GROWTH OF PLANT COVER ON AN ELECTRIC POWER UNDERGROUND TRANSMISSION PROTOTYPE: THE EFFECTS OF THERMAL STRESS

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SUMMARY

Heat is the major stress factor on plant growth covering an underground electric transmission system. These effects were examined during two growing seasons on an Ontario Hydro air-insulated underground transmission prototype (DAMUT) with test thermal load of 210 watts per metre of duct length and soil root-zone maximum temperatures of approximately 35°C; winter temperature did not fall below 0°C. Fresh and dry weight and plant height data indicate that turf growth was stimulated over the heated ducts in early spring and late fall while shrub growth remained unchanged compared to unheated controls. Yields of agronomic crop species were reduced by approximately 40 to 50% compared to controls, indicating that normal agricultural productivity could not be achieved on such transmission rights-of-way. Germination of spring-sowed crops was reduced, probably due to soil drying and not a direct thermal effect. No major nutrient or pH changes were observed in the heated soil over a two-year period. It thus appears that suitable plant cover consisting of turf, shrubs and selected agronomic crops could be established over electric power transmission systems having thermal losses up to 210 watts per metre of duct buried at 1.1 metre depth.

EXPERIMENTAL WORK

Preliminary studies of the effects of soil heating on plant growth by an underground electric power transmission prototype are reported in this paper. An air-insulated underground transmission model, DAMUT, was designed by Ontario Hydro's Research Division to carry very high electrical loads, 230 000 volts at 3 000 amperes. The thermal behaviour of such a design was examined for 2 years under field conditions at Kleinburg, north of Toronto. Air-insulated underground systems, though presently economically less attractive than overhead lines, would provide alternative methods of moving large blocks of power, reduce right-of-way size and improve visual impact.

Heat losses from the DAMUT model or other buried transmission systems of high ampacity cause soil warming which may affect plant and soil microbial life. The quality, growth and yield of agronomic and horticultural plants common to southern Ontario Hydro rights-of-way were measured during the 1974 and 1975 growing seasons for DAMUT-heated and control soils at Kleinburg. The data show that cover-crops may be established on warmed soils with summer temperature maxima of approximately 35°C which is 10 to 15°C above ambient.

Figure 1 outlines a vertical cross-section of a 2-duct DAMUT installation designed to simulate a multi-duct system of infinite length by insulating one sidewall and each endwall. Each duct of 9 metre length was buried to a depth of 1.1 metres in a 9 x 10 metre plot. An additional 9 x 11 metre area of native clay soil provided an unheated control plot for the vegetation studies. The ducts rested on a bed of sand covered with limestone screenings to provide optimal thermal conductivity and topped with 15 cm of native clay topsoil similar to the control area. This was considered the minimum depth of soil necessary to support herbaceous plant growth. Flooding of the ducts during heavy precipitation was prevented by sump pump drainage which may have had a cooling effect on duct operation. The ducts were loaded with resistive heaters at 210 watts per metre of duct length to simulate a 230 kV, 3 000 amp transmission line. Duct and control area temperatures were monitored daily by over 100 thermocouples placed at various soil depths and above ground. Figure 1 also shows the locations of thermocouples used to obtain data for plotting temperature profiles for the top surface of the inner duct (1.1 metre depth), the root-zone soil at 15 cm depth and ambient air 0.5 m above grade.

Temperature profiles for the past year, outlined in Figure 2, show the influence of high fluctuations in ambient air temperatures in modifying the soil root-zone profile, given rather smooth changes in temperature at the inner duct surface. The two most important features of the root-zone temperature profile are the maxima of approximately 35°C, achieved during the months of July and August, and the minima of about 7°C, reached during the the winter. At the soil surface where temperatures were cooler snow cover rarely remained for more than 2 to 3 days throughout the entire winter period.

During the initial 9 months, January 1974 to September 1974, operation of the ducts' similar temperature profiles were obtained; summer maxima reached 35°C in July and August, and winter temperatures did not fall below 0°C. The temperatures during both growing seasons in the root-zone above the outer duct were approximately 1 to 2°C cooler than for the inner duct.

Figure 3 compares the temperature profiles for soil at 15 cm depth for both inner duct and unheated control areas. At this depth, the duct raised the soil temperature throughout the year from 10 to 15°C above ambient. It is the effects of this temperature rise which are examined in the following vegetation studies.

The common agronomic crops, turf grasses, shrubs and vines tested for capability of growing in the warmed duct soils are listed in Table 1. The agronomic species and creeping red fescue were seeded in rows on June 7, 1974 except for wheat and crested wheatgrass which were sown September 26, 1974 and May 21, 1975, respectively. Shrubs, vines and bluegrass sod mixtures were transplanted on November 29, 1973. Agronomic crops were fertilized at time of seeding with 5-20-20 at approximately 3.9 kg/100 m^2 (8 lbs/1 000 ft^2), and turf grasses with 7-14-7 at 2.9 kg/100 m^2 (6 lbs/1 000 ft^2). Turf grasses were refertilized in the spring of 1974 and 1975 with 10-6-4, containing 60% milorganite, at 9.7 kg/100 m^2 (20 lbs/1 000 ft^2).

Throughout each growing season the overall quality of plant growth was assessed by visually rating symptoms attributable to thermal or moisture stress. This included foliar chlorosis, discoloration, necrosis and wilting. The quality ratings* for turf grasses grown during May to September 1975 are shown in Figure 4. The condition of all grasses was noticeably lower in the duct compared to control areas, with a sharp decline of all turf in early July. This corresponded to lack of any rainfall for the previous 3-week period, based on meteorological records for Toronto International Airport located 20 km SSE of Kleinburg. Although turf quality over the ducts was lower throughout the normal growing season, yield for 1974, shown later (Table 5), was higher in duct than control areas due to an extension of the growing period into early spring and late fall.

The quality of agronomic crops is summarized in Figure 5. These crops did not show as severe a decline in quality in early July as did the turf grasses. In both duct and control areas alfalfa and red clover appeared most sensitive to thermal and moisture stresses which in clover was accompanied by premature leaf senescence and blackened necrosis, especially in the duct area. Generally the appearance of the agronomic species remained similar in duct and control areas except for reed canary grass which displayed considerably lower quality throughout most of the growing season. Newly seeded crested wheatgrass displayed poor germination and lower vigor throughout the growing season. Similar effects were observed for the remaining agronomic species during their first year of growth (1974 data not shown).

Rather interestingly, the drought-resistant shrubs and vines listed in Table 1 did not show any noticeable difference in appearance between duct and control areas. Though growth data was not obtained, due to the very small number of specimens grown in the test plot, there did not visually appear to be any reduction of growth over the heated duct.

Though the appearance of agronomic crops was not very different between duct and control areas, yield data, based on shoot and root lengths, fresh weights and dry weights showed declines in both 1974--Table 2, and 1975 - Table 3. These yield reductions ranged generally from a few per cent up to nearly 100 per cent in duct versus control areas. Practically, shoot fresh and dry weights are most important and these ranged from 18 to 93% reductions in 1974, and from 1 to 57% in 1975, except for crown vetch and a second crop (August 5 - September 22, 1975) of red clover. Most of the growth of the latter occurred during September when temperature may have had a beneficial effect. At this time root-zone soil temperatures averaged about 25°C. Root/shoot length ratios increased over the duct area, due

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* - Visual estimates of foliar quality: 10 = excellent;
5 = intermediate;
0 = dead.

presumably to the effects of moisture stress in reducing shoot elongation. Absolute root lengths were less seriously affected by the warmed soil, contrary to what was expected.

The yield data just presented was based on the sampling and measurement of 10 plants at each of 2 sites in the duct and control areas. These figures, therefore, do not include any measurement of reduction in crop density which visual inspection indicates was reduced due to decreased germination rates in the duct area.

Yield of two grains, oats and barley, are shown in Table 4. Reductions occurred in lengths and fresh weights of roots and shoots and, most important, in seed number and seed fresh weight. The seed yield for both oats and barley declined by 26 to 55% in duct over control areas.

In contrast to agronomic crops, soil heating appeared to have a beneficial effect on the yield of turf grasses by extending the normal growing season into early spring and late fall. Based on height of clippings obtained May 4, July 4 and September 18, 1974 duct area turf height in spring and fall was more than double that of controls, Table 5. This accounted for approximately a 50% increase in the total turf cut from the duct area during the growing season. Based on visual appearance, this effect was not observed for other plants due in part to their susceptibility to frost injury outside the normal growing season. The recovery of turf in the fall indicates that significant root injury has not resulted from exposure to mid-summer temperatures up to 35°C.

Data shown in Table 6 indicate that the limestone screenings, 15-45 cm depth, of the duct area were uniformly low in moisture content both in the spring and fall. Only the clay topsoil, 0-15 cm depth, appears to contain sufficient moisture to support plant growth (moisture release curves not determined). No irrigation was used since it was an objective to determine the duct thermal behaviour under normal weather conditions.

It was expected that the limestone screenings of the duct area may have raised topsoil pH and calcium concentrations, thereby retarding plant growth and interfering with estimates of thermal effects on plant development. It was observed that there was a sharp demarcation in plant height between duct and control areas which did not correspond to the temperature gradient, but rather to the boundary line between areas with and without limestone screenings. After nearly 2 years of duct operation (January 1974 to October 1975) no significant changes were observed in duct soil pH and in levels of available soil calcium compared to control values. The concentrations of phosphorus, potassium and magnesium were also unchanged, Table 7. It is concluded that the reduction of plant growth over the ducts was due to a combination of thermal and moisture stresses. While there is insufficient evidence to establish the relative importance of each of these stresses, it is suggested that yield reduction was caused chiefly by thermally induced moisture stress. It is expected that temperatures in the range of 40 to 50°C are required before plant metabolism is seriously interrupted.

TABLE 1

LIST OF PLANTS GROWN IN DAMUT VEGETATION PLOT

COMMON NAME	BIOLOGICAL NAME	VARIETY
AGROMONIC CROPS		
ALFALFA	MEDICAGO SATIVA L	SARANAC
BIRDSFOOT TREFOIL	LOTUS CORNICULATUS L	EMPIRE
CROWN VETCH	CORONILLA VARIA L	
RED CLOVER	TRIFOLIUM PRATENSE L	ONTARIO DOUBLE-CUT
TALL FESCUE	FESTUCA ARUNDINACEA	
REED CANARY GRASS	PHALARIS ARUNDINACEA L	FRONTIER
CRESTED WHEATGRASS	AGROPYRON CRISTATUM	
WHEAT	TRITICUM VULGARE L	YORKSTAR - WINTER VARIETY
OATS	AVENA SATIVA L	RODNEY
BARLEY	HORDEUM VULGARE L	FERGUS
TURF GRASSES		
KENTUCKY BLUEGRASS (SOD)	POA PRATENSIS L	KENTUCKY (>90%) + CREEPING RED FESCUE MIXTURES
KENTUCKY BLUEGRASS (SOD)	POA PRATENSIS	KENTUCKY (>90%) + MERION MIXTURES
CREEPING RED FESCUE	FESTUCA RUBRA L	
SHRUBS AND VINES		
WINTERCREEPER	EUONYMOUS FORTUNEI	COLORATA
VIRGINIA CREEPER	PARTHENOCISSUS QUINQUEFOLIA	ENGELMANII
CHINESE MATRIMONY VINE	LYCIUM CHINENSE	
BUSH CINQUEFOIL	POTENTILLA FRUCTICOSA	FARRERI (GOLD DROP)

TABLE 2

1974 YIELD OF AGRONOMIC CROPS

CROP		LENGTH (cm) SHOOT	LENGTH (cm) ROOT	FRESH WEIGHT (g) SHOOT	FRESH WEIGHT (g) ROOT	LENGTH ROOT/SHOOT
ALFALFA	CONTROL	12.5	10.0	0.08	0.11	0.81
	DUCT	7.5	11.0	0.07	0.09	1.48
	% CHANGE	-40	+10	-13	-18	+82
BIRDSFOOT TREFOIL	CONTROL	14.0	11.0	0.67	0.19	0.79
	DUCT	10.5	9.5	0.43	0.10	0.91
	% CHANGE	-25	-14	-36	-90	+15
CROWN VETCH	CONTROL	14.0	19.0	0.44	0.32	1.36
	DUCT	6.0	10.5	0.12	0.09	1.75
	% CHANGE	-57	-45	-73	-72	+29
RED CLOVER	CONTROL	14.5	7.0	0.76	0.25	0.48
	DUCT	6.5	7.0	0.25	0.08	1.07
	% CHANGE	-55	0	-67	-68	+123
TALL FESCUE	CONTROL	21.5	5.0	0.39	0.15	0.24
	DUCT	18.5	3.5	0.10	0.01	0.21
	% CHANGE	-14	-30	-75	-93	-13
REED CANARY GRASS	CONTROL	27.0	4.5	0.29	0.20	0.17
	DUCT	17.5	3.5	0.22	0.15	0.21
	% CHANGE	-35	-22	-24	-25	+23

TABLE 3

1975 YIELD OF AGRONOMIC CROPS

CROP		LENGTH (cm)		FRESH WT(g)		DRY WT(g)		LENGTH
		SHOOT	ROOT	SHOOT	ROOT	SHOOT	ROOT	ROOT/SHOOT
ALFALFA	CONTROL	65.0	15.5	10.0	6.1	2.4	1.5	0.24
	DUCT	55.0	14.5	9.9	5.5	2.5	1.4	0.27
	% CHANGE	-15	-6	-1	-10	+4	-6	+13
BIRDSFOOT TREFOIL	CONTROL	31.8	19.2	7.75	3.09	2.00	0.84	0.61
	DUCT	26.2	18.4	3.35	1.62	0.79	0.37	0.71
	% CHANGE	-18	-4	-57	-48	-60	-56	+16
CROWN VETCH	CONTROL	22.9	20.5	2.03	1.83	0.42	0.54	0.90
	DUCT	17.7	21.8	2.85	1.85	0.59	0.50	1.25
	% CHANGE	-23	+6	+40	+1	+40	-7	+39
RED CLOVER (2ND CROP)	CONTROL	23.1	16.2	5.20	2.24	0.88	0.47	0.71
	DUCT	23.7	17.2	6.03	2.73	1.04	0.64	0.73
	% CHANGE	+3	+6	+16	+22	+18	+36	+3
TALL FESCUE	CONTROL	54.5	10.0	2.73	0.51	0.61	0.11	0.19
	DUCT	50.5	8.0	2.00	0.22	0.44	0.04	0.16
	% CHANGE	-7	-20	-27	-57	-28	-64	-16
REED CANARY GRASS	CONTROL	46.1	20.3	7.14	8.49	2.25	1.73	0.44
	DUCT	36.2	16.7	3.68	4.40	1.34	0.86	0.47
	% CHANGE	-21	-17	-48	-48	-40	-50	+7

TABLE 4

1974 YIELD OF AGRONOMIC CROPS - GRAINS

CROP		LENGTH (cm) SHOOT	LENGTH (cm) ROOT	FRESH WT (g) SHOOT	FRESH WT (g) ROOT	AVG NO SEEDS/PLANT	SEED FRESH WT PER PLANT (g)
BARLEY	CONTROL	56.4	7.2	1.69	0.26	19.0	0.94
	DUCT	48.0	5.7	1.20	0.26	14.0	0.59
	% CHANGE	-15	-21	-29	0	-26	-37
OATS	CONTROL	74.9	14.9	3.06	0.51	24.0	1.75
	DUCT	43.1	10.5	1.02	0.18	12.0	0.79
	% CHANGE	-42	-30	-67	-65	-50	-55

TABLE 5

YIELD OF TURF GRASSES

GRASS MIXTURE		AVERAGE HEIGHT (cm) HARVEST NO.1	HARVEST NO.2	HARVEST NO.3	TOTAL
KENTUCKY BLUEGRASS AND MERION BLUEGRASS	CONTROL	1.6	8.5	1.8	11.0
	DUCT	6.0	9.9	3.4	19.3
KENTUCKY BLUEGRASS AND CREEPING RED FESCUE	CONTROL	1.7	10.0	1.0	12.7
	DUCT	4.3	9.2	3.8	17.3

TABLE 6

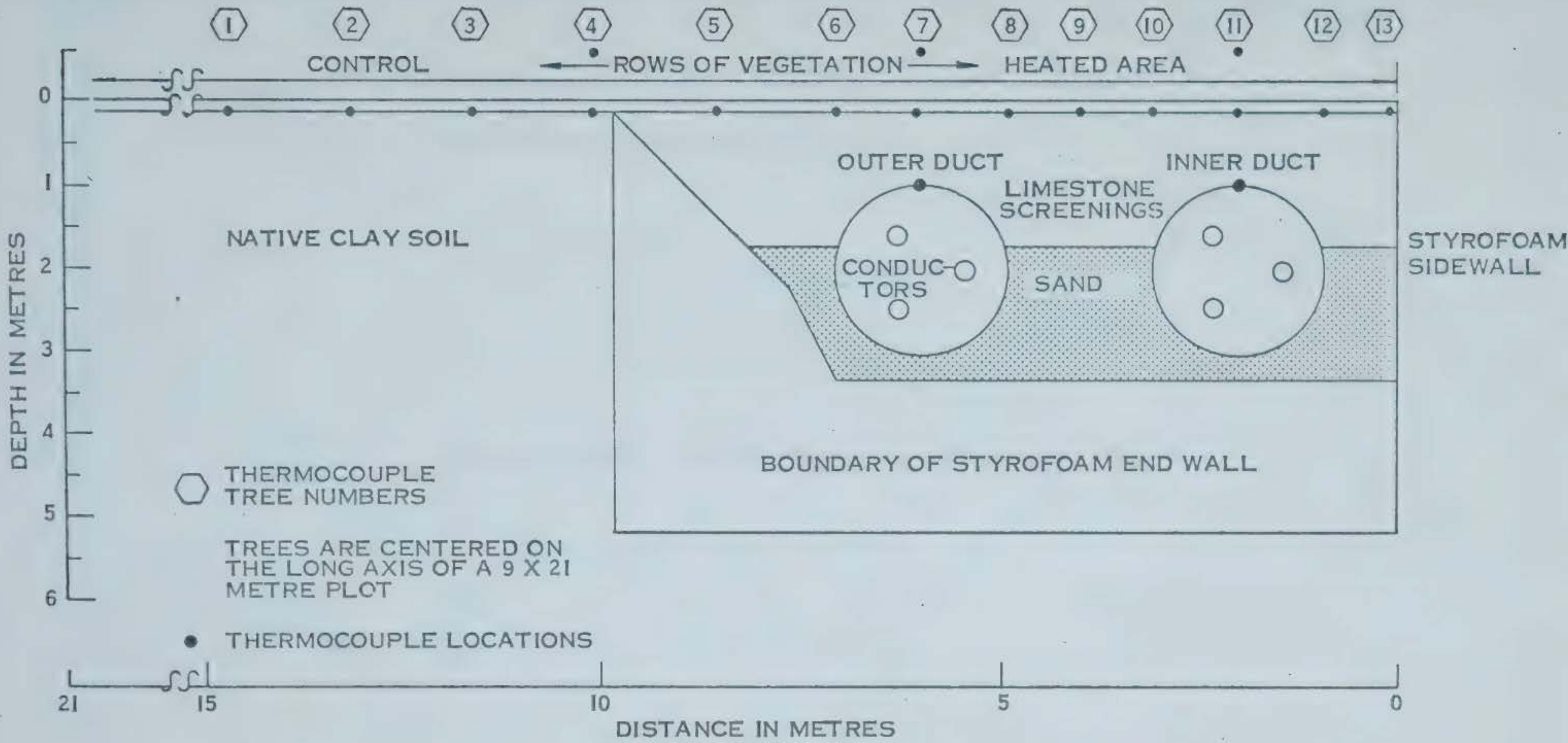
MOISTURE CONTENT OF HEATED AND CONTROL SOILS

DATE	DEPTH (cm)	PER CENT MOISTURE ON DRY WEIGHT BASIS				
			THERMOCOUPLE TREE NO			
		CONTROL	5	7	9	11
MAY 13, 1975	0 — 15	21.3	14.4	12.4	13.6	15.6
	15 — 45	21.6	5.3	4.7	4.6	4.6
AUG 1, 1975	0 — 15	—	11.4	14.1	12.6	11.1
	15 — 45	11.5	2.2	1.6	2.1	1.7.

TABLE 7

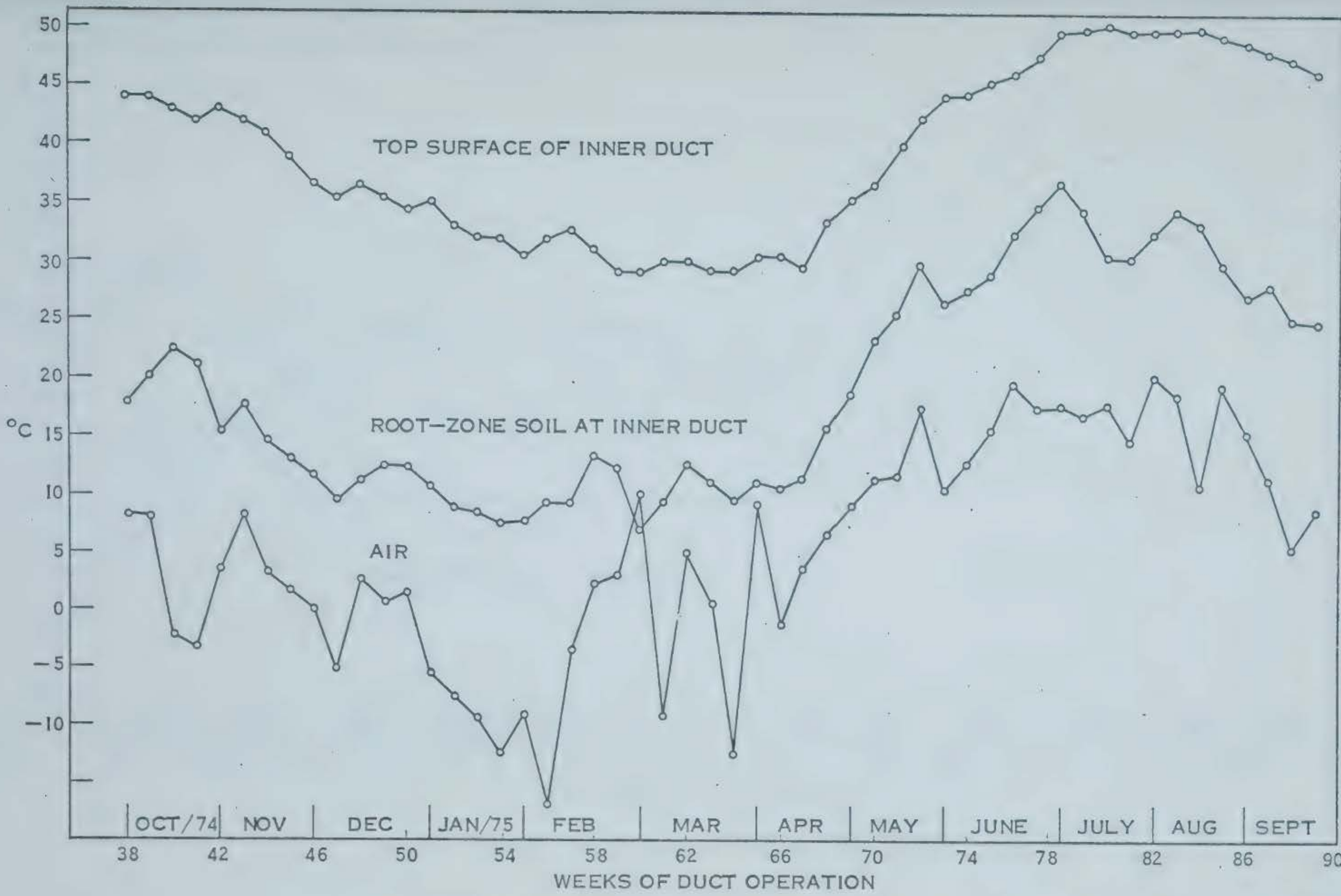
SOIL NUTRIENT LEVELS OF
HEATED DUCT AND CONTROL AREAS

DATE	AREA	pH	NUTRIENT CONCENTRATION (ppm)			
			P	K	Mg	Ca
OCT.3/74	CONTROL	7.2	8	160	236	5100
OCT.3/74	DUCT	7.3	9	150	252	6700
OCT. 1/75	CONTROL	7.7	9	116	212	5250
OCT. 1/75	DUCT	7.8	9	122	248	6750



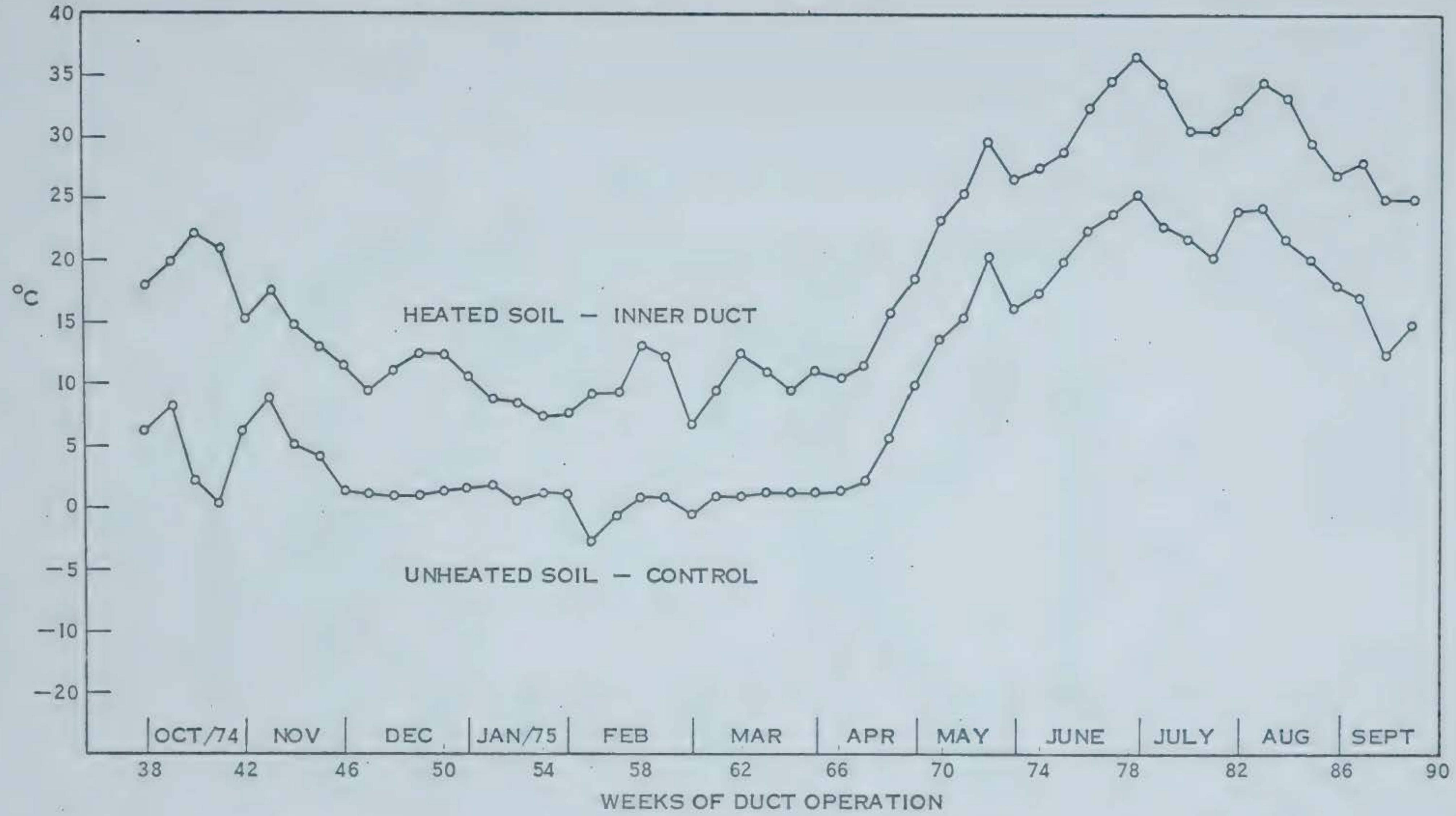
DAMUT PROTOTYPE: 2—DUCT SYSTEM WITH VEGETATION PLOT

Figure 1



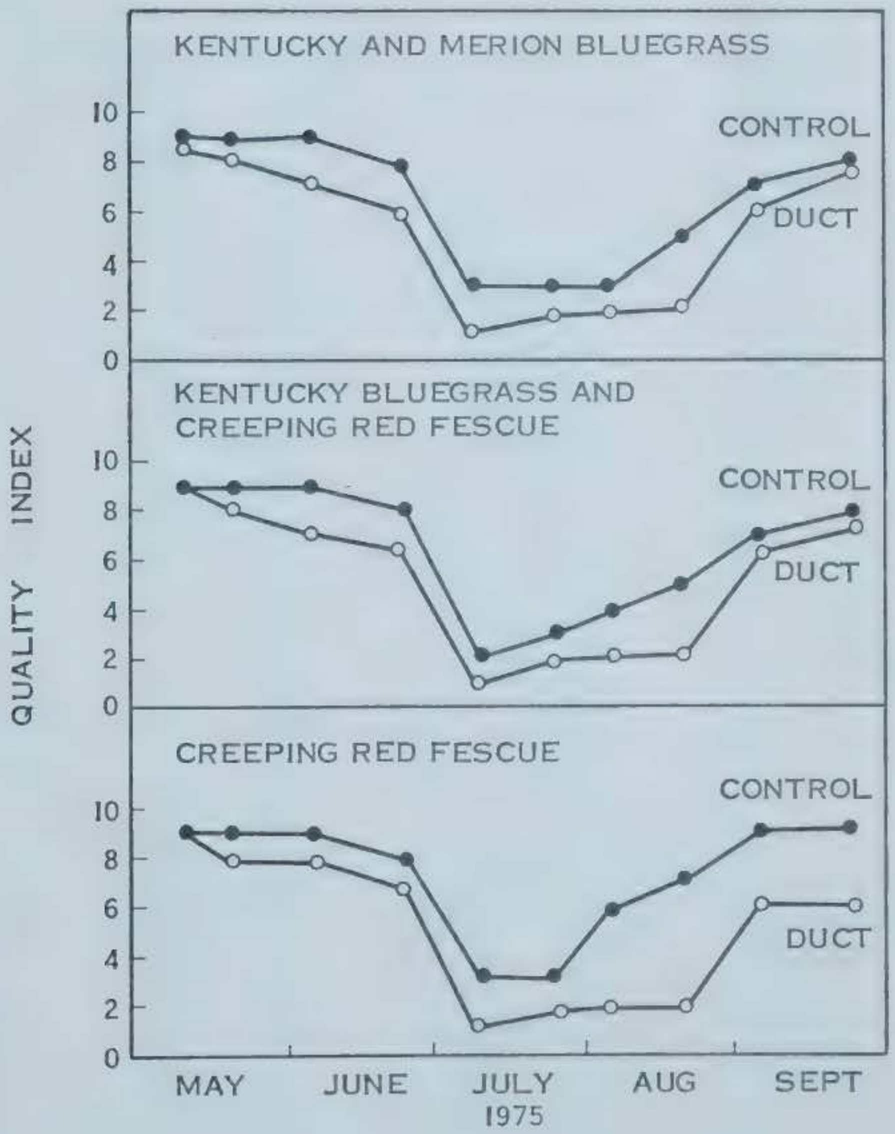
TEMPERATURE PROFILES FOR AIR, ROOT−ZONE SOIL AND TOP SURFACE OF INNER DUCT

FIGURE 2

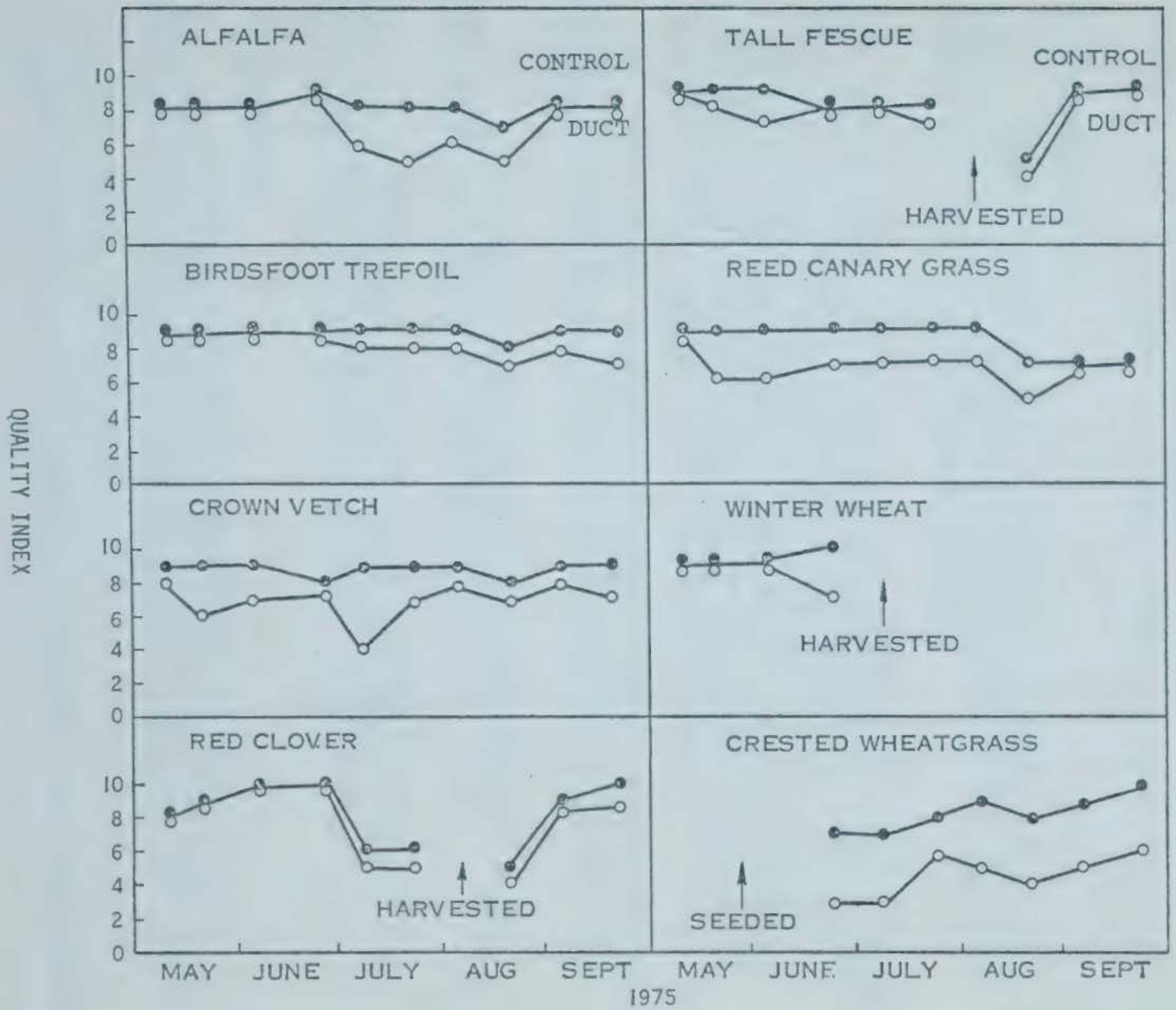


TEMPERATURE PROFILES FOR HEATED AND CONTROL SOILS

FIGURE 3



QUALITY OF TURF GRASSES



QUALITY OF AGRONOMIC CROPS

FIGURE 5

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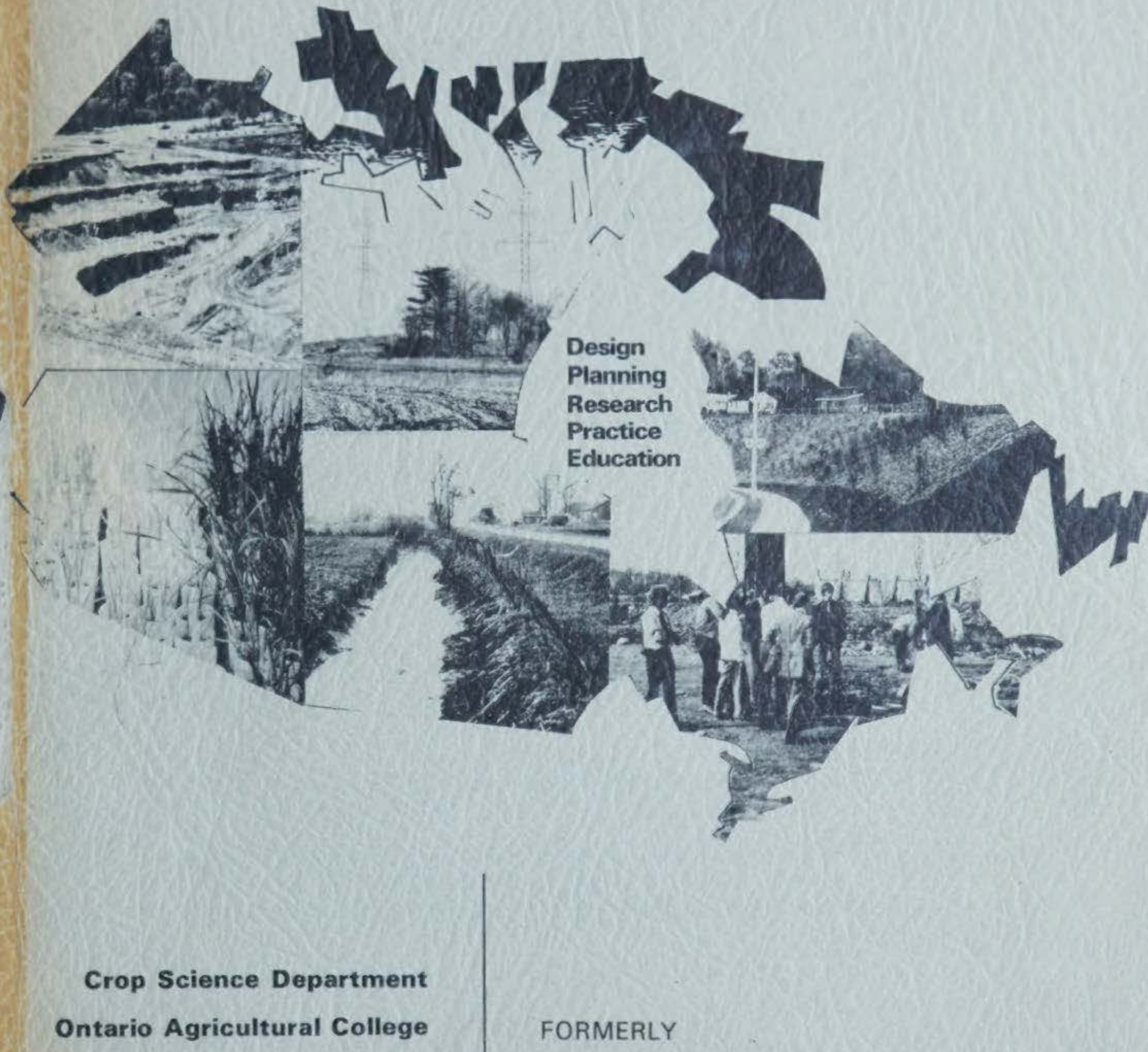

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