1973; 1976; Hall et al., 1981; Medappa & Dana, 1970a; Shawa et al., 1984; Somogyi et al., 1964; Torio & Eck, 1969). In addition, there are articles on macronutrients (Eck, 1971; Greidanus & Dana, 1972; Greidanus et al., 1972; Keir, 1972; Kender & Childers, 1959; Leschyson & Eaton, 1971; Shawa, 1982; Shawa & Kresge, 1976), seasonal changes (Chaplin & Martin, 1979), and minor elements (Chandler, 1955; Doughty, 1984; Medappa & Dana, 1970b; 1968).

There are general works on cranberry cultural practices (Beckwith, 1931; Crowley, 1954; Darrow et al., 1924a; 1924b; 1924c; Hall et al., 1981; Norton, 1969a; 1969b; Shawa et al., 1984; Tallman & Eaton, 1976). In addition, there are articles on water management (Bergman, 1953; Chandler, 1951; Gray, 1972; Hall, 1971), flooding (Bergman, 1931; 1925; 1922; 1921; Hull & Stevens, 1944; O'Donnell, 1968; Stevens et al., 1942), water table (Eck, 1976; Hall, 1971), frost (Bergman, 1961; Eaton, 1966; Norton, 1968a; 1968b; 1968c), weather relations (Franklin et al., 1943; Franklin & Cross, 1948; Stevens, 1917), bog microclimate (Bates, 1971), affects of salt (Chandler & Demoranville, 1959; Deubert, 1981), planting (Welker & Vass, 1983), pruning (Marucci, 1987), and sanding (Cross, 1978a; 1978b; Shawa, 1978).

CHAPTER IV

REMOTE SENSING OF VEGETATION

A remote sensing system may grade from experimental to operational and can be either qualitative or quantitative. The components of a remote sensing system consist of an energy source, atmosphere, scene, and sensor(s). An energy source is usually electromagnetic energy either naturally (such as reflected light from the sun or emitted heat from the Earth) or man-made (forms of radar, for example). This energy passes through the atmosphere before and after interaction with a scene. Scattering, absorption, and refraction in the atmosphere will alter the electromagnetic energy (Strahler et al., 1986; Curran, 1985).

A scene is a section of the Earth's surface that is of interest. The objects on the Earth's surface determine the amount and characteristics of electromagnetic energy leaving the Earth's surface. These objects can be classified into soil/geology, water, vegetation, and cultural features. A sensor is a device such as a camera or radiometer that records the electromagnetic energy (Jensen, 1983; Curran, 1985).

Stress Studies

Changes in vegetation appearance may be morphological, physiological, or both. Morphological injury is the change in the shape or form of the plant such as defoliation, breakage, and cellular collapse of plant parts. Physiological changes may be in the form of pigment deterioration or the disruption of nutrient translocation, for example. Of course, physiological damage results in morphological change including wilting, reduced biomass, top-killing, and necrosis of cells (Murtha, 1982).

To the interpreter, the knowledge of stress must be translated into spectral reflectance characteristics that deviate from the norm. In addition, there must be an understanding of how these spectral characteristics appear together within the canopy as a whole, on the remote sensing image.

Electromagnetic Spectrum

At this time, operational (qualitative and quantitative) remote sensing studies of vegetation utilize reflected natural electromagnetic energy within the wavelength range of 400nm to 2700nm (Figure IV.1). At shorter (UV) and longer (thermal IR) wavelengths, reflectance approaches zero and is fairly constant (Knipling, 1970). In the thermal IR (2700nm-14um) natural emitted electromagnetic energy is utilized, and beyond the thermal IR is microwave energy,

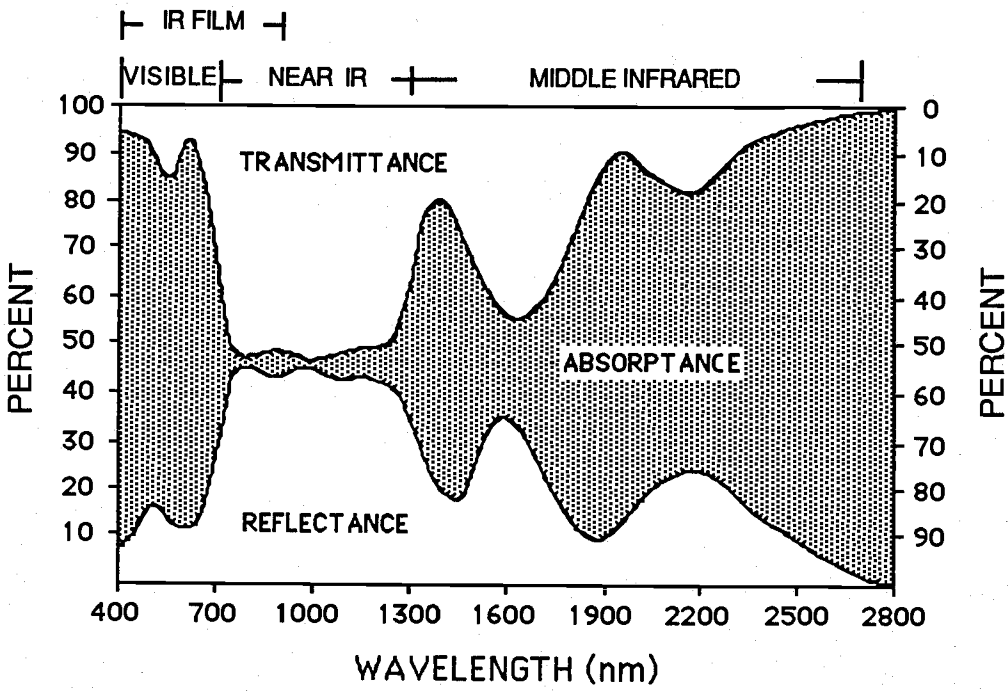


Figure IV.1. Reflectance, absorption, and transmittance from a typical, healthy green leaf (adapted from Knipling, 1970).

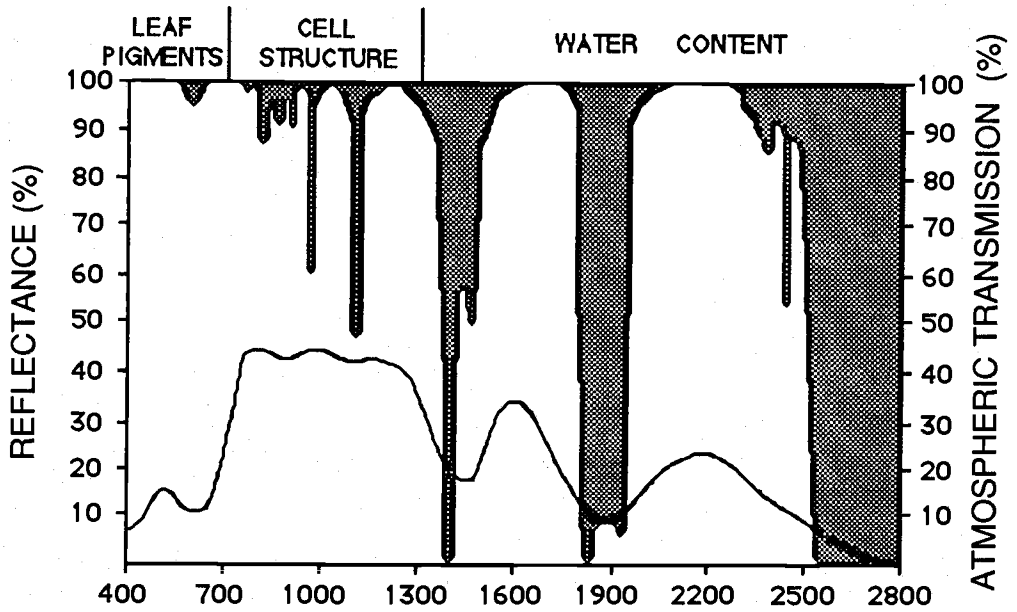


Figure IV.2. The dominant factors affecting the spectral reflectance of a healthy green leaf with regions of atmospheric attenuation (adapted from Jensen, 1983).

both of which are gaining increased attention for environmental studies (Price, 1986). Although research dealing with these longer wavelengths shows promise, it is presently in the experimental stage.

The wavelength range of interest (400-2700nm) is subdivided into the visible (400-700nm), near IR (700-1300nm) and middle IR (1300-2700nm), as shown in Figure IV.2. The dominant biophysical vegetation variables that may be detected within these wavelength ranges are chlorophyll (leaf pigments) in the visible, biomass (cell structure) in the near IR, and moisture content in the middle IR (Jensen, 1983; Knipling, 1970).

The cell structure of a cranberry leaf is shown in Figure IV.3, and a leaf optical system in Figure IV.4. Radiant energy is either reflected, absorbed, or transmitted. Typically for healthy green vegetation, much of the incident radiation is transmitted through the surface of the leaf. Approximately 2-3% is thought to be reflected by the cuticle (Tucker & Garratt, 1977).

Chloroplasts in the palisade mesophyll cells absorb much of the visible light (Jensen, 1983). Of the four main pigments chlorophyll a absorbs at wavelengths of 430nm (blue) and 660nm (red), chlorophyll b absorbs at 450nm (blue) and 650nm (red), B-carotene and xanthophyll absorb in the blue to green wavelengths (Curran, 1985). The spectral regions of 450-520nm and 630-690nm (Figure IV.5) are thought

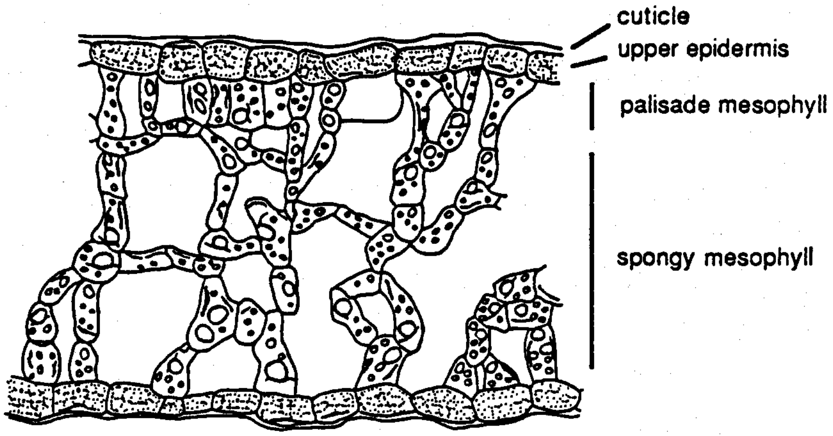


Figure IV.3. A transverse section of a cranberry leaf, Vaccinium macrocarpon (adapted from Pelluet, 1928).

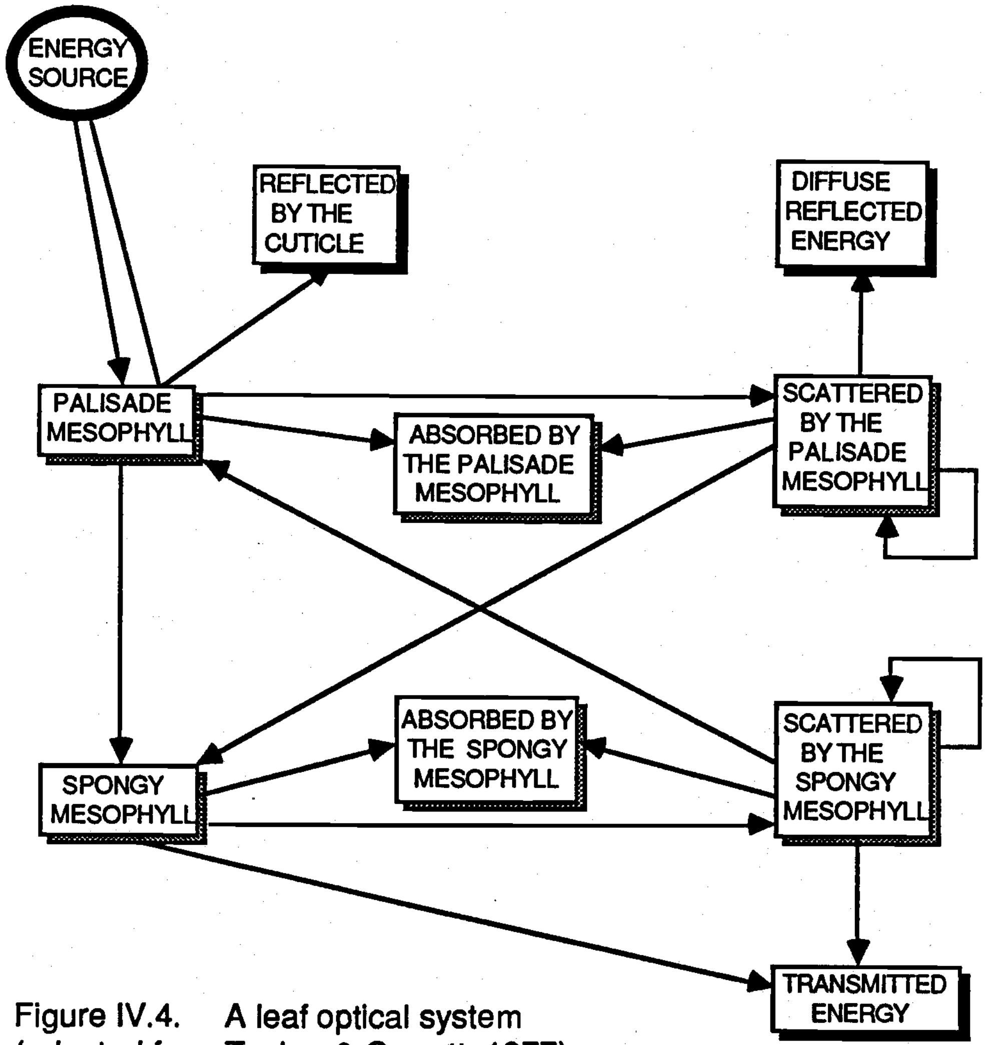


Figure IV.4. A leaf optical system (adapted from Tucker & Garratt, 1977).

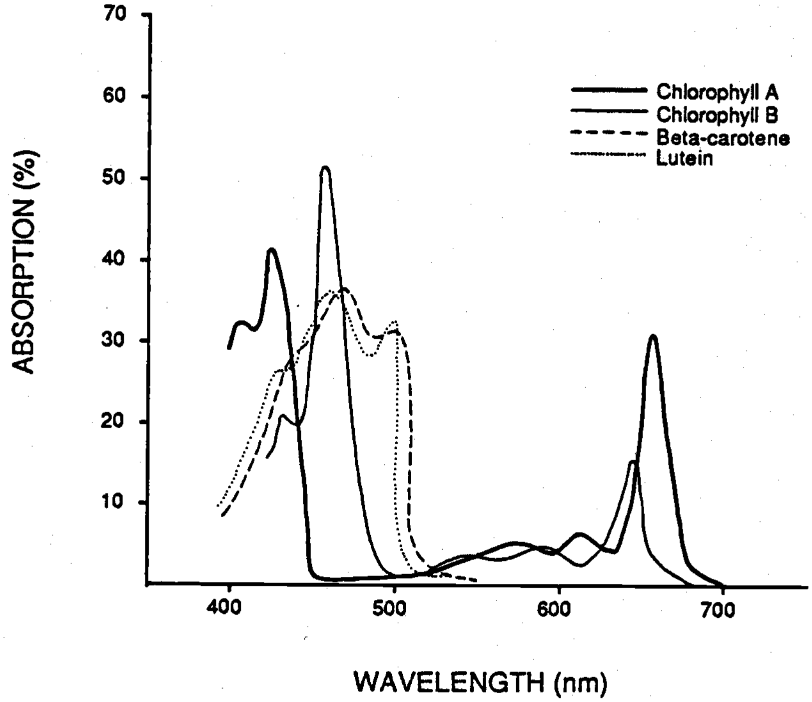


Figure IV.5. Absorption spectra of chlorophylls A and B, beta-carotene and lutein (a xanthophyll), adapted from Salisbury and Ross (1978).

to be the best for sensing chlorophyll and carotenoid absorption and chlorophyll absorption, respectively (Jensen, 1983).

At the cell wall/air interface of the spongy mesophyll much of the near IR energy (excluding a 920-980nm water vapor absorption region and one at 1100nm) is scattered, resulting in the relatively high leaf reflectance (Jensen, 1983). In addition to the high reflectance, there is also a high transmittance, so that sensors record near IR energy from combined leaf layers.

The water content in a leaf strongly absorbs energy in the middle IR. Generally, there is a negative correlation between both the water content and leaf thickness with reflectance in the middle IR. Due to high atmospheric water absorption at wavelengths near 1400nm, 1900nm, and 2700nm, atmospheric windows for remote sensing occur at 1500-1800nm and 2000-2600nm (Curran, 1985).

Stress Detection Of Individual Leaves

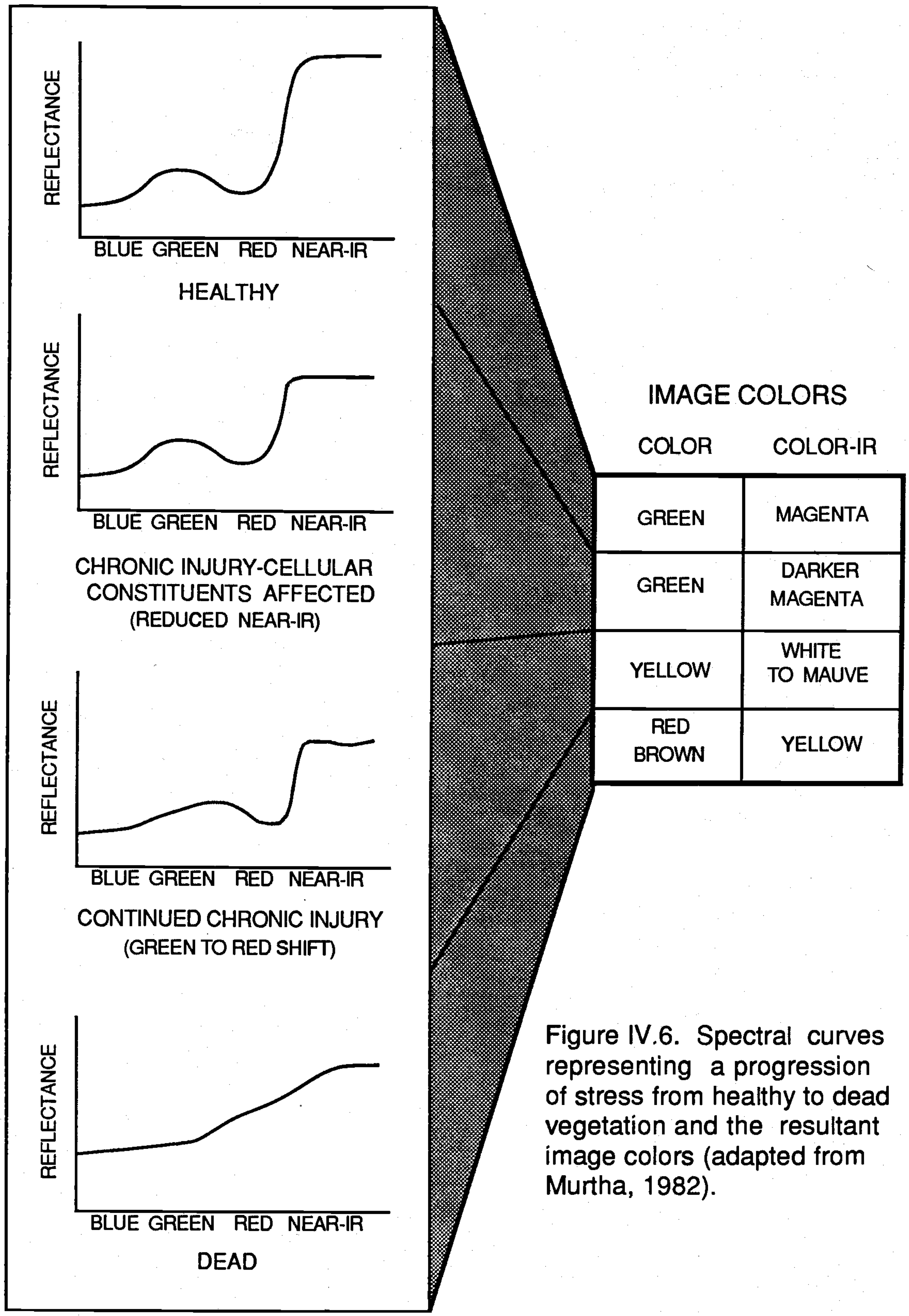
When there is chloroplast deterioration and changes in the amount of chlorophyll caused by metabolic disturbances, the spectral reflectance is altered. Therefore, a healthy green leaf turning yellow is an example of increased reflectance in the red chlorophyll absorption region. Higher reflectance in the visible wavelengths (i.e. pigments absorb less efficiently) has been associated with dehydration, diseases, nutrient deficiency, salinity stress, and senescence (Al-Abbas et al., 1974; Horler et al., 1980; Jackson, 1984; Tucker, 1977; Walburg et al., 1982). The position and slope of the sharp increase of reflectance between the red and near IR (the red edge) appear to be associated with geochemical stress and crop maturity (Goetz, 1984; Horler et al., 1980).

In the near IR, leaf components (stomata, nuclei, cell walls, crystals, and cytoplasm) all contribute to reflectance (Gausman, 1977). It has been estimated that the intracellular discontinuities of the cellular constituents, other than the cell wall/air interfaces, contribute 8% of the near IR reflectance (Woolley, 1971; Gausman, 1974). As previously noted, the major portion of near IR reflectance is due to the cell wall/air interfaces and accounts for the remaining 30-50%. Unlike in the visible wavelengths, stress in the infrared region varies considerably. Nutrient deficiency either increases or decreases according to the element and vegetation type. For example, Al-Abbas et al. (1974) have shown nitrogen (N) and phosphorus (P) deficiency to decrease reflectance in the near IR and have variable reflectance in the middle IR; potassium (K) and calcium (Ca) deficiency increases, sulfur (S) deficiency decreases, and magnesium (Mg) has variable reflectance throughout the near IR and middle IR. However, the study was conducted on maize leaves, i.e. a monocotyledon, which do not distinctly differentiate into layers of palisade and spongy mesophyll. Thomas and Oerther (1972), on the other hand, showed N deficiency to actually increase near IR reflectance and decrease middle IR reflectance for sweet pepper leaves. The stage of maturity for a leaf is also important since a young dicotyledon leaf will have compact mesophyll similar to a monocotyledon.

Gausman (1974), working with cotton leaves, showed dehydration and salinity stress to increase reflectance in the near IR and middle IR. Tissue collapsing in association with moisture stress (dehydration) would increase the number of air voids and thus have more cell wall/air interfaces (Sinclair et al., 1973).

Diseases have been shown to either increase or decrease IR reflectance. Fungal hyphae penetration is thought to decrease IR reflectance due to darker internal colorization caused by oxidation and polymerization (by polyphenol-oxidase), thus increasing absorptance (Cardenas et al., 1970; Gausman, 1974). Studies showing an increase of IR reflectance, however, may be due to measurements made on dehydrated diseased leaves.

Murtha (1982) suggests that previsual stress detection is due to changes within the 8% of near IR mentioned above. This would represent low levels of stress acting over time (chronic injury). Chloroplast deterioration would eventually follow. The cell wall/air interface reflectance would



COLOR	COLOR-IR
GREEN	MAGENTA
GREEN	DARKER MAGENTA
YELLOW	WHITE TO MAUVE
RED BROWN	YELLOW

Figure IV.6. Spectral curves representing a progression of stress from healthy to dead vegetation and the resultant image colors (adapted from Murtha, 1982).

represent changes that occur later and would be associated with structural changes such as wilting. These also appear as visual changes (see Figure IV.6).

Stress Detection Of Canopy Covers

Knowing the reflectance properties of single leaves is a basic prerequisite to understanding the reflectance properties of crop canopies. However, crop canopies are more complex, and a direct relationship may not hold true. Detection of stress, including insects, disease, water, salinity, and nutrients, often is based on reflectance characteristics recorded on an image which are not dependent solely on the differences between the reflectance of healthy and stressed individual leaves. A reduction in vegetation or reduced crop vigor are examples. Studies on individual leaves record hemispherical reflectance, whereas in the field, remote sensors record bidirectional reflectance from a vegetation canopy consisting of leaves, non-leaf plant structures, background components, and shadows (Curran, 1985; Knipling, 1970; Kimes, 1983; Colwell, 1983).

A measure of the leaf area within the canopy can be designated by the leaf area index (LAI) which is the unit leaf surface area per unit ground area. Generally, a vegetation canopy with a high LAI exhibits bidirectional reflectance properties similar to the hemispherical properties of the leaf. Furthermore, a low LAI for a vegetation canopy reduces near IR and green reflectance and increases red reflectance with the actual amounts depending on soil color and moisture (Curran, 1985; Jackson, 1984).

The geometry of the crop canopy is important, since this determines the amount of shadow, which is interrelated with the sensor look angle and energy source. Changes in the leaf orientation of a canopy without a change in LAI may also affect reflectance. For example, a change from a horizontal to a vertical leaf orientation caused by wilting generally decreases the near IR reflectance and increases the red reflectance. Seasonal changes in the vegetation should be known, in conjunction with climate and cultural practices. These include changes in leaf color as the vegetation comes in and out of dormancy, different growth stages, variety differences, the pruning and raking of vines, seasonal wet and dry periods, and irrigation/flooding practices, since soil moisture tends to reduce reflectance.

Reflectance from a crop canopy is also dependent upon the solar elevation, azimuth angle and sensor viewing angle. When the solar elevation is high, radiation penetrates deeper into the canopy (lower reflectance) than when the solar elevation is low (higher reflectance). Also, when solar elevation is low, the canopy shadow increases which decreases morning and evening reflectance mainly in the visible region with little effect in the near IR (Curran, 1985; Kimes, 1983).

Generally, the bidirectional reflectance of a canopy increases when the sensor faces the sun. Assuming a vertical sensor look angle, this would occur at lower solar angles. A change in the sensor look angle away from vertical reduces the soil component from a scene and tends to increase the bidirectional reflectance (Curran, 1985; Lillesand & Kiefer, 1979). Therefore, it is advantageous to keep the sensor look angle and solar elevation as constant as possible throughout the remote sensing study (vertical imagery at solar noon).

Atmospheric Effects

Radiance received by a sensor is derived from a variety of sources (Figure IV.7). The actual reflectance recorded on an image has a ground component previously discussed, a ground component from outside the sensor's field of view, and an atmospheric component. Radiation is altered in the atmosphere as a result of scattering, absorption, and refraction.

There are four types of atmospheric scatter: Rayleigh, Mie, non-selective, and Ramon. Rayleigh scattering is the most common and is due to particles (mainly gas molecules) smaller than the wavelength of radiation. This scatter is inversely related to wavelength; therefore, the short visible wavelengths are affected the most, resulting in haze and skylight. Mie scattering is due to spherical particles

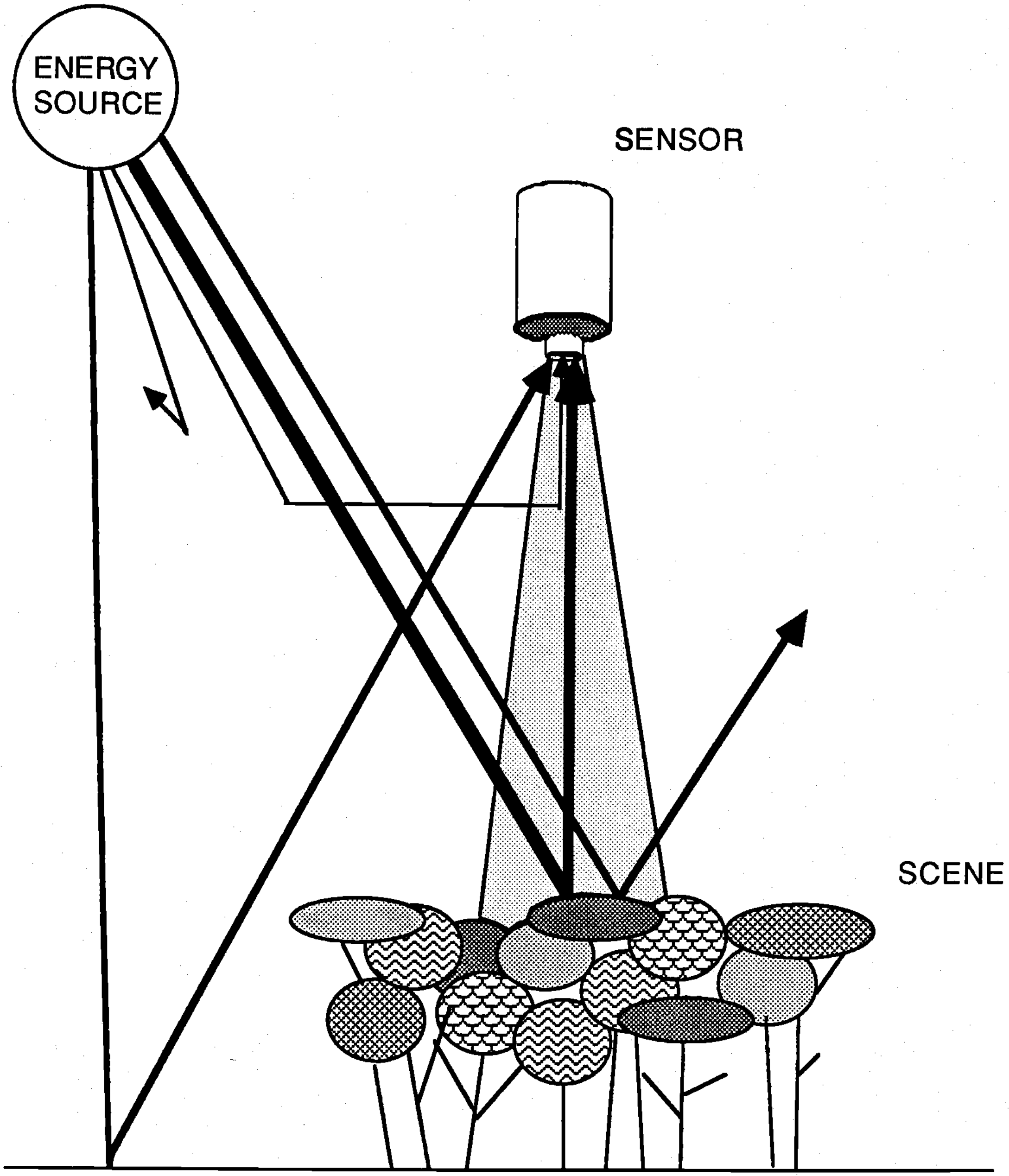


Figure IV.7. A sensor records radiance from energy interactions with a ground component within the field of view, from beyond the field of view, and from the atmosphere.

(water vapor, pollutants, and dust) that are of the same size as the wavelength. Mie scattering tends to affect longer wavelengths and is important under slightly overcast skies. Non-selective scatter is due to water droplets and dust particles larger than the wavelength of radiation resulting in clouds and fog. Ramon scatter is the least common and is due to any of a number of particles with variable effects (Curran, 1985; Lillesand and Kiefer, 1979; Colwell, 1983)

Atmospheric absorption is mainly due to the efficient absorbers (water vapor, carbon dioxide, and ozone), and tends to be in specific wavelength bands. Where absorption is low (atmospheric windows) remote sensing takes place. Within these windows, absorption produces variable effects: decreasing and increasing radiance received by a sensor (Curran, 1985; Lillesand and Kiefer, 1979).

Refraction occurs when radiation passes through different mediums. In a stable atmosphere the effects of refraction are predictable. However, in a turbulent atmosphere, the bending of radiation waves is unpredictable due to the random nature of turbulence. This may affect the geometric accuracy of images (Barrett and Curtis, 1976).

Generally, the higher the altitude the greater the atmospheric attenuation. In aerial photography, haze due to scattering of aerosols is the major problem. The effect is to increase skylight and reduce image contrast. Many aerosols tend to accumulate in the lower atmosphere, so even low altitude photography can be affected (Figure IV.8). Generally on a stable clear day, aerial photography taken at an altitude of 5000 feet or less should have a low haze reflectance factor (a 10% haze factor in the visible wavelengths is excellent), (Ross, 1973; Dave, 1978).

In cranberry growing regions, ideal conditions for image acquisition are seldom achieved. At the image scales necessary for stress detection, flying altitudes are generally low enough so that atmospheric effects are minimal. However, on what seemingly is a good clear day, two important conditions may occur. First, it is not uncommon to have great quantities of salt nuclei aerosols (Rayleigh scatter) travel inland from the coast increasing reflectance (reducing image contrast) due to turbulence. Secondly, low lying areas along the coast may have persistent patchy ground fog that may not lift until well into the afternoon. These unacceptable conditions should be stated to the remote sensing contractor well in advance.

Sensors and Imagery

Remote sensing can be divided into image-oriented and numerically oriented systems. Image-oriented remote sensing systems, such as aerial photography, collect radiance data (reflectance) and record data in analog form. An image is then processed and interpreted by human perception through

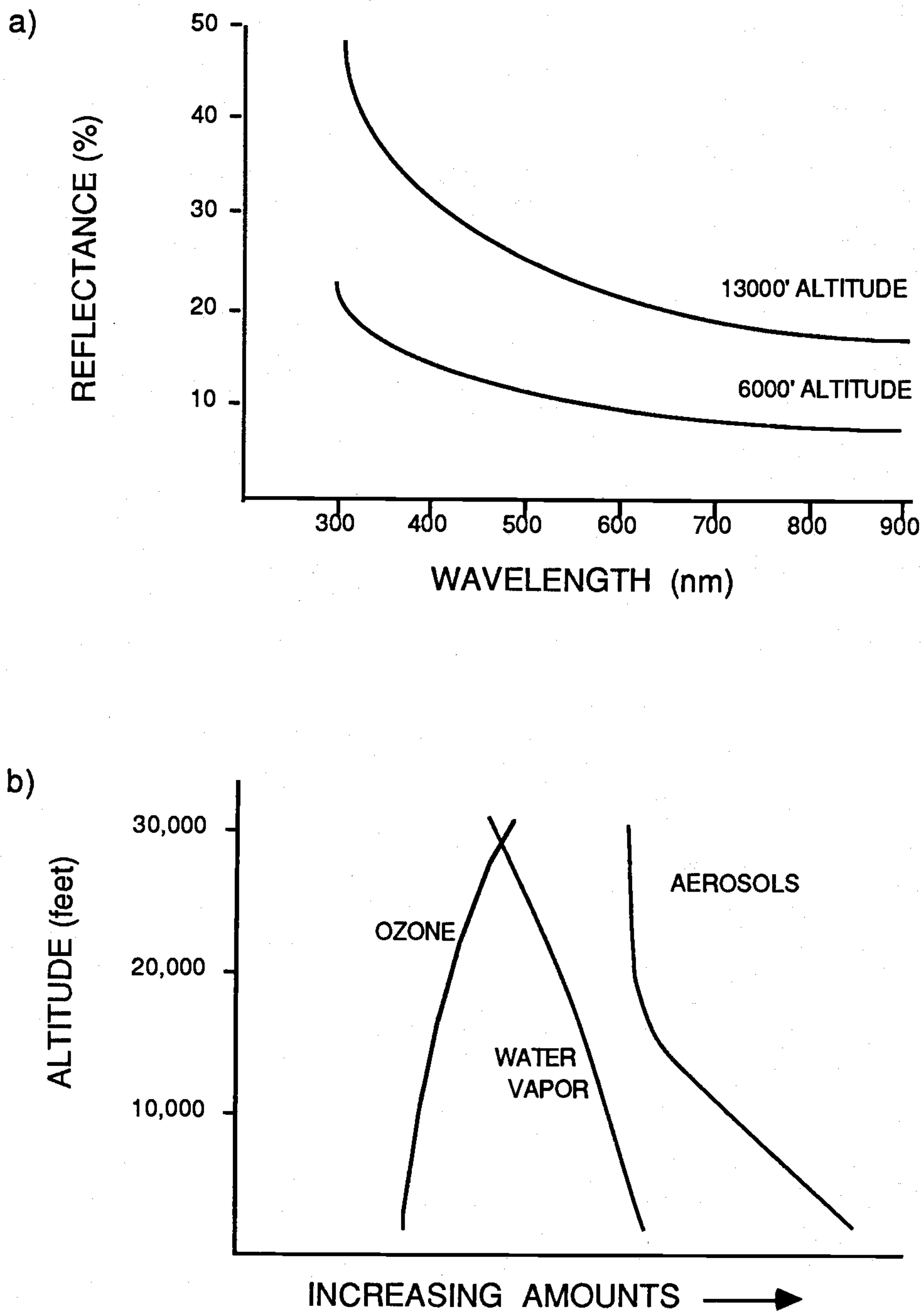


Figure IV.8. a) An example of atmospheric reflectance for two different altitudes (should be used as a comparison only, as actual percentages are variable, adapted from Ross, 1973). b) Typical variations of water vapor and ozone concentrations and aerosols as a function of height (Dave, 1978).

magnification and/or enhancement techniques. Numerically oriented remote sensing records brightness values in digital form (Price, 1986). Interpretations are made by human/computer interaction involving various image processing techniques. Images in analog form can be converted to digital form and vice-versa. There are advantages and disadvantages associated with both systems and methods of interpretation.

Aerial photography is the most widely used method of remote sensing. It is relatively inexpensive, easily obtained, and has good spectral and spatial resolution. The common formats are 9" x 9" (mapping cameras), 70mm, and 35mm (see Table IV.1).

Commercial films include black and white (good for the size, shape and location of fields, buildings, roads, and physical features), color (further definition of physical features: soils, vegetation, rivers, and lakes), and color-IR (better recognition of vegetation and its condition) (Flowerday, 1982). Original images may be either negatives or transparencies. Color negatives are generally cheaper and are of better quality than color transparencies; however, they are more difficult to interpret.

The spectral limits of photographic film are approximately 300-900nm. Thus, aerial photography is termed as being broad-band. To reduce this range, one or more of the many available filters are used. Another method is multiband photography.

TABLE IV.1

SCALE	FORMAT	FOCAL LENGTH	FLYING ALTITUDE	FEET/ INCH	GROUND COVERAGE (ft)	APPROX. SPATIAL RESOLUTION	
						COLOR[1]	COLOR-IR[2]
1:500	35mm	50mm	82'	41.7	59 x 39	0.3"	0.3- 0.6"
1:1000	35mm	50mm	165'	83.3	118 x 79	0.6"	0.6- 1.2"
1:2000	35mm	50mm	330'	166.7	236 x 157	1.2"	1.2- 2.4"
1:2500	35mm	50mm	410'	208.3	295 x 197	1.5"	1.5- 3.0"
1:2500	70mm	80mm	655'	208.3	454^2	2.4"	1.5- 3.0"
1:3000	70mm	80mm	790'	250.0	545^2	2.9"	1.8- 3.6"
1:4000	70mm	80mm	1050'	333.3	727^2	3.9"	2.5- 4.9"
1:5000	70mm	80mm	1310'	416.7	908^2	4.9"	3.1- 6.1"
1:6000	70mm	80mm	1575'	500.0	1090^2	5.9"	3.7- 7.3"
1:6000	9"x9"	6"	3000'	500.0	4500^2	5.9"	3.7- 7.3"
1:8000	9"x9"	6"	4000'	666.7	6000^2	7.8"	5.0- 9.8"
1:10000	9"x9"	6"	5000'	833.3	7500^2	9.8"	6.2-12.3"
1:12000	9"x9"	6"	6000'	1000.0	9000^2	11.8"	7.5-14.7"

[1] Based on Kodachrome 25 or 64 for 35mm, otherwise Kodak Aerochrome 2448 or color 2445. All are with a 1.6:1 test-object contrast.

[2] Based on Kodak Ektachrome IR 2443 (35mm format is numbered 2236). Low value is for a test-object contrast of 1000:1 (high contrast). High vlaue is for a test-object contrast of 1.6:1 (low contrast-haze).

Multiband photography employs the use of either multiple cameras or multiple lenses. Each lens has a different filter. For example, a system with either four lens or four cameras, produces four separate images for each scene: one recording the blue region of the EMS (400-500nm), a second for the green region (500-600nm), a third for the red region (700-800nm), and a fourth for the near IR (700-900nm). The advantages are narrower spectral bands (enables better use of enhancement techniques), and the images for each scene are in registry. The disadvantages are added cost and the fact that contractors are less readily available.

The disadvantage of aerial photography is that to gain the needed spatial resolution, the ground coverage area tends to be small. In addition there are variables associated with the camera system and film processing, including radial distortion of smaller format camera systems, within image and within roll film exposure differences, and exposure differences of multi-temporal images.

Usually aerial photographs are manually interpreted under magnification yielding qualitative information based on tone, texture, pattern, association, shape, size, and shadows. To improve or quantify an aerial photograph various hardware components are used (Table IV.2).

A multispectral scanner (MSS) is an example of a numerically-oriented remote sensing system. The advantages

TABLE IV.2

HARDWARE	APPLICATION TO INTERPRETATION	IMAGE ENHANCEMENT TECHNIQUE						IMAGE CLASSIFICATION
		ENLARGMENT	INCREASE CONTRAST	DECREASE CONTRAST	EDGE ENHANCEMENT	PRODUCING MULTIBAND COMPOSITES	DIRECTIONAL AND SPATIAL FILTERING	DENSITY SLICING
DIGITISER	measuring area							
ZOOM TRANSFER SCOPE	transfer information to base map							
PHOTOGRAPHIC ENLARGER	general aid	X	X	X	X	X		X
ELECTRONIC DODGER	exposing hidden detail			X				
SCANNING MICRODENSITOMETER	measuring radiance	X	X	X				X
ANALOG IMAGE PROCESSOR	measuring radiance; area	X	X	X	X			X
MULTI-ADDITIVE VIEWER	quick general interactive color manipulation		X	X		X		
OPTICAL PROCESSOR	selective detail removal						X	

(adapted from Curran, 1985)

of MSS data over aerial photography include the very high radiometric resolution in narrow bands (10nm for example), increased spectral resolution (300nm-14um), precise spatial resolution for all wavelength bands, and the calibration of recorded radiation. Also, an image in a digital format is tailor-made for quantitative analysis (Price, 1986; Curran, 1985).

The major disadvantages are the high cost for conducting the mission and the limited availability of the sensor. Thus, it is seldom used and rarely for low altitude vegetation studies. Other considerations include additional computer hardware, a considerable increase in the amount of data, and increased costs of digital image processing.

There are a great many digital image processing operations. In addition, these operations can be used on aerial photographs that have been converted to a digital format. These operations include image restoration and correction (radiometric, detector correction, geometric, and haze), and image enhancement (contrast stretching, band ratios, band subtraction, digital filtering, data compression, color display), image classification (density slicing, maximum likelihood, parallelepiped, etc.).

A remote sensing study starts with defining the object of interest. For vegetation studies, an understanding of the biophysical variables, timeliness (diurnally and seasonally), and how the object interacts with electromagnetic energy is necessary. Spectral regions of the electromagnetic spectrum are selected that give the best contrast between the object and background. A sensor is then selected that will record the object with the desired radiometric (sensor sensitivity to differences in recorded radiance), spectral, and spatial resolution. Spatial resolution is generally determined to be one-half the size of the smallest object to be detected (Jensen, 1983).

Remote sensing detection may involve identifying the agent that causes the stress (insect, disease, water etc.) or the degree of stress ranging from strain, injury, to damage as a result of the agent. Since there are many agents that may be acting at any one time, an agent may have many different strains, or many agents have very similar strains, cause and effect relationships are difficult to substantiate. Therefore, detection is primarily based on changes manifested by stress. Detection on the remote sensing image may be in the form of visual (able to be seen on the ground with the naked eye), previsual (recorded on the image from outside the visible spectrum before there are visual signs on the ground) or extravisual (recorded on the image from outside the visible spectrum with only the resultant damage to be seen on the ground) (Murtha, 1982; Murtha, 1978).

CHAPTER V

REMOTE SENSING OF LOPHODERMIUM SPP. TWIG BLIGHT

There are two known species of the ascomycete Lophodermium which attack the cranberry plant and cause twig blight. They are L. oxycocci, which also infects Vaccinium vitis-idaea, and L. hypophyllum, which also infects Vaccinium oxycocci. In 1931 the known geographical distribution of L. oxycocci was Europe and New England and L. hypophyllum was New York, Michigan, Wisconsin, Oregon, and Washington (Shear et al., 1931). Presently, Lophodermium spp. appears to be a problem only in Washington and Oregon bogs. The economic loss as a result of Lophodermium is directly related to the number of infected uprights. If 10% of the uprights in a bog are infected, then the yield is reduced by 10%.

Infection occurs on new growth apparently by direct penetration from June through August, and overwinters as mycelium. The first symptoms appear during late winter or early spring when plants come out of dormancy; the infected leaves turn brown, eventually assuming a faded brown or tan color and remain attached to the uprights. Only the previous year's growth dies. The fruiting bodies appear on the underside of the dead leaves, maturing by early summer. The disease is often noticed developing first on the margins of bogs and may occur in small areas or take over the entire bog (Shawa et al., 1984; Bristow, 1986a).

The differences between the two species are slight and are in terms of size and shape of asci and paraphyses. Both species have dark colored ellipsoid subcuticular or intraepidermal apothecia (500-600u by 250-350u). At maturity apothecia open along a longitudinal median slit when moist; walls are bent outward exposing the entire hymenial layer (Shear et al., 1931). Ascospore dispersal is by wind. After the infected leaf dies, the fungus lives as a saprophyte.

The control of twig blight is based on the protection of susceptible uprights during the infection period. A forecasting model was developed for L. oxycocci from data collected on the Long Beach peninsula, Washington. The start of the infection period is when 50% of the fruiting bodies contain ascospores plus 31 days. Fungicides are applied at three 14-day intervals for a 42-day protection, thus covering the infection period (Bristow 1986a; 1987). Fungicides used for control are benzene compounds (chlorothalonil), organic sulfur compounds-carbamates (ferbam, maneb, mancozeb, and zineb), or heterocyclic compounds (captan and captafol), and are usually applied by a boom sprayer or through a sprinkler system. During the dormant period in problem diseased bogs, a liquid lime sulfur application usually is made, which kills over-wintering fungi (Shawa et al., 1984; Agrios, 1978).

Three aspects are important for the detection and monitoring of twig blight: (1) the time of fruiting body maturity; (2) the period of infection; and (3) the amount and location of the damaged area. The first aspect is achieved by collecting uprights and conducting laboratory analysis that produces information used in a forecasting model covering the second aspect. At this time, remote sensing is most useful for the third aspect.

Methods and Materials

The study area is located in a water-harvested commercial bog of mature bearing McFarlin cranberries operated by Cranguyma Farms in Long Beach, Washington, (see Table A.1 for a comparison of the McFarlin variety to the other major varieties). There were two plot areas within the bog study area (Figures V.1-V.2). Plot area A is subdivided into 6 regions or treatment repetitions (I through VI) each consisting of 14 5ft X 5ft plots for a total of 84 plots (numbered 1 through 84). This numbering sequence continued for plot area B, which consisted of 2 regions (VII and VIII) each with 14 5ft X 5ft plots for a total of 28 plots (numbered 85 through 112). Plot area A and B are part of Lophodermium spp. infection timing experiment. The 14 plots within each region correspond to different fungicide

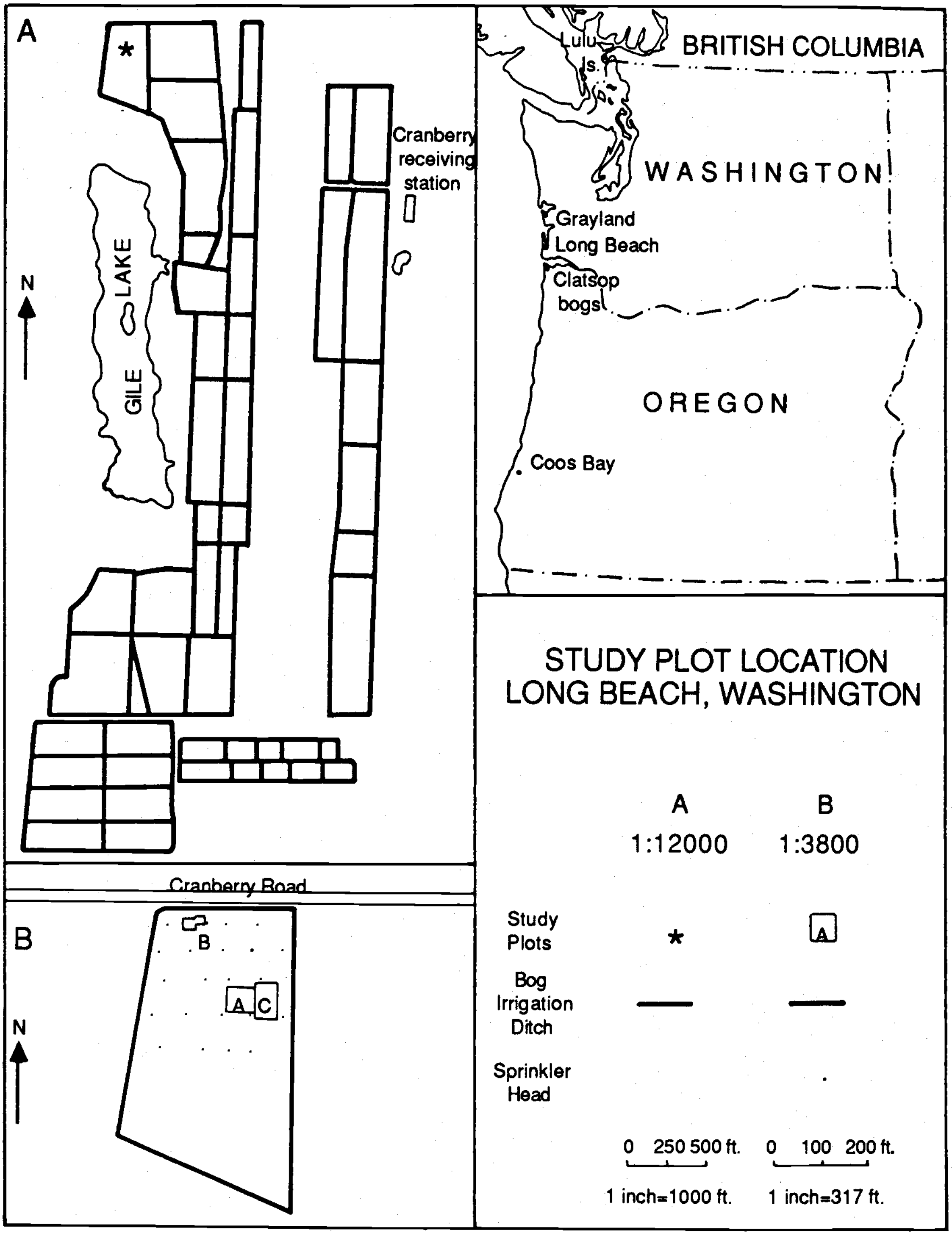
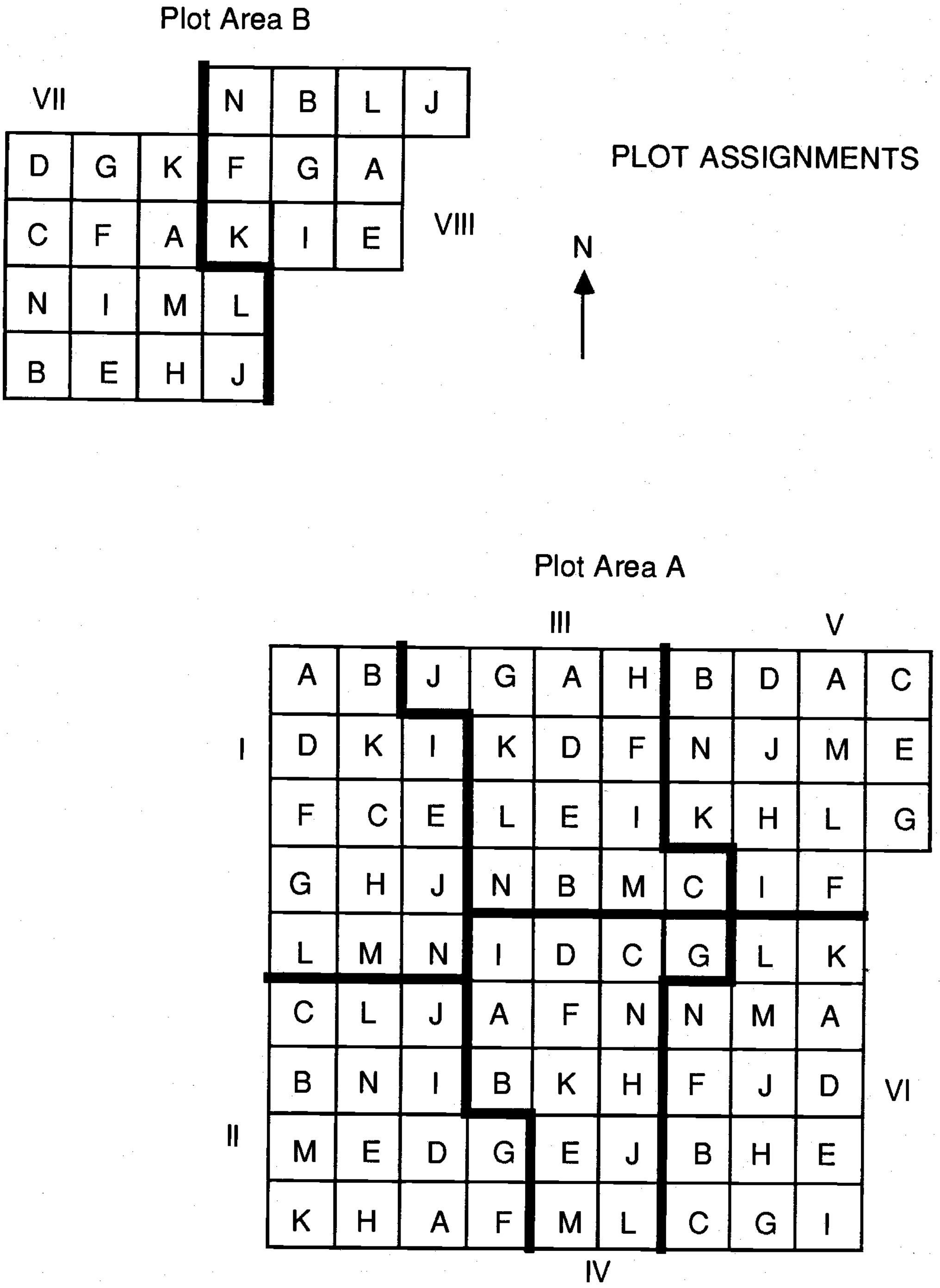


Figure V.1. Location of the study plots in Long Beach, Washington.



			N	B	L	J
D	G	K	F	G	A	
C	F	A	K	I	E	
N	I	M	L			
B	E	H	J			

A	B	J	G	A	H	B	D	A	C
D	K	I	K	D	F	N	J	M	E
F	C	E	L	E	I	K	H	L	G
G	H	J	N	B	M	C	I	F	
L	M	N	I	D	C	G	L	K	
C	L	J	A	F	N	N	M	A	
B	N	I	B	K	H	F	J	D	
M	E	D	G	E	J	B	H	E	
K	H	A	F	M	L	C	G	I	

Figure V.2. Study plot layout. Plot area A contains six regions and plot area B has two. Each region contains 14 plots corresponding to treatments A through N. Note that region VIII is missing four plots (treatments C, D, H, and M) due to sanding and replanting (adapted from Bristow, 1986).

(mancozeb) treatments (Bristow, 1986b). The treatment timing is shown in Table A.2.

There is an additional area (plot area C) with 104 plots. The experiment was to see the effect of fungicides on fruit set, berry development, and yield. These plots were analysed in 1985, but due to little fungi development, they were not treated or analysed in 1986 (Bristow, 1986b). However, ground imagery was acquired for these plots.

All fungicide treatments were applied with a backpack sprayer. Uprights were collected from each plot and analysed in the laboratory. This was accomplished by clipping a 4" X 12" area in the center of each plot. In addition, upright density was calculated for each plot from the sample clippings. Plot areas A and B were clipped on May 13, 1986. These experiments were designed and carried out by Dr. Peter R. Bristow, Plant Pathologist, Western Washington Research and Extension Center, Puyallup, WA and used as ground truth data in conjunction with ground imagery.

Weather data were compiled at the Coastal Washington Research and Extension Unit, Washington State University, Long Beach. The location of this unit is approximately two miles due south of the study plots.

Imagery acquisition was made at three different scales and with three different formats. Ground photographs of the study plots were acquired with a 35mm format SLR with a 28mm f/3.5 lens inverted on a homemade adjustable tripod.

Exposures were made at a height of 98 inches (2.5 meters and an image scale of approx. 1:90) with color IR and color films, all with 11 different filters every 2-4 weeks during the 1986 and early 1987 growing seasons.

Aerial photographs were acquired at two different altitudes with different formats, resulting in two different image scales. During the 1986 growing season aerial missions were made using a fixed mounted 70mm format Hasselblad with a Zeiss Planar C 80mm f/2.8T 500ELM lens at an altitude of approx. 1000 feet (305 meters and an image scale of approximately 1:3800). Both color and color IR film were employed with several different filters. Missions were undertaken by Dr. Charles L. Rosenfeld, Oregon State University Geography Department. In addition, aerial missions were flown using a 9" X 9" mapping camera with a 152.9mm lens at an altitude of approximately 6000 feet (1835 meters and an image scale of 1:12000) during the month of August 1983 through 1986. These missions were flown by Western Aviation Corp. of Eugene, Oregon. All imagery was acquired between 1000 and 1500 hours. Table V.1 shows the imagery acquisition dates, films, and filters.

Interpretations of all imagery were made by manual means (some experimentation was made using an analog image processor). The 35mm film transparencies were interpreted from an image projected onto a screen. The 70mm transparencies and the 9" X 9" transparencies and negatives

Table V.1.

Imagery Acquisition Dates, Films, and Filters for Obtainable Data

Year	Ground Imagery (1:90)			Aerial 70mm (1:3800)			Aerial 9"x 9" (1:12,000)		
	Date	Film[1]	Filters[2]	Date	Film[1]	Filters[2]	Date	Film[1]	Filters[2]
1983							8-7	Color IR	15
1984							8-20	Color IR	15
1985							8-19	Color IR	15
1986	3-15 3-22 3-28 4-17 5-15 5-29 6-21 7-18 8-4 8-24 9-19 10-18 11-21 12-10	Color Color IR	2B, 12, 47, 58, 25,92, & 70 12, 47, 58, 25, 92, 70, 89B, 88A, 87, 87C, & 87B	8-4	Color Color IR	2B 12, 58 70, 89B	8-14	Color IR	15
1987	1-16 2-20 3-15 4-28	(same as above)	(same as above)						

[1] Color film: Kodachrome 64 (35mm); Kodak Film No. 2448 (70mm)
Color IR film: Kodak Film No. 2236 (35mm); Kodak Film No. 2443 (70mm & 9"x 9")

[2] Kodak Wratten Filters

Filter	Description	Wavelength[3]	Filter	Description	Wavelength[3]
2B	Pale Yellow	400-900 nm	70	Dark Red	660-900 nm
12	Deep Yellow	510-900 nm	89B	Deep Red	700-900 nm
15	Deep Yellow	520-900 nm	88A	Infrared	730-900 nm
47	Blue	410-500 nm, 750-900nm	87	Infrared	760-900 nm
58	Green	500-580 nm, 720-900 nm	87C	Infrared	820-900 nm
25	Red	590-900 nm	87B	Infrared	870-900 nm
92	Red	630-900 nm			

[3] Greater than 10% transmittance and up to 900 nm (from Kodak).

were interpreted by the use of several different magnifications on a light table and by the use of paper prints. Color paper prints were made correcting for color balance shifts and for making experimental color shifts as an aid for interpretations with an enlarger employing a subtractive dichroic filtration system. Interpretations were made from original 35mm and 70mm imagery and first generation duplicate 9" X 9" imagery.

Climatic Conditions

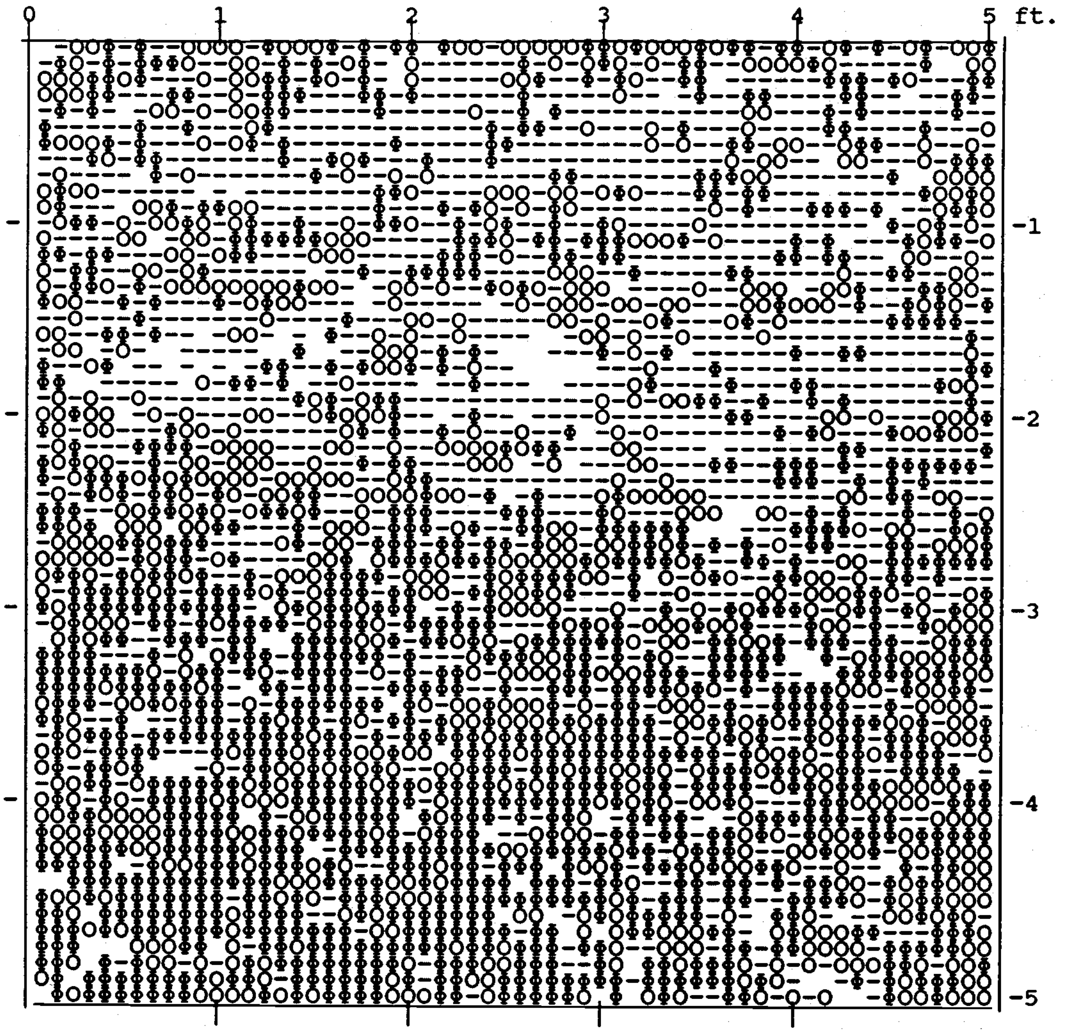
The 20 year average annual precipitation for Long Beach, Washington is 83.22 inches. The 1985 total precipitation was only 55.31 inches and was considered a very dry year. The 1986 growing season started off wet and mild. Bud injury due to frost by mid-March was 11.8% (15% is considered average). Mild weather and average precipitation continued through May. June was warmer and drier than normal. Much of July and August had overcast skies and pea soup fog. August was a dry month (0.22 inches compared to the 20 year average of 2.21 inches). Precipitation was slightly below normal for September through December and the year ended with a total of 78.55 inches of precipitation.

Results

Ground analysis of Lophodermium spp. study plots show that the percent of infected uprights (IU) varies with treatment, has no significant trend with region, and is independent of upright density (UD). Study plots with fungicide applications covering all or most of the infection period have less disease than plots with little or no fungicide applications during the infection period. The average percent infected uprights for the 8 regions does not vary significantly; however, there is a trend toward less average disease per region in a southeast direction (Regions I, III, VII, and VIII have higher averages than II, IV, V, and VI). Aerial photography shows dehydration symptoms south and east of the study plots and excessive moisture conditions north and west. See Figures A.1-A.8 and Tables A.3-A.5 illustrating these trends.

Ground imagery shows the progression of cranberry growth and damage symptoms from stress. The plot shown here (Figures V.3a-i) was analysed as having 43.6% infected uprights and an upright density of 78. The number of classes changes from 4 to 3 during the growing season. This is due to the apparently healthy uprights new growth extending above and casting into shadow the dead previously infected uprights. Therefore, if the upright density is revised (UD-REV) to exclude the number of infected uprights, there is somewhat of a negative trend between disease incidence and upright density. This condition would exist for imagery acquired after spring.

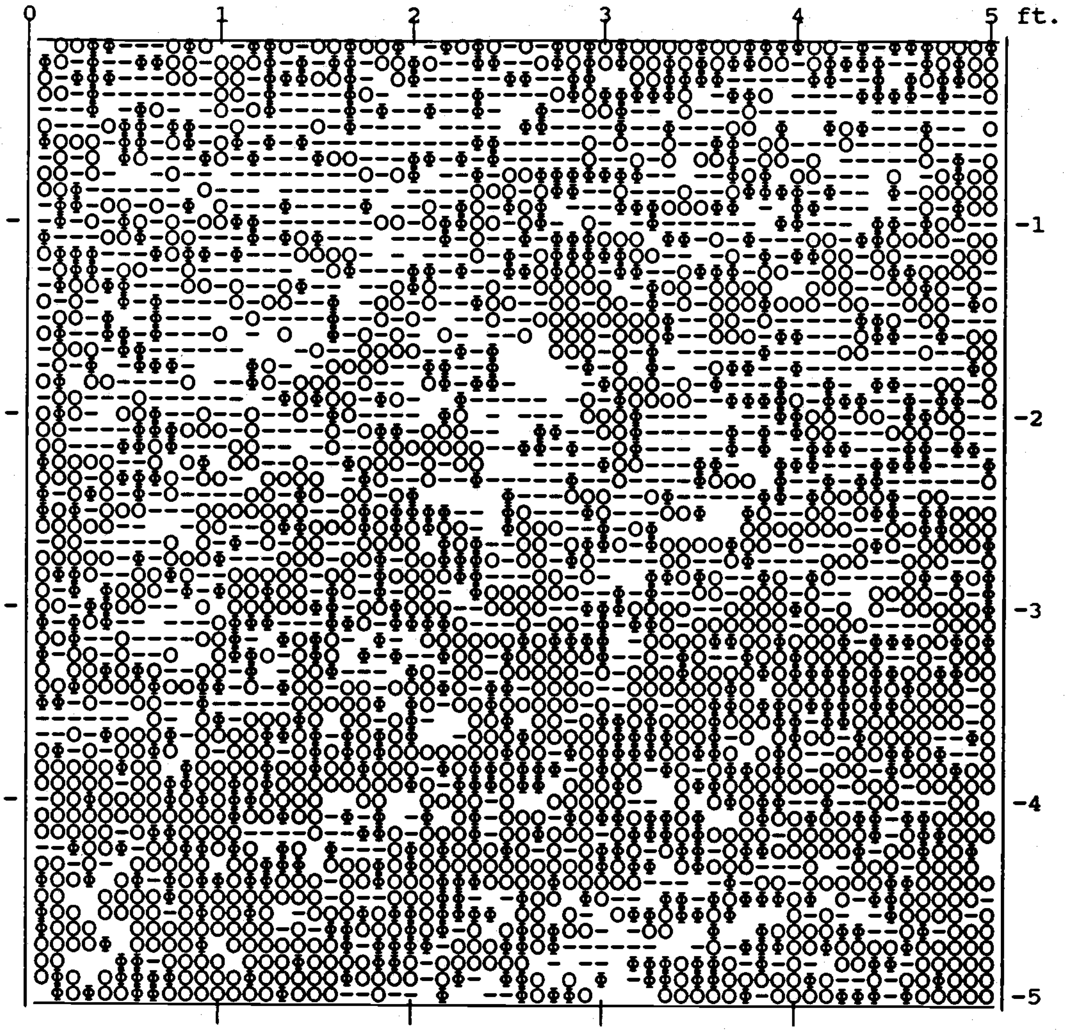
MARCH 28, 1986



OOOO OOOO	HEALTHY-GREEN CANOPY COVER	24.4%
ΦΦΦΦ ΦΦΦΦ	REDDISH-BROWN CANOPY COVER	36.8%
---- ----	DEAD-LIGHT TAN CANOPY COVER	35.2%
	SHADOWS OR MISSING CANOPY COVER	3.6%

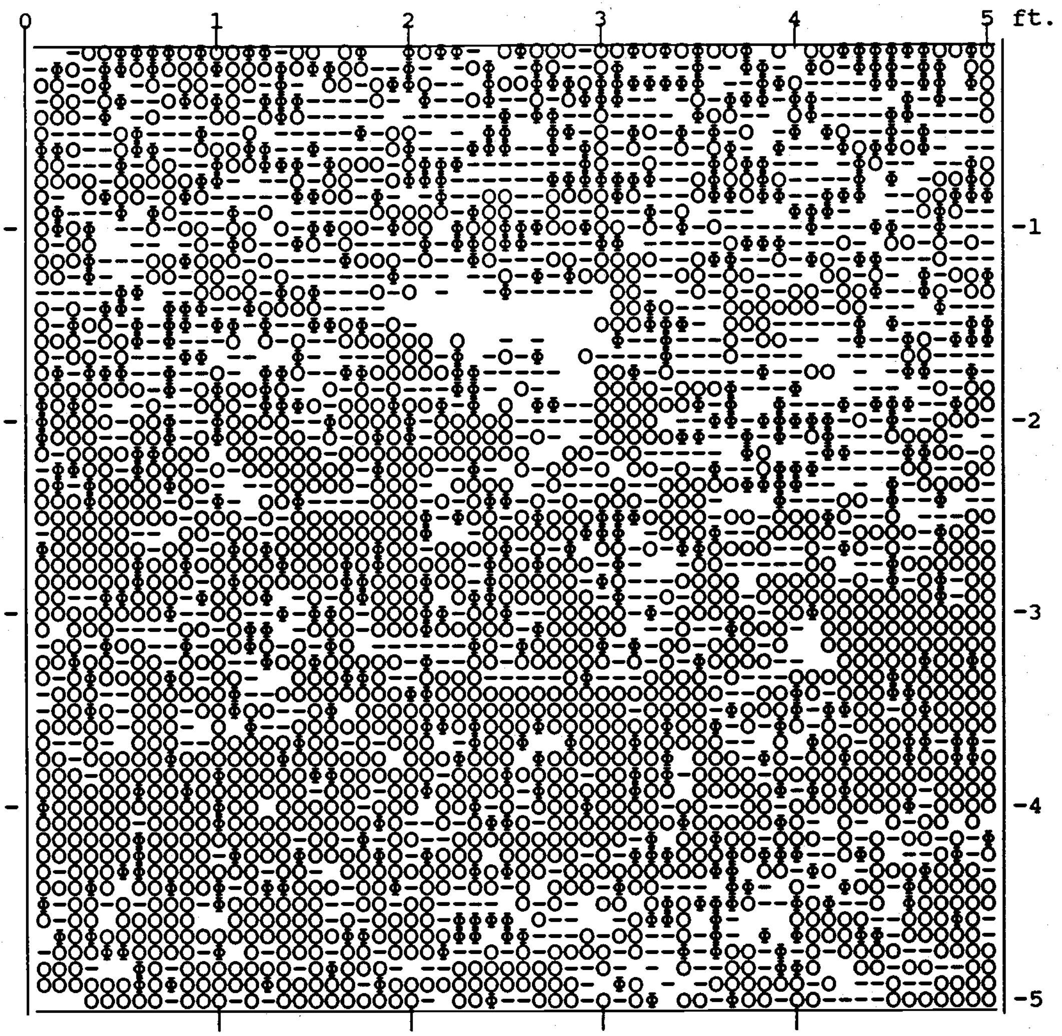
Figures V.3a-i. The following pages show the changes in canopy cover over the 1986 growing season for one plot (Region VII, treatment A). Each cell represents one square inch.

APRIL 17, 1986



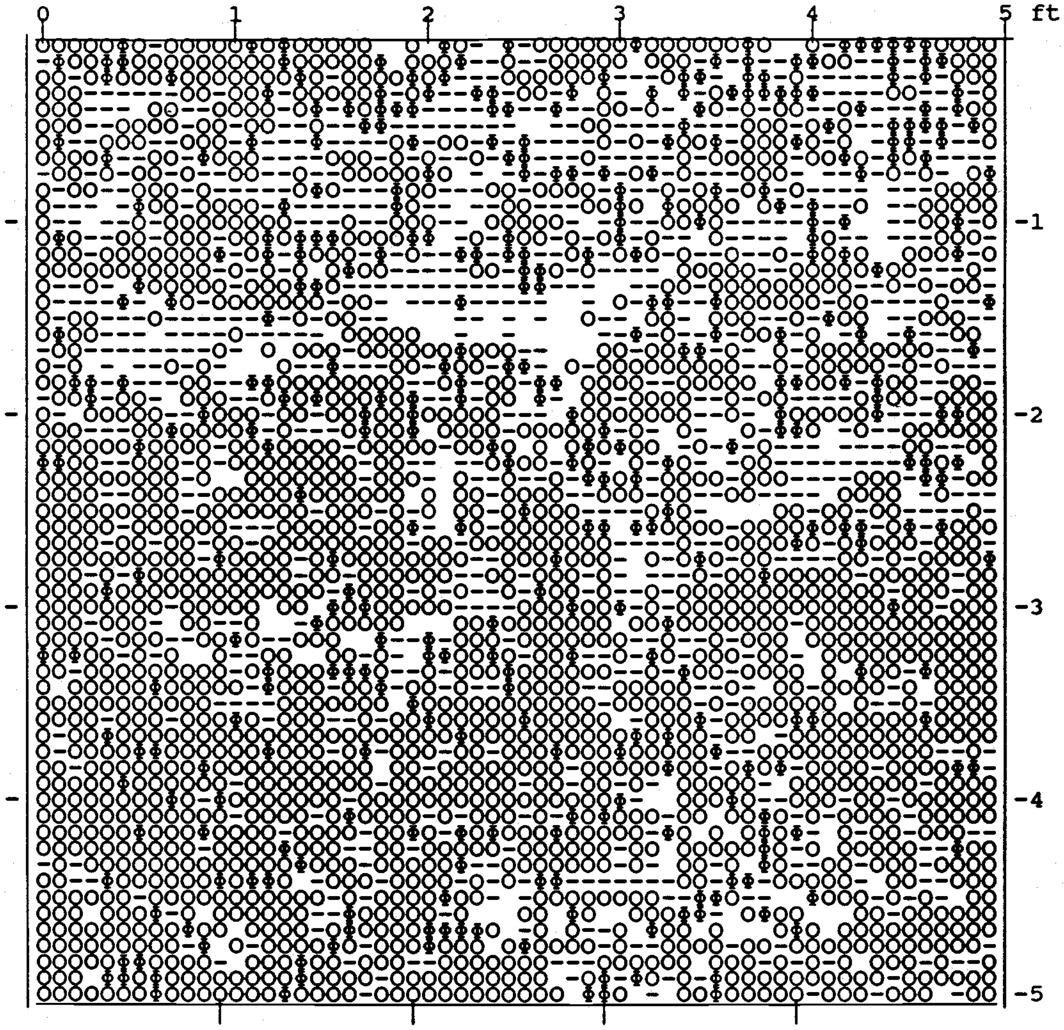
OOOO OOOO	HEALTHY-GREEN CANOPY COVER	39.7%
ΦΦΦΦ ΦΦΦΦ	REDDISH-BROWN CANOPY COVER	22.3%
---- ----	DEAD-LIGHT TAN CANOPY COVER	31.1%
	SHADOWS OR MISSING CANOPY COVER	6.9%

MAY 15, 1986



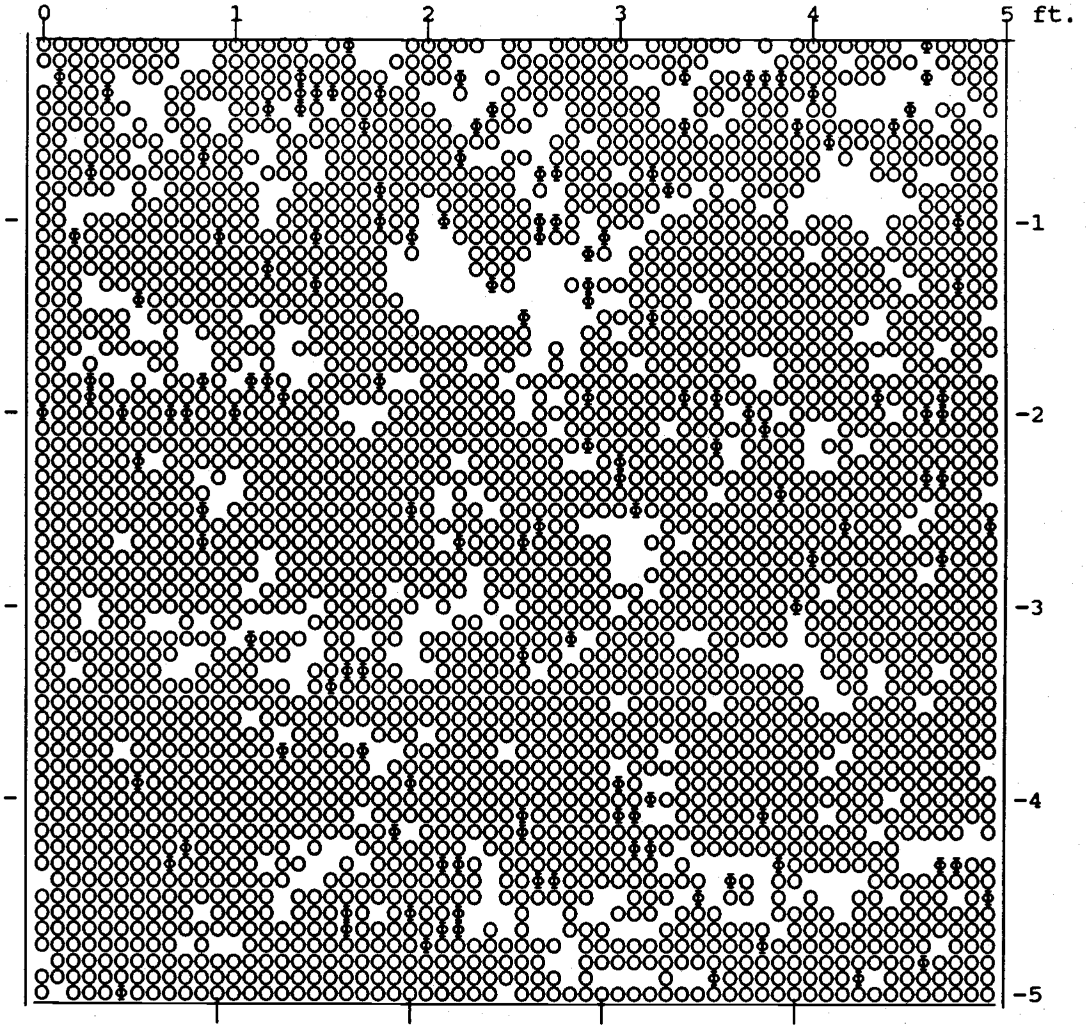
OOOO OOOO	HEALTHY-GREEN CANOPY COVER	48.7%
ΦΦΦΦ ΦΦΦΦ	REDDISH-BROWN CANOPY COVER	16.9%
---- ----	DEAD-LIGHT TAN CANOPY COVER	27.6%
	SHADOWS OR MISSING CANOPY COVER	6.8%

MAY 29, 1986



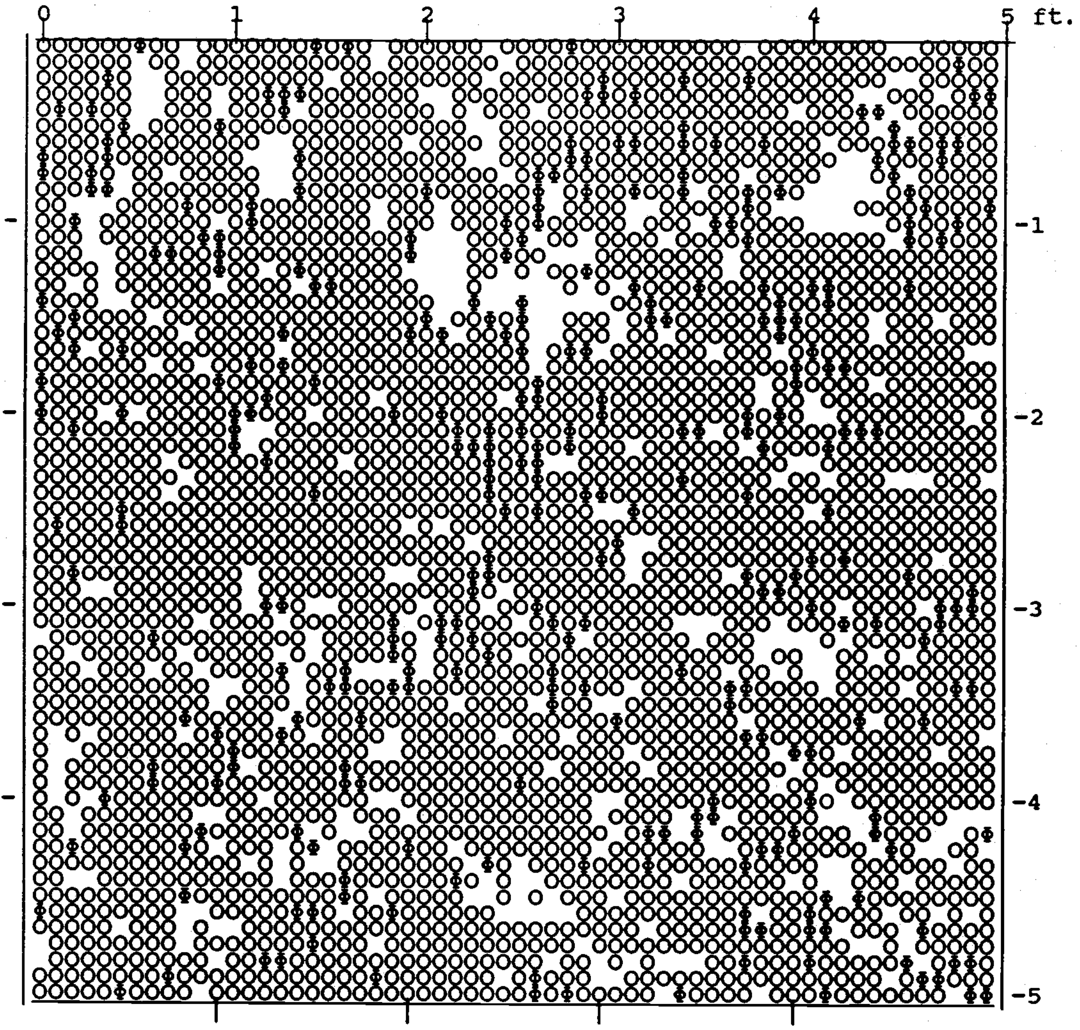
OOOO OOOO	HEALTHY-GREEN CANOPY COVER	58.4%
ΦΦΦΦ ΦΦΦΦ	REDDISH-BROWN CANOPY COVER	10.5%
---- ----	DEAD-LIGHT TAN CANOPY COVER	25.6%
	SHADOWS OR MISSING CANOPY COVER	5.5%

JUNE 21, 1986



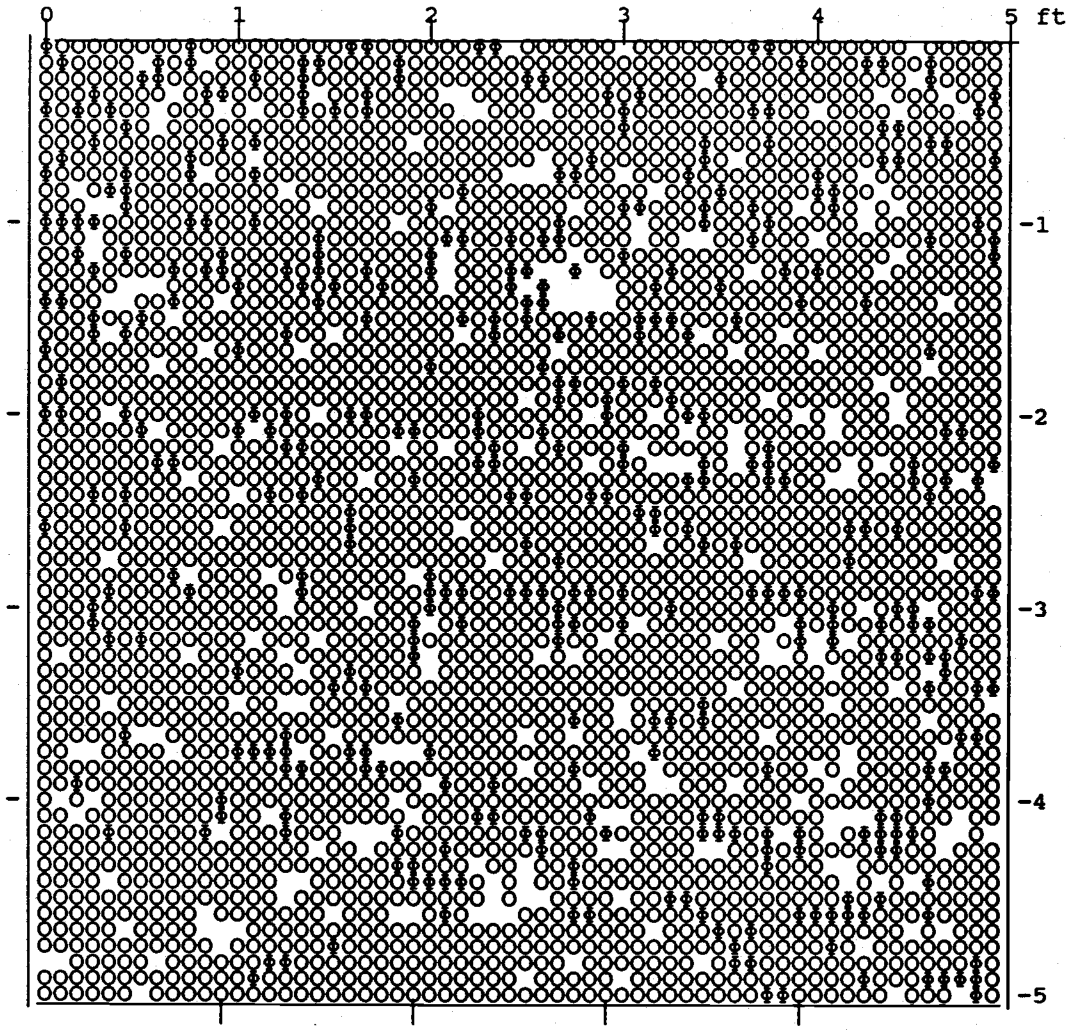
OOOO OOOO	HEALTHY-GREEN CANOPY COVER	82.2%
ΦΦΦΦ ΦΦΦΦ	REDDISH-BROWN CANOPY COVER	3.9%
	SHADOWS OR MISSING CANOPY COVER	13.9%

JULY 18, 1986



OOOO OOOO	HEALTHY-GREEN CANOPY COVER	79.2%
ΦΦΦΦ ΦΦΦΦ	REDDISH-BROWN CANOPY COVER	9.1%
	SHADOWS OR MISSING CANOPY COVER	11.7%

AUGUST 4, 1987

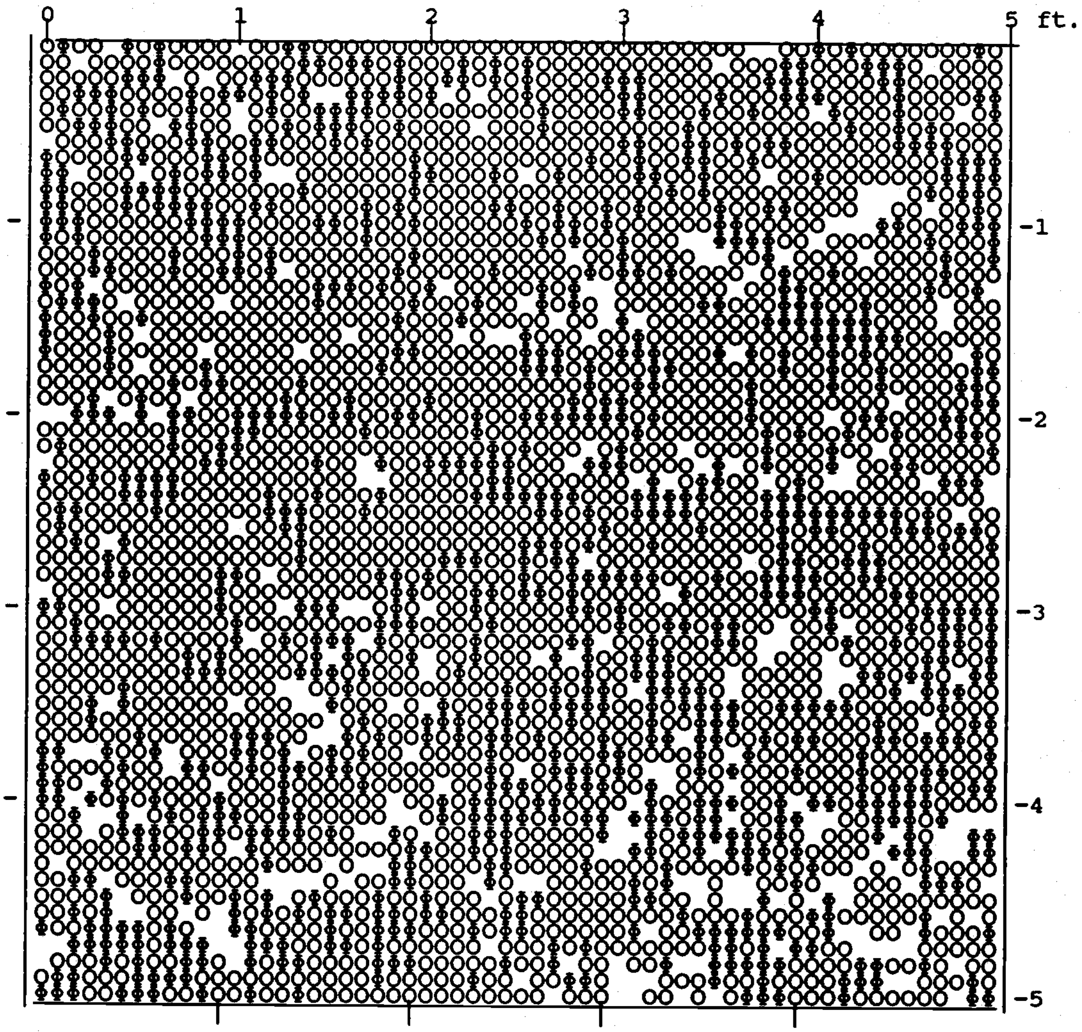


OOOO OOOO HEALTHY-GREEN CANOPY COVER 81.0%

ΦΦΦΦ ΦΦΦΦ REDDISH-BROWN CANOPY COVER 11.3%

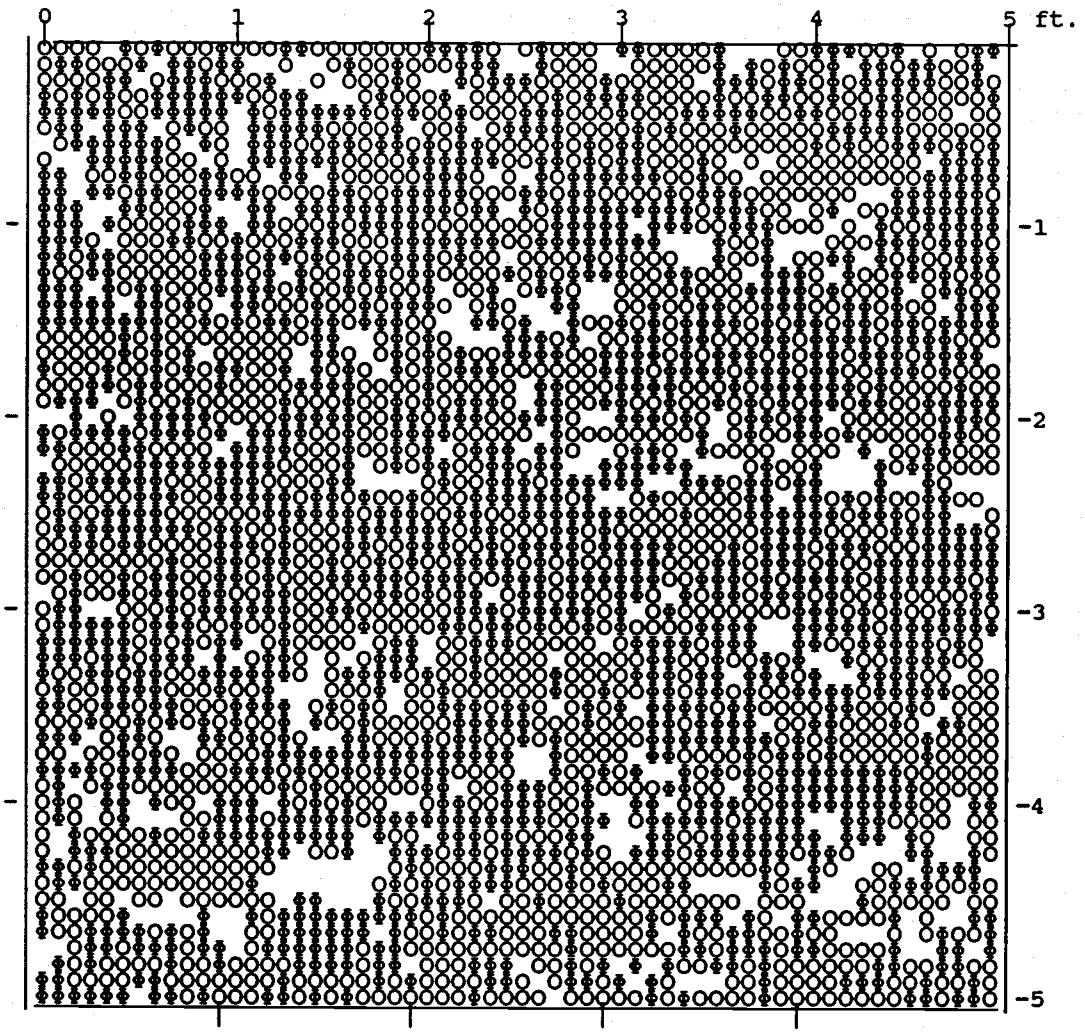
SHADOWS OR MISSING CANOPY COVER 7.7%

AUGUST 24, 1986



OOOO OOOO	HEALTHY-GREEN CANOPY COVER	64.3%
ΦΦΦΦ ΦΦΦΦ	REDDISH-BROWN CANOPY COVER	28.3%
	SHADOWS OR MISSING CANOPY COVER	7.4%

SEPTEMBER 19, 1986



OOOO OOOO	HEALTHY-GREEN CANOPY COVER	44.2%
ΦΦΦΦ ΦΦΦΦ	REDDISH-BROWN CANOPY COVER	46.4%
	SHADOWS OR MISSING CANOPY COVER	9.4%

The ground imagery also shows that leaf color can be a factor at certain growth stages. Leaves coming out of dormancy turn from reddish-brown to green. June imagery shows the minimum percentage of reddish-brown leaves (3.9%). The reddish-brown leaves during the early summer are the result of stress or necrosis. Later in the summer leaves begin to go into dormancy and change from green to reddish-brown.

Interpretations from the 1:3800 imagery were made employing three classes relating to the relative changes in image tone (light, medium, and dark). Interpretations from color IR transparencies corresponded to percent infected uprights and revised upright density but not upright density (Figures V.4-V.12). Light tones were associated with healthy plots and darker tones averaged greater disease incidence. These relationships progressively decreased as the images were acquired from narrow regions of the EMS (the no. 12 filter was best and the no. 70 filter was worst).

Color 1:3800 imagery showed very little perceptible differences in tone between plots. However, there were considerable differences in color (greens-vegetation type and yellow brown and reddish brown-moisture stress and soil background). Bare spots (brown) were difficult to distinguish from cranberry plants (dark-green) due to the perceptual similarity of the two colors and the occurrence

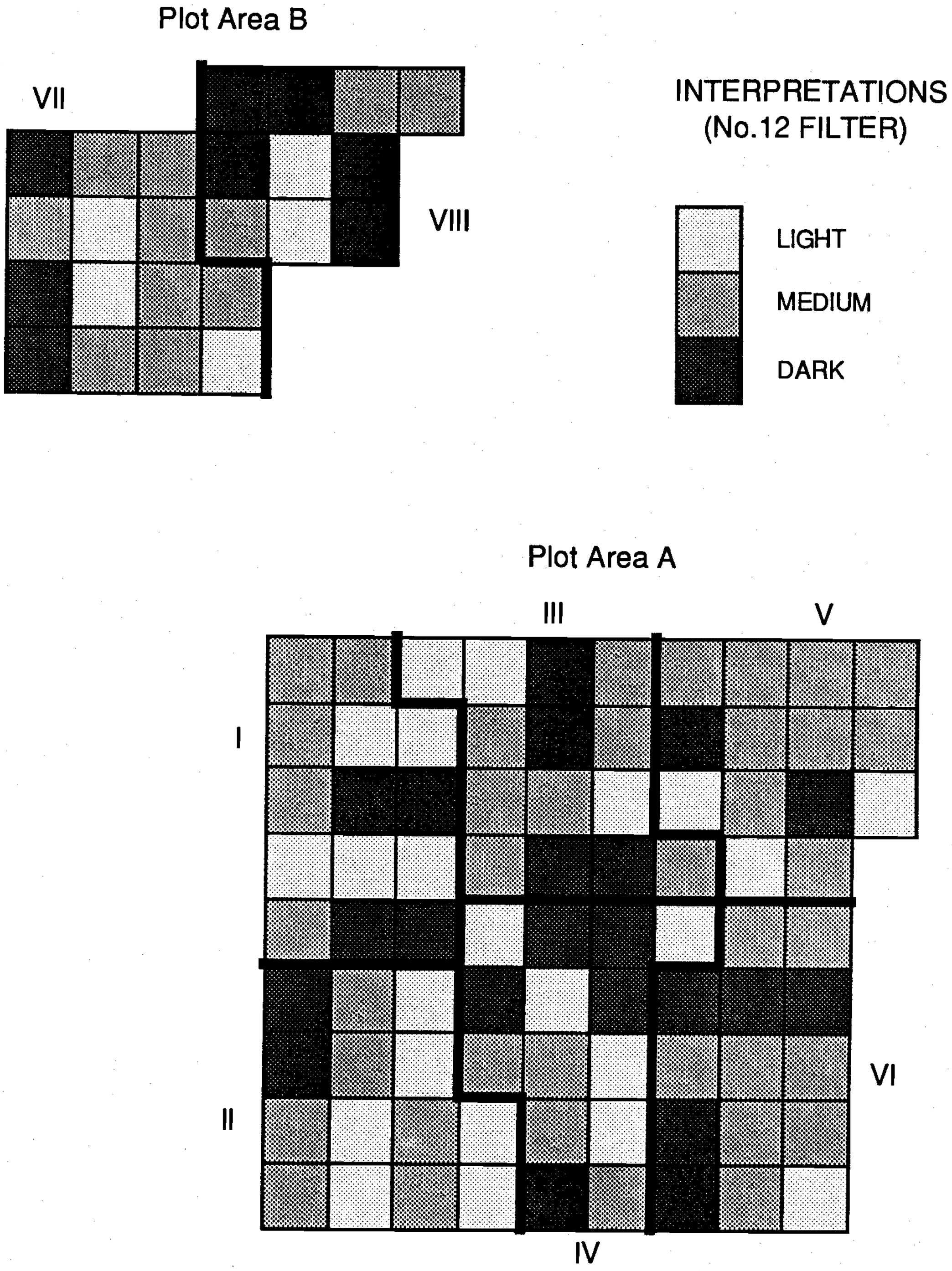


Figure V.4. Interpretations made with color IR film (1:3800) and a Wratten No. 12 (deep yellow) filter for plot areas A and B.

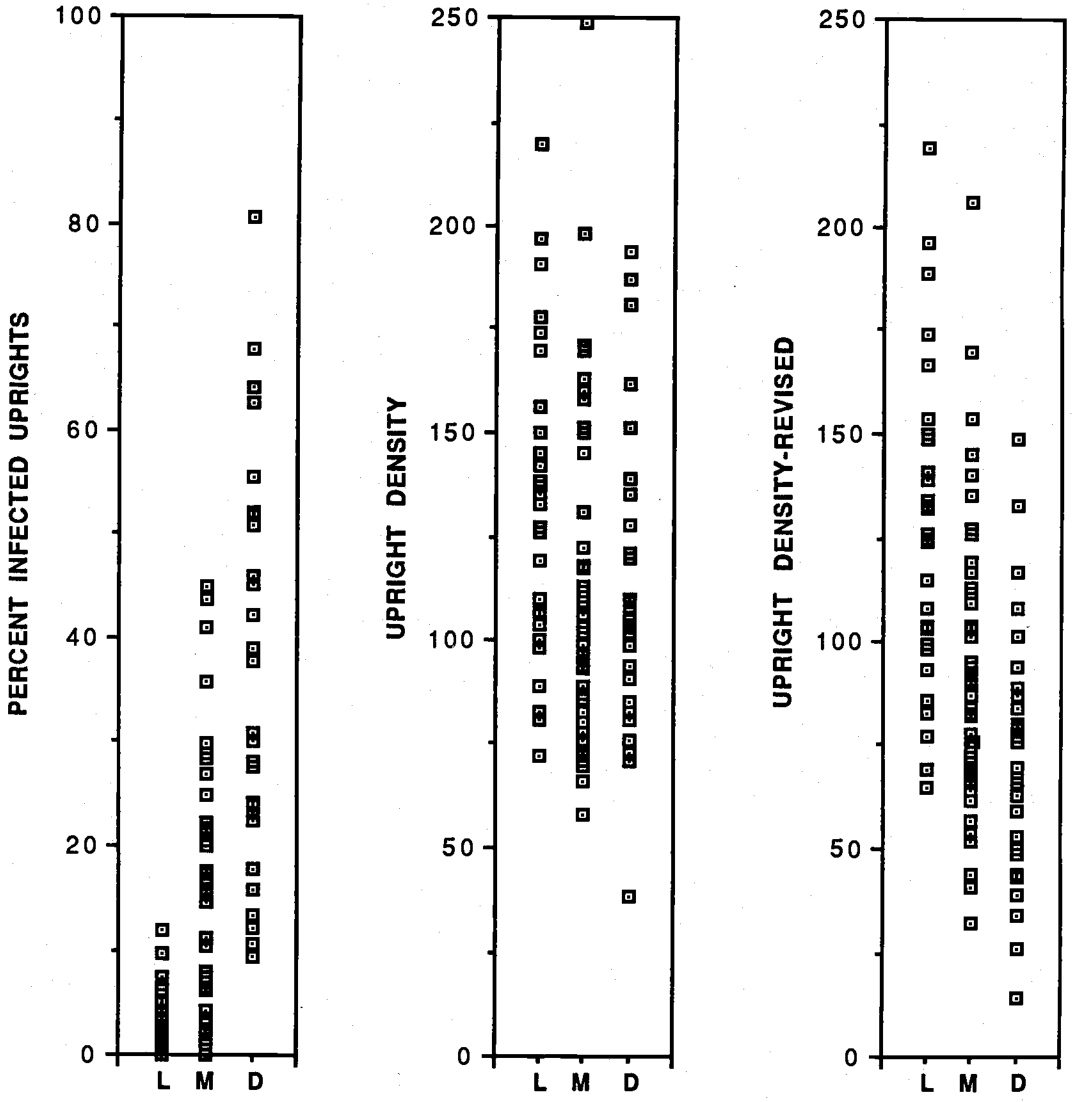
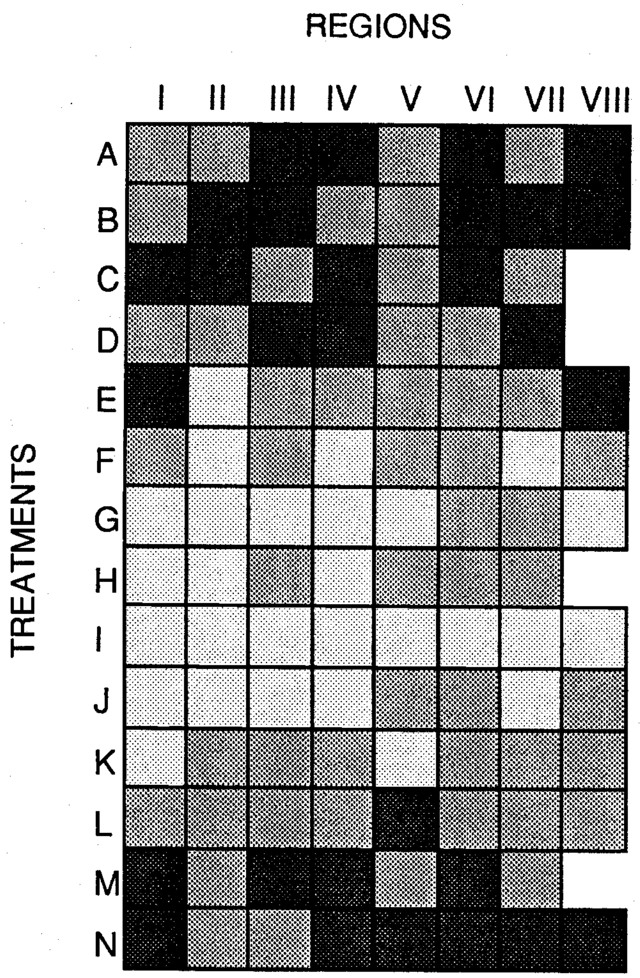


Figure V.5. The distribution of percent infected uprights, upright density and upright density-revised according to interpretations made with color IR film (1:3800) and a Wratten no. 12 (deep yellow) filter. (X axis: L=light, M=medium and D=dark.)

INTERPRETATION SUMMARY



Interpretations	No. of plots	Mean % infected uprights	Mean upright density	Mean upright density-REV
Light	28	3.2	130.7	126.9
Medium	50	15.0	109.3	93.0
Dark	30	36.3	114.8	72.3
Total	108	17.9	116.4	96.0

Figure V.6. A summary of the interpretations made with color IR film (1:3800) and with a Wratten No. 12 (deep yellow) filter.

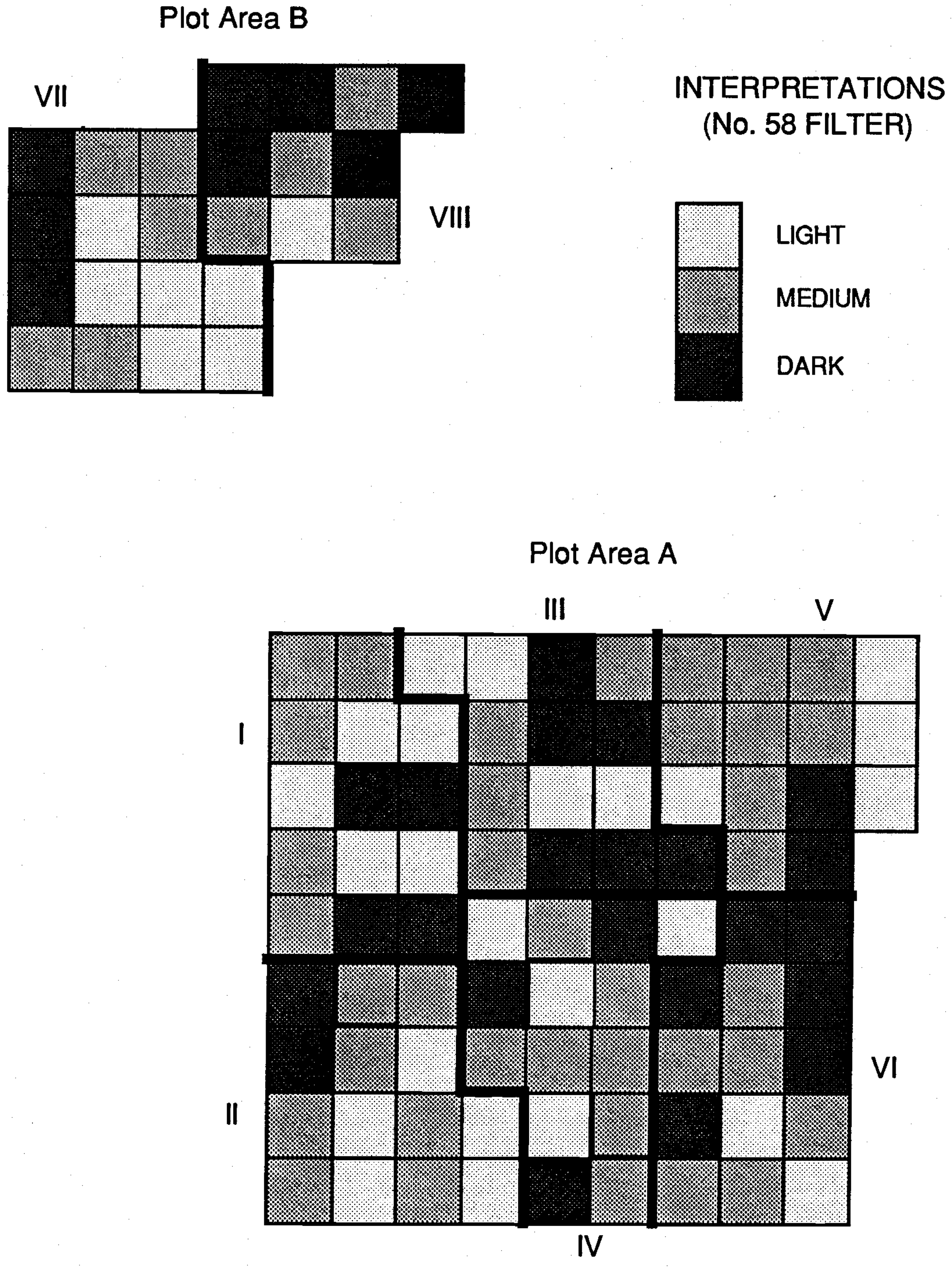


Figure V.7. Interpretations made with color IR film (1:3800) and a Wratten No. 58 (green) filter for plot areas A and B.

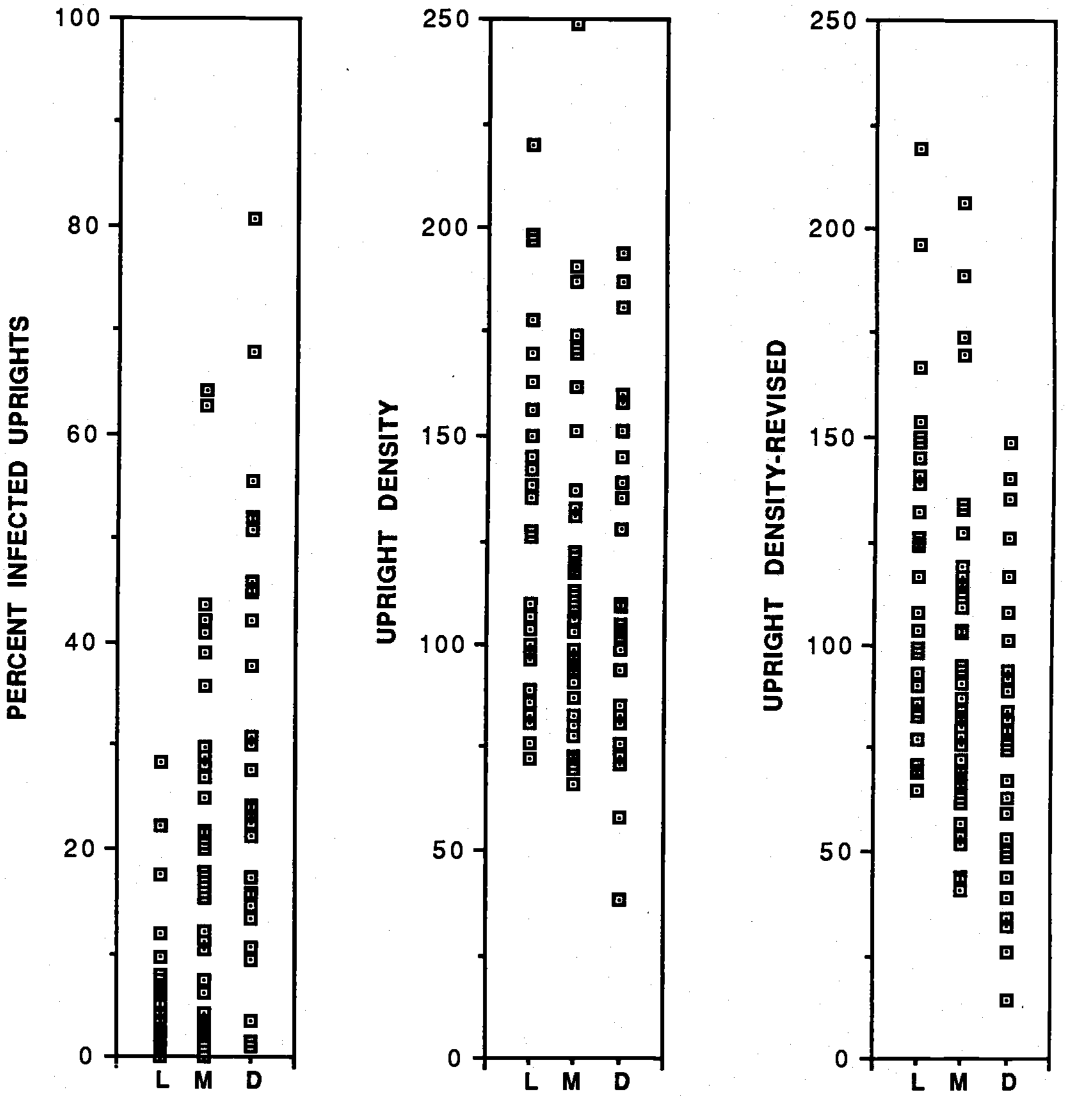
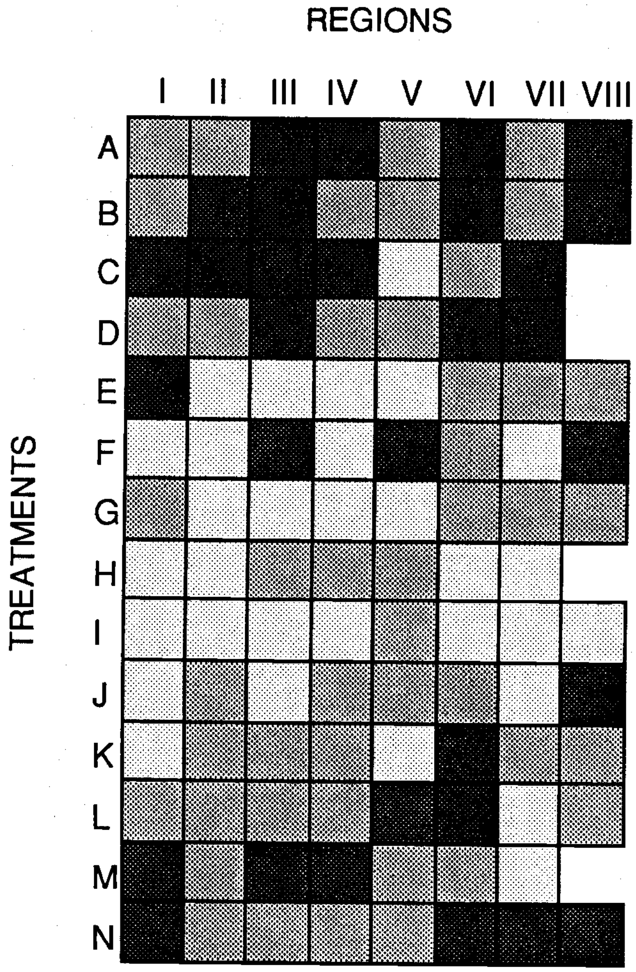


Figure V.8. The distribution of percent infected uprights, upright density and upright density-revised according to interpretations made with color IR film (1:3800) and a Wratten no. 58 (green) filter. (X axis: L=light, M=medium and D=dark.)

INTERPRETATION SUMMARY



Interpretations	No. of plots	Mean % infected uprights	Mean upright density	Mean upright density-REV
Light	31	5.7	123.5	116.2
Medium	46	17.5	114.9	94.8
Dark	31	30.4	111.4	77.8
Total	108	17.9	116.4	96.0

Figure V.9. A summary of the interpretations made with color IR film (1:3800) and with a Wratten No. 58 (green) filter.

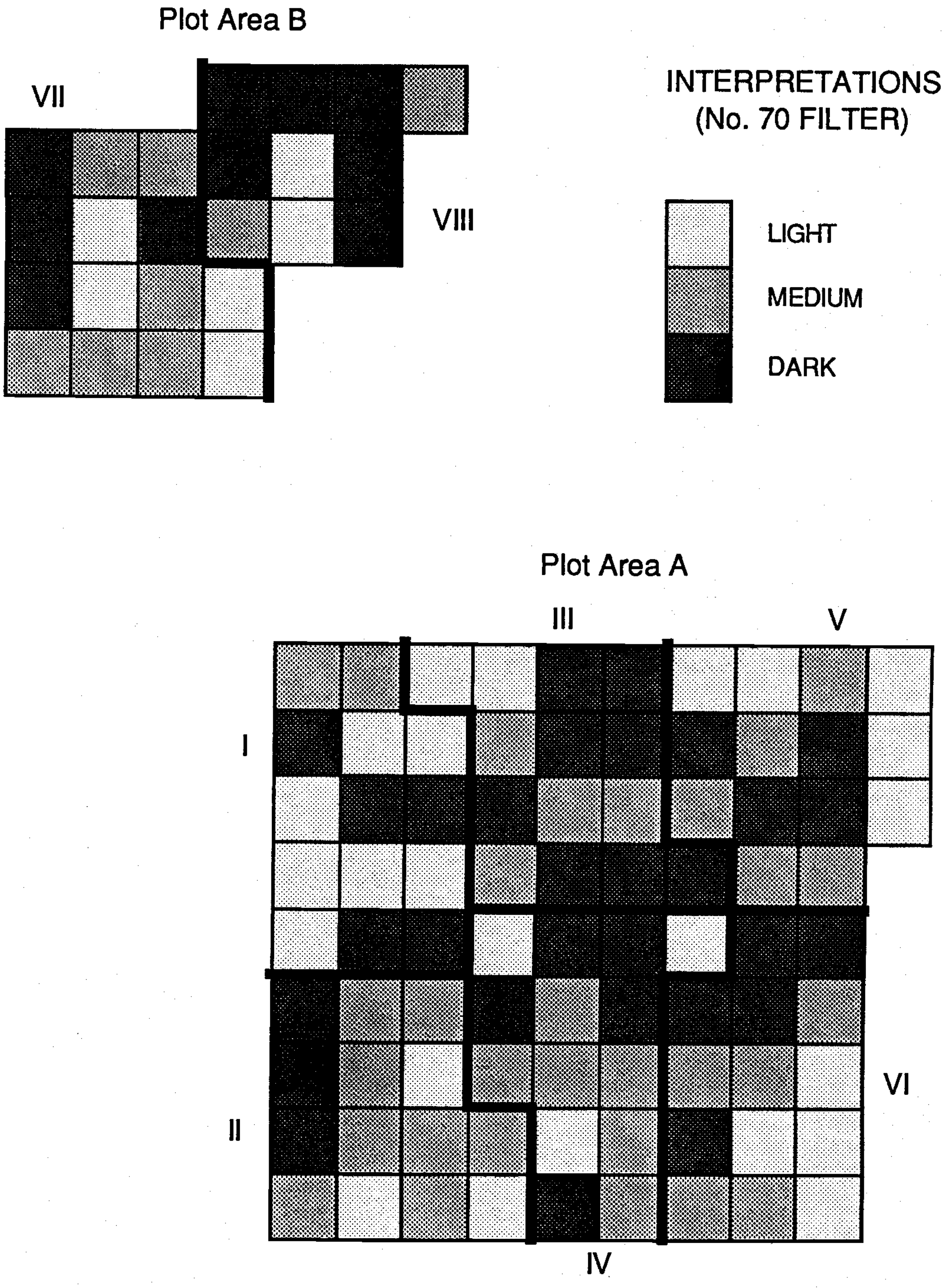


Figure V.10. Interpretations made with color IR film (1:3800) and a Wratten No. 70 (dark red) filter for plot areas A and B.

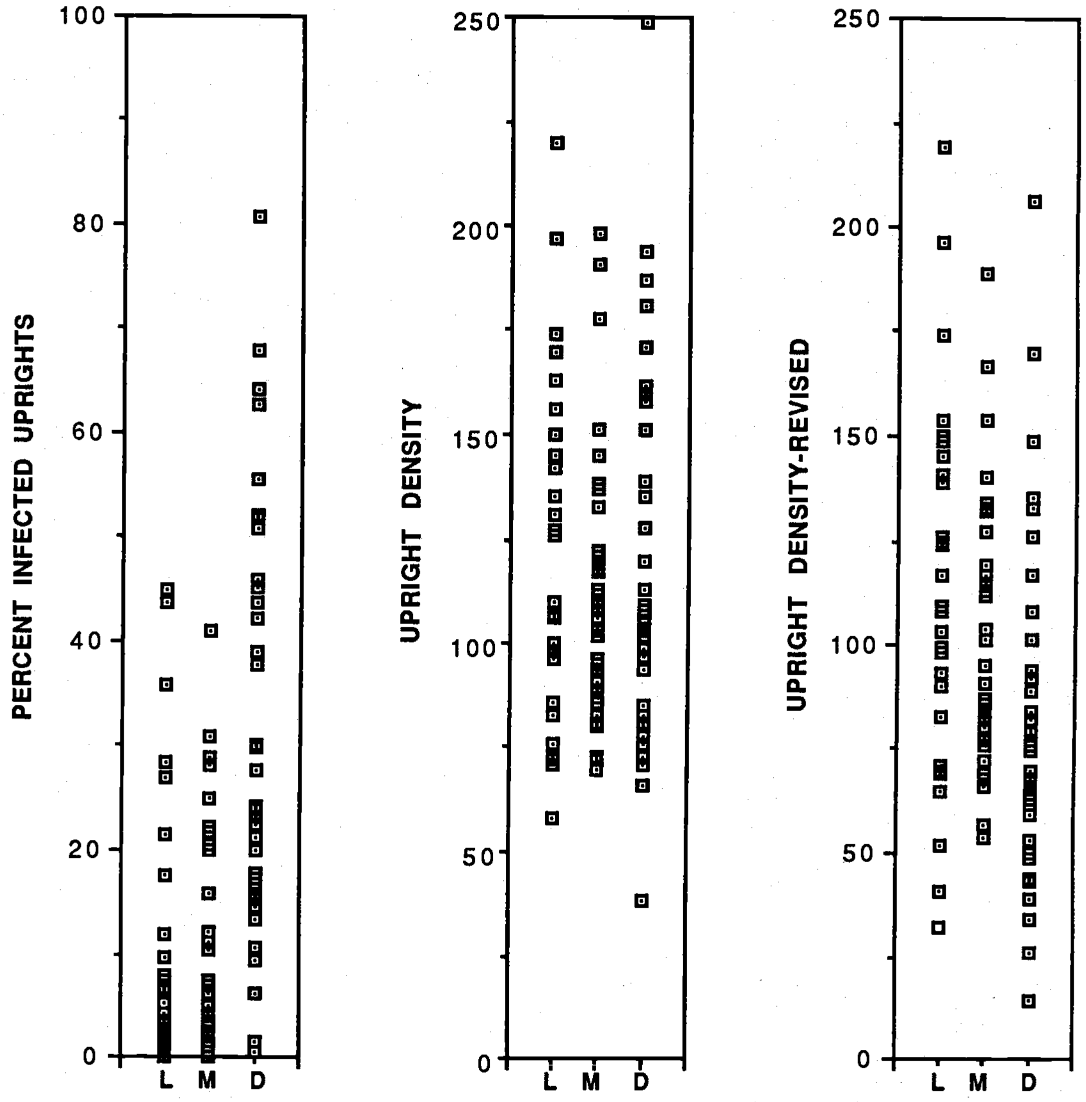
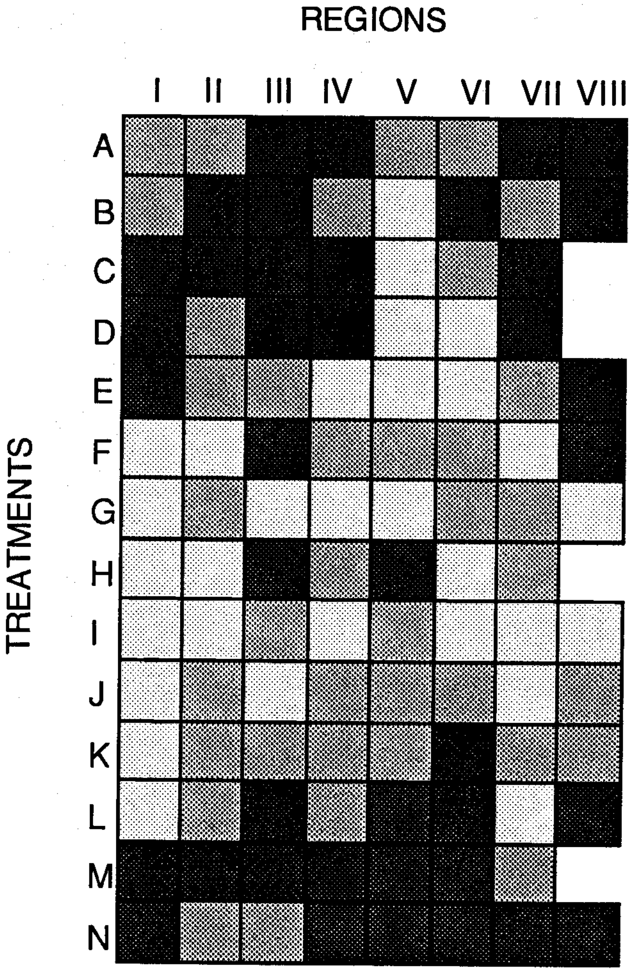


Figure V.11. The distribution of percent infected uprights, upright density and upright density-revised according to interpretations made with color IR film (1:3800) and a Wratten no. 70 (dark red) filter. (X axis: L=light, M=medium and D=dark.)

INTERPRETATION SUMMARY



Interpretations	No. of plots	Mean % infected uprights	Mean upright density	Mean upright density-REV
Light	30	10.1	121.7	110.9
Medium	38	10.2	111.6	100.4
Dark	40	31.0	116.9	80.7
Total	108	17.9	116.4	96.0

Figure V.12. A summary of the interpretations made with color IR film (1:3800) and with a Wratten No. 70 (dark red) filter.

of shadows (black) and a ground component within a stand of cranberry plants.

The 1:12000 imagery showed little tonal differences in plot areas. The imagery was too small-scale for individual plot interpretations. At this scale gross general bog conditions (stressed areas vs. non-stressed areas) could be seen. Also, differences in color were more apparent. For example, vegetation types (cranberry-red vs. weeds-magenta) and areas of moisture stress (dehydration-yellow orange) were evident. Bog traffic (trampling) and insect damage (defoliation) could be detected easily on color IR imagery at both 1:3800 and 1:12000 scales.

Discussion

The two main aspects that need to be evaluated further are the ground data and the film/filter interpretations. Since the study area was located in a commercial bog, control plots (Treatment A) are defined as supposedly having no fungicide applications. However, other cultural practices would be applicable to the entire bog. An unfortunate example of this was the sanding and replanting of four plots in region VIII. In addition, locating in a commercial bog meant that reasonable care of the cranberry plants had to be observed (i.e. whole sections of the bog could not be clipped). Also, the study area location was selected due to the known stressed condition of the bog; there was a good chance Lophodermium would become established. Therefore, this bog is not necessarily representative of the average acreage in production.

The first possible source of error is the assumption that the clipped area within a plot is representative of the entire plot for both infected uprights and upright density. Further, the ground imagery example (Figures 12a-i) shows that although 43.6% infected uprights may be representative of the entire plot, disease incidence is not uniformly distributed within the plot; most of the infected uprights were located in the top half of this particular plot. Therefore, the size and shape of the infected area are important considerations.

Secondly, the plots were analysed for only Lophodermium. Visual inspection had to suffice for other possible stresses. Since mancozeb is a broad-spectrum fungicide, the likelihood of other disease incidence would be based on treatment timing in relation to the infection period of the particular disease. This means that plots with treatments H and A would most likely be the healthiest and unhealthiest, respectfully. However, plots with other treatments would have varying amounts of disease (if the disease occurred at all). The diseases red leaf spot and Botryosphaeria (similar symptoms to Lophodermium) were observed within the study plot area along with chlorosis (possible nutrient deficiency), weeds, and water stress (dehydration in regions V and VI and excessive amounts in regions I, II, VII, and VIII). Plots containing weeds tend to be interpreted lighter ("healthier") while plots with excess water were interpreted as being darker or more stressed than the percent disease incidence data suggests.

Film quality is an important consideration. Film density is directly related to exposure and exposure is directly related to the reflectance of objects. Although this is a gross oversimplification, it relates the importance of exposure. Interpretations may or may not be made due to poor exposure more than anything else. As imagery is acquired from more narrow regions of the EMS, exposure generally has to be increased and becomes more critical.

Many factors affect film density and their consideration is necessary for quantitative analysis (and is beyond the scope of this paper). However, for manual (visual) interpretation of imagery the main effects of exposure are in terms of tone differences and color balance (exposure latitude). Often the importance of tone in the interpretation process increases with large scale imagery and the importance of color increases with small scale imagery.

For color IR films, the dye layers are not restricted to narrow regions of the EMS, however, their peak sensitivity corresponds to certain wavelengths. For example, the cyan dye layer (corresponding to the red color or IR sensitive region) peaks between 700 and 750nm, yet is sensitive throughout the range of the film. Although the cyan dye layer is approximately 1/10 as sensitive as the yellow and magenta dye layers, the increased reflectance of vegetation in the IR is high enough to saturate the image and possibly mask small tonal differences especially at lower altitudes.

The interpretation differences between the three filters on the 1:3800 color IR imagery can be attributed more to exposure than to anything else. The three classes appeared more similar (slight tonal differences) on imagery employing the 12 filter (hence, the many medium toned interpreted plots), and the most contrast was evident on imagery employing the 70 filter (fewest medium toned interpreted plots). The addition or subtraction of color or color balance may have caused these interpretation differences resulting from exposure differences or ground conditions. Color probably plays a secondary role with factors such as weeds, chlorotic areas, and soil background having an influence. With the 12 filter these factors can be seen as color differences, but with the 70 filter these factors are incorporated with all factors as tonal differences.

Ground imagery from 1987 shows an absence of Lophodermium damage. This implies that there was no infection in 1986 (plots were sprayed?). Thus, 1986 interpretations were based on 1985 infected uprights that show symptoms in 1986 plus any other stress variables. This absence of visual damage also shows how fast an area recovers, that is, how new growth together with pruning and raking act to fill in a damaged area. Therefore, imagery acquisition should be best soon after leaves come out of dormancy.

CHAPTER VI

DISCUSSION

It is evident that many variables and considerations exist for a successful remote sensing study. However, depending on the actual study definition (object of interest, qualitative or quantitative results, level of accuracy, and how the information will be used), many of the unknowns may be reduced.

To the individual grower, an ideal crop monitoring system would acquire imagery every day or so (as there is a positive correlation between usefulness and image acquisition frequency) and with information received on the order of minutes or hours (as there is a negative correlation between usefulness and interpretation results from time of acquisition). Obviously, at this time, costs are prohibitive for such a system. Therefore, it is the extent of chronic stress which is being monitored. This is usually accomplished by acquiring imagery several times or even once a year depending on the object(s) of interest.

Clearly, for a commitment to an ongoing stress detection and monitoring remote sensing system, ground studies are needed for an understanding of the physiological and morphological changes of the cranberry plant due to stress, and how these changes affect reflectance across the electromagnetic spectrum. These findings then will determine the best spectral regions for detection and, further, the sensor system and perhaps the interpretation technique(s). Much of remote sensing research, however, has dealt with technique development which is then used to show benefits. Therefore, the methods are fairly well developed, but identifying the cause of stress is still a problem.

A remote sensing study for cranberry plant stress detection involves the selection of a suitable site, ground based analysis, sensor and image selection and acquisition, and image interpretation and evaluation. A study site must be selected where the object(s) of interest is established or may be introduced, along with a healthy cranberry control area necessary for comparisons. The areal extent must be large enough so that smaller areas within may be clipped for laboratory analysis at various times during the year, and so that one can still detect the remaining areas at various photographic scales. A cranberry bog should be selected with cranberry plants of the same age and variety, soil composition, and cultural practices (including soil moisture conditions).

Ground based studies at the very least should include the identification of all stress agents, areal extent of the various stresses, leaf color, leaf area, upright density, canopy geometry, soil moisture, and soil color (for example, light colored sand has a greater reflectance than dark organic matter). In addition, a multispectral approach (a portable spectroradiometer, for example) is desirable. This enables the identification of specific wavelength bands for optimal stress detection and can be used for specific monochromatic (narrow-band) filter selection for aerial photography.

Aerial photography may be the most cost effective method of remote sensing, and should be explored in depth before entertaining other possibilities. Multiband photography is more versatile and may increase information, yet the costs may not warrant its usage. Color-IR film transparencies with a Kodak Wratten no. 12 (or no. 15) should be used. If the multiband approach is used, then a minimum of three bands should be employed, representing the green, red, and near IR regions of the electromagnetic spectrum.

The timing of imagery acquisition is based on relevant stress variables in relation to the crop calendar and is further complicated by weather conditions. For diseases the timing of infection, crop vigor, changes in crop geometry, and visual symptoms determine image acquisition. Feeding habits for insects are the most important factor. For nutrient deficiency detection, leaf color usually is not the dominant factor. Instead, the dominant factors during the growing season will be reduced crop vigor, changes in canopy geometry, and reduced leaf area. Moisture stress (dehydration) is quite evident during the late summer months due to sprinkler irrigation system inefficiencies (stressed areas show an increase of reflectance in the red visible region of the EMS, which is in sharp contrast to the characteristic circular patterns of healthy vegetation). Water drainage problems may be detected on spring imagery due to abundant water supplies and an incomplete canopy cover. Weed infestations are easily interpreted on an image apparently at any time due to their increased vigor (increased reflectance). Spring imagery provides information on the extent of perennial weeds, while both annual and perennial weeds are detected later in the growing season.

Stress variables then need to be compared to variables associated with the crop calendar. Imagery acquired during dormancy may not be very useful. Lower sun angles, increased shadows, various cultural practices increasing energy interaction complexity, reduced photosynthesis activity, and the reddish-leaf color would most likely mask any stress symptoms occurring during this period. During the growing season leaf maturity, leaf color, and percent canopy cover all influence reflectance. Young leaves that have not yet differentiated mesophyll layers have reduced reflectance. Leaf color may be light green, green, dark green, and/or reddish green during the growing season and may reduce interpretation accuracy if not accounted for. An incomplete canopy cover increases the background effect (decreases reflectance on organic soils and dense vine growth and increases reflectance for light colored sand) and reduces the layering effect, also decreasing reflectance. Therefore, the overall single best time for imagery acquisition is late summer with the specific period depending on the object(s) of interest. This is due to a majority of stresses exhibiting some symptom at this point, leaves being mature, and the canopy cover being at its greatest.

Since we are concerned with small spectral changes that may be masked by atmospheric attenuation, the apparent coalescing of vegetation, or any number of variables, the selection of spatial resolution is one of the most important considerations. If no spectral changes (which indicate stress) are recorded on an image, no interpretation technique will provide the desired information. There appears to be a threshold at a scale of 1:5000-6000 for biological stress detection of vegetation. The success rate at smaller scales, appears to be highly variable (and questionable), while assessment accuracies generally have improved as scales become larger (1:4000-1:1000). Therefore, image scale comparisons of 1:1000, 1:2000, 1:4000, and 1:6000 are desirable for a study. At these larger scales, maximum airplane speed and shutter speed must be stated to the contractor, as image blur and poor exposure are the two major factors reducing image resolution and, hence, usefulness.

The usefulness of aerial photography often is reduced by the inabilities of the interpreter and a lack of knowledge of what is being recorded, of film properties, and of the hardware needed to interpret and obtain measurements. Physiological and morphological changes in cranberry plants are recorded on color-IR photographs as patterns and shapes of color differences in tone and intensity. These color differences must be delineated by the photointerpreter with the cause identified.

A common problem in remote sensing plant stress detection studies is the identification of the stress agent. Biological and nutrient stress detection have been shown to be successful when there has been prior knowledge of the stress occurring. Without this prior knowledge, stress may not be detected or, more likely, the stress agent can not be determined. Therefore, the interpreter needs to be familiar with the crop and cropping systems, crop management information, and ground truthing.

Important crop information includes: the age and variety of cranberry plant; leaf analysis data; soil test data; sanding and pruning; kind, rate, and method of herbicide, fungicide, and insecticide application; irrigation and other water management practices; harvest method; and any historical information. This information may be obtained through an interview or by the mailing of a crop reporting form. In practice this is usually difficult as growers generally don't see the usefulness or are unwilling to comply for various reasons. However, after the initial study is completed and a grower can actually see the results, a very persuasive case can be presented.

Ground truthing may be necessary to identify the cause of stress. For example, a portion of a bog has a weed infestation problem readily interpreted on aerial photographs. Many weeds thrive in high moisture conditions and act to maintain these conditions, which are also favorable for fungal growth. Slight decreases of near IR radiation are then detected (as darker red tones) on the photographs extending beyond the weeds. This may be due to several reasons (loss of vigor due to moisture conditions, fungi, and/or nutrient deficiencies for example). Therefore, a field inspection or plant analyses should be conducted. Once a certain level of confidence is obtained in the interpretation process, then ground truthing may not be necessary.

Qualitative analyses should be undertaken first. These will provide a better understanding of the benefits derived from conventional methods and the prospects for future systems. The three methods of interpretation are the convergence of evidence (the situation above is an example), interpretation keys (which are also helpful for employee training) and image enhancement techniques. Viewing transparencies on a light table under high magnification is a good start. Information should then be added to a base map (by a zoom transfer scope, for example) and/or entered into a information based system (GIS). This information then becomes part of a historical record which aids future interpretations, is a part of a monitoring system, and is a possible input to increasing the precision of a crop forecasting model.

If qualitative analysis is not adequate and/or quantitative analysis is desired, then the selection of a method and the acquisition of hardware may be undertaken with a clear idea of what is needed. This is mentioned because some methods require expensive hardware, are somewhat complex, and may require highly trained personnel.

The costs of a remote sensing system can be summarized as involving the initial start-up, continual imagery acquisition, system support activities (ground truthing for example), and training personnel. The actual costs depend on the specific object(s) of interest. The construction of a utility guide provides a convenient means of comparing cost with utility. The desired use of a remote sensing system is related to a certain scale and associated costs. For example, imagery at a scale of 1:12000 is useful for mapping the boundaries of cranberry bogs (say on a utility scale of 0-100, a 95) and costs x amount of dollars/acre of ground coverage. However, water stress detection on 1:12000 imagery may have a utility score of only 50, a score of 20 for weed detection, and a 5 for disease, insect, and nutrient stresses. The cost and utilities at different scales are then determined and compared.

A final consideration is the level (individual grower, regional, or national) at which remote sensing may be best suited for. The concerns differ at each level. The individual grower is concerned with the efficiency of specific acreage. Regional concerns are in terms of preventing and controlling epidemics, establishing guidelines for control measures, and testing and registering chemicals. Regional agencies also serve as a link between growers and regulating bodies, disseminate the latest information, and are often used as a weather station (weather warning systems). National concerns are primarily in terms of supply and demand relationships, insuring a steady flow of cranberries to processing plants and market. This means the general condition of bogs, the number of acres (planted and bearing), and varieties are of interest and usually serve as an input to prediction models. Of course there are aspects that are similar at all levels, such as crop quality and hopefully social-environmental concerns.

A general utility chart was constructed corresponding to different levels of concern (Figure VI.1). For the overall general condition of a bog, remote sensing can be

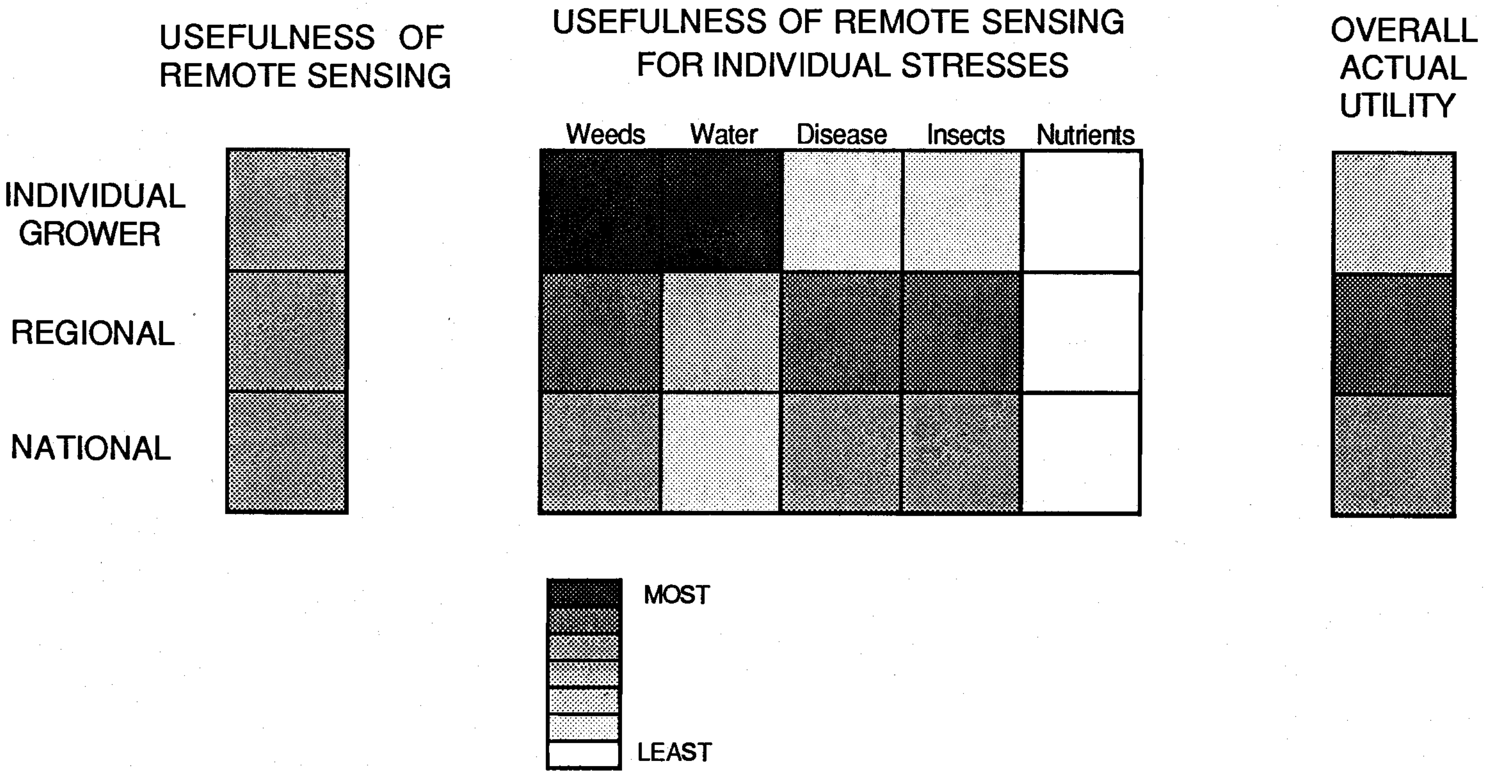


Figure VI.1. The utility of remote sensing for cranberry stress detection and monitoring. Remote sensing can be used for general bog conditions equally well at all levels of management. However, the usefulness and importance of remote sensing varies with type of stress and level of use. Therefore, in practice the utility of remote sensing would vary with level of use.

used equally well at all levels. However, there is considerable variation in the utility of remote sensing for specific stresses and for the particular level of usage. Furthermore, when the importance of the different stresses is considered at different levels, the overall actual utility varies with the level of concern.

The important points are whether or not remote sensing can be used for the detection and monitoring of certain stresses, at what level is the detection of certain stresses most useful, and at what level is remote sensing best suited. For example, weeds and water stress may be detected extremely well with a wide range of image scales and useful at all levels, yet this information is more important at the individual grower level. However, the average grower can not justify an imaging system for these problems alone. Nutrient stress detection, on the other hand, would be very useful for the individual grower, but remote sensing is not well suited for this task (at this time). Diseases and insects are also important problems for the individual grower, and a detection and monitoring system would be most useful. Here the problem is that remotely sensed data is only somewhat useful for most individual growers. In this case a remotely sensed image is like taking a picture of a fatal accident. For the unfortunate individual, the damage is done. For the funeral party, however, knowledge of the cause of death and possible prevention may be important for their own well being. At a higher level the event is used as an added statistic. So, although disease and insect detection and monitoring is more important at the individual grower level, remote sensing is better applied at a higher level.

At this time the overall best use of remote sensing for stress detection and monitoring is at the regional level. At this level there is generally a better understanding of the local environment and climate, closer ties to the growers, potentially easier and better interpretations, and quicker information dissemination. Since research stations devoted to cranberries are located in all of the major cranberry growing areas, the use of remote sensing at this level is certainly feasible.

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APPENDIX

LOPHODERMIUM STUDY DATA

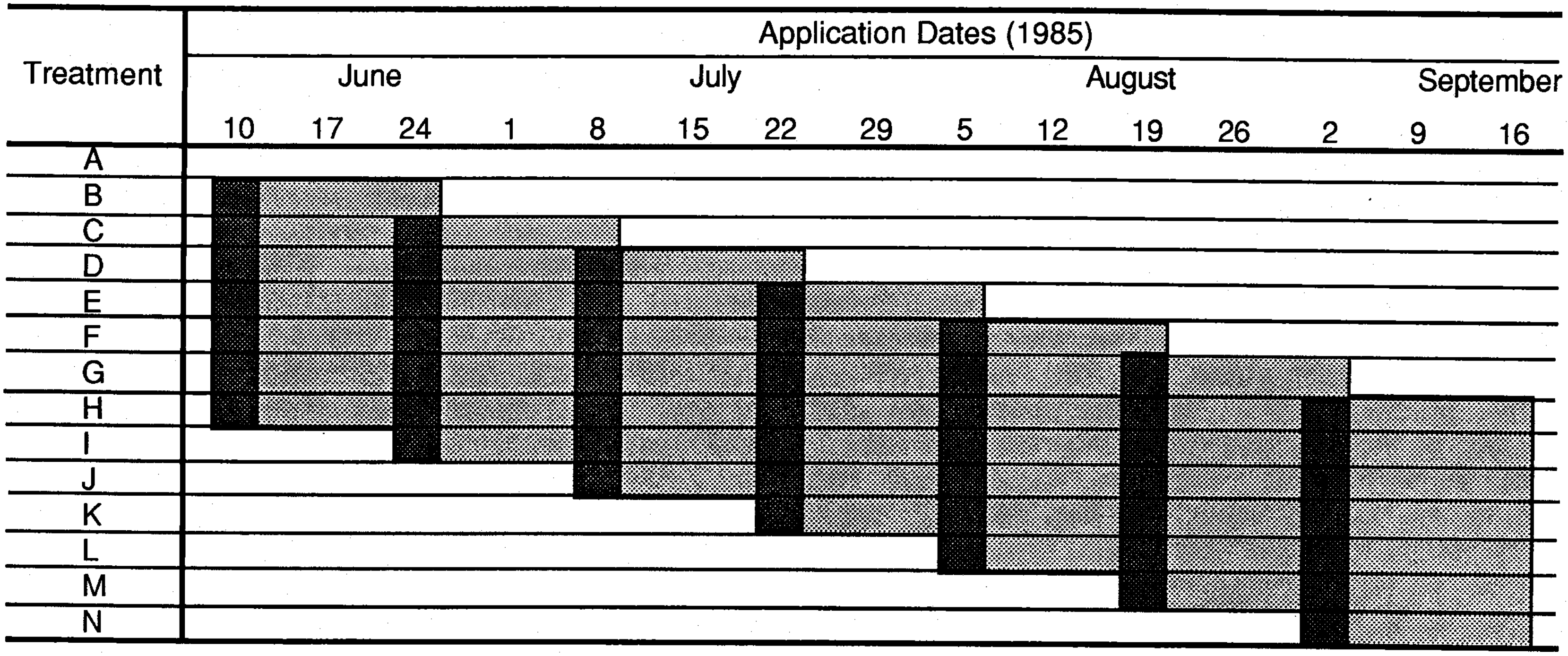
Table A.1
A Comparison of the Main Cultivated Varieties

VARIETY	DISCOVERED	N. AMERICAN ACREAGE	WASHINGTON ACREAGE	HARVEST SEASON	VINE TEXTURE	UPRIGHT LENGTH	LEAF SIZE	LEAF SHADE (GREEN)
Early Black	1852 Mass.	31%	—	Early	Fine	Short	Small	Light
Howes	1843 Mass.	15%	—	Late	Coarse	Tall	Large	Dark
McFarlin	1874 Mass.	14%	97%	Late	Coarse	Short	Medium	Light
Searles	1893 Wisc.	14%	—	Mid	Medium	Tall	Medium	Light
Stevens	1940 NJ	13%	2.75%	Mid	Coarse	Tall	Large	Dark
Ben Lear	<1901 Wisc.	4%	—	Early	Medium	Medium	Medium	Dark
Crowley	1940's Wash.	2%	0.25%	Mid	Coarse	Short	Medium	Light

(adapted from Dana,1983; Chandler &Demoranville, 1958; and Tallman & Eaton, 1976)

Table A.2

Fungicide Treatment Timing For The Study Plots



Treatment	Application Dates (1985)														
	June			July					August				September		
	10	17	24	1	8	15	22	29	5	12	19	26	2	9	16
A															
B	▓	░	░												
C	▓	░	▓	░	░										
D	▓	░	▓	░	▓	░	░								
E	▓	░	▓	░	▓	░	▓	░	░						
F	▓	░	▓	░	▓	░	▓	░	▓	░	░				
G	▓	░	▓	░	▓	░	▓	░	▓	░	▓	░	░		
H	▓	░	▓	░	▓	░	▓	░	▓	░	▓	░	▓	░	░
I			▓	░	▓	░	▓	░	▓	░	▓	░	▓	░	░
J					▓	░	▓	░	▓	░	▓	░	▓	░	░
K							▓	░	▓	░	▓	░	▓	░	░
L									▓	░	▓	░	▓	░	░
M											▓	░	▓	░	░
N													▓	░	░

▓ Application Date ░ Effective Coverage

(adapted from Bristow, 1986)

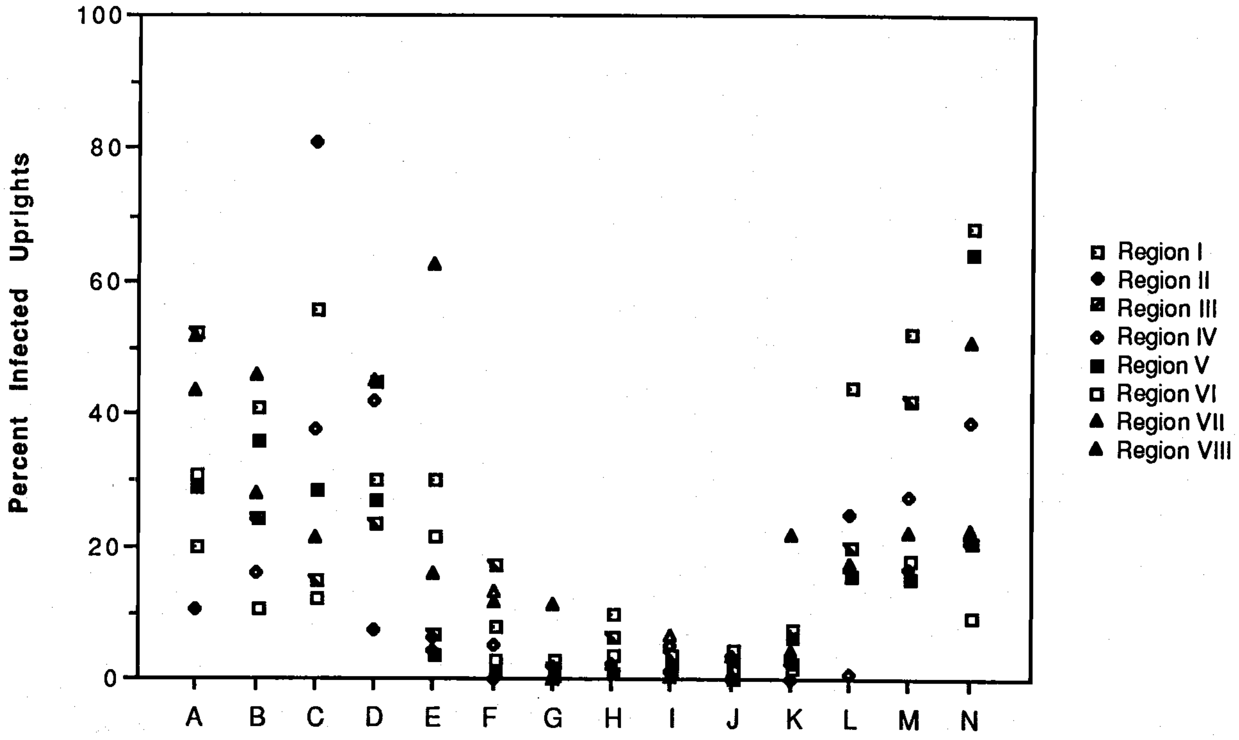


Figure A.1. The percent of infected uprights with Lophodermium spp. according to treatment for the 108 study plots. The concavity of the scatter plot is expected as treatment H has complete fungicide coverage during the infection period and treatments B and N have the least. Plots with treatment A are unsprayed.

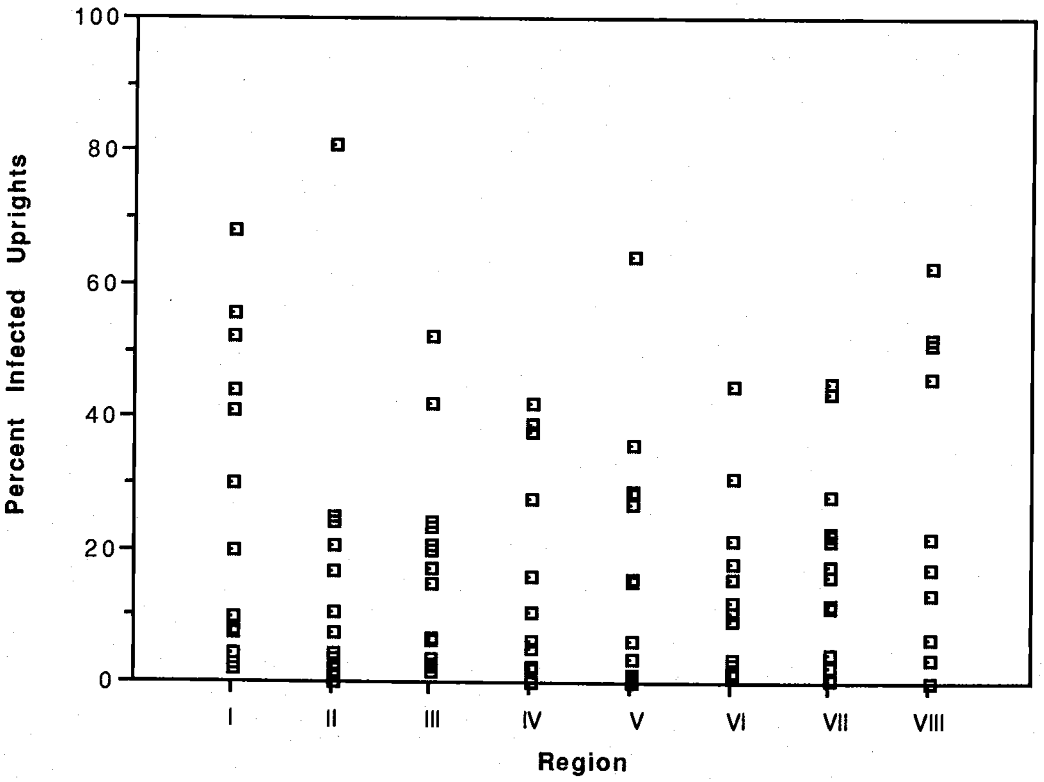


Figure A.2. The percent of infected uprights with Lophodermium spp. according to region for the 108 study plots. Although the percent infected uprights do not significantly vary with region, there is a trend of less average disease per region in a southeast direction (Regions I, III, VII and VIII have higher averages than regions II, IV, V, and VI).

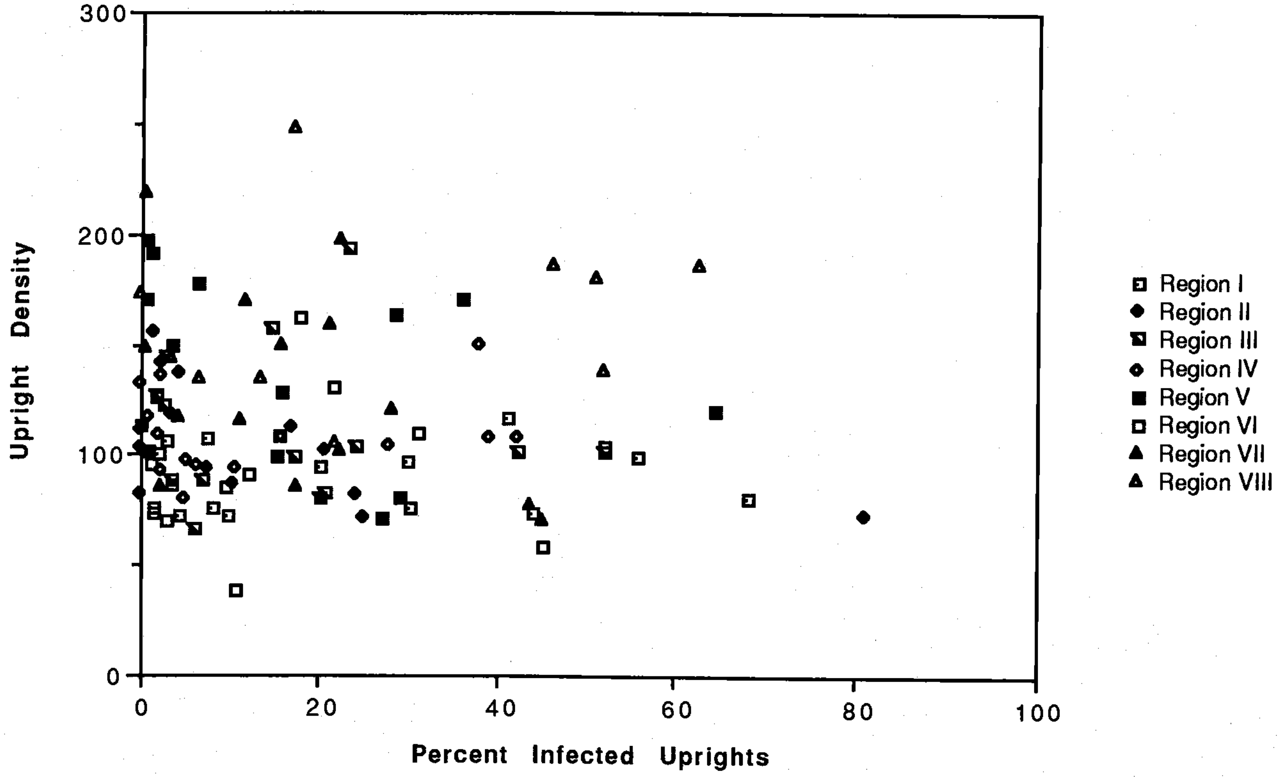


Figure A.3. The percent of infected uprights with <u>Lophodermium</u> spp. according to upright density for the 108 study plots. The percent of infected uprights is independent of upright density.

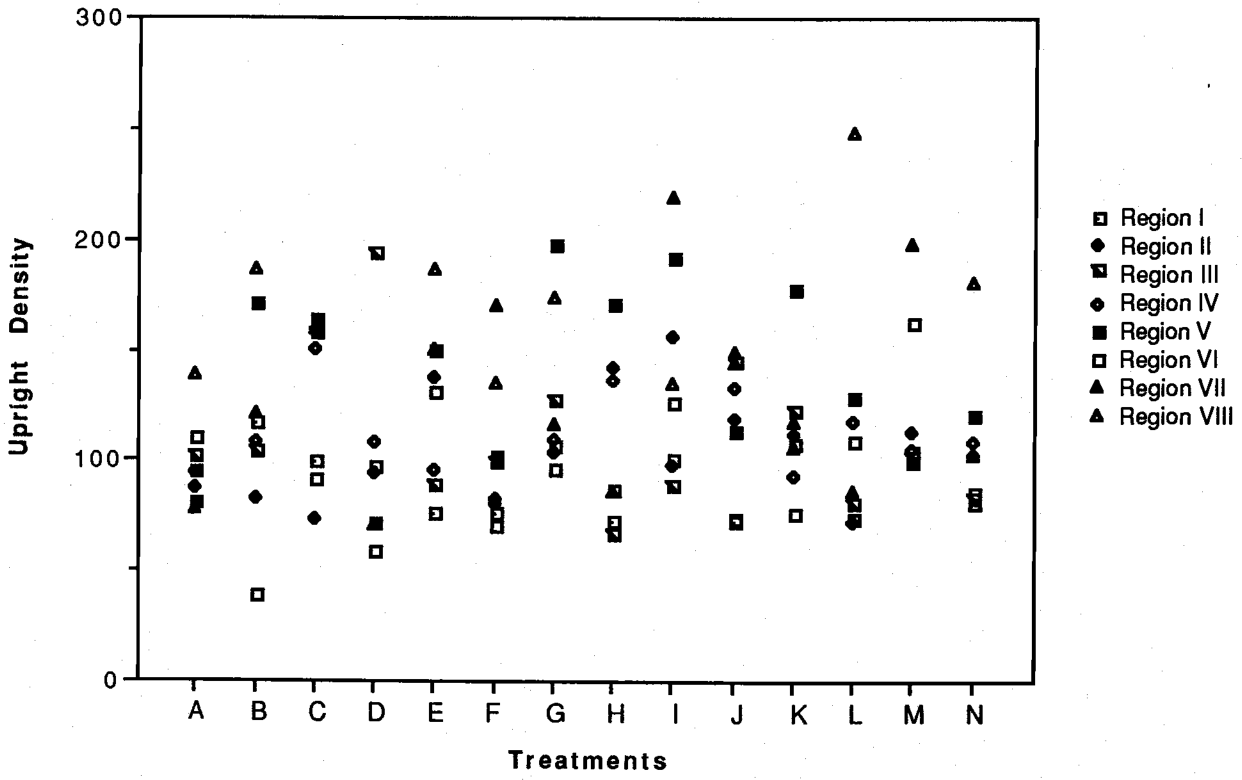


Figure A.4. The upright density according to treatment.

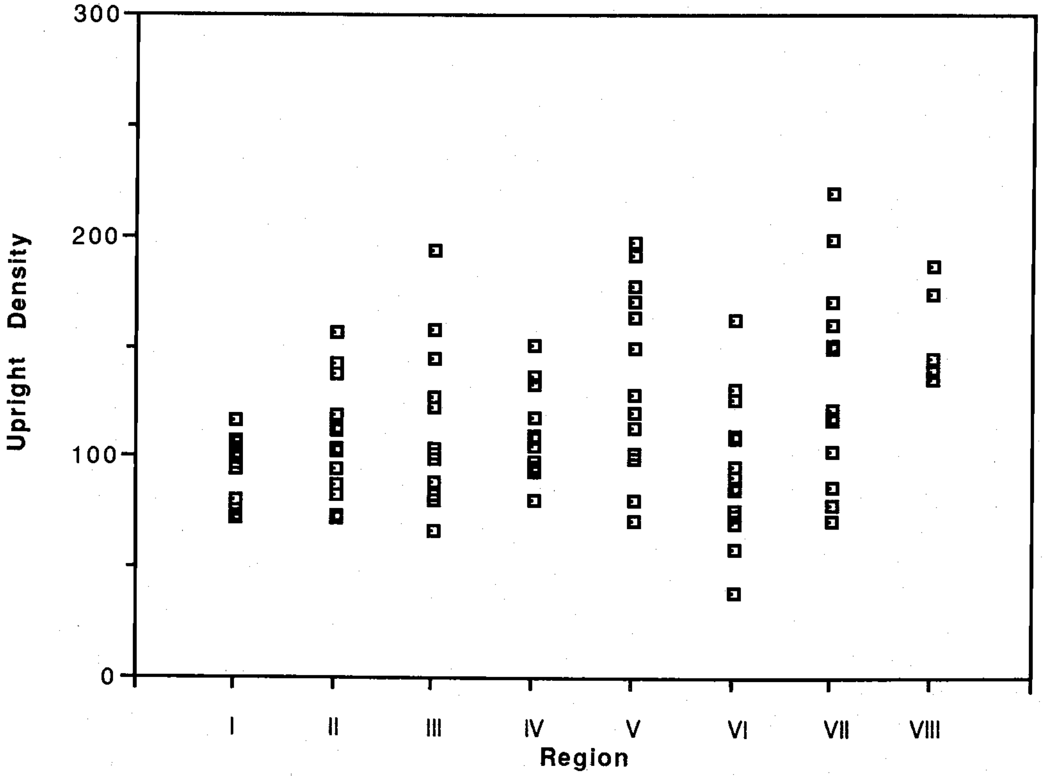


Figure A.5. The upright density according to region

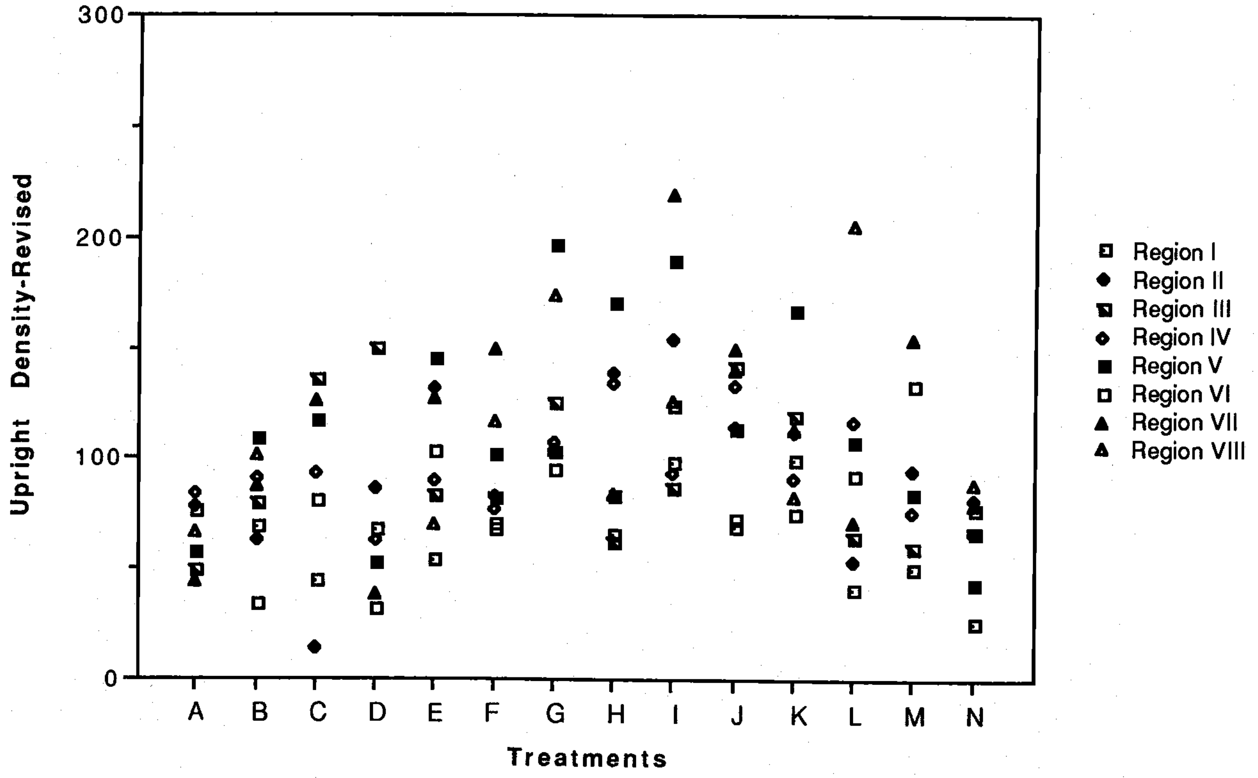


Figure A.6. The upright density-revised according to treatment. Upright density-revised is the upright density minus the number of infected uprights. The convex scatter of the 108 study plots shows that aon the average 'healthier' plots (treatments F through K) have a higher upright density-revised.

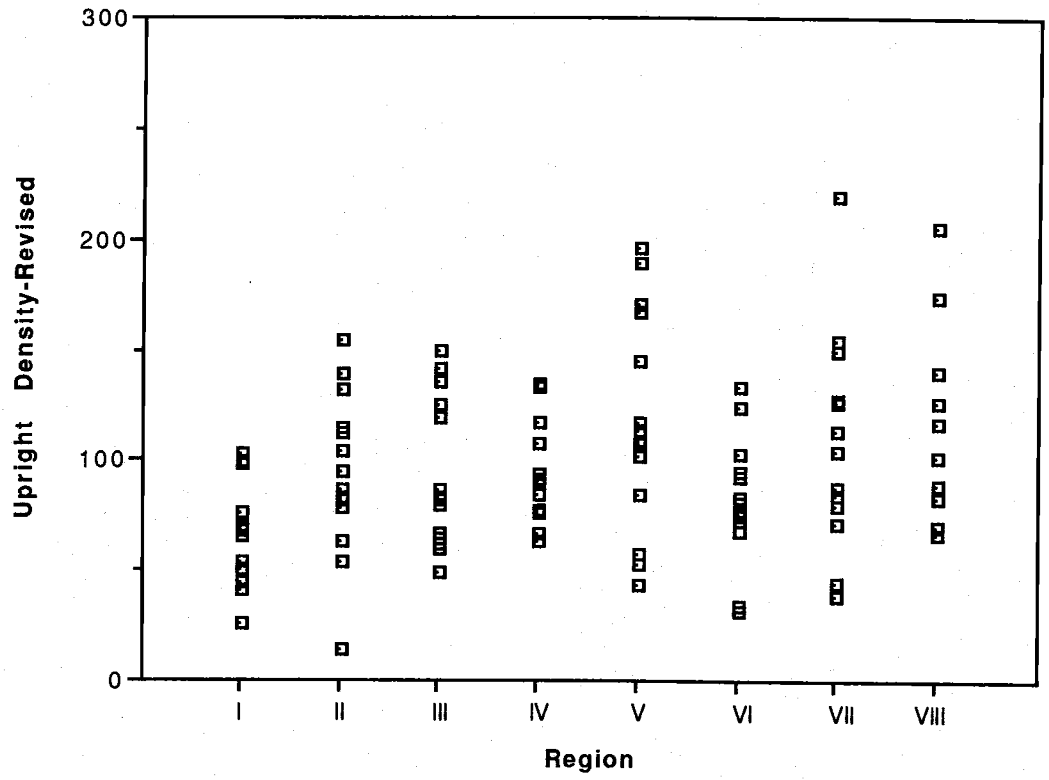


Figure A.7. The upright density-revised according to the eight regions (108 study plots).

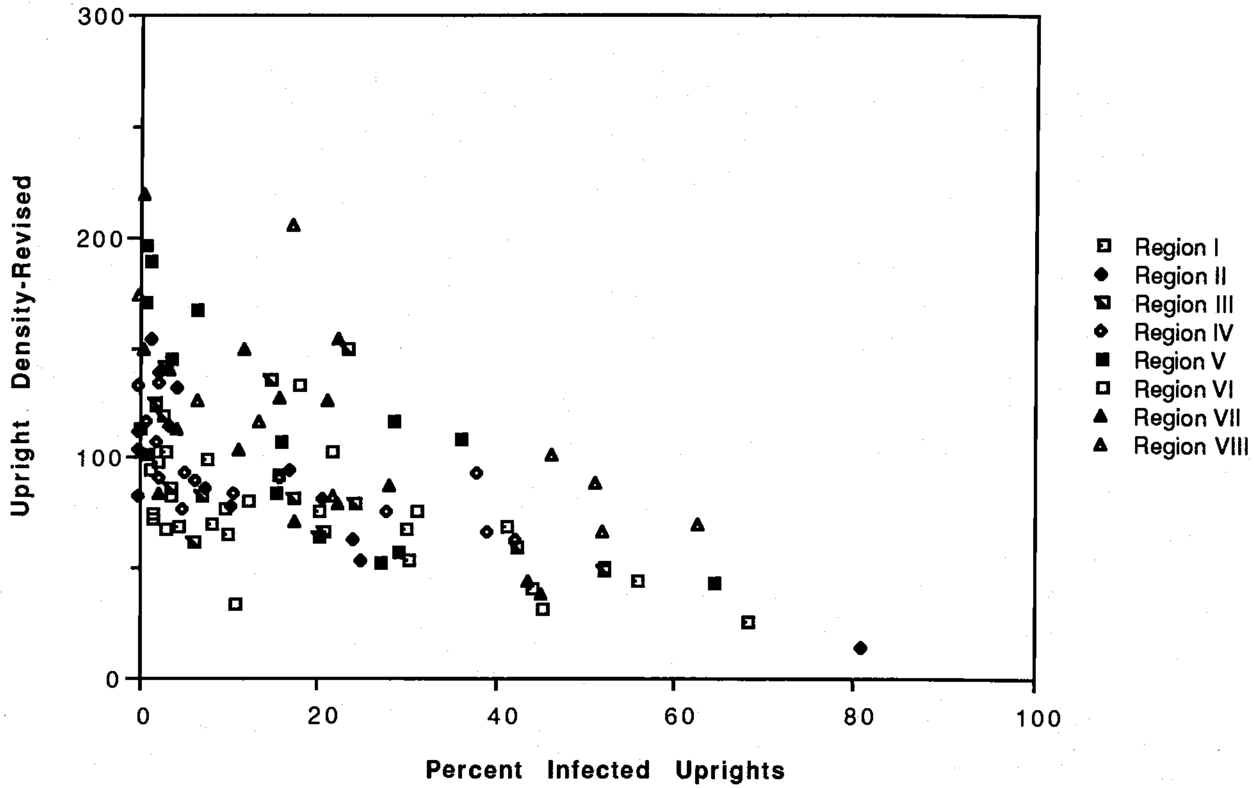


Figure A.8. The percent of infected uprights with Lophodermium spp. according to upright density-revised for the 108 study plots. The expected negative trend shows that plots with a high number of uprights infected with twig blight generally have a lower upright density-revised.

Table A.3

PERCENT INFECTED UPRIGHTS

	REGION								
TREATMENT	I	II	III	IV	V	VI	VII	VIII	$\bar{x}$
A	20.0	10.4	52.0	10.7	28.8	30.9	43.6	51.8	31.0
B	41.0	24.0	24.1	15.8	35.9	10.6	28.1	46.0	28.2
C	55.5	80.8	14.6	37.8	28.3	12.1	21.3		35.8
D	29.9	7.5	23.2	42.2	26.8	44.9	45.1		32.2
E	30.0	4.3	6.8	6.3	3.4	21.4	15.9	62.6	18.8
F	7.9	0.0	17.2	5.0	1.0	2.9	11.8	13.4	7.4
G	2.8	0.0	1.6	1.9	0.5	1.1	11.2	0.0	2.4
H	9.7	2.2	6.1	2.2	0.6	3.5	2.4		6.6
I	2.0	1.3	3.4	5.1	1.1	1.6	0.5	6.7	2.7
J	4.2	3.4	2.8	0.0	0.0	1.4	0.7	3.5	2.0
K	7.4	0.0	2.5	2.2	6.2	1.4	4.3	21.7	5.7
L	43.8	25.0	20.0	0.9	15.7	15.6	17.5	17.3	19.5
M	52.0	16.8	42.2	27.7	15.2	17.9	22.3		27.7
N	67.9	20.5	20.5	38.9	64.2	9.5	22.4	50.9	36.8
$\bar{x}$	26.7	14.0	16.9	14.1	16.3	12.5	17.7	27.4	

(Adapted from Bristow, 1986)

Table A.4

UPRIGHT DENSITY (PER 1/3 SQ. FEET)

REGION

TREATMENT	I	II	III	IV	V	VI	VII	VIII	$\bar{x}$
A	95	87	102	94	80	110	78	139	98
B	117	83	104	108	170	38	121	187	116
C	99	73	158	151	163	91	160		128
D	97	94	194	109	71	58	71		99
E	76	138	89	96	150	131	151	187	127
F	76	83	99	81	102	70	170	135	102
G	106	104	127	110	197	96	117	174	129
H	72	142	66	137	171	86	86		109
I	100	156	89	98	191	126	220	135	139
J	72	119	145	133	113	73	150	145	119
K	107	112	122	93	178	76	118	106	114
L	73	72	80	118	128	109	86	249	114
M	104	113	102	105	99	162	198		126
N	81	103	83	108	120	85	103	181	108
$\bar{x}$	91	106	111	110	138	94	131	164	

(Adapted from Bristow, 1986)

Table A.5

UPRIGHT DENSITY- REVISED (PER 1/3 SQ. FEET)

TREATMENT	REGION								
	I	II	III	IV	V	VI	VII	VIII	$\bar{x}$
A	76	78	49	84	57	76	44	67	66
B	69	63	79	91	109	34	87	101	71
C	44	14	135	94	117	80	126		87
D	68	87	149	63	52	32	39		70
E	53	132	83	90	145	103	127	70	100
F	70	83	82	77	101	68	150	117	94
G	103	104	125	108	196	95	104	174	126
H	65	139	62	134	170	83	84		105
I	98	154	86	93	186	124	219	126	136
J	69	115	141	133	113	72	149	140	116
K	99	112	119	91	167	75	113	83	107
L	41	54	64	117	108	92	71	206	94
M	50	94	59	76	84	133	154		93
N	26	82	66	66	43	77	80	89	66
$\bar{x}$	66	94	93	94	118	82	110	117	