MUNICIPAL YARD WASTE COMPOSTING: PROCESS PARAMETERS, WINDROW GASES, AND LEACHATE QUALITY

by

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ABSTRACT

A Municipal Yard Waste Composting Research and Demonstration Project was conducted to examine the process, quality of leachate, and viability of this technology for large-scale, low-technology application. Project research objectives were: 1) to characterize C/N, temperature, and moisture relationships of yard waste during composting and the elemental composition of the finished compost; 2) to investigate the oxygen (O_2), carbon dioxide (CO_2) and methane (CH_4) relationships in the composting yard waste; and 3) to quantify water quality parameters of the leachate from yard waste composting mixes. Mixes of 3 parts leaves/1 part grass, 2 parts woodchips/1 part grass, and leaves alone were composted in windrows. Process control was by a front-end loader/back-hoe according to a 60°C maximum temperature set-point, initially, and by temperature plateaus or moisture conditions following most active composting. Composting was more efficient with the presence of grass clippings. Some CH_4 was observed within windrows microsites, even under overall aerobic conditions. Occasional methane production not in excess of approximately $4x10^{-2}$ mmol/l reflects inconsequential anaerobiosis. Leachate from individual windrows was minimal but contained high concentrations of total Kjehldahl nitrogen (TKN), total phosphorus, and biological oxygen demand. Soil degradation processes should ameliorate these. The leaf/grass mix generated the greatest quantities of carbon dioxide, strongly correlated oxygen and carbon dioxide concentrations, steepest temperature profile, and the highest concentrations of plant nutrients in material composted for between 8 and 24 weeks. Low-technology composting of yard wastes can be an effective, low-cost alternative to landfilling, with substantial societal and environmental benefits.

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1. INTRODUCTION

The composting of waste materials has been undertaken for a variety of purposes over a great number of years, and the benefits have been well documented. This practice reduces the quantities of waste being landfilled and produces materials such as potting soil mixes and daily landfill cover (May and Simpson, 1990; OTA, 1989; Shiralipour *et al.*, 1993). Compost improves soil chemical, physical and biological properties, and suppresses plant pathogens (Dick and McCoy, 1993; Shiralipour, *et al.*, 1992; Chen *et al.*, 1992; McConnell, *et al.*, 1993), and is, thus, a beneficial amendment for agricultural soil and disturbed land (Bugbee, 1989; Brady, 1990; NRAES, 1992; Shiralipour *et al.*, 1993). Composting may also be used as a method for the bioremediation of contaminated soils and the degradation of hazardous substances (Lemmon & Pylypiw, 1992; Williams and Keehan, 1993).

Many existing landfills are nearing capacity and newly proposed landfills often face overwhelming economic and social obstacles. It is projected that the average landfill cost in Virginia will reach $500,000 per acre within the decade (Simpson and May, 1990). Many states, including Virginia, have begun to require reduction in waste stream flow to landfills (Glenn, 1992a). In 1989, the U.S. Environmental Protection Agency (USEPA) established a 25 percent reduction target for the national solid waste stream by 1995, through source reduction and recycling (USEPA, 1989). The composting of yard trimmings can serve as an important strategy in achieving this goal, given that the national waste stream flow of these materials is estimated to be 33.5 million tons in 1996 (Kashmanian, 1993). An estimated 34 to 35 million tons of yard wastes were generated in 1992 (Kashmanian, 1993), representing approximately 12 percent of the total municipal waste stream of 291.7 million tons in that year (Steuteville and Goldstein, 1993). The diversion and composting of the nearly one million tons of yard wastes collected annually in Virginia is projected to result in savings to the state of $30 million per year (Simpson & May, 1990).

Efficient composting should produce a useable end-product without compromising public health and the environment. Most composting research has been conducted in the laboratory, where ideal conditions are created to study the process. The application of laboratory-based information to field operations has limitations, because of the great variability in the nature and condition of raw materials, climatic conditions to which composting materials may be exposed, and the management systems utilized by facilities. Insufficient understanding and poor process management have resulted in odor problems, detrimental effects on agricultural and horticultural crops incurred from application of poorly processed material, and water quality problems due to discharge of pollutants (Chen and Inbar, 1993; Kissel *et al.*, 1992; Glenn, 1992b; Libbey, 1991). The dearth of scientifically-based, practical information can lead to inappropriate regulations that hinder the utilization of this technology. Overly stringent regulations provide economic disincentives to private investment. Alternatively, regulations that fail to prevent worker overexposure to harmful materials, the development of odor problems, or the contamination of groundwater and/or surface waters from by-products of the process work to discredit composting as a viable means of waste disposal and resource recovery.

Potential problems in the preparation and use of compost derive as much from the source and condition of raw materials, as from process management. Wastes from livestock agriculture are fairly uniform, yet can pose handling difficulties (Brady, 1990). The composting of municipal wastes requires strict management, because these materials contain primary human pathogens, secondary pathogens and their toxins, volatile and semi-volatile organic chemicals, persistent lipophilic organic chemicals, allergans, and corrosive, caustic and explosive materials (Gillet, 1992).

Fewer potential problems are associated with the composting of such wastes as yard trimmings and those from food processing and service/dining facilities. Generally easily source separated and amenable to contamination control, these materials are considered more benign in terms of their risks to human health and safety and the environment (NRAES, 1992; Taylor and Kashmanian, 1989). Yard wastes, in addition, have not been reported to contain pathogens. Given the indicated benefits of yard waste composting and the limited perceived hazards and difficulties in its production, it is deemed highly desirable to research this technology as a means to further its successful implementation in Virginia.

Parameters that should be assessed are those related to composting efficiency, compost quality, and environmental quality. Composting efficiency involves the utilization of appropriate techniques for rapid and thorough processing of material. The ratio of carbon to nitrogen has been used as a guide in establishing proper raw material mix and in the determination of the point at which the composting process is complete and the finished material is safe for use in crop/plant production. Regular monitoring for moisture control is an important aspect of process efficiency. The regular monitoring, as well, of compost temperatures allows for control through aeration to maintain a desired temperature range, and achieve necessary oxygenation of the compost environment. Oxygen concentration is important from an environmental as well as process efficiency perspective, because the formation of undesirable gases occurs under anaerobic conditions (Miller, 1993). Evaluation of gas relationships within windrows can potentially enhance process efficiency by providing more comprehensive information about optimum aeration status, and further identification of process control practices effective in limiting undesirable gas formation.

Carbon dioxide is one of the major products of the composting process. Its presence is an indicator of microbial activity and tracing its concentration over time can help illustrate the composting process further. In addition, the continued production of CO_2 has been utilized as an indicator of incomplete decomposition (Chen and Inbar, 1993). Carbon dioxide is also considered to be what is called a greenhouse gas, because its buildup in the atmosphere, primarily from the combustion of fossil fuels, is causing the blocking of essential heat radiation back to space (Committee on Earth Sciences, 1991). The predicted subsequent gradual warming of the earth's surface, known as global warming, has serious implications, including the possible melting of polar ice leading to rises in sea level, and desertification of presently productive agricultural areas (Bernard, 1993; Revelle and Revelle, 1988). Because of concern about global warming, and the fact that CO_2 presently constitutes between 50 and 85 percent of the greenhouse gases (Hileman, 1993; Bernard, 1993), it could be asked if the contribution to the total atmospheric CO_2 pool from potential composting operations might be a significant factor. Using figures from Michel *et al.* (1993) and Suler and Finstein (1977), approximately 50 mg of CO_2 will evolve per gram (dry weight) of compost over a 55 day period for a properly controlled yard waste mix of 2 leaves:1grass (v/v). With further extrapolation, it is projected that roughly 800,000 tons of CO_2 would be generated from composting all 35 million tons of yard waste collected each year in this country. This contribution to the atmospheric pool is insignificant, when compared with the greater than 10 billion tons of CO_2 produced annually from the combustion of fossil fuels (O'Neill, 1985; Revelle and Revelle, 1988).

The production of methane in the compost environment results from anaerobic conditions, which are highly undesirable in that they slow the process and make possible the production of other undesirable gases (Kissel, *et al.,* 1992). Methane is also a greenhouse gas. Collectively, methane and the other greenhouse gases- chloroflourocarbons, nitrous oxide and ozone- are considered to have potentially as large an effect on global warming as CO_2, because they are more efficient heat trappers (Bernard, 1993; Khalil, 1993). Anthropogenic sources of methane, which contribute 55 to 70 percent of the approximately 500 million metric tons/year total emissions (Czepiel *et al.*, 1993; Muirhead, 1990), can potentially be controlled, if identified and determined to be excessive. Total increases in atmospheric methane have, after thousands of years of stability, doubled in the past few hundred (Revelle and Revelle, 1988), reaching nearly 1.7 ppm by 1990 (Khalil, 1993). Methane emissions occur from wastewater treatment plants (~5%/yr) (Czepiel *et al.*, 1993); animal waste lagoons and gas releases from livestock (~18%/yr) (Muirhead, 1990); flooded rice fields (~20%/yr) (Muirhead, 1990); and fossil fuel production leakages, landfills and the burning of tropical rain forests (Khalil, 1993; Muirhead, 1990; Brock & Madigan, 1988). A benefit of the composting of organic wastes is that the process is more likely to produce CO_2 than CH_4 ; whereas methane would be produced from the same material, were it landfilled. Little investigation into the extent of methane evolution within composting systems has been conducted, however, as evidenced by the lack of published work on the subject. Most of the compost odor development and control research has focused on ammonia and volatile sulfur compounds (Miller, 1993, Kissel *et al.*, 1992). Both ammonia and hydrogen sulfide, however, can be initial excretion products in the breakdown of organic wastes, even in aerobic environments (O'Neill, 1985). Other sulfur compounds emitted from compost operations are very numerous and the study of any one could serve to illuminate the anaerobic environments in compost. Methane, however, is produced in the most reduced environments (redox potential = -0.1 to -0.2 V), as opposed to those for sulfides (redox potential = 0 to -0.15 V) (Kissel *et al*, 1992; Miller, 1993). And because of the lack of investigation it has received, methane offers a somewhat new area of inquiry for compost research.

Another aspect of environmental quality that should be assessed in compost technology is the generation of undesirable leachates. Leachate is minimal in properly managed compost operations, but its presence has elicited some concern about the potential for harm to humans and wildlife, if discharged into surface or groundwater. Presently, regulations concerning leachate collection and treatment vary from state to state and from system to system (Schoenecker & McConnell, 1993; Glenn, 1992a; Kashmanian, 1992; Logsdon, 1993b). In the case of yard waste composting, no state or locality required a paved site as of 1989 (Glenn, 1989). Virginia state regulations (VDWM, 1992) require a hard surface for facilities located only where the "seasonal high water table lies within twenty-four inches of the ground surface". Facilities utilizing a hard surface for composting, however, must provide for collection and treatment of any generated leachate. For all Virginia yard waste compost facilities, "control and proper management of runon, runoff and leachate" is required, and direct discharge of any leachate into surface waters is prohibited (VDWM, 1992). Some of the important parameters of compost leachates that should be assessed are nitrate, ammonium, total Kjeldahl nitrogen, phosphorus, total suspended solids, and biological oxygen demand.

Nitrate, which is commonly found in compost leachate (Diaz & Trezek, 1979; Cole, 1994; Richard & Chadsey, 1990), is one of the compounds of concern in non-point source pollution of groundwater (Revelle & Revelle, 1988; Brady, 1990). Nitrate is subject to legal limits in drinking water, because it poses serious health risks (O'Neill, 1985). The primary human health risk from excessive nitrate concentrations in drinking water, infant methemoglobinemia (blue-baby disease), results in a reduction in the oxygen carrying capacity of the blood and can cause death in infants less than six months old (Revelle & Revelle, 1988; O'Neill, 1985). Nitrate has been linked to increased potential for certain cancers (Zublena et al., 1990; Canter, *et al.*, 1990) and heart and behavioral problems (Bouwer, 1990). Additionally, a possible connection between fetal malformations and elevated nitrate concentrations in groundwater has been established in Australia (Rajagopal and Tobin, 1989). Risks to wildlife also exist (O'Neill, 1985).

Groundwater is the water source for roughly half of the households in the U.S. (Revelle and Revelle, 1988), and many documented cases of nitrate presence in drinking water wells have been recorded across the United States and in other countries (Bouwer, 1990). Of 1663 agricultural counties surveyed nationwide in 1987, 28 percent had groundwater nitrogen (nitrate-N) contamination greater than 3 ppm (Nielson & Lee, 1987). Eighty-seven of these exceeded the EPA's interim MCL (maximum contaminate level) of 10 ppm (Nielson & Lee, 1987). A 1990 EPA study revealed that 54.6 percent of rural wells and 50.9 percent of community well systems tested showed nitrate presence (USEPA, 1990).

In the case of saturated environments, nitrate can also be converted by microbes to gaseous forms, predominantly nitrous oxide (N_2O) and nitrogen gas, in the process of denitrification (Brady, 1990). Nitrous oxide is a contributor to acid rain, because it combines with water, creating nitric acid (O'Neill, 1985). At high elevations, nitrous oxide is readily converted to nitric oxide (NO), a factor in ozone depletion (Revelle and Revelle, 1988; O'Neill, 1985).

Nitrate-nitrogen is also a concern in coastal surface waters and estuaries because it can contribute to eutrophication, the nutrient over-enrichment of water bodies that results in prolific algae growth. The algal bloom causes degradation of water quality (O'Neill, 1985). The subsequent respiration of microbes involved in the decomposition of dying algae seriously decreases oxygen concentration, suffocating fish and other aquatic life (Revelle & Revelle, 1988). Run-off of agricultural fertilizers and other non-point source contributions of nitrate-nitrogen have caused serious problems in coastal bays and estuaries, because nitrate is generally the limiting nutrient in sea water (O'Neill, 1985).

The ammonium ion is considered harmful to fish and a contributor to oxygen depletion in surface water bodies (Revelle & Revelle, 1988). There is relatively little concern for adverse effects of the ammonium ion entering a soil environment in compost leachate, since it would most likely be readily fixed by negatively charged clay particles, adsorbed to humus, and/or immobilized by soil microbes (Brady, 1990). The possible conversion of leachate ammonium to nitrate by the process of nitrification, although not likely in well-managed facilities because the quantity of leachate produced would be small, might be considered a potential hazard.

Phosphorus is a serious factor in fresh water eutrophication (Revelle & Revelle, 1988), The contribution to eutrophication from phosphates has been largely attributed to that in sewage effluent and to detergent effects (Revelle & Revelle, 1988) because these contain soluble condensed phosphates (O'Neill, 1985); however, the concentrations of condensed phosphates are usually low in yard waste compost leachates. The phosphate ion released from the decomposition of organic materials is readily fixed in most soils, forming insoluble phosphates with calcium, or aluminum and iron (Brady, 1990). Phosphate leaching to groundwater is, therefore, not a concern.

Water clarity, an important characteristic of waters used for processing foods and other products, is another potential concern with any surface water discharges. It is affected by the concentration of total suspended solids, a measurable parameter (APHA, 1985). In addition, assessing the capacity of a particular leachate or discharge flow to deplete the oxygen in a receiving body is possible by measuring biochemical oxygen demand (BOD) (Revelle & Revelle, 1985).

Compost quality can be partially determined by assessing nutrient concentrations in the material following processing. Among the major and macronutrients commonly analyzed are nitrogen, phosphorus, potassium, calcium, magnesium, manganese, and iron. Concern surrounding heavy metal concentrations in composts has been narrowed to that of lead in municipal solid waste composts, since many researchers have documented the ready complexation of metals with humic materials (Chaney and Ryan, 1993). Significant human health risks are associated with ingestion of lead (Epstein *et al.*, 1992).

A field-scale municipal yard waste composting research and demonstration project was conducted at the New River Resource Authority Landfill in Radford, Virginia, from July 1992 to July 1993, to investigate these several aspects of municipal yard waste composting. Low-technology compost management (unpaved site, no chemical treatment of leachate, front-end loader/backhoe for turning of windrows) was utilized to ensure applicability of the results to the minimally capitalized facilities that may operate under Virginia's permit-by-rule authorization (VDWM, 1992). The results of this research were anticipated to aid the state in determining the technical appropriateness of the existing regulations and to provide information for future regulatory modifications based on technical issues.

Objectives. The project research objectives were:

Objective 1. to characterize C/N, temperature, and moisture relationships of yard waste during composting and the elemental composition of the finished compost;

Objective 2. to investigate the oxygen (O_2), carbon-dioxide (CO_2) and methane (CH_4) relationships in the composting yard waste;

Objective 3. to quantify water quality parameters of the leachate from yard waste composting mixes.

2. LITERATURE REVIEW

2.1 COMPOSTING SCIENCE

2.1.1 General Description. Composting is the predominantly microbially mediated aerobic decomposition of organic solid waste material (Golueke, 1972), which results in volume reduction and the production of a stable, humic material that has potential agronomic, horticultural and land-reclamation uses (Finstein & Morris, 1975; May & Simpson, 1990). The microbiological organisms use the solid substrate as a source of carbon and energy in carrying out the decomposition (Stevenson, 1982). Composting is governed by the environmental conditions imposed upon the microorganisms and the principles of heat and mass transfer (Keener, *et al.*, 1993). Carbon dioxide, water, and heat, as well as the stabilized humic material are the primary ultimate products of this process (Golueke, 1972).

In the composting of most organic wastes, a rapid rate of decomposition is desirable for: a) odor prevention (Golueke, 1972; Finstein *et al.*, 1986); b) increased stability and manageability of the end product (Finstein and Miller, 1985); and c) minimization of space requirements and, thus, improved cost-effectiveness, because of the ability to process greater volumes of material within a given period of time (Finstein *et al.*, 1986). The composting process can be controlled to achieve rapid decomposition (MacGregor *et al.*, 1981, Golueke, 1972, Finstein *et al.*,1986).

Heterotrophic microorganisms require an optimum environment to rapidly and efficiently decompose organic wastes. There are several factors that can be effectively manipulated in an effort to achieve these conditions including: maximum temperature level, moisture content, aeration level, the initial ratio of carbon to nitrogen in the mix of raw waste materials, particle size of the materials, and the size and shape of the composting pile (Poincelot, 1975; Keener *et al.*, 1993). Additional factors which affect the process rate, such as the type of process and mixing equipment, are generally predetermined by the raw materials to be composted, and the facility size and location (Keener *et al.*, 1993).

2.1.2 Decomposition and its Microbiology. The aerobic decomposition of organic material occurs when proper moisture, oxygen and nutrients are present. The nutrients of primary interest in composting, carbon and nitrogen, are contained in plant matter in the form of cellulose, hemicellulose, lignin, protein, sugars, amino sugars, organic acids and amino acids (Paul and Clark, 1989). The microorganisms that actually decompose the organic materials are the eubacteria, actinomycetes and the higher fungi (Keener *et al.*, 1993). Bacteria are the most prevalent of these organisms, and are active decomposers at the optimum temperature and moisture regimes (Golueke, 1972; Finstein and Morris, 1975). According to Finstein and Morris (1975), the fungi prefer the lower-end composting temperatures and survive less well than bacteria in very moist conditions. Actinomycetes are slow to colonize the compost environment as compared to bacteria and fungi, although they tolerate the high-end temperatures of composting. Their appearance, then, occurs later in the composting process. The fungi and actinomycetes generally occupy the outer portions of the pile in windrow composting (Golueke, 1972).

The three plant polymers - lignin, cellulose and hemicellulose are the primary source of the carbon for the microbial population in plant matter compost production (Lynch, 1993). Lignin, which makes up, for example, 28% of pine wood, 20% of birch wood, and 14% of wheat straw (Lynch, 1993), is the most recalcitrant of these polymers to biodegradation, because of its structural heterogeneity (Golueke and Diaz, 1987). The fungi are primarily responsible for the decomposition of lignin (Paul and Clark, 1989).

Polymeric cellulose, the largest component of plant residues, is made up of glucose monomer units, and is decomposed by a variety of bacteria; whereas, hemicelluloses, which are often complexed with other materials, are degraded initially by fungi, followed by actinomycetes (Paul and Clark, 1989). These materials, from which the microorganisms obtain their nutrients, are not necessarily readily available to large groups of the microbial population, given that they are far more complex than substances such as the simple sugars. Through decomposition to increasingly simpler compounds, however, the wastes are made accessible to an increasingly broader spectrum of microbes (Golueke, 1972; Finstein and Hogan, 1993).

Nitrogen, which is present in both organic and inorganic forms in the raw materials, predominates in the organic form (Kissel *et al.*, 1992). The organic nitrogen is transformed to ammonium through mineralization; whereas nitrification (NH_4^+ -->NO_3^-) and denitrification (NO_3^--->N_2) are the major inorganic transformations (Kissel *et al.*, 1992). Additionally, nitrogen is immobilized through incorporation into new microbial biomass (Paul and Clark, 1989). While individual amino acids and some of the proteins in plant material are readily decomposed by bacteria, certain of the fibrous proteins require the action of actinomycetes or some of the fungi (Paul and Clark, 1989). Figure 1 presents a simplified representation of the transformations.

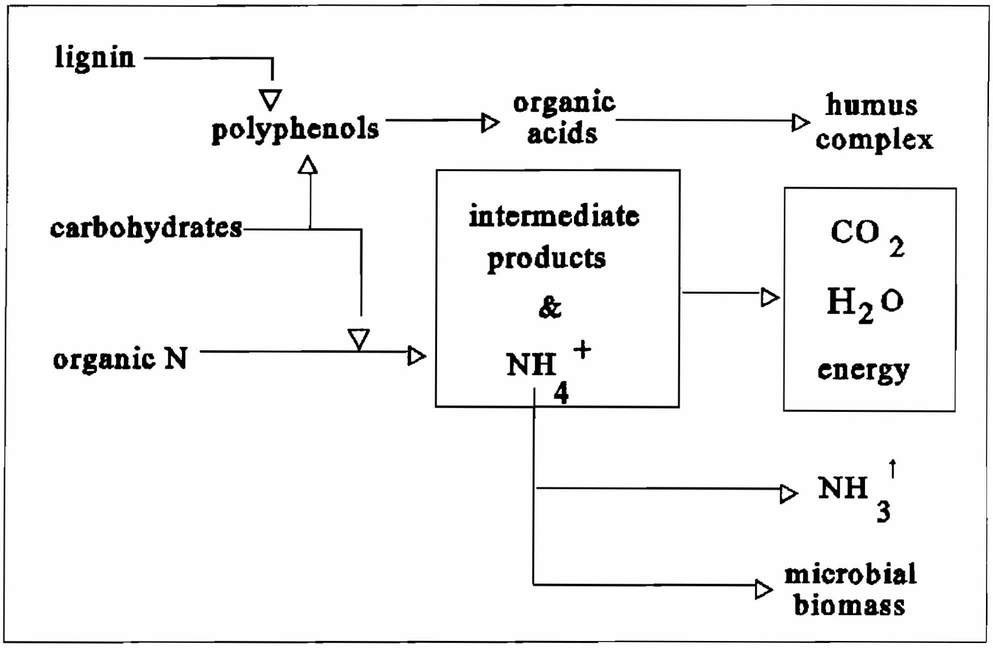


Figure 1. Decomposition Transformations (Golueke, 1972; Lynch, 1993).

A maximum rate of decomposition occurs when the ratio of carbon to nitrogen is optimum for microbial growth. Kissel *et al.* (1992) report that the constant microbial incorporation of nitrogen occurs at a C:N of 8-10:1. Lynch (1993) identifies an optimum ratio of 10-15:1. It should be recognized that these ratios apply when both the carbon and nitrogen are readily available. Considerably higher ratios are established initially for composting, because so much of the carbonaceous material utilized in yard waste composting is composed of highly resistant polymers. Typical C:N values for compostables are presented in Table 1.

2.1.3 Temperature. Biological respiration by the microorganisms in an ideal composting environment generates heat (Finstein & Morris, 1975; MacGregor *et al.*, 1981). The heat generated by the microorganisms during the process can raise composting environments to temperatures of 75-80 C (Finstein and Morris, 1975; Finstein and Hogan, 1993). The microbiological system involved in composting is self-limiting, because excessive heat produces temperatures that kill the most efficient microorganisms (Finstein *et al.*, 1986); and, thus, reduce the decomposition rate (Poincelot, 1972; Finstein *et al.*, 1986). Research has also indicated that above 60°C, microbial diversity is reduced, slowing decomposition (Finstein and Morris, 1975; McKinley and Vestal, 1984).

The three temperature-based classes of soil microbial life are: psychrophilic (optimum range= 5-15°C), mesophilic (30-37°C) and thermophilic (55-60°C) (Bohn *et al.*, 1985). The composting process encompasses the meso and thermophilic ranges (Golueke, 1972). Because each group of microorganisms thrives within a particular temperature range, outside of which, populations decline, microbial diversity is considerably affected by composting temperature (Michel *et al.*, 1993; Strom, 1985). Mesophilic organisms colonize the composting environment during the initial stages, followed by thermophilic microbes, the boundary between the two being from approximately 45 to 52°C (Finstein and Morris, 1975;

Table 1. Carbon to nitrogen ratios for selected compostables.[†]

Material	C/N ratio(wt/wt) (range or avg.)	Material	C/N ratio (wt/wt) (range or avg.)
broiler litter	12-15	digested sewage sludge	16
cattle manure	11-30	hay	15-32
horse manure	22-50	straw	48-150
turkey litter	16	newsprint	398-852
crab & lobster wastes	4.6-8.2	paper mill sludge	54
fish wastes	2.6-5.0	softwood chips	641
food wastes	14-16	grass clippings	9-25
vegetable wastes	11-13	leaves	40-80
domestic refuse paper	127-178	shrub trimmings	53

[†] NRAES, 1992.

Finstein and Hogan, 1993). Microbes favoring the lower portion of the thermophilic range are more efficient degraders than others (Golueke, 1972; Strom, 1985), although the mesophiles produce greater system activity and are considered capable of decomposing a broader range of materials (Finstein and Hogan, 1993). Bacteria predominate at the lower thermophilic temperatures (Michel et al, 1993; Strom, 1985). Some fungi are also present, although they prefer even lower temperatures (Finstein and Morris, 1975; Finstein and Hogan, 1993). Thermophilic temperatures impart the benefit of thermal kill of most primary human pathogens (Epstein and Epstein, 1989), although secondary human pathogens responsible for respiratory and eye irritation, such as some actinomycetes and fungi, especially *Aspergillus spp.*, can be promoted at 45 to 60°C (Gillet, 1992). Most plant pathogens and/or their vectors (in the case of viruses) are inactivated in the thermophilic temperature range, with the exceptions being the tobacco mosaic virus and possibly the club root fungus, *P. brassicae* (Bollen, 1993). Thermal kill for some of these is only possible at 60°C (Bollen, 1993). At temperatures greater than 60°C, the spore-forming bacteria dominate the microbial population (Golueke, 1972), and non-spore-formers and fungi die off (Finstein and Hogan, 1993). The activity of bacteria in the spore-forming stage is reduced, and overall, at temperatures greater than 60°C the majority of the microbial populations are inactivated (Finstein and Morris, 1975; McKinley and Vestal, 1984; Keener *et al.*, 1993; Finstein and Hogan, 1993).

2.1.4 Moisture and Aeration. Water is both necessary for microbial growth and a product of the composting process (Finstein & Morris, 1975; Finstein *et al.*, 1986; Golueke, 1972). Researchers agree that composting is significantly impacted by moisture content, and direct correlations between moisture content and windrow temperature have been established (Reinhart *et al.*, 1993; Suler and Finstein, 1977). Independent moisture management in composting is not obviated by these relationships, however, because heat capacity is dependent on water content (Finstein and Morris, 1975).

Optimum moisture levels vary depending on substrate (Jeris and Regan, 1973; Finstein and Hogan, 1993). In aerobic environments the interstices of the matrix must contain both air and water for microbial metabolic activities (Stevenson, 1982); therefore, structure of the compost medium is very important in insuring sufficient available moisture. A deterioration of structure will reduce pore space, which can result in anaerobic conditions (Golueke, 1972). When anaerobic conditions are allowed to develop, microbial activity is reduced and decomposition is less complete (Miller *et al.*, 1989). Methane and odorous compounds, such as some nitrogen and sulfur compounds and volatile fatty acids, can be produced and released from the anaerobic pockets upon turning and mixing (Kissel *et al.*, 1992; Miller, 1993; Miller and Macauley, 1988; NRAES, 1992).

Water content varies with conditions within the compost and climatic factors. Moisture must be added as decomposition proceeds to maintain the process, because large water loss occurs (approximately 90% of it by evaporation), and only 10% of that is replenished through metabolic production (Finstein *et al.*, 1986). Since the bacteria responsible for the majority of the decomposition are non-filamentous, their growth in compost is dependent on the presence of a film of moisture on particle surfaces (Robinson and Stentiford, 1993). Under low moisture conditions, fungi predominate as the major decomposers (Frost *et al.*, 1992); however, because the fungi numbers are significantly smaller than those of the bacteria, decomposition rate is slower (Finstein and Morris, 1975).

In yard waste composting, sufficient available moisture has been provided with total moisture content of between 50 and 65 percent (500-650 $g \cdot kg^{-1}$) (weight basis) (Schulze, 1961; Suler and Finstein, 1977; Finstein & Morris, 1975; Marugg *et al.*, 1993; Nakasaki, 1994).

The nature and products of decomposition of waste materials are largely governed by the availability of oxygen (Miller, 1993). Because odor problems can arise from anaerobic conditions and oxygen is necessary for microbial activity, optimum aeration level within the compost environment is of interest to both researchers and facility operators. At least 5 percent (50 $g \cdot kg^{-1}$) oxygen concentration has been commonly recommended to maximize process efficiency and prevent production of odorous gases (USEPA, 1989a; Golueke, 1972; NRAES, 1992; Finstein *et al.*, 1985), though Suler and Finstein (1977) reported odorous gases at this level of oxygenation. Ammonia emissions have occurred from even highly aerated composts in a pilot-scale system (Marugg *et al.*, 1993). Alternatively, oxygen concentrations as low as 0.5% in municipal solid waste composting exhaust gas have not inhibited decomposition (Finstein and Morris, 1975). Optimum oxygen concentrations appear to be specific to the mix, process stage, and, perhaps, other factors. Combining oxygen concentration with other measurements, therefore, may prove useful in characterizing desirable decomposition conditions.

Proper aerobic composting results in the production of considerable water. In sludge composting, this has been determined to be approximately 3.4 lbs water/lb of dry sludge (Haug, 1986). Minimal leachate production has been reported from composts (Cole, 1994; Logsdon, 1993a), however, because the release of water as vapor exceeds the quantity of water produced (Finstein & Morris, 1975; Cole, 1994). Cole (1994) estimated that leachate produced from a windrow of grass clippings and brush maintained at 51 percent moisture content (average) was approximately 1 liter per cubic meter of compost over a 50 day period. Some research on the quality of leachate from yard waste compost has been hindered by the lack of sufficient production (Richard and Chadsey, 1990). The majority of investigators of compost leachate quality have reported contaminants in units of ppm or mg/l, while failing to report total leachate volumes.

Leachate can result where excessive moisture is allowed to accumulate in the compost, and some concern about the potential for harm to humans and wildlife may be warranted, if it is allowed to reach ground or surface waters. Some of the components and characteristics of compost leachate that pose concern, such as hydrogen ion concentration (pH) and pesticide and heavy metal content, have received attention (Cole, 1994; Chaney and Ryan, 1993; Richard & Chadsey, 1990; Diaz & Trezek, 1979). The seemingly benign nature of yard waste compost, in comparison to that of municipal waste or sludge compost, has likely led to the limited investigation of its leachate characteristics. Cole (1994) found higher concentrations of both ammonium and nitrate in a yard waste compost than in the leachate or runoff, and concluded that both ionic species are readily held in the compost material. Thus, as long as saturation levels are avoided, leaching of these potentially undesirable compounds is unlikely (Cole, 1994). Richard & Chadsey (1990), using suction lysimeters beneath composting windrows, found that phenols exceeded the groundwater discharge standard of 0.002 mg/l. The naturally occurring phenols found in yard wastes are non-toxic and their presence poses an issue of odor only (Richard & Chadsey, 1990). Further investigation of the presence in yard waste compost leachates of compounds such as nitrate-nitrogen and phosphorus, which can negatively impact water resources, would inform both the composting process and regulations.

2.1.5 Gas Production. Carbon dioxide is one of the primary products of composting, and its rate of production is sometimes used to assess the activity of the microbial population. Researchers have reported generation of 30g CO_2 per 100g of compost over 96 hours when composting a mixture of food wastes and newspaper (Suler and Finstein, 1977). Michel *et al.*(1993) measured maximum CO_2 production from leaves only and leaves/grass mixes of between 1.1 and 3.2 g CO_2/kg dry wt/hr over the first fifteen days of composting in a controlled pilot-scale system. After 22 days, a constant CO_2 production rate of approximately 0.8 g/kg dry wt/h had been reached. The production of this gas is greatly affected by temperature and aeration (Suler and Finstein, 1977), indicating the importance of these factors in process efficiency.

Undesirable gases, both odorous and not, can also be produced during the decomposition process. In fact, at least 25 compounds have been identified or implicated in odor problems at compost facilities (Miller, 1993). Under proper compost management, many of the elements of organic matter originally made available in a reduced state are further oxidized, (e.g., (a) the ammonium ion to nitrate, rather than to ammonia gas; (b) the sulfides to sulfur, sulfates and sulfide minerals, rather than to hydrogen sulfide, carbon disulfide or several others; and (c) carbon compounds to CO_2 rather than to methane or acetic or propionic acid) (Brock and Madigan, 1988; Kissel *et al.*, 1992). It is well accepted that the production of undesirable volatile compounds is often the result of reducing conditions brought on by excessive moisture and poor compost structure (Miller, 1993; Kissel *et al.*, 1992).

Odor problems are created when many of these gases are released into the atmosphere with the turning and mixing of anaerobic piles (Glenn, 1990; Miller and MacCauley, 1988). Most of the investigation surrounding odor production and control has focused on the sulfur-based compounds arising in municipal solid waste, sludge, and mushroom substrate composting (Miller, 1993; Kissel *et al.*, 1992; Miller and Macauley, 1988). Aside from sulfur compounds, ammonia, volatile fatty acids and phenolics are the predominant odor sources in composting of vegetative wastes, because of the initial relatively greater concentrations of the contributing elements in those materials (Miller, 1993). Phenolics result from lignin decomposition (Miller, 1993).

Aeration is, of course, the determining factor in maintaining oxygenated conditions and minimizing anaerobicity. Because the development of anaerobic conditions seems to be inevitable in microsites of field-scale operations (NRAES, 1992; Kissel *et al.*, 1992; Marugg *et al.*, 1993), controlling resulting odorous emissions requires a thorough understanding of the factors involved in combining compost feedstock and properly managing all aspects of the compost process.

2.1.6 Compost Characteristics. Composts are comprised of both humic and non-humic fractions (He *et al.*, 1992). The non-humic fraction is made up of as yet undegraded compounds, such as polysaccharides, and low molecular weight acids (He *et al.*, 1992). Humic substances, which are the result of the decomposition reactions in the composting environment (Golueke, 1972), are relatively high molecular weight materials (Stevenson, 1982), that are polyaromatic and polyacidic complexes existing in a heterogenous mixture (Tits, 1990). Michel, *et al.* (1993) found finished yard waste compost produced under controlled laboratory conditions to contain 38-49% ash, less than 13% cellulose and hemicellulose, and 27-33% lignin (plus some proteins and humic acids, i.e. acid-insoluble organic matter). Final organic matter contents for the 3 composts in their research ranged from 48-60%.

The organic matter content of compost, which derives primarily from the humic material, provides long-recognized benefits to soils, such as increase in cation exchange capacity (CEC), improvement in soil aggregate stability, increased capacity to buffer pH, and increased complexation of potentially harmful metal ions (He *et al.*, 1992; Stevenson, 1982;

Saviozzi *et al.*, 1989; Bohn *et al.*, 1985; Epstein *et al.*, 1976; Chaney and Ryan, 1993). Composts also contain substantial concentrations of some essential plant nutrients, including many of the trace elements (Schlauder and Pejak, 1992; Vogtmann *et al.*, 1993; Dick and McCoy, 1993). Values of some of these reported in the literature for a range of composts are presented in Table 2.

Increases in crop yields and improvements in container plant and turf grass growth resulting from the use of a variety of composts have been widely reported (Roe *et al.*, 1993; Tester, 1990; Shiralipour *et al.*, 1993; Singh and Yadav, 1986). Reduction in commercial fertilizer quantities and improved inorganic fertilizer use efficiency have also been associated with compost applications (van der Werf, 1993; McConnell *et al.*, 1993; Buchanan and Gliessman, 1991; Dick and McCoy, 1993). Utilizing composts as an alternative to conventional nitrogen fertilization practice is limited, because large amounts are required to match the concentrations in manufactured fertilizers (Dick and McCoy, 1993). Compost nitrogen does become available, although slowly (Tisdale, *et al.*, 1985; He *et al.*, 1992; Hornick *et al.*, 1984).

Generally, heavy metals have proved of minimal concern in composts because of their ready complexation with humic materials and, thus, immobilization (Petruzelli, 1989; Sims and Kline, 1991; Livens, 1991). The presence of lead in composts destined for use in applications where children may directly ingest contaminated soil or dust is considered a potential health risk, however, since lead in soil is partially bioavailable (Rosen & Munter, 1985; Chaney and Ryan, 1993). Excessive blood concentrations of Pb result in serious

Table 2. Elemental composition of composts and soil.

Composts	N	P	K	Ca	Mg	Mn	Fe	Pb
			(g·kg^{-1})				(mg·kg^{-1})	
grass+brush[1]		1.45	3.41	43.92	12.21	351	106	45.7
leaves[2]	0.06	0.40	11.10	18.40	5.90		267	31.7
poultry litter&carcasses + straw[3]	0.41	0.61		24.60	15.00	227		
sewage sludge + woodchips[4]	0.14							
leaves (day 32)[5]	0.11							
2leaves:1grass (day 32)[5]	0.18							
1leaves:2grass (day 32)[5]	0.25							
soil[6,7]	0.03-0.40	0.45	5.0-25.0	7.0-15.0	0.005-0.05	0.02-3.0	7.0-550.0	2.6-25
soil[8]	0.15	0.5	17.0	4.0	3.0			

1 Cole, 1994.
2 Richard & Chadsey, 1990.
3 NRAES, 1992.
4 Epstein *et al.*, 1978.
5 Michel *et al.*, 1993.
6 Tisdale *et al.*, 1985.
7 Epstein *et al.*, 1992.
8 Brady, 1990.

neurological impairment (Epstein *et al.*, 1992). Some states have established maximum Pb concentrations for application of composts to both food (300-500 mg Pb/kg compost) and non-food crops (500-1000 mg/kg) (OTA, 1989). Soil levels for this element below 500 mg/kg have been considered safe for home gardens (Rosen & Munter, 1985). A lead concentration limit of 300 mg/kg dry weight is now recommended for land applied sludge and compost (Chaney and Ryan, 1993). The EPA has established new maximum pollutant ceiling concentrations for sludge application to lands which limit total Pb additions to 630 mg/kg (USEPA, 1993).

2.2 COMPOSTING TECHNOLOGY

Composting technology involves the control of a variety of factors of aerobic decomposition. Presented below is a discussion of those factors of primary interest in non-capital intensive, field-scale yard waste composting.

2.2.1 Initial Carbon to Nitrogen (C:N) Ratio. Carbon and nitrogen in available forms must be appropriately balanced for efficient composting (Golueke, 1972). A C:N ratio that is too low results in volatile N losses (Marugg *et al.*, 1993; Michel *et al.*, 1993; Richard and Chadsey, 1990; Kissel *et al.*, 1992). One of these volatile N compounds, ammonia, is a source of odor problems often associated with composting (Golueke, 1972). Ammonia production is enhanced by the elevated pH occurring in rapid decomposition, and its volatilization is accelerated at high temperatures (Golueke, 1972). A low C:N ratio (<20:1) can also result in the production and subsequent leaching of nitrate (Richard and Chadsey, 1990).

A C:N ratio that is too high limits the microbial population because less nitrogen is available for incorporation into microbial tissue than required for the available carbon. This condition limits both the degree and rate of decomposition (Golueke, 1972). Nitrogen deficiency becomes a concern when attempting to compost materials high in difficult -to-degrade materials (Lynch, 1993). Kissel *et al.*, (1992) consider a 30:1 ratio as the level above which basically all the nitrogen is incorporated into microbial biomass.

To summarize, several desirable goals that can be achieved with an appropriate C:N ratio are: a) the promotion of rapid decomposition, because the balance of the two elements is optimum for initial microbial utilization; b) the minimization or prevention of odor problems that would result from excess nitrogen being converted to ammonia; and c) the limiting or prevention of leaching of potential nitrate to groundwater.

The generally utilized method to establish a C:N within the proper range is by co-composting different raw materials. Although the microbial population responds most rapidly to an 8 to 15:1 ratio of readily available carbon and nitrogen (Kissel *et al.*, 1992; Lynch, 1993), researchers and practitioners have found a range of 25 to 30:1 necessary, because of the great variability in resistance to degradation among the many carbonaceous materials in waste streams (NRAES, 1992; Golueke, 1989; Richard and Chadsey, 1990; Willson, 1989). Golueke (1989) and Finstein and Hogan (1993) have recommended even larger ratios when composting material highly resistant to microbial breakdown.

As might be expected, in practice, specific raw material ratios have ranged broadly. Grass clippings and leaves have been composted together in volume-to-volume mixes of 1:1, 1:2 and 1:3 (USEPA, 1989a; Barnes and Heimlich, 1992; Reinhart, 1993). Woodchips, another yard waste material, have been composted with grass as well as in combination with grass and leaves (Logsdon, 1992; Kelly, 1993; Glenn, 1992b). One of the most recommended mixes is at least 2:1 leaves to grass (Michel *et al.*, 1993). Mix ratios based on measured or estimated carbon and nitrogen in the waste material and the moisture content of those materials can be calculated (NRAES, 1992), but because of the expense and time constraint of analysis and the fact that there is so much variability in weather, the way materials are handled prior to windrow construction, amount of fertilizer nitrogen used on turf grass, and even the variety of turf grass to be composted, predicting optimum mixes is difficult. The acquired skill that comes from experience should not be discounted in low-technology yard waste composting (Logsdon, 1993b).

2.2.2 Temperature Control. Heat generation is probably the most important of the controllable factors in yard waste composting. Given that the rate of heat generation varies over time with the availability of readily useable substrate (Finstein and Hogan, 1993), so must the rate of heat removal, in order to prevent limiting decomposition. Ventilation achieves heat removal during composting. In the case of windrow (elongated piles of material) or pile composting, the primary mechanisms are forced ventilation through pipes inserted in material piles, or the turning of windrows with a specifically designed turner or a front-end loader/backhoe.

An efficient management scheme provides ventilation based primarily on a temperature set-point, in order to avoid rate-limiting temperature conditions (Golueke, 1972; Miller *et al.*, 1989). The most commonly recommended set-point has been at or slightly lower than 60°C (Suler and Finstein, 1976; Miller *et al.*, 1989; Golueke, 1972). Establishing this maximum level allows rapid decomposition and prevents the temperature from rising to an inhibitory point.

2.2.3 Moisture and Aeration Management. Excessive moisture in the composting environment can facilitate anaerobic conditions, which result in the production of undesirable gases and reduction in composting efficiency. Alternatively, too little moisture inhibits decomposition. Generally, the maximum moisture content in the composting environment is determined by the structural strength of the raw materials (Golueke, 1972), indicating the need to take into account the type and quantity of the various materials making up the mix to be composted. Reduced microbial activity has been reported, when the moisture level is roughly 35 to 45 percent (weight basis) (350-450 $g \cdot kg^{-1}$) (Frost, *et al.*, 1992; Golueke, 1972); whereas, successful composting occurs, when moisture is between 50 and 65 percent (500-650 $g \cdot kg^{-1}$) (Schulze, 1961; Suler & Finstein, 1977; Nakasaki, 1994). Michel *et al.*(1993) found that maintaining 60°C and 60 percent (600 $g \cdot kg^{-1}$) moisture content resulted in stable compost after only 52 days in a laboratory scale yard waste composting system. Achieving a desired weight-based total moisture content is not necessarily insurance of effective moisture management. Available moisture is largely determined by particle size and degree of mixing, and should be considered an important parameter in composting.

Ventilation is the standard means to control process-limiting temperatures and excessive moisture in the composting environment. Controlling excess moisture aids in maintaining optimum oxygen concentrations for the microbial population (Haug, 1986; Golueke and Diaz, 1987). Insufficient oxygen concentrations have been cited as the initial limiting factor in managed composting systems in general (Finstein *et al.*, 1983; Richard, 1992). Adequate oxygenation should be achieved with the practice of ventilation to control against process-limiting temperatures because microbial respiration requires approximately nine times less oxygen than that necessary for heat removal (Miller and Macauley, 1988; Haug, 1986). However, the requisite diffusion of oxygen into the compost aggregates is not necessarily assured, given that gas transfer is greatly affected by the presence of water as well as the size and structure of the composting material (Miller, 1993). Oxygen levels that are too high are also undesirable in that they can cause excessive drying and temperature reduction such that the most active degraders are inhibited (Finstein and Morris, 1975).

Efficient moisture management is dependent upon adequate assessment of compost conditions in advance of limiting conditions. Frequent monitoring, including as often as daily, has been recommended in both windrow and aerated static pile applications in order to avoid compost that is either too dry or wet (Golueke, 1972; Robinson and Stentiford, 1993). Temperature plateaus or declines are an often utilized indicator of insufficient moisture, and adding water at turning/mixing is the most common means to correct for overdry conditions. Ascertaining the development of excessive moisture conditions before the process becomes limited and odors become a problem is constrained by available technology and principles in low-technology yard waste composting. Monitoring oxygen and carbon dioxide within windrows to gauge process status/completion has been practiced by operators, but achieving and maintaining target concentrations of these gases in microsites is not insurance against odor-causing conditions. Measuring for anaerobically produced gases could provide a distinct advantage in preventing excessive moisture levels and minimizing odors, although no economical method is presently available for that purpose.

2.2.4 Compost Maturity/Stability. Parameters are required by which to assess the maturity or stability of compost. Determinations of process completion have focused on visual, physical and laboratory assessments. Researchers in the past decade have pointed to the importance of biologically-based finish point determination, citing cases of immobilization of soil nitrogen, when seemingly mature composts (based on physical characteristics and in some cases C/N ratio) have been applied to soils (Finstein *et al.*, 1986). Chen and Inbar (1993) reported a multitude of negative soil and plant reactions to immature composts in reviewing research on this subject, including nitrogen immobilization and deficiency, the presence of acidic and other toxic fermentation products, and high salt contents. It is generally recognized that composts should undergo a stabilization or curing period before use in order to insure completion of the most active phase of decomposition, allow full colonization by mesophiles and the entry of microfauna into the material (Chen and Inbar, 1993; NRAES, 1992).

C/N ratio is sometimes considered a significant indicator of process completion (Finstein & Morris, 1975; Finstein *et al.*, 1986), and may predict degree of humification (Inbar, *et al.*, 1990) and of soil environment response (Kissel *et al.*, 1992); however, Finstein *et al.* (1986) reported that C/N is too insensitive for determining degree of process completion. The recommended range for finished compost has been between 12 and 15:1, with a maximum of 20:1 in order to avoid nitrogen immobilization (Golueke, 1972). Some researchers have suggested that utilization of C/N determination from aqueous extracts is far more reliable than the ratio derived from dried material analysis in predicting compost quality

(Finstein *et al.*, 1986; Chen and Inbar, 1993). A related measurement, that of soluble C, seems to show good promise (Chen and Inbar, 1993), although cost and some time delay would still limit its application.

A stability determination used widely in Germany is the Rottegrad index, which relates oxygen uptake to heat generation potential and compost stability over a range of five categories (Michel *et al.*,1993). Stable composts, i.e., with low self-heating potentials, have higher RI's than do unfinished, unstable composts (Michel et al.,1993). Considerations of moisture content during composting and moisture content during the assessment would seem critical to applying this tool, since unfinished composts can appear stable when too dry.

Other investigatory methods for assessing degree of completion have been proposed. Change in percent volatile solids over time is considered to be insufficiently specific or sensitive enough (Finstein *et al.*, 1986). Dry matter loss and volatile organic fraction changes have both proved to lack broad applicability, because yard wastes vary so widely in biodegradability (Frost *et al.*, 1992; Marugg *et al.*, 1993). Frost *et al.* (1992) suggest combining percent volatile solids loss and oxygen uptake for specific stability values, but consider such a method useful only when the efficiencies of processing similar raw material composts are compared. Marugg *et al.* (1993) propose utilizing compost equilibrium values, which are related to volatile solids content, and mass ratio (a dimensionless parameter which describes the degree to which decomposition has progressed) for yard waste maturity determination. The authors acknowledge, however, that this model fails to fully account for effects of particle size and temperature on the process kinetics.

One promising technique is the utilization of dissolved oxygen respirometry, which measures mean percent oxygen in the exhaust air in small pilot-scale incubators (Frost *et al.*, 1992). The limitation for researchers is that this method establishes only relative rates of respiration, without a quantitative determination of oxygen uptake rate (Michel *et al.*, 1993), thus preventing comparison among samples. Additionally, further research with this method revealed that the correlation of observed energy balances with rates of dry matter loss (calculated from oxygen uptake rates determined by dissolved oxygen respirometry) is not maintained in the thermophilic temperature range (Iannotti, *et al.*, 1993). For samples at or near the end of the decomposition process, however, one can calculate absolute uptake rates, and when samples are collected and handled to maintain proper moisture content, dissolved oxygen respirometry can potentially prove to be a reliable, inexpensive method for on-site determination of stability. However, highly heterogenous samples would likely be found to be poorly assessed for stability.

Measurement of CO_2 from incubated samples has been in wide use as a means of determining if a compost is still biologically active (Chen and Inbar, 1993). Its disadvantages for facility operators are that it takes several days to conduct the analysis and it utilizes a small and, therefore, potentially poorly representative sample (Frost *et al.*,1992). Hand-held analyzers for instantaneous CO_2 measurement are beginning to be utilized in the field (Luebke, 1989), but their readings may misrepresent stability status if non-optimum conditions exist. With experienced process management, this technique can be considered a viable method.

Cessation of temperature rise following mixing and turning has been the primary field method for determining process completion (Golueke, 1972; Reinhart *et al.*, 1993). It is certainly the least expensive of the methods investigated. This approach is potentially inadequate, as well, however, in that the lack of response in composts that are too dry or too wet may result in erroneous determinations, despite the continued presence of readily degradable materials (Miller, 1989; Golueke, 1972). This method can be considered reliable, when employed by experienced operators.

3. MATERIALS & METHODS

3.1 EXPERIMENTAL DESIGN.

A. Site. The composting was conducted at the New River Resource Authority landfill in Radford, Virginia, at a site previously used to stockpile soil for daily cover. Plots were graded to establish a slope of not less than 5 percent, surface water diversion trenches, and berms. A 1.54 mm thick high-density polyethylene landfill liner was placed on the bed of each plot to funnel leachate/runoff into a 0.3 m deep, 0.38 mm thick UV-resistant greenhouse plastic lined leachate collection trench that ran along the downslope length of the composting area. A 30 cm thick woodchip base was then applied to the whole site to protect the liners and berms and to prevent erosion and traction problems which could develop with inclement weather. The leachate flowed through a stone filter at the end of the leachate collection trench, and into a 30 m long grass-lined waterway leading to a 1.5 m deep (at the center) retention pond with a 30 m^2 surface area. A shallow stone filter was installed at the pond overflow and below it, a 5 m^2 grassed filter strip. This system served as a treatment facility as required by Virginia regulations (VDWM, 1992). Figure 2 provides a site layout plan.

B. Raw Materials. Leaves from local municipal collection were transported to the landfill. Woodchips were produced at the landfill by tub-grinding woody materials such as brush and pallets brought for disposal. The grass clippings were collected from Virginia Tech and Radford University grounds maintenance departments and supplemented from the segregated grass disposed at the landfill.

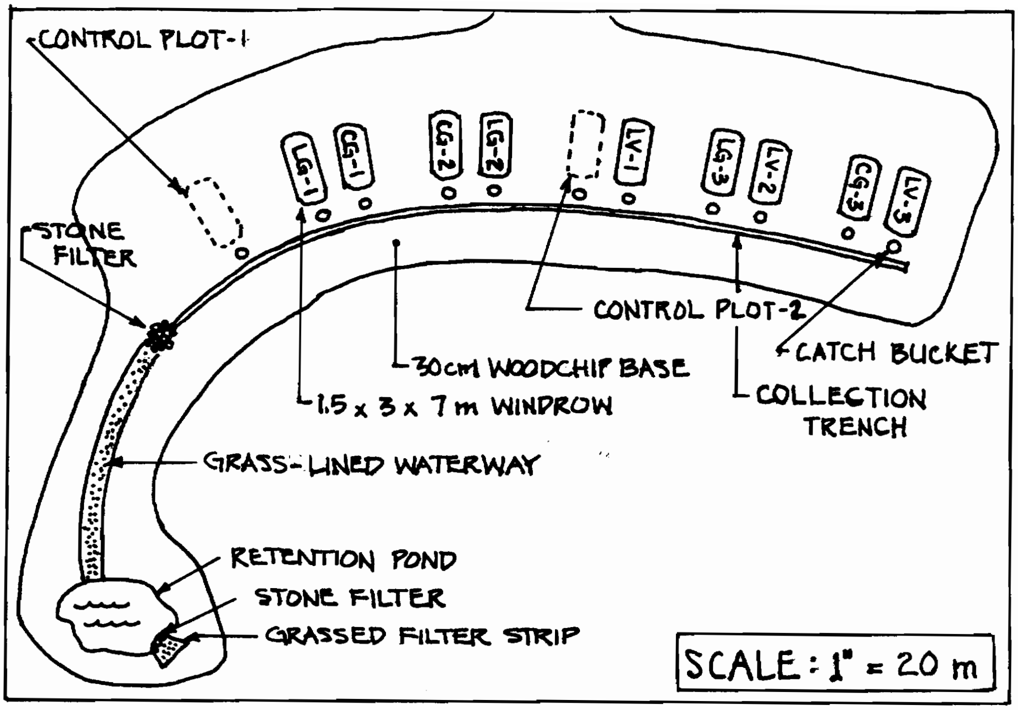


Figure 2. Site Layout Plan.

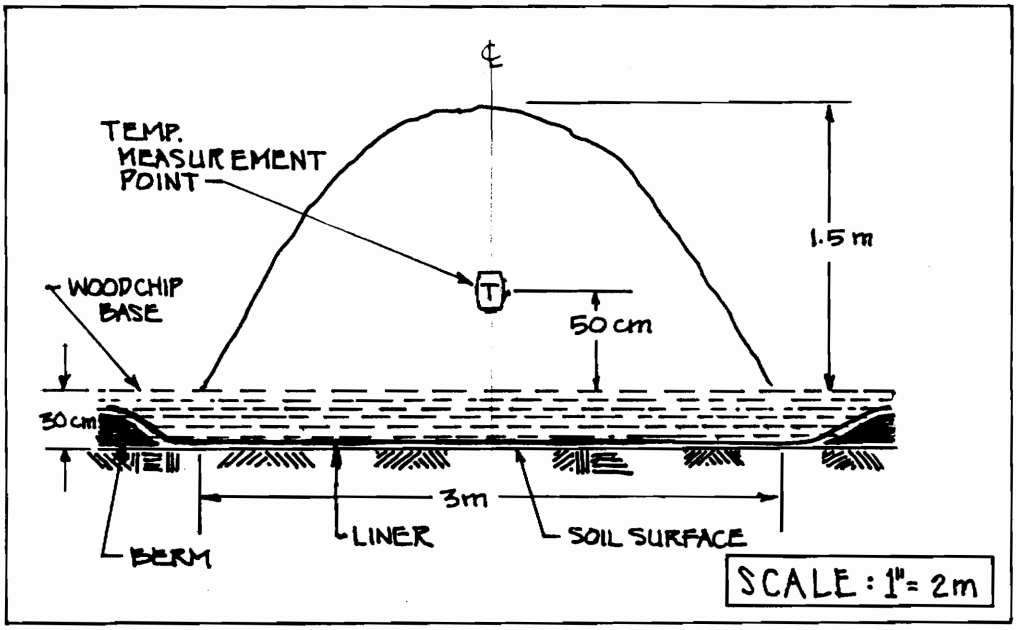


Figure 3. Windrow Cross-section.

C. Windrows. The following treatments were established: 1) 3:1 (v/v) leaves:grass (LG); 2) 2:1 (v/v) woodchips:grass (CG); and 3) leaves only (LV). Three replications of each windrow, which measured 7 m long, 3 m wide, and 1.5 m high, were constructed of each of these mixes (Figure 2). Total volume per windrow was approximately 23 m^3. Windrows were designated LG-1 through 3, CG-1 through 3, and LV-1 through 3. Windrows were formed by layering the raw materials, using a front-end loader, and adding water to each successive layer to achieve an approximate moisture content of 65 percent (650 $g \cdot kg^{-1}$) (fresh weight basis). Compost windrows were not covered. Two control plots, consisting only of the woodchip base, were constructed for the leachate quality investigation. Table 3 presents windrow construction dates and C/N ratios.

D. Leachate/Runoff Collection. Leachate/runoff was collected from selected windrows and the control plots by channeling liquid that had seeped onto the liner through a 7.6 cm diameter poly-vinyl chloride (PVC) pipe into an 18.9 liter, loosely-capped bucket positioned between the windrow and the collection trench. Leachate was sampled from two of the three replicates of each compost treatment, the two control plots, and the retention pond.

3.2 MONITORING.

Windrow temperatures were measured using long-stemmed temperature probes constructed of copper-constantan wire inserted into 1.3 cm diameter PVC pipes and secured at the ends in rubber-stoppered galvanized fitting ensembles. The plug end of each

Table 3. Windrow construction dates and C/N ratios.

Windrow	Construction Date	Days Composted	C/N Ratio		
			Initial	Range	Final
LG-1	9/23	203	30	18 - 32	18
LG-2	10/14	182	19	18 - 28	19
LG-3	11/06	162	23	20 - 33	24
CG-1	9/23	204	153	29 -156	61
CG-2	10/13	183	213	40 -213	67
CG-3	12/23	113	na‡	59 -111	51
LV-1	11/03	165	40	31 - 52	30
LV-2	11/06	162	40	32 - 44	31
LV-3	12/29	100	na‡	47 - 81	47

‡ Samples not analyzed.

thermocouple wire extended beyond the 96 cm long probe pipe and was equipped with an Omega Type OGP connector. Temperature was measured at three locations in each windrow (at 1.75, 3.5 and 5.25 m from the windrow end, initially) approximately 50 cm (initially) above the woodchip base and at the midpoint across the windrow (Figure 3). Daily temperature monitoring was accomplished using an Omega Model HH21 hand-held microprocessor thermometer.

Moisture content was monitored by determining percent moisture of random samples collected between 10 and 15 times from all windrows except CG-3 and LV-3, which were sampled only 8 and 7 times, respectively, because they were constructed later than the other windrows. Sampling procedure is described in Section 3.4.

3.3 COMPOST WINDROW MANAGEMENT.

When the internal temperature of a windrow attained 60°C at two of the three temperature probes, the windrow was turned with a front-end loader/backhoe. As decomposition proceeded and temperatures no longer attained 60°C , windrow turning was based on a combination of temperature and aeration status.

3.4 SAMPLING.

Samples for determining C/N ratio were taken from initial composite raw material grab samples collected at windrow construction and from between 4 and 8 subsequent composite random samples from all but windrows CG-3 and LV-3, which were sampled only twice following construction. Both interior and surface materials were gathered in the 6 samples collected from each window (approximately 750 ml/sample). Both interior and exterior samples were taken at a depth of approximately 60 cm from the windrow surface at 3 evenly spaced intervals along each windrow. Samples from each windrow were mixed together thoroughly and approximately 750 ml were transferred to a paper bag for transport and drying prior to processing for analysis. The material samples taken at the end of the study period for C/N ratio determination were also analyzed for elemental composition.

Samples for moisture content assessment were taken at a depth of approximately 60 cm horizontally from the windrow surface, at ½ the windrow height, and at 3 evenly spaced intervals along one side of each windrow. Samples of approximately 750 ml each were randomly collected. The material from each windrow was mixed thoroughly by hand and approximately 250 ml removed and sealed in a plastic bag for transport. Samples were weighed, dried at 65°C for 72 hours, and then weighed again to determine percent moisture content.

Windrows were sampled internally to determine gas composition one to three times per week from three positions within each windrow. The samples were taken longitudinally and cross-sectionally, at approximately the same locations as the temperature probes, and vertically at 1/3rd of the total height below the center top of the windrow. Samples were collected with a 6.35 mm (outside diameter), 90 cm long stainless steel tube, soldered closed at the insertion end and drilled with 12 small holes along the first 5 cm of its length, and connected to a flexible polyethylene tube. This tube was joined to 15 ml glass sample vials for sampling. A 60 ml syringe was used to evacuate each rubber-stoppered vial and to draw the sample. The inlet and outlet tubes of the vial were clamped closed for transport to the laboratory. The samples were analyzed on a Hewlett Packard 5890 gas chromatograph equipped with a TCD detector. Carbon dioxide and methane were separated using Porapak-N, while oxygen was separated using molecular sieve. Helium was the carrier gas.

The leachate/runoff collected in the buckets at the end of each windrow and control plot included in the water quality study was stirred prior to sampling. Retention pond samples were collected at the pond edge, generally within 4 meters of the point at which discharge from the grass filter strip emptied into the pond. Approximately 400 ml of leachate was sampled for analysis. Following sampling at windrows and control plots, the liquid remaining in the buckets was emptied into the collection trench that drained through a stone filter onto a grassed waterway and into a retention pond. Twelve to 23 samples were collected per windrow throughout the study, except for the LV-1 and LV-2 plots, which were sampled 8 and 7 times, respectively. Samples were collected once every 5.3 to 7.6 days until March of 1993, when the site became inaccessible because of the weather and the road conditions into the composting area.

3.5 CHEMICAL ANALYSIS.

Compost samples for elemental composition were dried at 60°C to reach standard moisture content and ground in a Wiley mill. Total nitrogen content was determined on duplicate samples of 0.1 g by the Kjehldahl method (Bremner & Mulvaney, 1982), and analyzed for NH_4^+ content in the digest with a Lachat Model 1600 colorimeter (Lachat Instruments, Mequon, WI). Total carbon was determined per Nelson and Sommers (1982) on triplicate samples of 0.2 g by dry combustion and infrared detection of CO_2 in a Leco Carbon Analyzer (model #CR12, Leco, Inc. St.Joseph, MI). Carbon to nitrogen ratio for the initial mix was calculated using estimated bulk densities for each material. Following is an example calculation for the 3 parts leaves:1 part grass mix (v/v):

	volume	mass	C/N
leaves	3	0.64 kg.	40
grass	1	0.45 kg.	15

\- -

leaves	0.64 (40C) : 0.64 (N)			
grass	0.45 (15C) : 0.45 (N)			
	32.35 C : 1.09 N	=	30 C/N	

Duplicate samples for nutrient and lead content analysis were prepared by perchloric acid digestion (Lim and Jackson, 1982) of 1.0 g of sample. Elemental analysis was conducted with a Jarrell-Ash ICAP 9000 simultaneous spectrometer, except for Pb content, which was determined with a Jarrell-Ash Atomscan 2400 sequential (scanning) spectrometer (Thermo Jarrell Ash Corporation, Franklin, MA) per Virginia Tech soil testing and plant analysis laboratory procedures (Donohue & Heckendorn, 1994).

Leachate samples were analyzed according to U.S. Environmental Protection Agency standard methods (Kopp & McKee, 1983) for total suspended solids (TSS) by Method 160.2; nitrate (NO_3^-) by Method 353.2; ammonium (NH_4^+) by Method 350.1; filterable and total Kjeldahl nitrogen (FTKN, TKN) by Method 351.2; orthophosphorus (OP) by Method 365.1;

and filterable and total phosphorus (FTP, TP) by Method 365.4. Some samples were also analyzed for pH by Method 9045 (Kopp & McKee, 1983), and for biochemical oxygen demand (BOD). BOD_5 analysis, which assesses the oxygen requirements of water bodies, was by the 5-day incubation method, utilizing initial and final dissolved oxygen measurements to yield mg/l of biochemical oxygen demand (APHA, 1989).

3.6 Statistical Analysis. Because all windrows were not constructed within hours or days of each other, statistical analyses not requiring replicated treatments was applied to several parameters examined in the study. Other parameters were evaluated with simple statistics and comparative discussion. Time series-based autoregression was performed on the temperature data of the windrows, and overlays of the resulting upper and lower confidence limits were used to compare temperature patterns within treatments, and in windrows built at the same time (i.e., within 3 days). Correlation tests between CO_2 and O_2 within windrows were performed, as well as two sample correlations within and between treatments. Leachate comparison between windrows was limited to means and standard deviations, because of the small number of samples analyzed. Analysis of variance with multiple comparisons was applied to the elemental concentrations of the compost material sampled at the end of the study.

4. RESULTS AND DISCUSSION

4.1 WINDROW MANAGEMENT.

Several operational challenges arose during the project that affected the data collection for this research, among these being that windrow turning and watering were the responsibility of site personnel who had superseding duties. This resulted in some delays in windrow turning and erratic moisture management. Severe winter weather conditions created difficulties in data collection during a portion of the composting period. No data was collected between March 1 and March 29, 1993. The retention pond received runoff from areas other than the composting site and was easily accessed by wildlife; thus, the filtering effect of the grass waterway could not be assessed.

The composting process was also impacted by weather conditions. Windrows were exposed to both wind and precipitation, partially negating the insulating effect of windrow size. In March 1993, rainfall totalled 18.9 cm and prolonged icy conditions prevailed. Windrows CG-3 and LV-3 were constructed at the end of December 1992, after the onset of winter, and were, therefore, subjected to the more severe weather during a greater portion of their primary composting. These windrows showed little decomposition by April 1993.

Because the focus of the research was on low-technology management, the challenges posed by the less-than-optimal circumstances provide important insights for formulating recommendations for adequate compost management.

4.2 PROCESS VARIABLES.

4.2.1 Carbon and Nitrogen. The C/N ratios varied greatly over time (Table 3). In fact, the final measured C/N ratios for LG-2 and LG-3 were no lower than the initial value. It is likely that insufficient mixing of the initial material with the low-technology equipment utilized in this research resulted in an artificially low ratio. The broad range of C/N ratios recorded for the woodchip/grass windrows occurred both because of the turning/mixing equipment constraint, and because samples were not screened prior to analysis. Thus, woodchip particles, composed primarily of difficult to degrade lignin, were included in the material analyzed. Additionally, the grass utilized in CG-3 was from a field of livestock forage grass, which was cut late in the season, just prior to windrow construction. The nitrogen concentration in this material was lower than that in the grass used for other windrows and likely less-readily available. In general, C/N ratios decreased with time. Final values for leaf/grass and leaves-only windrows were comparable with those reported by Michel et al.(1993) for the same or similar mixes after 32 days of composting. They were not, however, as low as the recommended range of approximately 12 to 15:1 for agricultural and horticultural application. The little change in C/N ratio in the LV windrows is expected, since composting without a readily available nitrogen source results in a longer period of decomposition.

4.2.3 Temperature and Moisture. The greater relative availability of N in the LG windrows than in the other treatments resulted in a longer period of sustained high temperatures (Figures 4-12), representing more vigorous biological activity. The LG windrows contained a smaller volume of grass than the CG windrows; but the leaves present provided additional nitrogen not available in the latter. The LG windrows completed their primary active composting within the first 8 weeks following construction, after which their temperatures began to drop steadily toward ambient temperature (Figures 4-6). During those first 8 weeks, temperatures recovered rapidly to high levels following turning, and generally remained above 40°C. Excessive water added at construction prevented as rapid an initial temperature rise in LG-1 as in the other LG windrows. Assessing bulk density or porosity of the raw materials in addition to the C/N ratio can help prevent such conditions. High moisture contents in LG-1 and 2 on 10/28/92 (722 and 731 $g \cdot kg^{-1}$) are reflected in the leveling-off of the respective temperature profiles for a short period following that date. Temperatures in the CG-1 and CG-2 windrows peaked, following turning, above 50°C during the first 35 days, after which they declined and hovered between 25 and 35°C for three or more months. The high temperatures during the initial primary decomposition nearly matched those of the LG-1 and LG-2 windrows. After that period, the microbial populations had exhausted the most readily available supply of nutrients, i.e. those present in the grass, and were left with difficult-to-degrade woodchips. The more erratic fluctuation in the CG than in the LG windrow temperatures is likely the result of the greater heterogeneity of particle size in the mix, resulting in higher levels of aeration and lower moisture contents. The CG

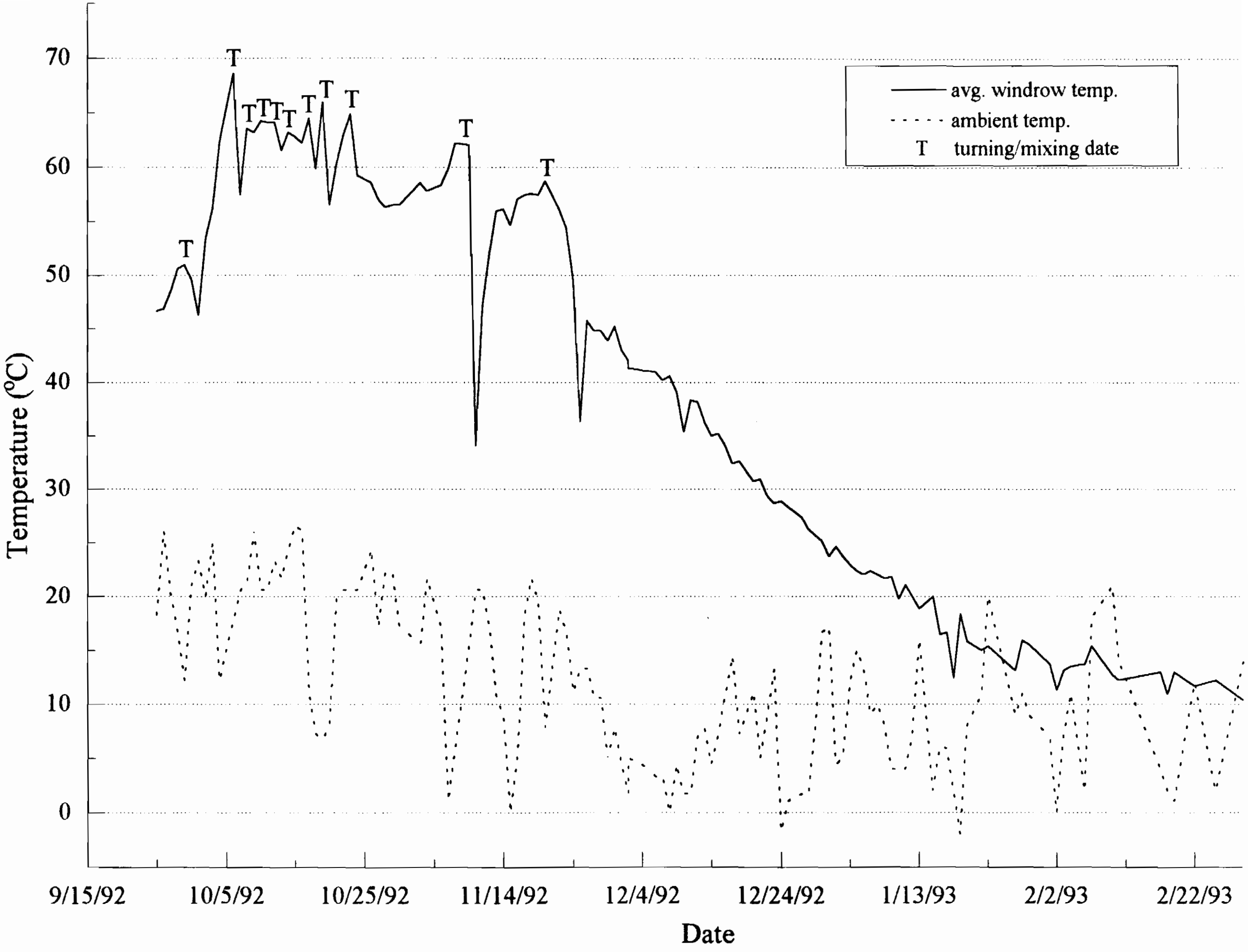


Figure 4. Temperature Profiles: Windrow LG-1 (leaves/grass-1) and Ambient

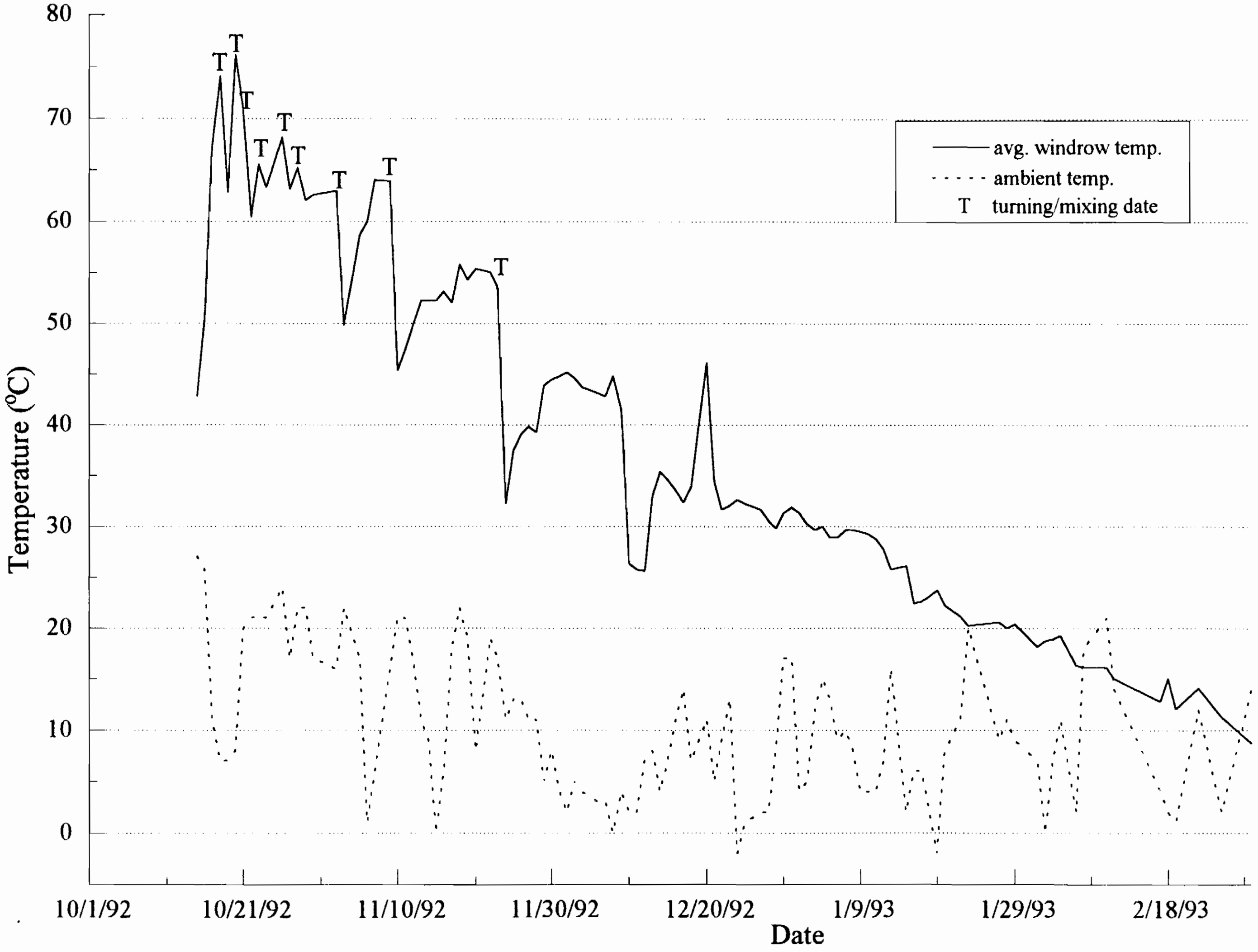


Figure 5. Temperature Profiles: Windrow LG-2 (leaves/grass-2) and Ambient

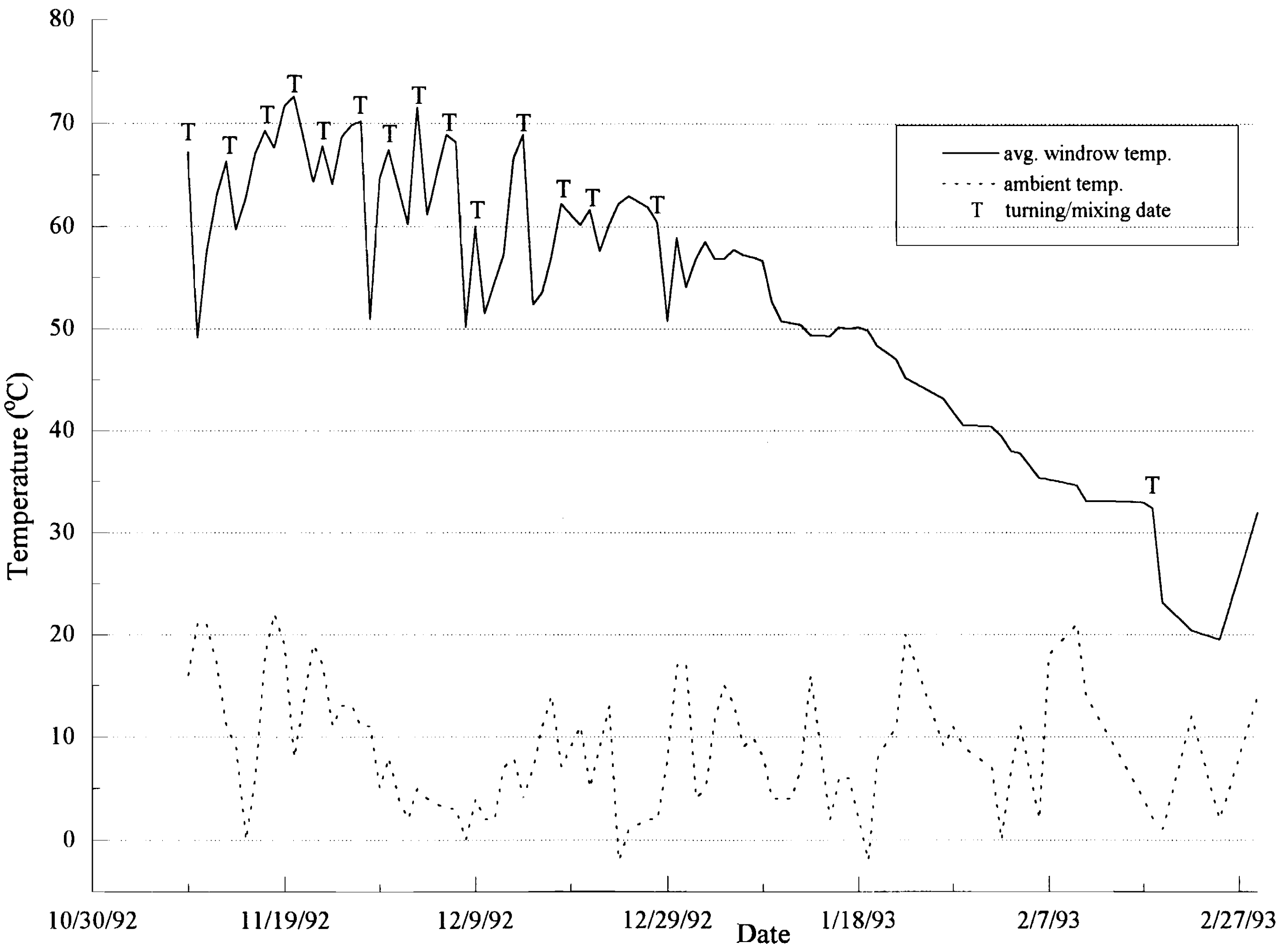


Figure 6. Temperature Profile: Windrow LG-3 (leaves/grass-3) and Ambient

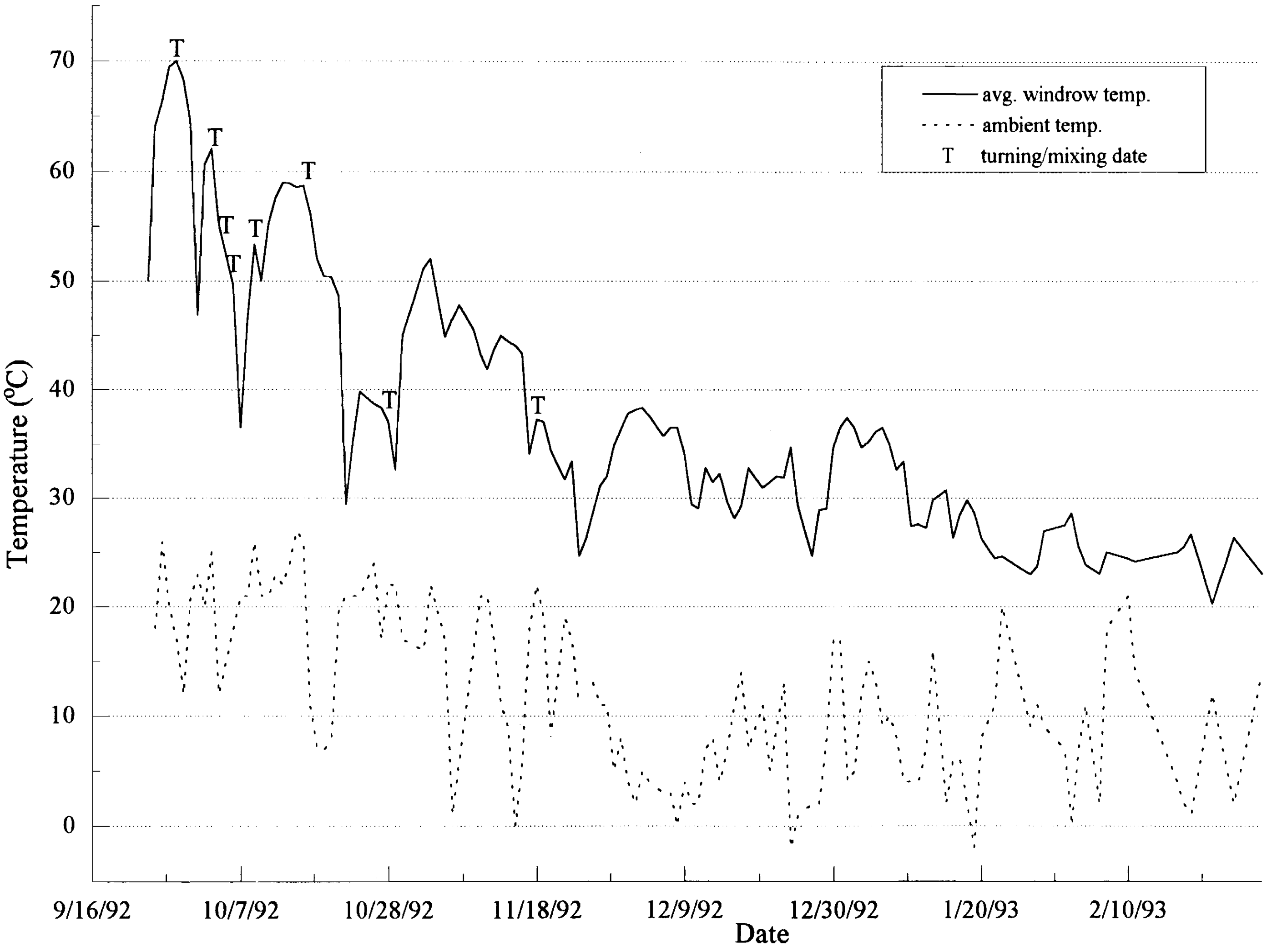


Figure 7. Temperature Profiles: Windrow CG-1 (woodchips/grass-1) and Ambient

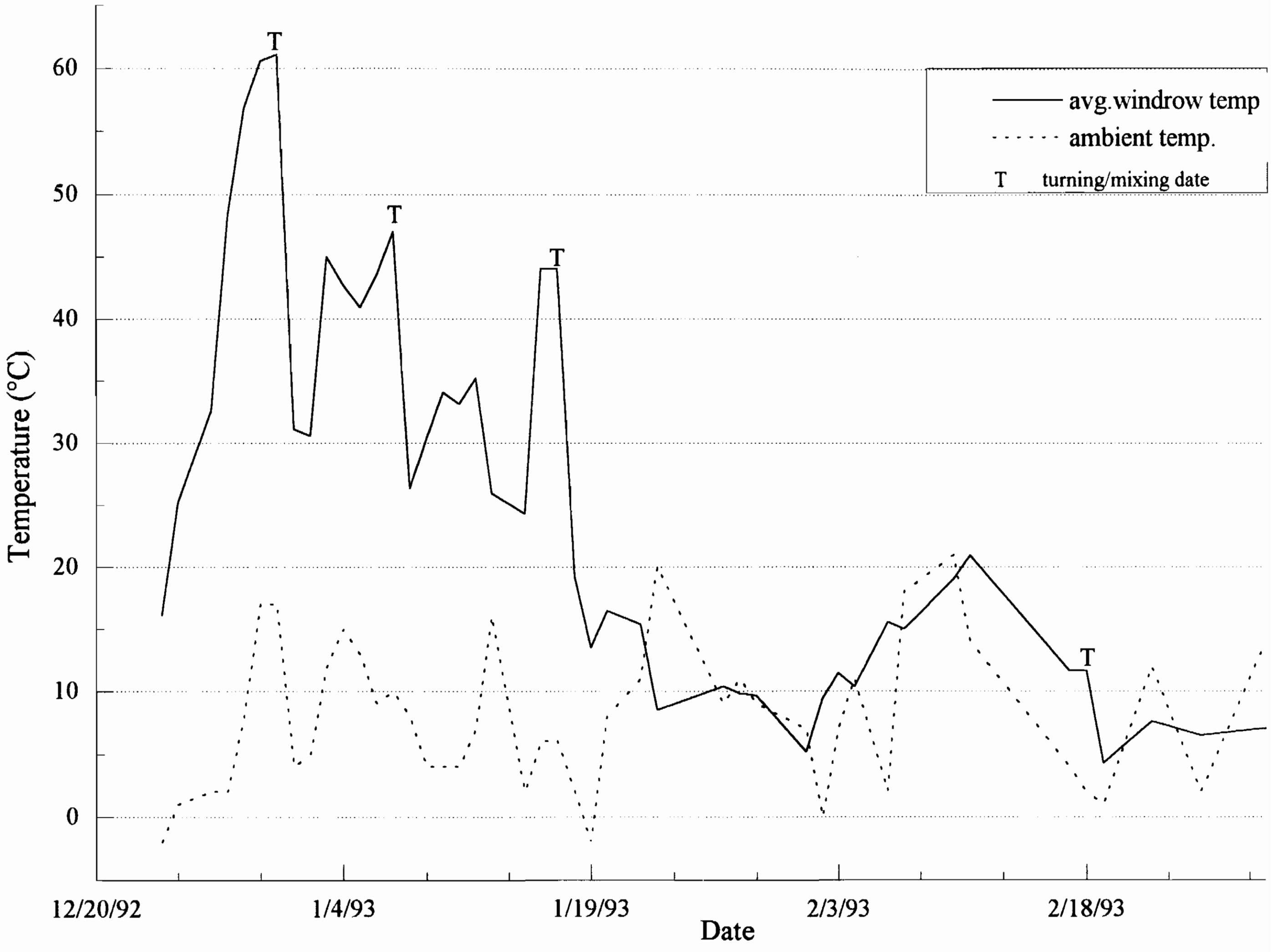


Figure 9. Temperature Profiles: Windrow CG-3 (woodchips/grass-3) and Ambient

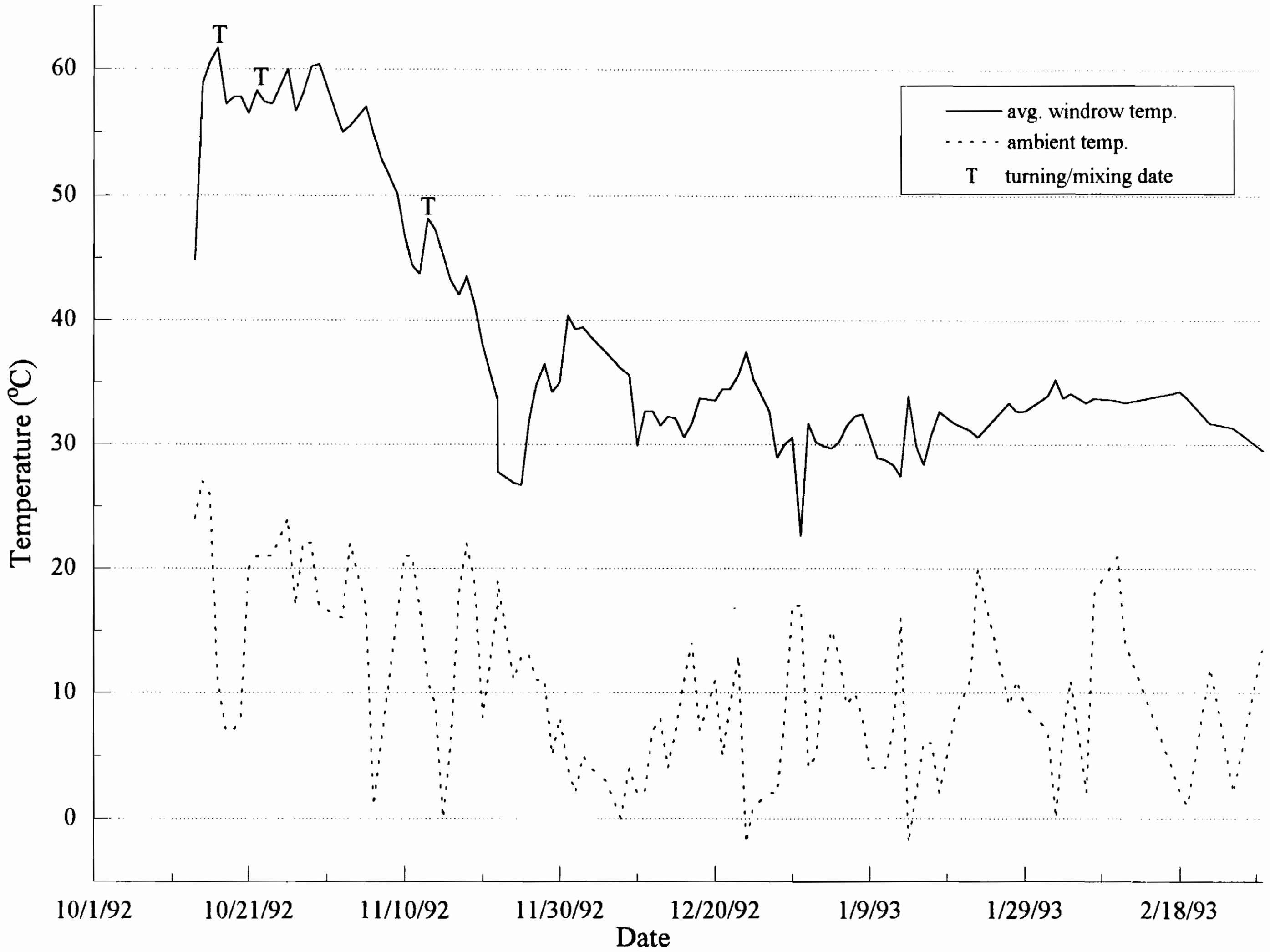


Figure 8. Temperature profiles: Windrow CG-2 (woodchips/grass-2) and Ambient

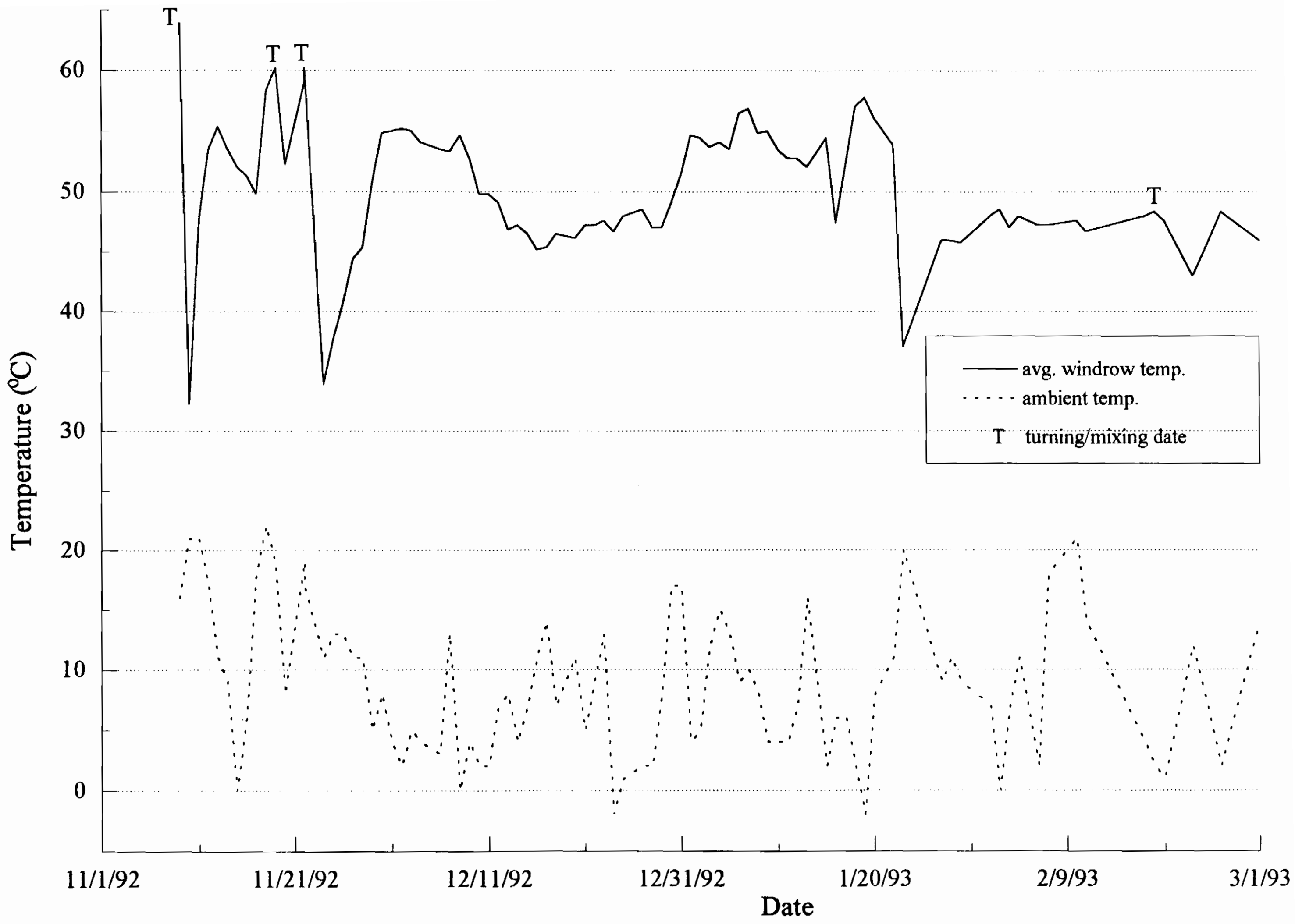


Figure 10. Temperature Profiles: Windrow LV-1 (leaves only-1) and Ambient

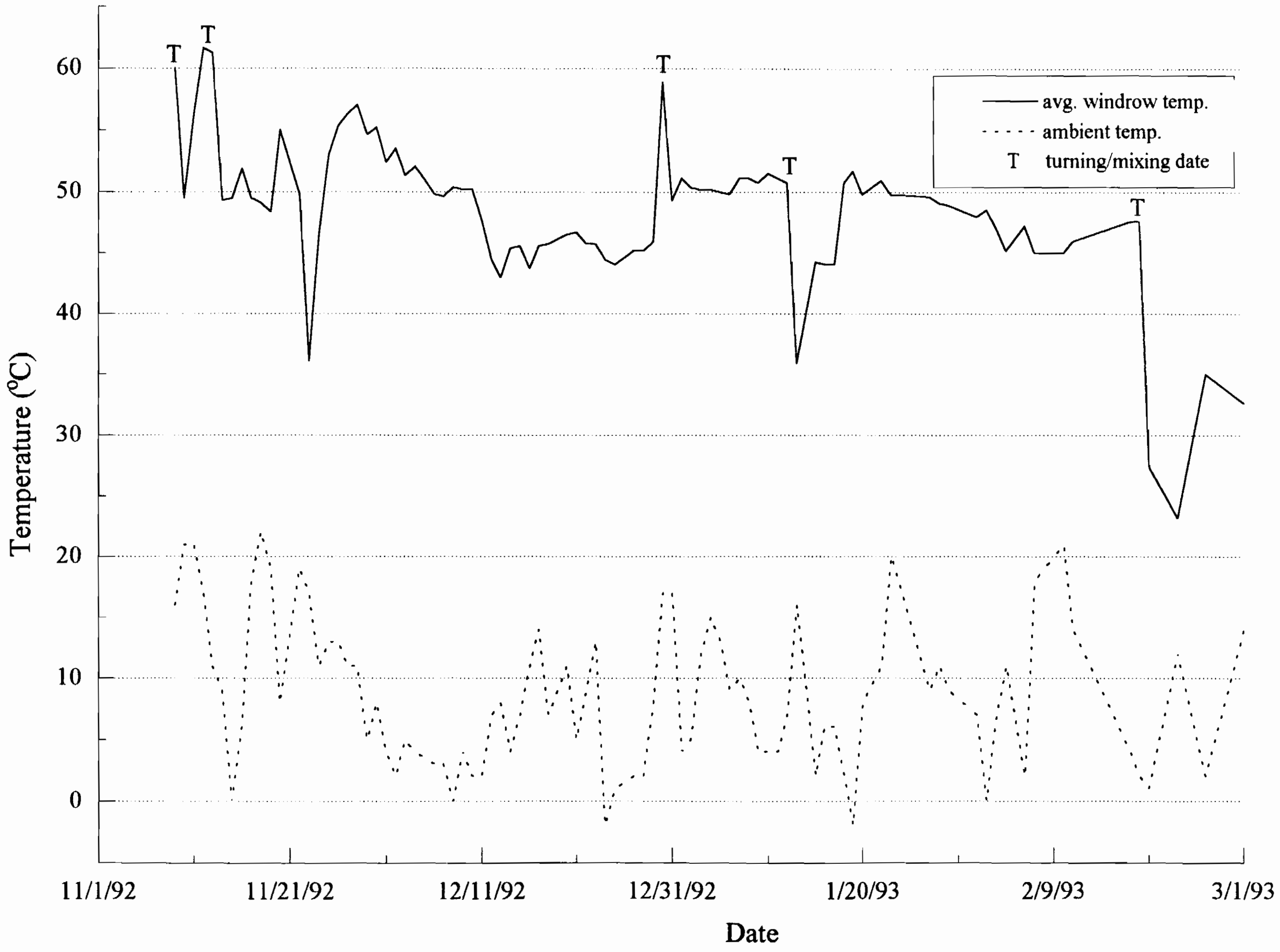


Fig. 11. Temperature profiles: Windrow LV-2 (leavesonly-2) and Ambient

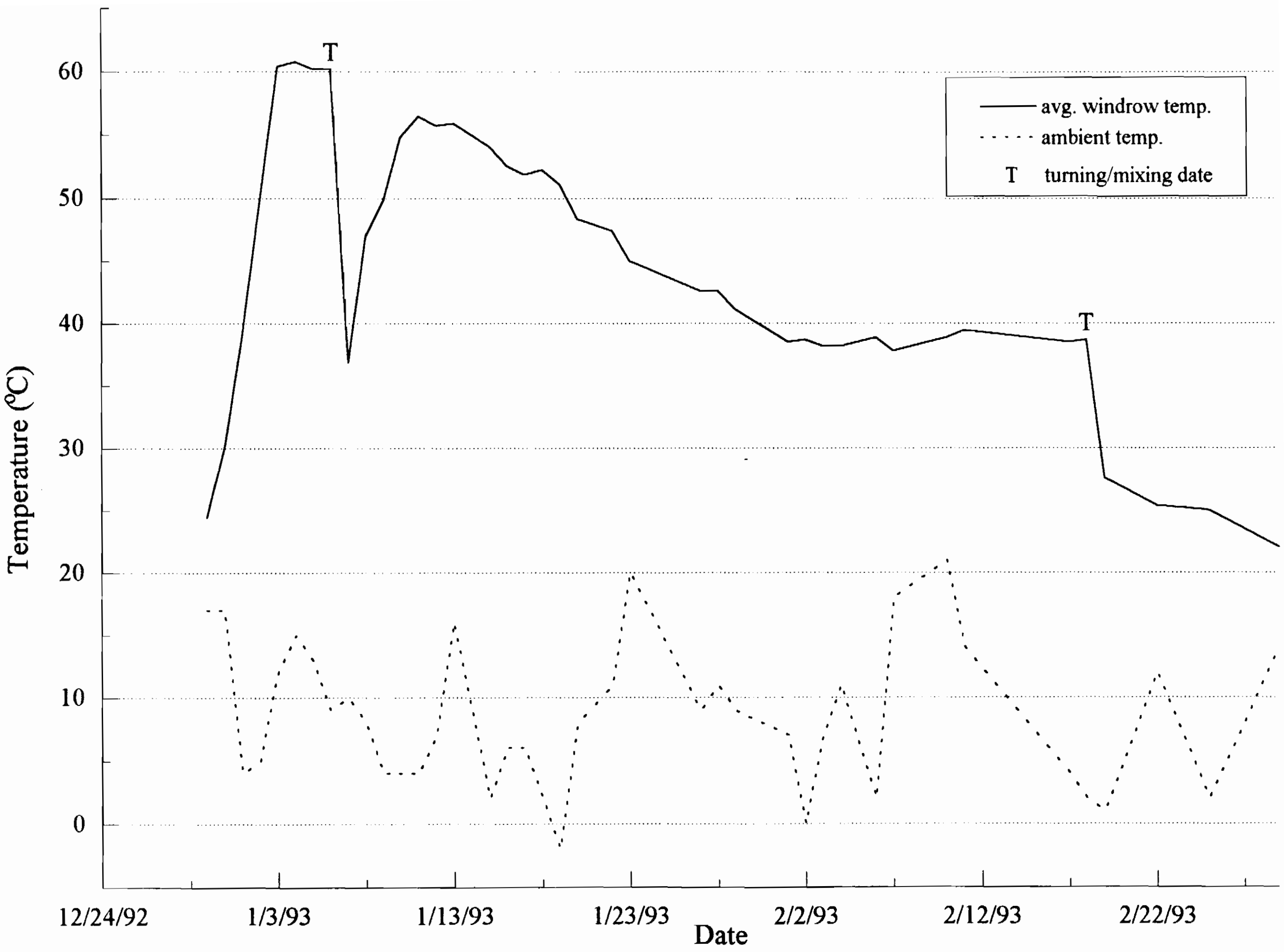


Figure 12. Temperature Profiles: Windrow LV-3 (leaves only-3) and Ambient

windrows were on average almost 5% drier (606 $g \cdot kg^{-1}$ average) than the LG windrows (649 $g \cdot kg^{-1}$ average) and nearly 10% below the average moisture content of 702 $g \cdot kg^{-1}$ in the LV windrows (Table 4). The presence of woodchips in the CG windrows may have created a greater number of macropores than in the LG windrows, resulting in greater oxygen diffusion and lower CO_2 concentrations. It is not clear whether establishing and maintaining greater moisture levels would have contributed to higher composting temperatures in the CG windrows. The decomposition rate was not apparently limited by moisture content for CG-1 and 2, given that these windrows had reached temperatures consistently below 40°C within 8 weeks (Figures 7 and 8). Temperatures in the two LV windrows remained near 50°C for 3½ months, reflecting substantial microbial activity, but not exhibiting the same predictability in temperature peaks found in the LG and CG windrows. The lack of decline in temperatures over the study period indicates a slow process of decomposition, an expected pattern with materials in which nitrogen is limiting. Additionally, decomposition was probably limited by the high average moisture content of 702 $g \cdot kg^{-1}$.

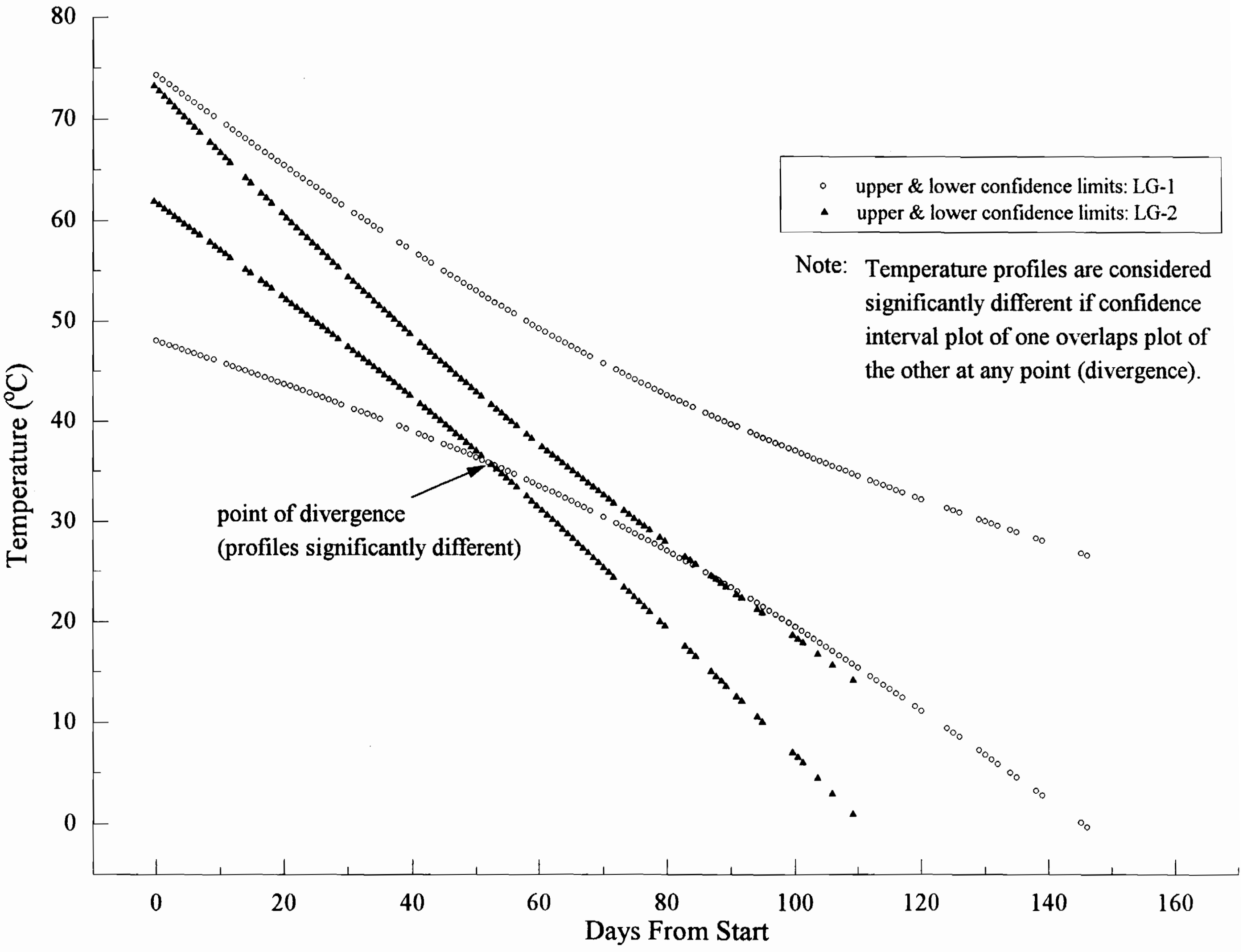
In order to assess the degree to which temperature profiles were similar within and between treatments, temperature confidence intervals were determined with a time series-based autoregression of the temperature data. Plots of the upper and lower limits of these confidence intervals for selected windrows were then overlaid to determine to what extent, if any, they overlap (Figures 13-18). For each comparison, temperature profiles are considered significantly different at the specified confidence level, if the limits for one do not lie entirely within the limits of the other, or if the limits overlap at any point. Comparisons

Table 4. Rainfall data and moisture content of windrows. (Units for windrow moisture content = g·kg^{-1})

Date	Rainfall (cm)*	LG-1	LG-2	LG-3	CG-1	CG-2	CG-3	LV-1	LV-2	LV-3
10/16/92		587			568					
10/21/92	0.30	629	587		580	411				
10/28/92	0.53	722	731		603	696				
11/06/92	3.63	680	693		612	597				
11/14/92	1.27	596	657	616	546	465		483	629	
11/20/92	0.00	575	649	578	628	597		615	644	
11/28/92	7.75	655	692	643	636	671		654	669	
12/05/92	1.40			570	636	597		614	710	
12/09/92	0.00	695	622	630	595	370		689	799	
12/17/92	2.72			648				763	808	
12/29/92	2.67	608	642	649	658	623	653	784	777	
1/14/93	5.33	‡	‡	711	‡	‡	688	704	790	610
1/22/93	2.74			646			578	770	789	668
1/26/93	1.27			763			615	682	805	730
2/01/93	0.00						646		687	720
2/15/93	1.22			674			726	720	771	716
3/02/93	6.02			673			656	768	777	618
average		638	659	650	606	558	652	687	742	677
average by mix		649			606			702		

* Cumulative between dates.

‡ Primary composting complete. Sampling terminated @ 12/29/92.



Note: Temperature profiles are considered significantly different if confidence interval plot of one overlaps plot of the other at any point (divergence).

Figure 13. Temperature profile confidence limits: Windrows LG-1 and LG-2

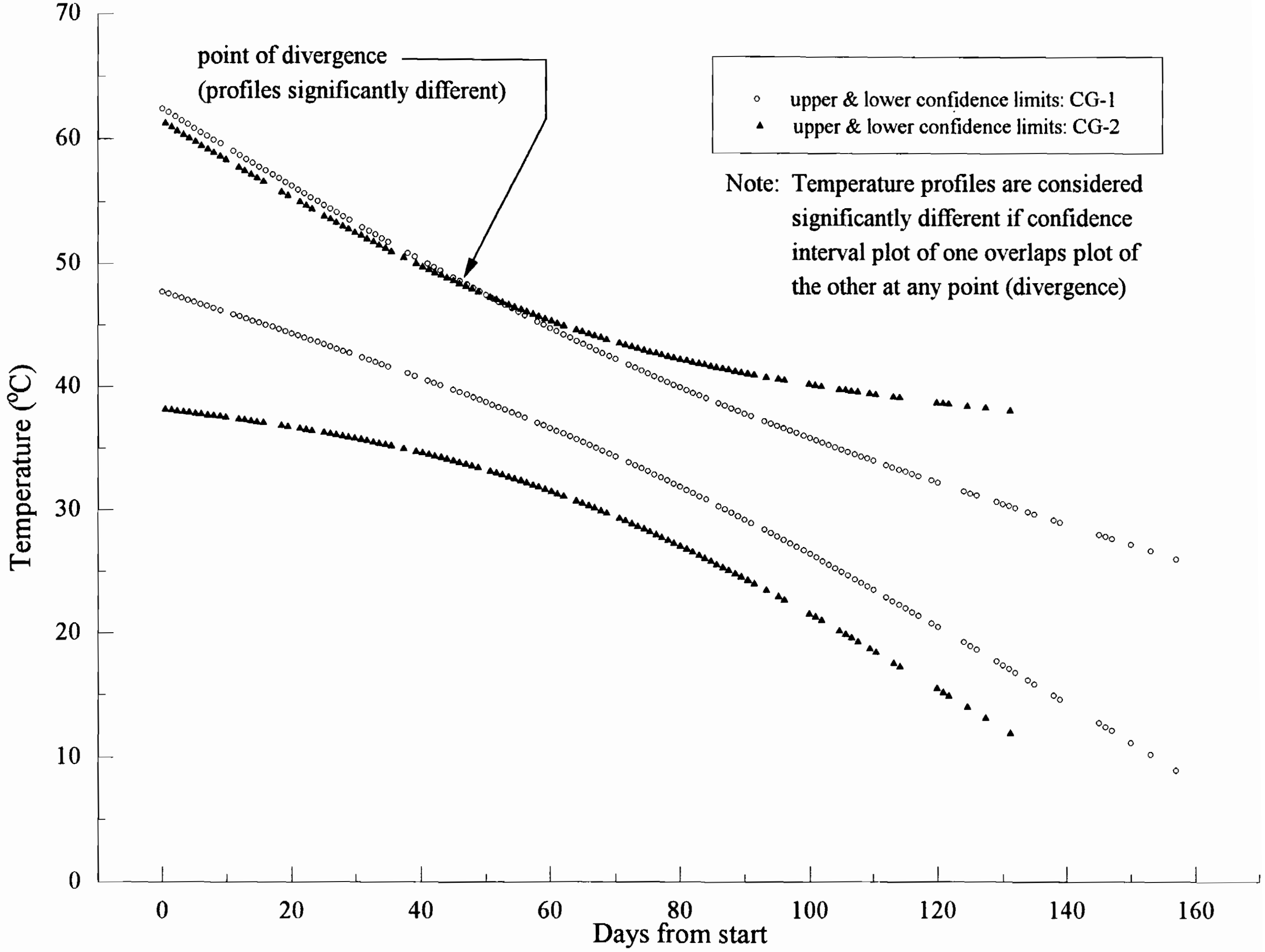
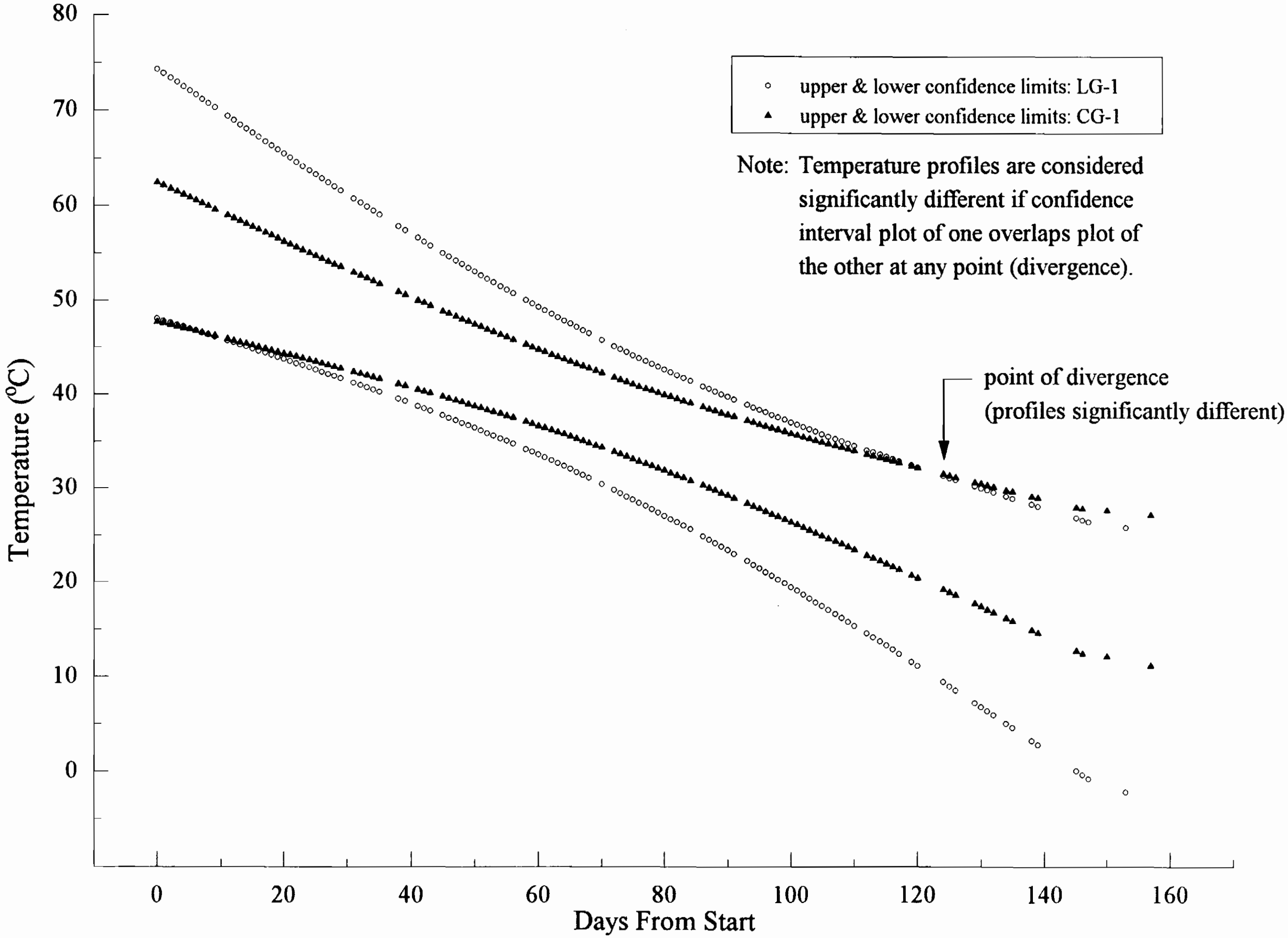
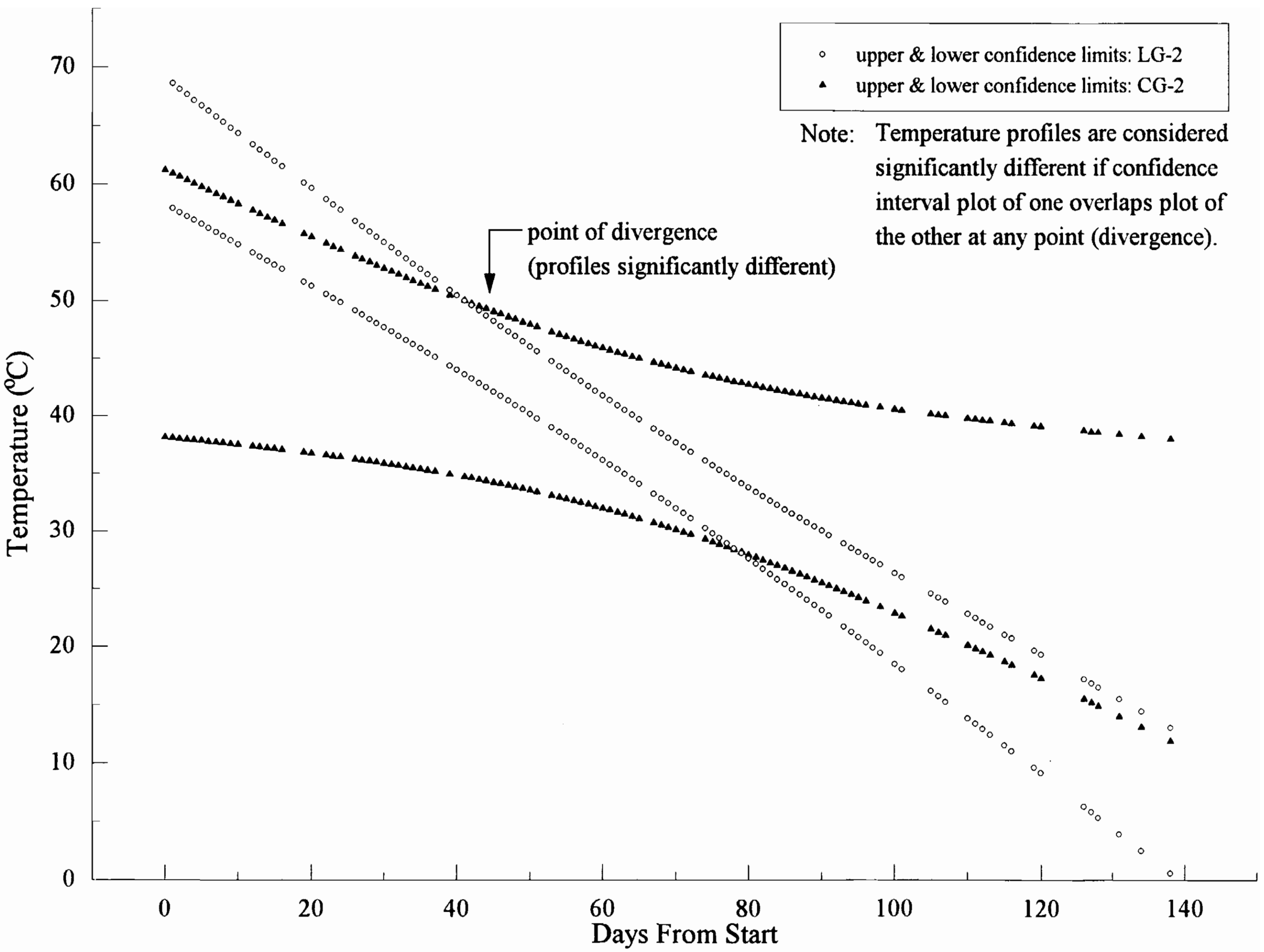


Figure 14. Temperature profile confidence limits: Windrows CG-1 and CG-2



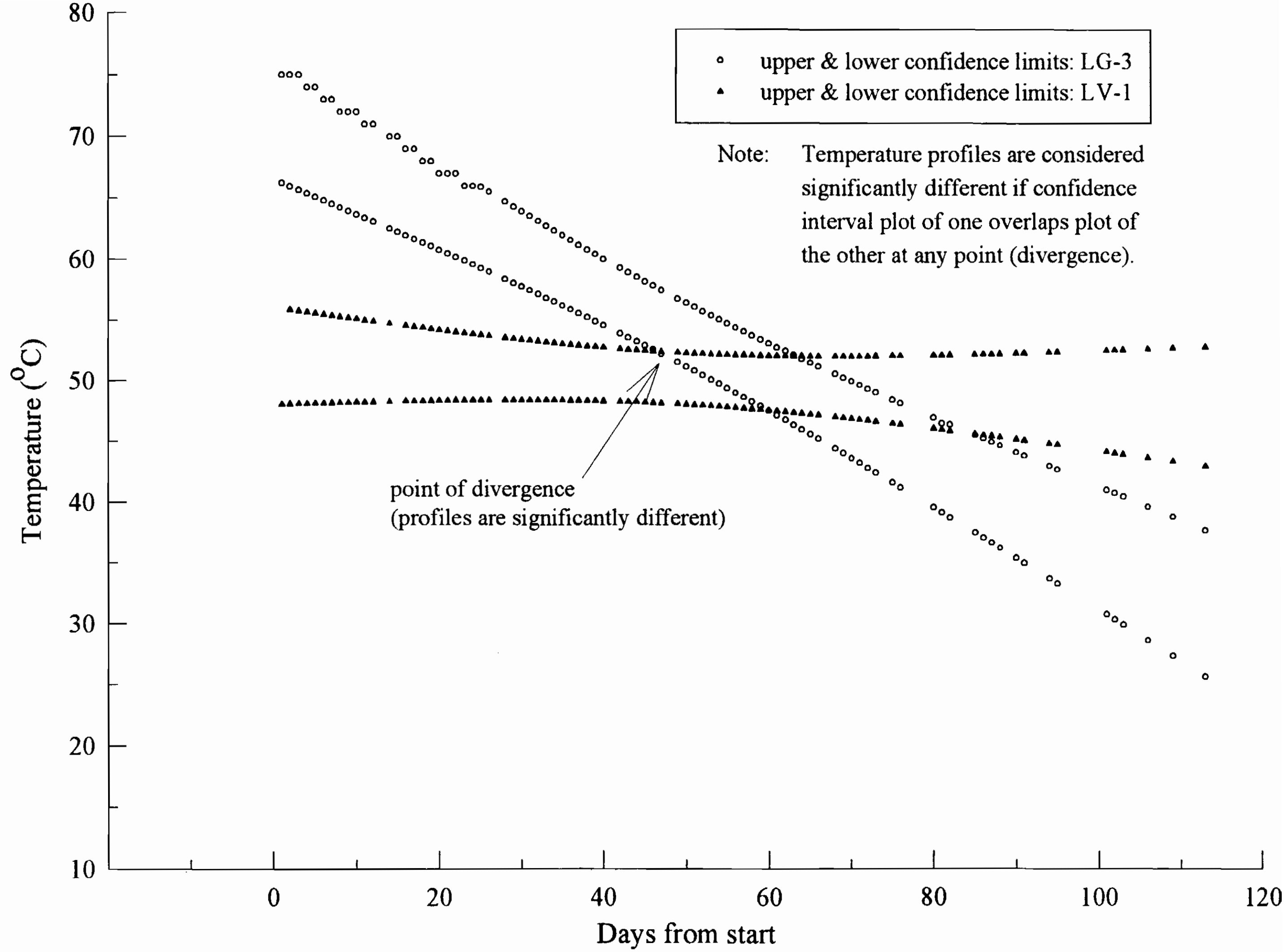
Note: Temperature profiles are considered significantly different if confidence interval plot of one overlaps plot of the other at any point (divergence).

Figure 15. Temperature profile confidence limits: Windrows LG-1 and CG-1



Note: Temperature profiles are considered significantly different if confidence interval plot of one overlaps plot of the other at any point (divergence).

Figure 16. Temperature profile confidence limits: Windrows LG-2 and CG-2



Note: Temperature profiles are considered significantly different if confidence interval plot of one overlaps plot of the other at any point (divergence).

point of divergence
(profiles are significantly different)

Figure 17. Temperature Profile Confidence Limits: Windrows LG-3 and LV-1

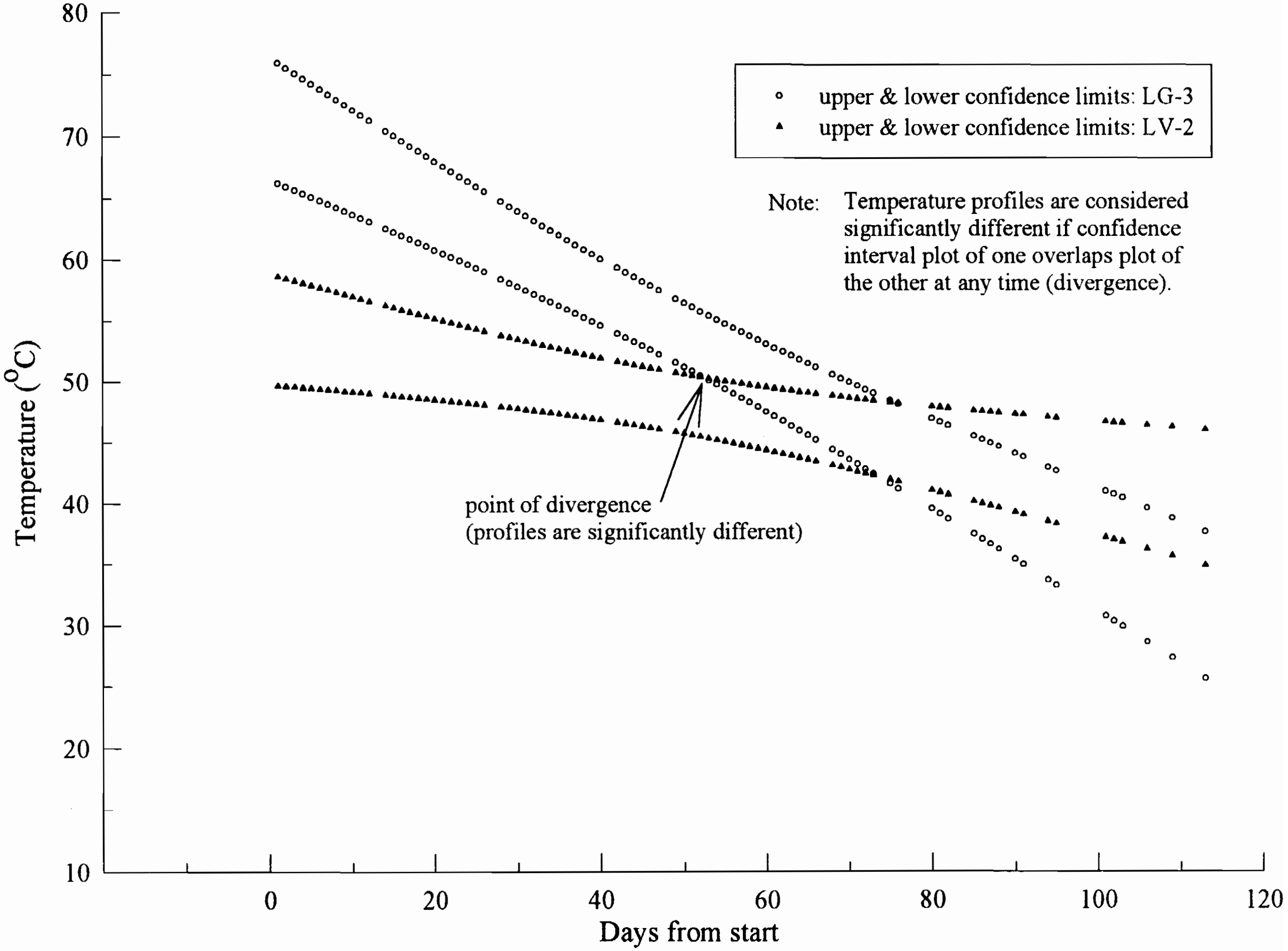


Figure 18. Temperature Profile Confidence Limits: Windrows LG-3 and LV-2

were made of LG-1 and 2 (Figure 13), CG-1 and 2 (Figure 14), LG-1 and CG-1 (Figure 15), LG-2 and CG-2 (Figure 16), LG-3 and LV-1 (Figure 17), and LG-3 and LV-2 (Figure 18). To control for the lack of independence of data sets, the first four comparisons were conducted at the 0.0125 (0.05/4) level, and the last two at the 0.025 level (0.05/2). This comparison-wise error rate renders the experiment-wise error rate to be approximately 0.05 using the Bonferroni approach (Neter *et al.*, 1990).

These figures reveal that the two temperature profiles in each of the comparisons are significantly different. In Figure 13 the divergence of confidence intervals for LG-1 and 2 occurs at the beginning of the composting period and continues for 40 days from the construction of LG-2. LG-1 was constructed 3 weeks prior to LG-2, so this early divergence may not be surprising. As described above, the temperature profiles for these two windrows (Figures 4 and 5) indicate a steady decline from initial high temperatures. Interestingly, the plots with the fewest points of divergence were those of LG-1 vs CG-1 (Figure 15). This occurred after 155 days, which was February 25th, 1993, and the beginning of the most severe weather. The differences between windrows CG-1 and CG-2 (Figure 14) are more striking than those between the LG-1 and 2 windrows, with the plot for CG-2 indicating a less steep decline in temperature. Moisture content probably played a primary role in this difference, since percent moisture for CG-2 averaged about 5% lower than that for CG-1 (Table 4). The plots for LG-2 vs CG-2 (Figure 16) indicate quite divergent patterns of change in temperature over the composting period. Although constructed on consecutive days and, thus, subject to the same climatic conditions, these windrows underwent dissimilar patterns of biological activity as reflected in their temperature profiles. Because the short period of high temperatures exhibited by CG-2 at the beginning of the process (approximately 30 days), was followed by an extended period of temperatures averaging only slightly higher than 30°C (Figure 8), the confidence interval plot for this windrow over the nearly 4 month period does not reflect the rapidity of the initial decomposition. Moisture content in CG-2 averaged approximately 10% lower than in LG-2 and 5% lower than in CG-1 during the measurement period for that parameter (Table 4) and, thus, may have been too dry on average for optimum decomposition. Figures 16 and 17 reveal a greatly different trend in temperature change for LG-3 as compared to LV-1 and LV-2, respectively. The presence of grass clippings in LG-3 provided considerably more of the readily available nitrogen necessary for efficient composting than was present in the LV windrows. The high moisture content of the LV windrows also likely hindered decomposition and, therefore, the achievement of higher temperatures.

Overall, windrows were prevented from consistently achieving maximum possible temperature peaks below the set-point after turning/mixing, because of both too much and too little moisture.

4.2.4 Gas Relationships. During the most active composting period, more optimum conditions existed in leaf/grass windrows than in woodchip/grass or leaves-only windrows, as reflected by the production of carbon dioxide at concentrations up to 4 times greater in the former. The general trends in all 3 gases were similar for the CG (Figures 22-24) and LV

(Figures 25-27) windrows, as opposed to the pattern exhibited in the LG windrows (Figures 19-21), where there were steeper rises in O_2 concentrations and steeper declines in CO_2 concentrations throughout, as well as more frequent measured presence of CH_4 in 2 of the three LG windrows. Carbon dioxide production in the LG windrows during the first 8 weeks ranged up to roughly 8.5 mmol/l (Figures 19-21), and was substantially greater overall than in the other two treatments, for which recorded maximum CO_2 concentrations were 2.07 mmol/l (CG) (Figures 22-24) and 2.79 mmol/l (LV) (Figures 25-27). The temperature/gas profiles for all three treatments reveal that CO_2 remained below 2.00 mmol/l in almost all samples, when temperatures fell below 40°C. The likelihood that greater particle-size variability in the CG windrows led to greater aeration is supported by the oxygen concentrations indicated in Figures 22-24 (CG) and Figures 19-21 (LG) in the initial composting period. Within a particular microsite, greater aeration can result in a higher O_2 concentration without a corresponding decrease in CO_2 production. Comparison of these microsite concentrations of windrow gases with the quantities of evolved gases reported in the literature is not possible, since those studies were conducted in enclosed pilot-scale/bench-type systems.

In another perspective, the CG windrows, which were the most dry on average, generally exhibited the lowest average concentrations of CO_2 (Figures 22-24). For the two CG windrows constructed first, temperatures remained below those considered optimum for an extended period; yet, decomposition seemed to proceed more readily and steadily than in the LV windrows. It is possible that this particular mix has a lower optimum moisture

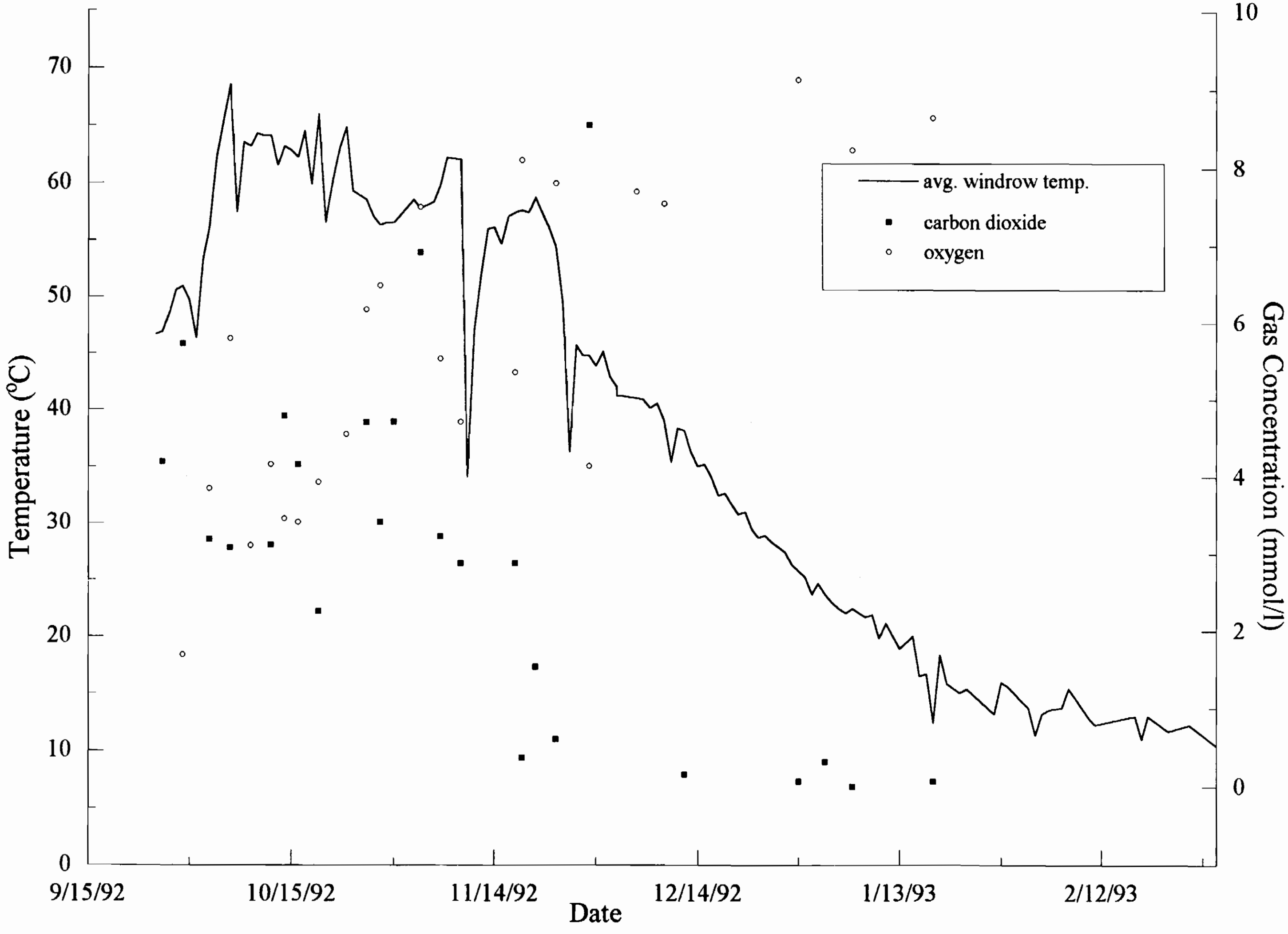


Figure19. Temperature/Gas Relationships: Windrow LG-1 (leaves/grass-1)

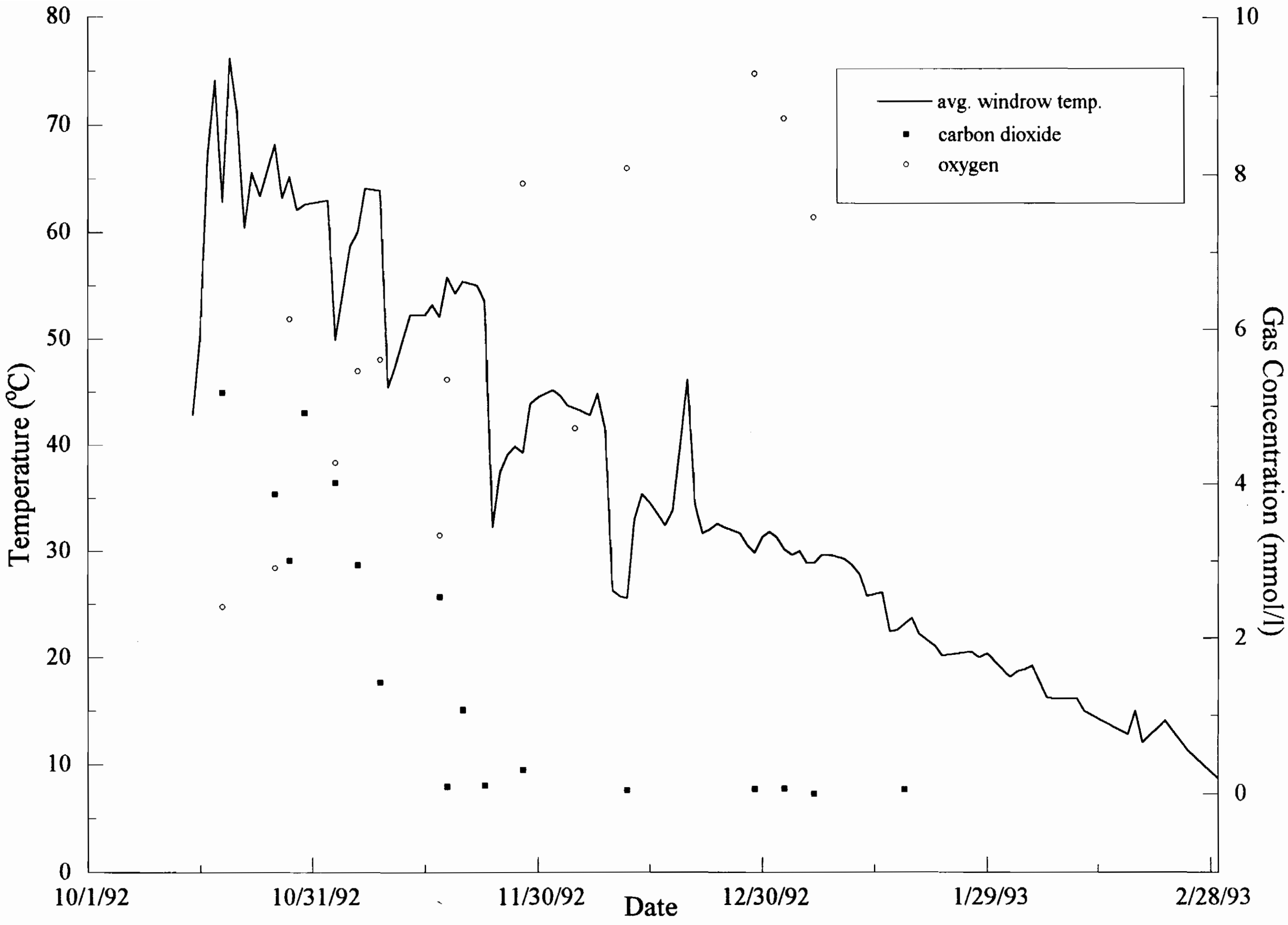


Figure 20. Temperature/Gas Relationships: Windrow LG-2 (leaves/grass-2)

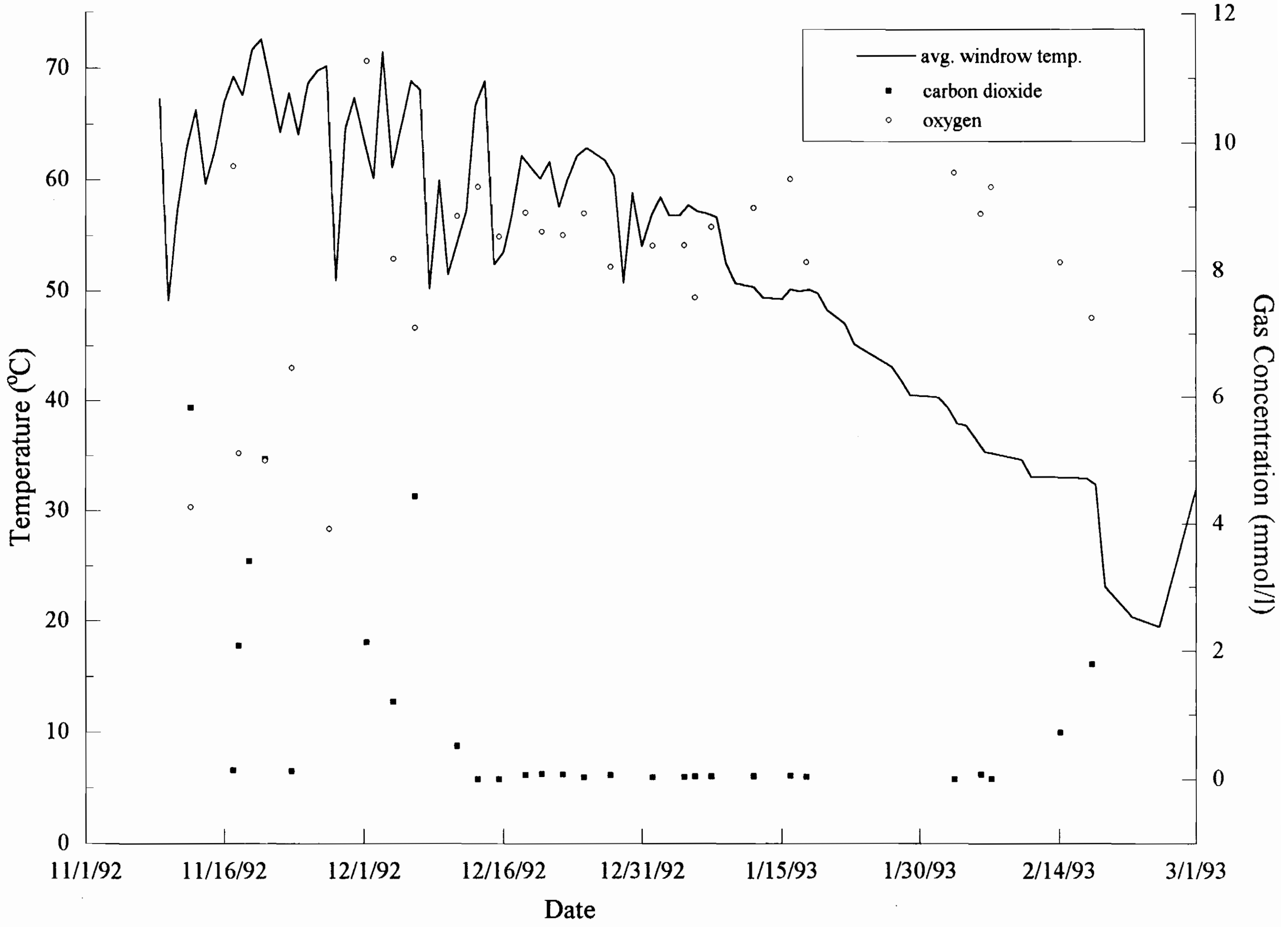


Figure 21. Temperature/Gas Relationships: Windrow LG-3 (leaves/grass-3)

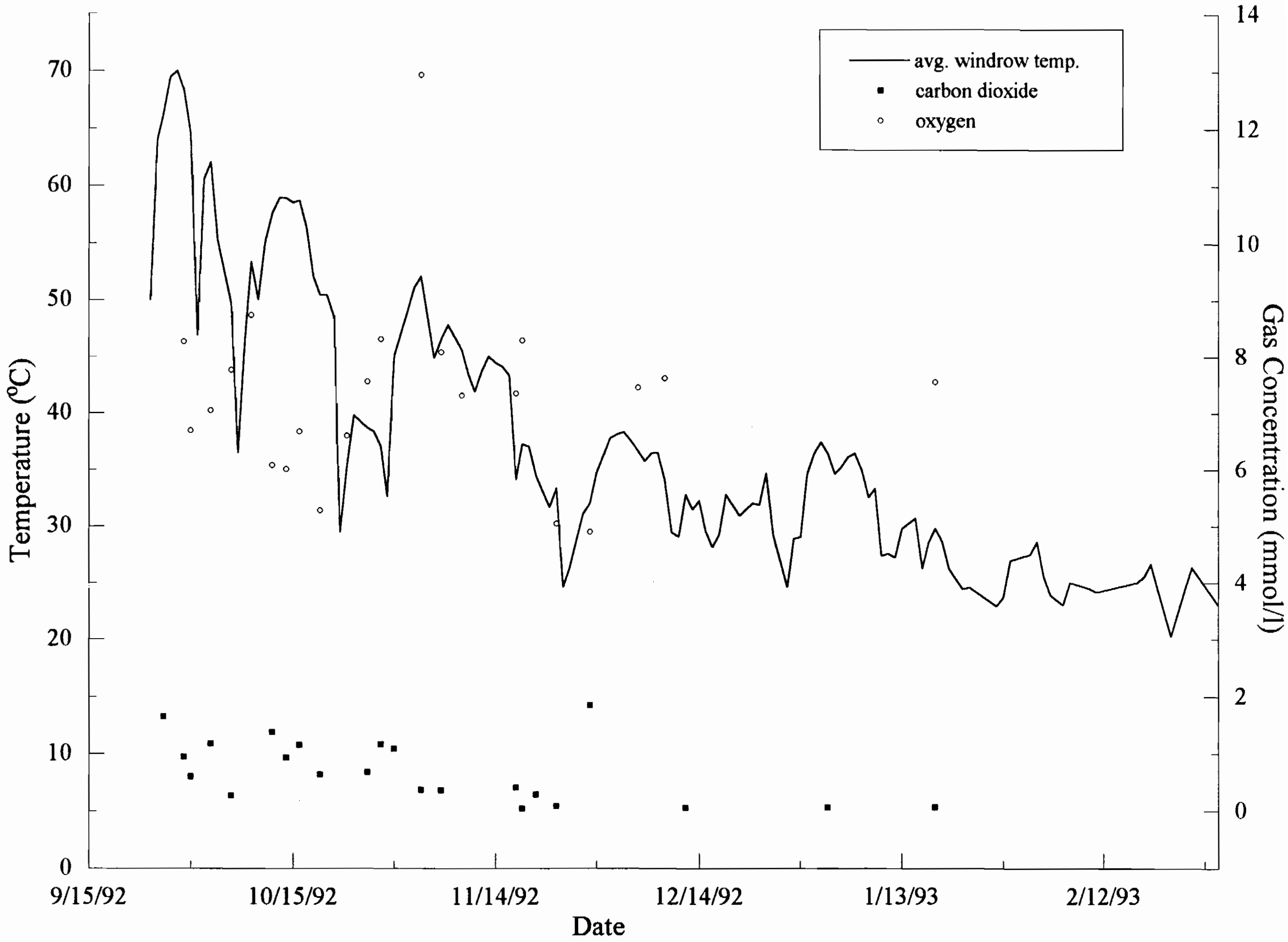


Figure 22. Temperature/Gas Relationships: Windrow CG-1 (woodchips/grass-1)

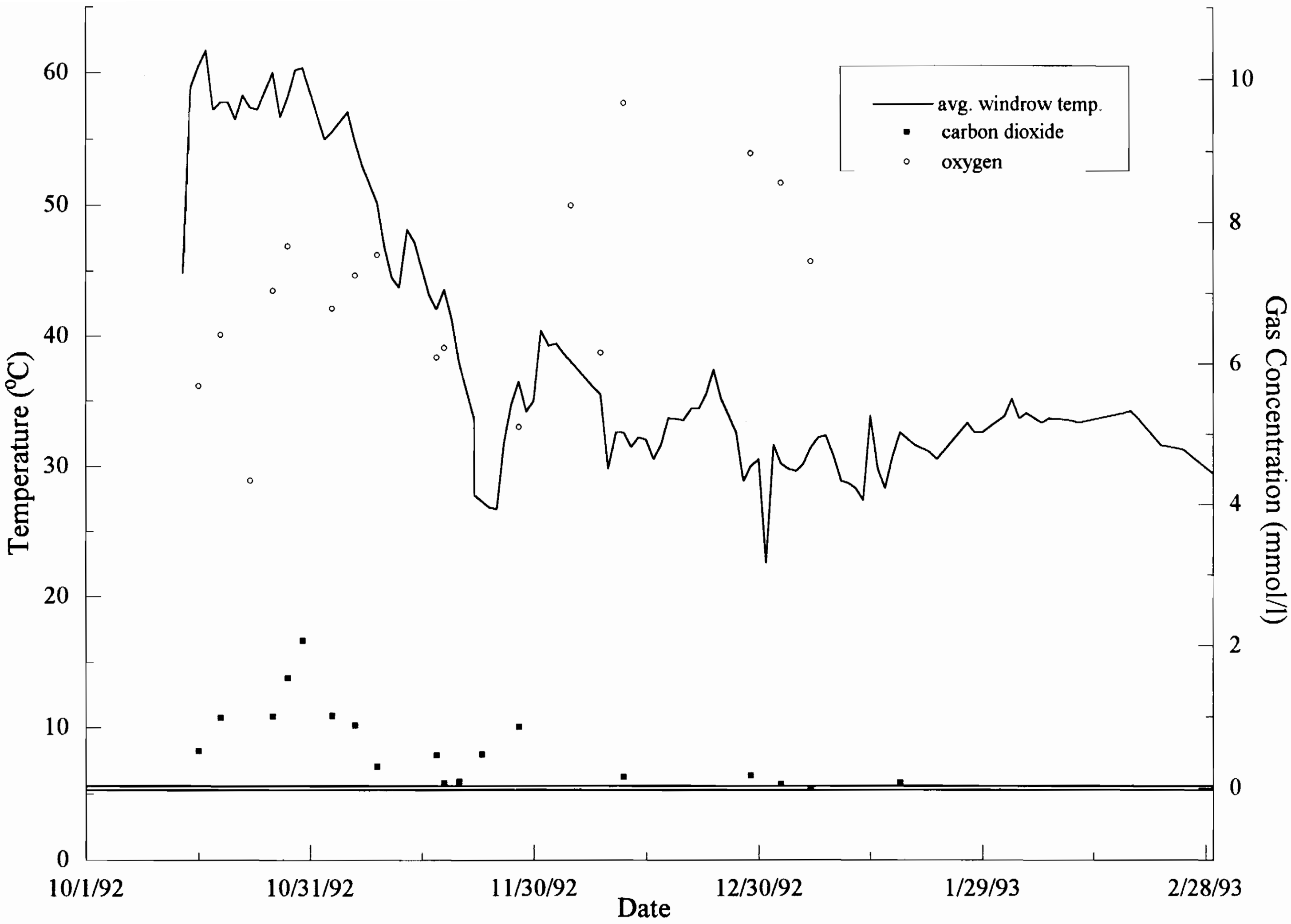


Figure 23. Temperature/Gas Relationships: Windrow CG-2 (woodchips/grass-2)

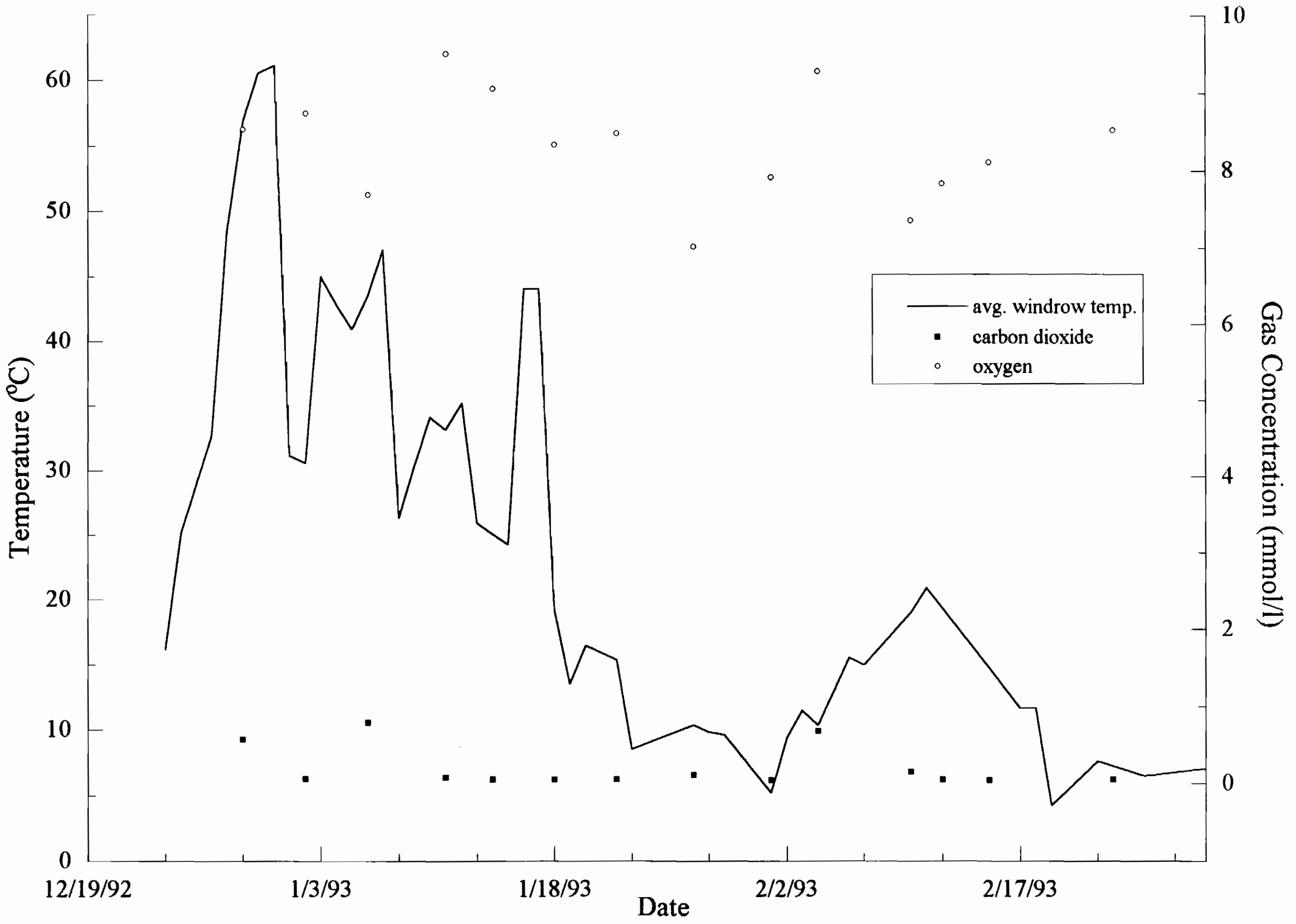


Figure 24. Temperature/Gas Relationships: Windrow CG-3 (woodchips/grass-3)

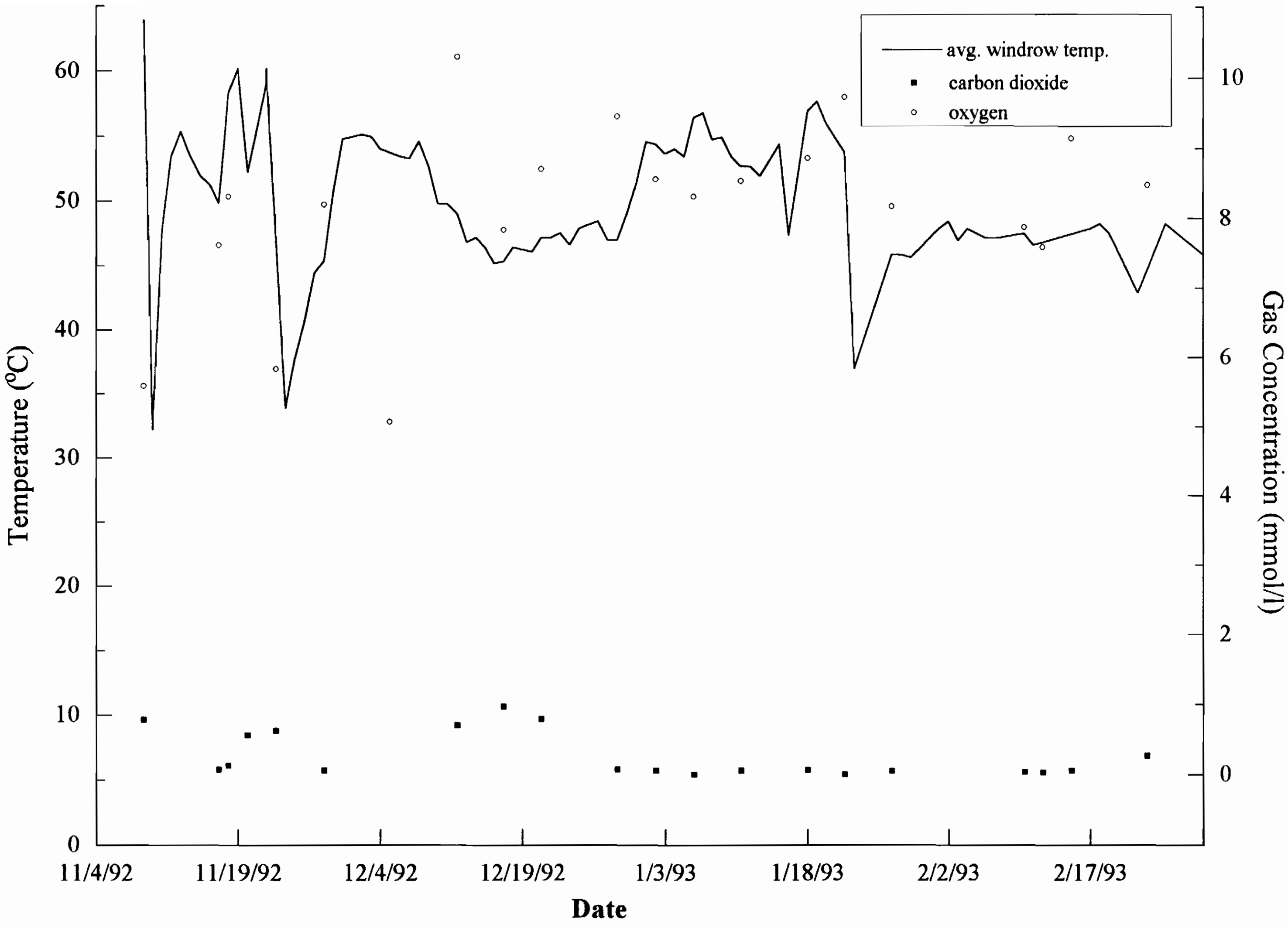


Figure 25. Temperature/Gas Relationships: Windrow LV-1 (leaves only-1)

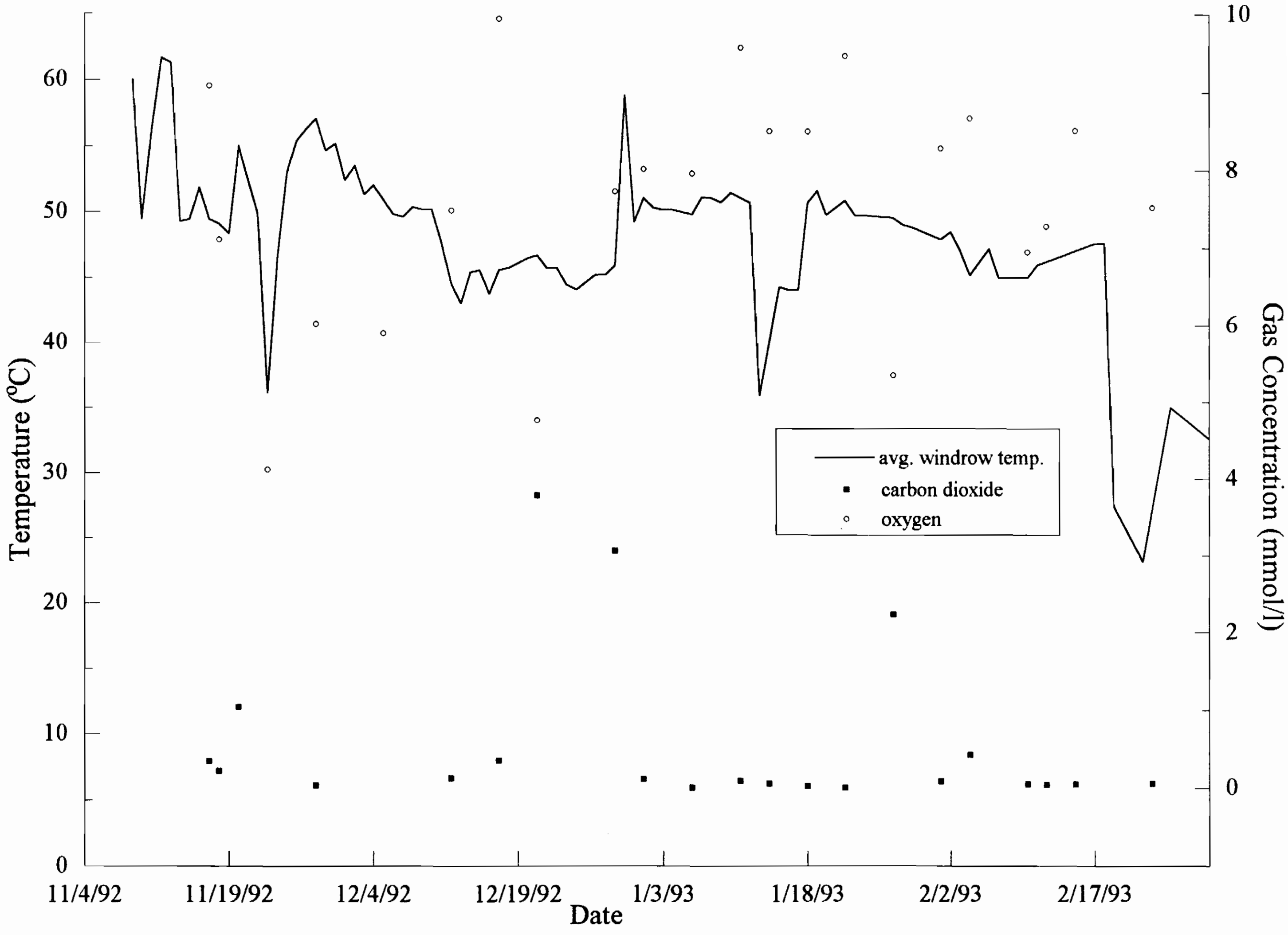


Figure 26. Temperature/Gas Relationships: Windrow LV-2 (leaves only-2)

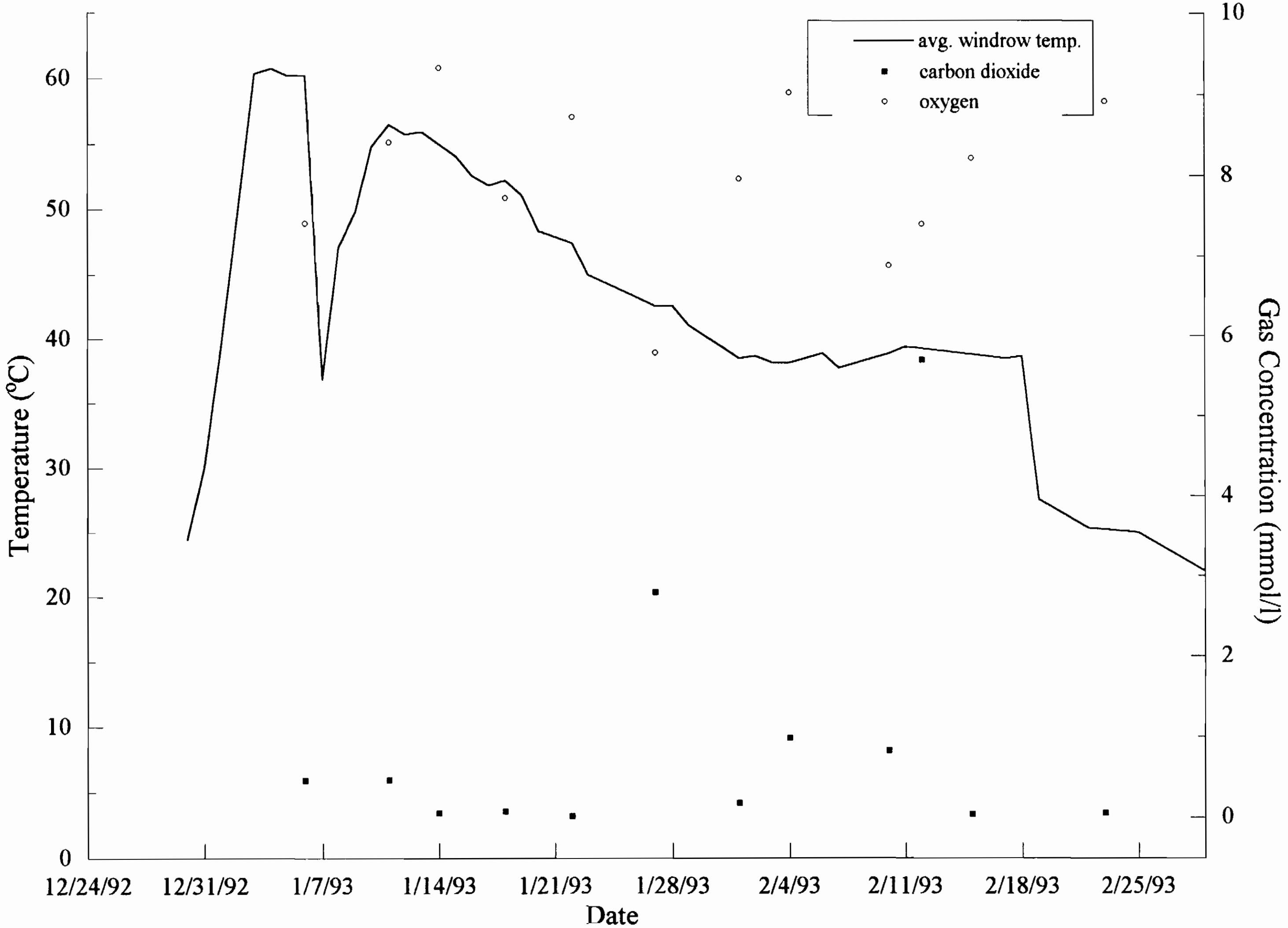


Figure 27. Temperature/Gas Relationships: Windrow LV-3 (leaves only-3)

content because of particle size distribution or that aspect in combination with others. The highest concentrations of CO_2 in CG-1 and 2 occured during initial decomposition, and were accompanied by their highest temperatures.

Measured CO_2 concentrations in LV-1 were never greater than 2.5 mmol/l (Figure 25), despite the fact that windrow temperatures remained almost entirely between 40 and 60°C from onset of decomposition to early March 1993. This windrow exhibited very little decomposition as reflected by the limited decline in C/N ratio from 40:1 to 30:1. Average moisture content (Table 4) was high (687.2 $g \cdot kg^{-1}$). LV-2 exhibited a similar average moisture content (742.7 $g \cdot kg^{-1}$) and change in C/N ratio (41 to 32:1), yet, had a generally higher measured concentration of CO_2 (Figure 26). This would seem to suggest very little relationship between temperature changes and CO_2 production in the LV windrows. The fact that frequent measurements of CO_2 concentrations greater than 1.25 mmol/l in LV-1 and 2 (Figures 25 and 26) equaled or exceeded those in the CG windrows does not necessarily indicate a greater rate of decomposition in the LV windrows, given that average moisture contents in the LV windrows were near or in excess of 700 $g \cdot kg^{-1}$ (Table 4), and that CO_2 production results from anaerobic as well as aerobic conditions. These factors, and the prevalence of undecomposed leaves in the samples collected at the close of the study period, reflect the likelihood that the LV windrows were subject to process limiting moisture conditions. The minimum and mean pH measurements of 6.18 and 6.98, respectively, in the leachate from LV-2 (Table 8) may suggest anaerobiosis, since organic acids contributing to low pH result under those reduced conditions.

Although insufficient data points precluded the possible establishment of a causative relationship between carbon dioxide and oxygen concentration within or between treatments, statistical correlations were found to exist between these gases in some windrows. These are reported in Table 5. For LG-1, LG-3, and LV-3, O_2 and CO_2 can be considered to be moderately negatively correlated, whereas, they are strongly negatively correlated in LG-2 and LV-2. P-values exceeded the alpha level for the correlations in the other windrows. Oxygen and carbon dioxide were most closely correlated ($r^2 = 0.663$) in LG-2. The O_2-CO_2 relationships for LG-1, LG-3, LV-2 and LV-3 can be characterized 40 to 50% of the time. A two-sample test was created to determine whether correlations are significantly different between mixes, i.e., whether a characteristic correlation between oxygen and carbon dioxide might exist in the leaves/grass mix and be different than in the leaves/only mix. Such relationships, if present and identifiable, might enable better process management. The results of this analysis are also reported in Table 5 and indicate that the correlations for LG-1 and LG-2, LG-1 and LG-3, LG-2 and LG-3, and LV-2 and LV-3 are not significantly different at the 0.0125 level (0.05/4); e.g., the correlation of O_2 to CO_2 in LG-1 was not significantly different from that in LG-2, and so forth, for the other three comparisons. To accommodate the lack of independence in the comparisons, the Bonferroni approach was used to control the alpha level to result in an experiment-wise error rate of approximately 0.05 (Neter *et al.*, 1990). This approach yields conservative determinations, because a significant difference is more difficult to establish. Larger data sets and perhaps an alternative sampling regime might provide stronger support for the hypothesis that O_2-CO_2 correlations can be mix-specific.

Table 5. Correlation of carbon dioxide to oxygen within and between windrows.

Windrow	r	r^2	P value ($\propto = 0.05$)	Windrows	Test statistic[1] Z*	P value ($\propto = 0.0125$)
LG-1	-0.631	0.398	0.0029[‡]	LG-1 & 2	1.0540	0.290[2]
LG-2	-0.814	0.663	0.0020[‡]	LG-2 & 3	-0.8650	0.389
LG-3	-0.682	0.465	0.0010[‡]	LG-1 & 3	0.2885	0.774
CG-1	-0.314		0.2040			
CG-2	-0.430		0.0963			
CG-3	-0.038		0.8690			
LV-1	-0.430		0.0318[‡]			
LV-2	-0.703	0.494	0.0010[‡]			
LV-3	-0.668	0.446	0.0018[‡]	LV-2 & 3	-0.2060	0.834

[‡] P value < 0.05. Correlation is significant

[1] Test Statistic: $Z^* = (z_{r1} - z_{r2}) / \sqrt{[1/(n_1-3)] + [1/(n_2-3)]}$
Statistic created to test whether 2 correlations are statistically different
where: r = calculated correlation;
$z_{r1} = \frac{1}{2} \ln [(1+r^1)/(1-r^1)]$, and n_1 = sample size of data for r^1;
$z_{r2} = \frac{1}{2} \ln [(1+r^2)/(1-r^2)]$, and n_2 = sample size of data for r^2

[2] The p value corresponds to the calculated Z* (utilizing a standard normal table). For $p > \propto$, correlations are not significantly different at the 0.0125 level.

Methane was measured in LG-1 on 15 of the first 20 sampling days (collected between 9/29 and 11/28/92) with concentrations ranging from 1.13×10^{-2} to 2.34 mmol/l. Of the seven occasions on which methane presence was detected in LG-2, the maximum concentration was 0.453 mmol/l. Windrow LG-3 had minimal, but measured methane concentrations on two sampling days ($\leq 5.854 \times 10^{-6}$ mmol/l). This windrow received better process management, and was turned several more times than LG-1 and 2 during the initial rapid decomposition period, promoting better aeration as a by-product of temperature control. A maximum methane concentration of 4.14×10^{-2} mmol/l was measured in CG-1, which exhibited microsite anaerobiosis in several samples on 5 days. A single CH_4 concentration of 3.53×10^{-2} mmol/l was recorded for CG-2 and very small concentrations were measured once in the first two LV windrows (3.6×10^{-3} and 2.34×10^{-6} mmol/l in LV-1 and 2, respectively). No methane was detected in samples from CG-3 and LV-3. The lack of more frequent CH_4 measurement in the LV windrows does not preclude the presence of anaerobic conditions, since reduced environments can exist in which methanogensis does not occur.

The low-technology composting process in this research produced little methane. Because methane is a more pernicious greenhouse gas than carbon dioxide, composting is the more desirable strategy for yard waste management, as compared to landfilling, from an atmospheric protection perspective.

4.3. LEACHATE CHARACTERISTICS.

Results of leachate quality analyses are presented in Tables 6 through 8. Comparison between leachate from different mixes is complicated, because each windrow underwent different moisture management. Windrows were not always watered when they were turned, and were likely watered excessively on some occasions. The amount of leachate varied greatly, due to the sampling schedule, watering pattern, and quantity and duration of precipitation. In many cases, too little leachate volume was produced for sampling. The retention pond was sufficiently large to avoid overflow onto the filter strip. The quantities of generated leachate, though not measured, were visually assessed at collection. Over any 7 day period throughout the study, the leachate overflowed the 18.9 liter collection bucket on several, but not more than 5 occasions at each plot. The total leachate per windrow is estimated not to have exceeded 100 liters between construction and March 1, 1993, a considerably smaller volume than those for which the discharge standards reported in Tables 6 and 8 were established. Approximately 66 percent of the total wastewater flow in the United States is handled at treatment plants which discharge greater than 38 million liters of treated waste water per day (Metcalf & Eddy, 1991). It is projected that the leachate generated during the composting of Virginia's 1 million tons of annually collected yard waste would be less than 10×10^6 l per year.

Nitrate-nitrogen (NO_3^--N) concentrations remained generally constant over the composting period for all the sampling sites. Differences between the concentrations in the windrow leachates, the retention pond, and the control plots were insignificant. NO_3^--N

Table 6. Concentration of nitrogen compounds in compost leachate.

PLOT	NO_3^--N (mg/l) min. max.	NO_3^--N (mg/l) mean std.dev.	$NH4^+$-N (mg/l) min. max.	$NH4^+$-N (mg/l) mean std.dev.	TKN (mg/l) min. max.	TKN (mg/l) mean std.dev.
LG-1	0.093	0.912	0.301	1.546	20.531	44.188
	3.965	1.288	6.041	1.653	73.291	17.008
LG-2	0.202	0.510	0.129	1.953	14.157	39.419
	3.271	0.837	8.299	2.372	76.483	20.252
CG-1	0.158	0.649	0.353	1.390	16.804	37.44
	4.001	0.927	6.391	1.442	63.039	11.54
CG-2	0.200	0.450	0.751	1.542	21.953	39.839
	2.500	0.573	3.969	1.078	61.603	13.607
LV-1	0.103	0.145	0.427	1.166	15.878	18.222
	0.270	0.070	3.052	1.020	41.383	10.052
LV-2	0.072	0.138	0.203	0.489	9.497	26.047
	0.235	0.060	1.285	0.407	47.404	16.737

Table 6. Concentration of nitrogen compounds in compost leachate (continued).

	NO$_3^-$-N (mg/l)		NH4$^+$-N (mg/l)		TKN (mg/l)	
PLOT	min. max.	mean std.dev.	min. max.	mean std.dev.	min. max.	mean std.dev.
Control 1	0.048	0.443	0.239	1.694	8.788	28.306
	4.322	1.075	7.390	1.892	41.684	11.070
Control 2	0.094	0.206	0.187	0.757	5.978	21.574
	0.402	0.139	1.321	0.348	41.383	14.607
Retention Pond	0.015	0.517	0.068	0.318	2.676	8.791
	2.410	0.796	0.681	0.203	43.372	11.797
Drinking water standards	10.0[1]					
VA water quality standards	5.0[4] 0.5[5]		24.00[2] 2.59[3] 0.025[4,5]		≤1.00[6]	

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[1] Cotruvo and Vogt. 1990.

[2] VA Acute Ammonia Standard for Freshwater: Warm Water Habitats; @pH=7.00, temp.=15°C (VR680-21-00,1992).

[3] VA Chronic Ammonia Standard for Freshwater: Warm Water Habitats; @pH=7.00, temp.=15°C (VR680-21-00.1992).

[4] VA GW Standard Applicable by Physiographic Province: Coastal Plain, Piedmont and Blue Ridge, and Ridge and Valley. VR680-21-04.4, 1992, p40.

[5] VA GW Standard Applicable by Physiographic Province: Cumberland Plateau. VR680-21-04.4, 1992, p40.

[6] VA GW Special Standards and Requirements: Potomac Embayment Standards. VR680-21-07.1, 1992, p43.

Table 7. Concentration of phosphorus compounds in compost leachate.

PLOT	Phosphorus Compounds			
	Orthophosphorus (mg/l)		Total Phosphorus (mg/l)	
	min. max.	mean std.dev.	min. max.	mean std.dev.
LG-1	1.608	6.321	2.254	9.884
	14.263	4.042	19.438	5.362
LG-2	0.419	10.243	1.421	15.010
	23.593	8.235	34.126	11.997
CG-1	0.333	7.711	0.071	10.628
	18.747	5.001	24.261	5.942
CG-2	0.007	9.103	0.492	14.839
	21.377	6.359	66.300	16.035
LV-1	0.054	2.826	0.439	7.195
	11.491	3.735	36.831	12.340
LV-2	0.243	2.612	0.056	3.700
	6.146	2.613	11.429	4.487

Table 7. Concentration of phosphorus compounds in compost leachate (continued).

PLOT	Phosphorus Compounds			
	Orthophosphorus (mg/l)		Total Phosphorus (mg/l)	
	min. max.	mean std.dev.	min. max.	mean std.dev.
Control 1	0.040 19.698	10.429 5.577	0.812 26.673	12.604 8.285
Control 2	0.621 18.346	7.798 7.843	0.334 39.844	11.574 14.811
Retention Pond	0.017 9.395	1.982 3.234	0.257 1.817	0.711 0.506
Water Quality standards			0.20[1] 0.10[2]	

[1] VA GW Special Standards and Requirements: Potomac Embayment Standards. VR680-21-07.1, 1992, p43.

[2] VA GW Special Standards and Requirements: Chickahominy Watershed (monthly avg.). VR680-21-07.1, 1992, p46.

Table 8. Concentration of total suspended solids (TSS), pH , and biological oxygen demand (BOD) in compost leachate.

	TSS (g/l)		pH		BOD (mg/l)	
PLOT	min. max.	mean std.dev.	min. max.	mean std.dev.	min. max.	mean std.dev.
LG-1	0.014	0.122	6.56	7.78	26.9	48.32
	0.390	0.089	8.35	0.518	123.9	33.33
LG-2	0.028	0.100	7.50	7.78	38.8	39.43
	0.258	0.071	8.03	0.206	106.0	35.95
CG-1	0.018	0.086	6.50	7.62	11.9	36.33
	0.188	0.050	7.97	0.392	61.2	17.86
CG-2	0.022	0.086	7.48	7.75	11.9	38.84
	0.400	0.094	7.98	0.187	116.4	29.41
LV-1	0.012	0.027	7.29	7.44	88.1	80.25
	0.084	0.025	7.60	0.133	186.6	54.85
LV-2	0.078	0.071	6.18	6.98	12.9	72.26
	0.332	0.069	7.21	0.536	188.1	68.69

Table 8. Concentration of total suspended solids (TSS), pH, and biological oxygen demand (BOD) in compost leachate (continued).

PLOT	TSS (g/l) min. max.	TSS (g/l) mean std.dev.	pH min. max.	pH mean std.dev.	BOD (mg/l) min. max.	BOD (mg/l) mean std.dev.
Control 1	0.028	0.086	7.01	7.71	17.2	47.0
	0.160	0.035	8.11	0.37	76.1	24.03
Control 2	0.038	0.038	7.55	7.86	23.9	43.12
	0.066	0.022	8.10	0.20	56.7	14.19
Retention	0.010	0.056	7.56	8.29	0.0	20.06
Pond	0.134	0.040	8.99	0.56	53.7	19.10
Discharge	0.03[1]		6.0 to		30.00[1]	
and water	0.005[2]		9.0[1]		3.00[3]	
quality					6.00[2]	
standards					1.00[4]	

[1] Metcalf & Eddy, Inc. 1991. Minimum national standards for secondary treatment. p.122-123. *In* Wastewater Engineering: Treatment Disposal and Reuse. 3rd ed. McGraw Hill Pub. Co., NY, NY.

[2] VA GW Special Standards and Requirements: Chickahominy Watershed. VR680-21-07.1, 1992, p44-46.

[3] VA GW Special Standards and Requirements: Potomac Embayment Standards. VR680-21-07.1, 1992, p43.

[4] VA GW Special Standards and Requirements: Rappahannock River Basin. VR680-21-07.1, 1992, p46.

content in the LV-1 and LV-2 plot leachates averaged lower than at any of the other sampling locations, likely because nitrogen was limited in those windrows. Influxes of nitrate-nitrogen are a concern in estuaries and other coastal waters, where excessive amounts contribute to eutrophication. Its presence in groundwater is considered a public health issue, as well. None of the leachate samples contained NO_3^--N concentrations greater than the national public drinking water limit of 10 mg/l (Cotruvo and Vogt, 1990), although the final value for LG-1 (2.487 mg/l) did exceed the limit for the Virginia Groundwater Standards for the Cumberland Plateau region of 0.5 mg/l (Virginia State Water Control Board Regulations, 1992). Minimal concern for groundwater nitrate-N contamination seems warranted, given the small quantities of yard waste leachate generated.

The relatively large difference between TKN and NH_4^+-N values (Table 6), indicates substantially greater concentrations of organic nitrogen than of NH_4^+-N. As decomposition proceeded, the level of TKN clearly decreased, except in the leachate from CG-2. This decrease can be attributed to the mineralization of the organic nitrogen because the ammonium ion content remained relatively constant over the composting period. In leachates from all but two of the plots (Control-2 and LV-2) the Virginia Chronic Ammonia Standard for Freshwater was exceeded at least once (Virginia State Water Control Board Regulations, 1992). The highest concentration of 8.299 mg/l measured at LG-2 was far below the state's Acute Ammonia Standard for Freshwater of 24.00 mg/l, and values for NH_4^+-N in the retention pond never exceeded 0.7 mg/l. An important distinction to make is that the Virginia State Water Control Board Regulations are water quality, not discharge standards.

Concentrations of pollutants from compost leachates would, thus, not be subject to control unless they caused unacceptable changes in the quality of the receiving waters. With respect to TKN, both the LG and CG windrows produced leachate with concentrations which averaged nearly twice as much as those in the leaves-only and control plot leachates. This result may indicate a direct relationship between leachate TKN and the presence of readily available nitrogen, such as grass clippings, in the raw material mix. The retention pond concentrations for TKN were far less (8.79 mg/l average) than in any of the plot leachates, possibly because the organic nitrogen (the predominant component of TKN in these leachates) was being readily converted to ammonium and undergoing subsequent volatilization. Throughout the study period, TKN concentrations at all sampling locations exceeded the Virginia special groundwater quality standard for the Potomac Embayment of 1.00 mg/l (Virginia State Water Control Board Regulations, 1992). This raises concern for surface waters, because of the potential for conversion of organic nitrogen to ammonium and its subsequent impact on fish and oxygen levels. This concern is mitigated by the fact that leachate quantities are relatively small, and the NH_4^+-N concentrations averaged from 0.49 to 1.95 mg/l in the plot leachates and 0.32 mg/l in the retention. One often used technique in composting is the recirculation of any collected leachate back onto the windrows. This practice allows further utilization of the leachate organic nitrogen by the microbes in the compost and a decrease in the amount of water necessary from other sources to maintain optimum windrow moisture content. Groundwater sources would likely not be threatened by the measured TKN concentrations, because soil processes would decrease TKN concentrations in percolating leachates.

Total phosphorus (TP) leachate concentrations exceeded the state groundwater quality standard for the Potomac Embayment (0.20 mg/l) and the Chickahominy Watershed (0.1 mg/l) from all plots and the retention pond (Table 7) (Virginia State Water Control Board Regulations, 1992); but the retention pond concentrations were the lowest. The obvious concern with high TP levels is in the potential for these to lead to eutrophication. The standards are specific to waters requiring special protection and are, therefore, more stringent than for general water resources in Virginia. As previously indicated, as well, the leachate quantity from yard waste composting is exceedingly small. Adsorption to soil particles is effective in preventing leaching of phosphorus. Final concentrations for both ortho- and total phosphorus concentrations in the leachate from the LG and CG windrows exceeded those from the LV windrows and control plots, which indicate a relationship between high TP concentrations and the presence of grass in the raw material mix. Leachate from the control plots and LV windrows had final TP concentrations of less than 1.0 mg/l. Ortho- and total phosphorus concentrations declined with time in all plots.

Concentrations of TSS, plot averages of which ranged from 0.03-0.12 g/l, were well below the discharge standard of 30.00 g/l (Table 8) (Metcalf & Eddy, Inc, 1991). In fact, the maximum concentration, which was recorded for LV-2 leachate, was only 0.078 g/l. These results indicate that yard waste compost leachate would be unlikely to diminish the clarity of surface waters.

Leachate pH, which varied from 6.18-8.99 during the study (Table 8), ranged between

7.93 and 8.18 in final samples. These results correspond with those of other researchers, who have found that final pH of finished compost extract and leachate is slightly higher than the range found in soils in this region. For this reason, it would be important to consider the alkalinity of finished composts when planning application to soils and in potting mixes, since the ideal for soil pH is between 6 and 7 for most agronomic plants, and slightly lower for some ornamentals and trees.

Biochemical oxygen demand (BOD) remained above 10 mg/l and averaged above the treated wastewater discharge limit of 30.00 mg/l (Metcalf & Eddy, Inc., 1991) throughout the study. A decrease over the composting period occurred only for the leachate from LV-2. The highest BOD measurement for the retention pond of 53.7 mg/l occurred in April 1993 and was followed the next day by the nearly lowest measured value of 6.97 mg/l. Ready access to the retention pond by deer and other wildlife contributed to the erratic measurements. In order to protect against the detrimental effects of high biological oxygen demand, large volumes of yard waste compost leachate should not be permitted to flow into surface water.

4.4 ELEMENTAL COMPOSITION.

Comparative concentrations of the nutrient elements in the composts from this study are presented in Table 9, indicating similar concentrations to those found in related composts (Table 2). Nitrogen, phosphorus, and calcium concentrations are substantially greater than in mineral soils (Tables 2, 9). In addition, the concentration of the essential plant nutrients,

Table 9. Elemental concentrations of compost material collected at end of study.

Windrow	N	P	K	Ca	Mg	Mn	Fe	Pb
	(g·kg^{-1})					(mg·kg^{-1})		
LG-1	16.6	2.50	9.40	60.01	17.54	870	12,895	37.0
LG-2	16.4	2.65	8.19	59.79	18.46	875	12,530	33.5
LG-3	14.3	1.86	11.03	40.94	15.73	720	16,400	21.5
LG mean	15.8^{c}*	2.34^{c}	9.54	53.58^{b}	17.24^{b}	822^{b}	13,942^{b}	30.7
LG sd	1.3	0.42	1.42	10.95	1.39	88	2,137	8.1
CG-1	6.5	1.70	8.40	25.18	10.95	360	14,840	35.5
CG-2	6.3	1.15	6.24	21.40	8.95	330	8,890	23.5
CG-3	7.5	0.68	3.09	12.87	4.78	175	4,575	9.5
CG mean	6.8^{a}	1.18^{a}	5.91	19.82^{a}	8.23^{a}	288^{a}	9,435^{b}	22.8
CG sd	0.6	0.51	2.67	6.30	3.15	99	5,154	13.0
LV-1	13.6	1.76	7.18	45.96	9.50	680	4,415	26.5
LV-2	13.2	1.63	6.34	43.47	9.97	830	3,035	9.5
LV-3	8.4	1.16	5.35	29.38	6.76	780	3,120	14.5
LV mean	11.7^{b}	1.52^{b}	6.29	39.61^{b}	8.74^{a}	763^{b}	3,523^{a}	16.7
LV sd	2.9	0.32	0.91	8.94	1.73	76	773	8.9

* Means followed by different letters within columns are significantly different at the 0.05 level according to the LSD test.

Mg, Mn and Fe, are at least one order of magnitude greater than in mineral soils. Higher average concentrations of all measured nutrients occurred in the LG windrows (Table 9). The lower values found in the samples from the CG windrows may be due to the high proportion of woodchips, which were not screened out prior to analysis. Nitrogen and phosphorus concentrations were significantly different between all treatments. Those for the LG and LV mixes were significantly greater than in the CG mix. This difference may have also been the result of the relatively high carbon content in the CG composts. No significant differences between mixes were exhibited for potassium concentrations. Magnesium concentrations were equal in the CG and LV composts, both of which were significantly lower than those in the LG composts. Iron concentrations were higher in the LG and CG than in the LV composts. On average, the LG compost contained more than twice the concentrations of N, P, Ca, Mg and Mn as the CG composts, and concentrations of all elements but iron were higher in the LV than the CG compost.

The Pb concentrations were not significantly different between treatments and ranged from an average of 16.7 mg/kg (LV mix) to 30.7 mg/kg (LG mix). These concentrations are comparable to those reported in the literature (Table 2) and well below the maximum allowable concentration of 630 mg/kg for total sludge applications to land (USEPA, 1993).

5. CONCLUSIONS

5.1 PROCESS MANAGEMENT

Carbon to nitrogen (C/N) ratios can be effective in establishing the initial mix of materials, if consideration is given to the availability of those elements, as well as to the moisture content and porosity of the raw materials. The C/N ratio, however, is not likely to be a valuable measurement for process monitoring at low-technology facilities, where equipment shortcomings often result in poorly mixed material.

Low-technology windrow composting is rapid for 3:1 (v/v) leaf/grass and 2:1 (v/v) woodchip/grass mixes, lasting approximately 8 weeks for both. Windrow-specific characteristics such as material source, initial moisture content and subsequent water additions, elemental composition, and the degree of homogeneity achieved at turning/mixing result in similar, but significantly different temperature profiles for different windrows of the same mix. Striking differences in temperature profiles and required composting periods between yard waste mixes with and without grass clippings are attributable to the absence of readily available nitrogen in those without grass.

Maintaining optimum moisture content and oxygenation is an on-going challenge in low-technology windrow composting, regardless of material mix. Excessive moisture inhibits decomposition, causing temperatures to plateau prematurely. Greater particle size differences in a woodchip/grass mix contribute to lower overall moisture contents as compared to leaves/grass and leaves-only mixes. Inadequate mixing of materials and failure to assess and adjust moisture content at each turning and at regular intervals can compromise the maintenance of optimum conditions in yard waste composting. A 3:1 (v/v) mix of leaves to grass proved the most desirable of three mixes assessed in terms of process efficiency, when moisture content was optimized.

Moisture contents not in excess of 650 g·kg-1 in a 3:1 (v/v) leaf/grass mixes, and ranging from 550 to 600 $g \cdot kg^{-1}$ in a 2:1 (v/v) woodchip/grass mix are effective. A moisture content of 700 $g \cdot kg^{-1}$ is excessive for efficient decomposition in leaves-only windrows, despite the fact that it does not necessarily result in evidence of anaerobiosis.

5.2 GAS PRODUCTION

A strong negative correlation can exist between oxygen and carbon dioxide during composting in a 3:1 (v/v) leaf/grass mix and in very moist leaves-only mixes. Further research may establish the usefulness of this relationship in understanding and maximizing the composting process. Anaerobiosis can occur in microsites of leaves/grass mixes, even in windrows that are well-managed, do not experience odor problems, and produce high-quality finished compost. Occasional methane production not in excess of approximately 4×10^{-2} mmol/l reflects inconsequential anaerobiosis. Greater understanding of gas relationships in yard waste windrow composting will improve management potential.

5.3 LEACHATE GENERATION AND CHARACTERISTICS

Very little leachate is generated in properly managed yard waste windrows, effectively mitigating the potential for negative impacts on either groundwater or surface water from several potentially harmful compounds and characteristics. The Virginia regulations for water quality protection are sufficient, without requiring a non-permeable composting surface, to protect against these compounds. The handling and disposal of accumulated leachate is thus avoided.

For leachate entering the soil environment at unpaved facilities, high TKN concentrations in compost leachates do not translate to increased concentrations of the ammonium ion. Soil processes are expected to be effective in reducing concentrations of BOD and total phosphorus in excess of existing standards for sensitive locations in Virginia watersheds. At facilities which collect leachate, treatment to reduce unacceptable concentrations of ammonium ion, total phosphorus, and BOD may be necessary prior to discharge into surface waters.

5.4 END-PRODUCT ELEMENTAL COMPOSITION

Yard waste composts contain very low concentrations of lead and, thus, are safe for use in settings where soil and soil dust ingestion by children can occur. The composting of yard wastes results in an end-product with substantial concentrations of many of the essential plant nutrients. Efficient processing of leaves and grass in a 3:1 (v/v) ratio produced finished material with overall fertilizer value exceeding that in finished compost of 2:1 (v/v) woodchips/grass and in partially composted leaves, when final product was analyzed on unscreened samples. Specifically, compost from 3:1 (v/v) leaves/grass exhibited significantly greater concentrations of nitrogen, phosphorus and magnesium.

5.5 SUMMARY

Low-technology, municipal-scale composting can be an effective waste management strategy to reduce landfill disposal of yard wastes and create a valuable product for use as a soil amendment, potting media, landscaping cover and in other applications. Of primary importance in achieving the desired goals of efficiency, freedom from process problems, and a high-quality end-product is the effective management of the composting process according to well-developed principles. It has been demonstrated that a variety of yard waste material mixes are readily compostable without process or odor problems, except when severe winter conditions inhibit decomposition. Localized anaerobicity does not result in the generation and release of unacceptable quantities of undesirable gases from composting yard waste. Leachate compounds that exceeded established groundwater and surface water quality concentration standards do not pose a threat to aquatic environments, when allowed to percolate into the soil, because small volumes of leachate are generated and soil processes are expected to effectively treat leachates. Low-technology composting of yard wastes can be an effective, low-cost alternative to landfilling, with substantial societal and environmental benefits.

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APPENDICES

APPENDIX A1. TEMPERATURE- WINDROW LG-1

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
09/25/92	1	129	108	111	53.9	42.2	43.9	18.3	46.7
09/26/92	1	130	109	110	54.4	42.8	43.3	26.1	46.9
09/27/92	1	131	114	113	55.0	45.6	45.0	20.0	48.5
09/28/92	1	133	118	118	56.1	47.8	47.8	16.7	50.6
09/29/92	1	134	119	118	56.7	48.3	47.8	12.2	50.9
09/30/92	1	133	118	113	56.1	47.8	45.0	21.1	49.6
10/01/92	1	126	109	111	52.2	42.8	43.9	23.3	46.3
10/02/92	1	154	117	113	67.8	47.2	45.0	20.0	53.3
10/03/92	1	156	124	119	68.9	51.1	48.3	25.0	56.1
10/04/92	1	164	139	129	73.3	59.4	53.9	12.2	62.2
10/06/92	1	159	163	144	70.6	72.8	62.2	17.8	68.5
10/07/92	1	131	134	141	55.0	56.7	60.6	20.6	57.4
10/08/92	1	144	147	148	62.2	63.9	64.4	21.1	63.5
10/09/92	1	147	144	146	63.9	62.2	63.3	26.1	63.1
10/10/92	1	155	147	141	68.3	63.9	60.6	20.6	64.3
10/11/92	1	156	146	140	68.9	63.3	60.0	20.6	64.1
10/12/92	1	155	146	141	68.3	63.3	60.6	23.3	64.1
10/13/92	1	150	141	137	65.6	60.6	58.3	21.7	61.5
10/14/92	1	153	143	141	67.2	61.7	60.6	24.4	63.1
10/15/92	1	147	147	141	63.9	63.9	60.6	26.7	62.8
10/16/92	1	141	143	148	60.6	61.7	64.4	26.1	62.2
10/17/92	1	146	147	151	63.3	63.9	66.1	11.1	64.4
10/18/92	1	116	155	148	46.7	68.3	64.4	7.2	59.8
10/19/92	1	148	156	148	64.4	68.9	64.4	6.7	65.9
10/20/92	1	128	140	133	53.3	60.0	56.1	8.3	56.5
10/21/92	1	138	146	137	58.9	63.3	58.3	20.0	60.2
10/22/92	1	141	151	144	60.6	66.1	62.2	20.6	63.0
10/23/92	1	146	152	148	63.3	66.7	64.4	20.6	64.8
10/24/92	1	139	133	144	59.4	56.1	62.2	20.6	59.3
10/26/92	1	136	137	139	57.8	58.3	59.4	24.4	58.5
10/27/92	1	142	129	133	61.1	53.9	56.1	17.2	57.0
10/28/92	1	140	130	130	60.0	54.4	54.4	22.2	56.3
10/29/92	1	141	130	130	60.6	54.4	54.4	22.2	56.5
10/30/92	1	141	130	130	60.6	54.4	54.4	17.2	56.5
11/02/92	1	145	133	134	62.8	56.1	56.7	15.6	58.5
11/03/92	1	143	132	133	61.7	55.6	56.1	21.7	57.8
11/05/92	1	137	138	136	58.3	58.9	57.8	17.2	58.3
11/06/92	1	138	141	140	58.9	60.6	60.0	1.1	59.8
11/07/92	1	140	146	146	60.0	63.3	63.3	6.1	62.2
11/09/92	1	140	146	145	60.0	63.3	62.8	15.6	62.0
11/10/92	1	93	87	100	33.9	30.6	37.8	20.6	34.1
11/11/92	1	115	115	120	46.1	46.1	48.9	20.6	47.0
11/12/92	1	124	128	124	51.1	53.3	51.1	17.2	51.9
11/13/92	1	128	138	132	53.3	58.9	55.6	10.6	55.9
11/14/92	1	130	135	134	54.4	57.2	56.7	8.9	56.1
11/15/92	1	121	135	135	49.4	57.2	57.2	0.0	54.6
11/16/92	1	130	136	138	54.4	57.8	58.9	5.6	57.0

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
11/17/92	1	132	136	138	55.6	57.8	58.9	18.3	57.4
11/18/92	1	135	136	136	57.2	57.8	57.8	21.7	57.6
11/19/92	1	135	136	135	57.2	57.8	57.2	19.4	57.4
11/20/92	1	139	135	139	59.4	57.2	59.4	7.8	58.7
11/22/92	1	133	134	132	56.1	56.7	55.6	18.8	56.1
11/23/92	1	129	129	132	53.9	53.9	55.6	16.7	54.4
11/24/92	1	119	121	123	48.3	49.4	50.6	11.1	49.4
11/25/92	1	53	120	119	11.7	48.9	48.3	13.3	36.3
11/26/92	1	111	118	114	43.9	47.8	45.6	13.3	45.7
11/27/92	1	108	116	114	42.2	46.7	45.6	10.6	44.8
11/28/92	1	109	116	113	42.8	46.7	45.0	10.6	44.8
11/29/92	1	107	114	112	41.7	45.6	44.4	5.0	43.9
11/30/92	1	105	113	122	40.6	45.0	50.0	7.8	45.2
12/01/92	1	106	112	110	41.1	44.4	43.3	4.4	43.0
12/02/92	1	103	111	109	39.4	43.9	42.8	1.7	42.0
12/02/92	1	102	110	107	38.9	43.3	41.7	5.0	41.3
12/04/92	1	102	110	106	38.9	43.3	41.1	4.4	41.1
12/06/92	1	102	111	104	38.9	43.9	40.0	3.3	40.9
12/07/92	1	100	110	103	37.8	43.3	39.4	3.3	40.2
12/08/92	1	101	111	103	38.3	43.9	39.4	0.0	40.6
12/09/92	1	97	110	100	36.1	43.3	37.8	4.4	39.1
12/10/92	1	75	113	99	23.9	45.0	37.2	1.7	35.4
12/11/92	1	97	109	97	36.1	42.8	36.1	1.7	38.3
12/12/92	1	97	110	95	36.1	43.3	35.0	7.2	38.1
12/13/92	1	94	107	91	34.4	41.7	32.8	7.8	36.3
12/14/92	1	91	103	91	32.8	39.4	32.8	4.4	35.0
12/15/92	1	92	105	89	33.3	40.6	31.7	7.2	35.2
12/16/92	1	90	104	86	32.2	40.0	30.0	11.1	34.1
12/17/92	1	88	99	84	31.1	37.2	28.9	14.4	32.4
12/18/92	1	88	100	84	31.1	37.8	28.9	7.2	32.6
12/20/92	1	85	97	80	29.4	36.1	26.7	11.1	30.7
12/21/92	1	85	98	80	29.4	36.7	26.7	5.0	30.9
12/22/92	1	84	94	77	28.9	34.4	25.0	8.9	29.4
12/23/92	1	76	92	83	24.4	33.3	28.3	13.3	28.7
12/24/92	1	82	93	77	27.8	33.9	25.0	-1.7	28.9
12/25/92	1	82	92	75	27.8	33.3	23.9	1.1	28.3
12/27/92	1	80	91	73	26.7	32.8	22.8	1.7	27.4
12/28/92	1	79	89	70	26.1	31.7	21.1	1.7	26.3
12/29/92	1	77	88	70	25.0	31.1	21.1	7.8	25.7
12/30/92	1	76	82	74	24.4	27.8	23.3	16.7	25.2
12/31/92	1	73	80	71	22.8	26.7	21.7	17.2	23.7
01/01/93	1	75	81	73	23.9	27.2	22.8	4.4	24.6
01/02/93	1	74	79	71	23.3	26.1	21.7	5.0	23.7
01/03/93	1	72	78	70	22.2	25.6	21.1	12.2	23.0
01/04/93	1	71	77	69	21.7	25.0	20.6	15.0	22.4
01/05/93	1	71	76	68	21.7	24.4	20.0	13.3	22.0
01/06/93	1	71	77	69	21.7	25.0	20.6	9.4	22.4
01/07/93	1	71	76	68	21.7	24.4	20.0	10.0	22.0
01/08/93	1	71	75	67	21.7	23.9	19.4	8.3	21.7

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
01/09/93	1	71	75	68	21.7	23.9	20.0	4.4	21.9
01/10/93	1	66	70	67	18.9	21.1	19.4	3.9	19.8
01/11/93	1	70	73	67	21.1	22.8	19.4	4.4	21.1
01/12/93	1	69	71	64	20.6	21.7	17.8	6.7	20.0
01/13/93	1	66	69	63	18.9	20.6	17.2	16.1	18.9
01/15/93	1	68	71	65	20.0	21.7	18.3	2.2	20.0
01/16/93	1	61	68	56	16.1	20.0	13.3	6.1	16.5
01/17/93	1	64	64	58	17.8	17.8	14.4	6.1	16.7
01/18/93	1	65	40	58	18.3	4.4	14.4	2.2	12.4
01/19/93	1	67	70	58	19.4	21.1	14.4	-1.7	18.3
01/20/93	1	65		56	18.3		13.3	8.3	15.8
01/22/93	1	55		63	12.8		17.2	10.6	15.0
01/23/93	1	61	63	55	16.1	17.2	12.8	20.0	15.4
01/27/93	1	63	48	56	17.2	8.9	13.3	9.4	13.1
01/28/93	1	61	69	52	16.1	20.6	11.1	10.6	15.9
01/29/93	1	61	66	53	16.1	18.9	11.7	8.9	15.6
02/01/93	1	59	59	52	15.0	15.0	11.1	7.2	13.7
02/02/93	1	61	43	53	16.1	6.1	11.7	0.0	11.3
02/03/93	1	58	58	51	14.4	14.4	10.6	6.7	13.1
02/04/93	1	59	52	58	15.0	11.1	14.4	11.1	13.5
02/06/93	1	65	51	54	18.3	10.6	12.2	2.2	13.7
02/07/93	1	58	69	52	14.4	20.6	11.1	17.8	15.4
02/10/93	1	57	56	52	13.9	13.3	11.1	20.6	12.8
02/11/93	1	56	55	51	13.3	12.8	10.6	14.4	12.2
02/17/93	1	58	56	52	14.4	13.3	11.1	3.9	13.0
02/18/93	1	58	44	53	14.4	6.7	11.7	2.2	10.9
02/19/93	1	58	55	53	14.4	12.8	11.7	1.1	13.0
02/22/93	1	55	54	50	12.8	12.2	10.0	11.7	11.7
02/25/93	1	57	55	50	13.9	12.8	10.0	2.2	12.2
03/01/93	1	56	44	52	13.3	6.7	11.1	14.4	10.4
03/29/93	1	54	53	51	12.2	11.7	10.6	11.7	11.5
04/07/93	1	51	55	53	10.6	12.8	11.7	15.0	11.7
04/12/93	1	55	56	54	12.8	13.3	12.2	17.8	12.8
04/13/93	1	57	57	54	13.9	13.9	12.2	15.0	13.3
04/14/93	1	52	55	54	11.1	12.8	12.2	21.1	12.0
04/18/93	1	60	60	59	15.6	15.6	15.0	18.8	15.4
04/19/93	1	57	59	58	13.9	15.0	14.4	19.4	14.4
04/20/93	1	59	59	58	15.0	15.0	14.4	21.1	14.8
04/26/93	1	65	61	62	18.3	16.1	16.7	12.2	17.0
04/27/93	1	77	63	60	25.0	17.2	15.6	13.3	19.3
04/28/93	1	68	63	60	20.0	17.2	15.6	23.9	17.6

APPENDIX A4. TEMPERATURE- WINDROW LG-2

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
10/15/92	4	110	110	107	43.3	43.3	41.7	27.0	42.8
10/16/92	4	127	122	119	52.8	50.0	48.3	26.0	50.4
10/17/92	4	158	150	151	70.0	65.6	66.1	11.0	67.2
10/18/92	4	167	162	167	75.0	72.2	75.0	7.0	74.1
10/19/92	4	130	157	148	54.4	69.4	64.4	7.0	62.8
10/20/92	4	170	165	172	76.7	73.9	77.8	8.0	76.1
10/21/92	4	166	164	150	74.4	73.3	65.6	20.0	71.1
10/22/92	4	145	143	134	62.8	61.7	56.7	21.0	60.4
10/23/92	4	156	150	144	68.9	65.6	62.2	21.0	65.6
10/24/92	4	154	147	137	67.8	63.9	58.3	21.0	63.3
10/26/92	4	155	155	154	68.3	68.3	67.8	24.0	68.1
10/27/92	4	140	144	153	60.0	62.2	67.2	17.0	63.1
10/28/92	4	146	147	155	63.3	63.9	68.3	22.0	65.2
10/29/92	4	145	138	148	62.8	58.9	64.4	22.0	62.0
10/30/92	4	147	142	145	63.9	51.6	62.8	17.0	62.6
11/02/92	4	161	139	136	71.7	59.4	57.8	16.0	63.0
11/03/92	4	116	128	121	46.7	53.3	49.4	22.0	49.8
11/05/92	4	142	139	132	61.1	59.4	55.6	17.0	58.7
11/06/92	4	144	141	135	62.2	60.6	57.2	1.0	60.0
11/07/92	4	149	148	145	65.0	64.4	62.8	6.0	64.1
11/09/92	4	148	148	145	64.4	64.4	62.8	16.0	63.9
11/10/92	4	125	123	93	51.7	50.6	33.9	21.0	45.4
11/11/92	4	114	126	112	45.6	52.2	44.4	21.0	47.4
11/12/92	4	116	120	129	46.7	48.9	53.9	17.0	49.8
11/13/92	4	120	132	126	48.9	55.6	52.2	11.0	52.2
11/14/92	4	119	132	127	48.3	55.6	52.8	9.0	52.2
11/15/92	4	119	132	127	48.3	55.6	52.8	0.0	52.2
11/16/92	4	120	134	129	48.9	56.7	53.9	6.0	53.1
11/17/92	4	118	132	127	47.8	55.6	52.8	18.0	52.0
11/18/92	4	125	136	136	51.7	57.8	57.8	22.0	55.7
11/19/92	4	121	133	135	49.4	56.1	57.2	19.0	54.3
11/20/92	4	120	139	136	48.9	59.4	57.8	8.0	55.4
11/22/92	4	125	135	133	51.7	57.2	56.1	19.0	55.0
11/23/92	4	122	132	131	50.0	55.6	55.0	17.0	53.5
11/24/92	4	92	85	93	33.3	29.4	33.9	11.0	32.2
11/25/92	4	97	104	97	36.1	40.0	36.1	13.0	37.4
11/26/92	4	97	111	99	36.1	43.9	37.2	13.0	39.1
11/27/92	4	98	112	101	36.7	44.4	38.3	11.0	39.8
11/28/92	4	97	110	101	36.1	43.3	38.3	11.0	39.3
11/29/92	4	104	115	114	40.0	46.1	45.6	5.0	43.9
11/30/92	4	106	114	116	41.1	45.6	46.7	8.0	44.4
12/01/92	4	105	113	120	40.6	45.0	48.9	4.0	44.8
12/02/92	4	106	113	121	41.1	45.0	49.4	2.0	45.2
12/03/92	4	105	112	120	40.6	44.4	48.9	5.0	44.6
12/04/92	4	103	110	119	39.4	43.3	48.3	4.0	43.7
12/06/92	4	102	110	117	38.9	43.3	47.2	3.0	43.1
12/07/92	4	101	109	117	38.3	42.8	47.2	3.0	42.8

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
12/08/92	4	102	119	117	38.9	48.3	47.2	0.0	44.8
12/09/92	4	99	108	113	37.2	42.2	45.0	4.0	41.5
12/10/92	4	83	83	72	28.3	28.3	22.2	2.0	26.3
12/11/92	4	82	83	70	27.8	28.3	21.1	2.0	25.7
12/12/92	4	81	83	70	27.2	28.3	21.1	7.0	25.6
12/13/92	4	85	95	94	29.4	35.0	34.4	8.0	33.0
12/14/92	4	87	102	98	30.6	38.9	36.7	4.0	35.4
12/15/92	4	85	101	97	29.4	38.3	36.1	7.0	34.6
12/16/92	4	83	99	95	28.3	37.2	35.0	11.0	33.5
12/17/92	4	80	98	93	26.7	36.7	33.9	14.0	32.4
12/18/92	4	83	101	95	28.3	38.3	35.0	7.0	33.9
12/20/92	4	106	125	114	41.1	51.7	45.6	11.0	46.1
12/21/92	4	87	100	95	30.6	37.8	35.0	5.0	34.4
12/22/92	4	78	97	92	25.6	36.1	33.3	9.0	31.7
12/23/92	4	78	98	93	25.6	36.7	33.9	13.0	32.0
12/24/92	4	79	99	94	26.1	37.2	34.4	-2.0	32.6
12/25/92	4	78	98	94	25.6	36.7	34.4	1.0	32.2
12/27/92	4	77	96	94	25.0	35.6	34.4	2.0	31.7
12/28/92	4	75	94	92	23.9	34.4	33.3	2.0	30.6
12/29/92	4	73	93	91	22.8	33.9	32.8	8.0	29.8
12/30/92	4	76	96	93	24.4	35.6	33.9	17.0	31.3
12/31/92	4	84	93	91	28.9	33.9	32.8	17.0	31.9
01/01/93	4	77	96	92	25.0	35.6	33.3	4.0	31.3
01/02/93	4	74	94	91	23.3	34.4	32.8	5.0	30.2
01/03/93	4	74	93	89	23.3	33.9	31.7	12.0	29.6
01/04/93	4	76	93	89	24.4	33.9	31.7	15.0	30.0
01/05/93	4	73	91	88	22.8	32.8	31.1	13.0	28.9
01/06/93	4	71	92	89	21.7	33.3	31.7	9.0	28.9
01/07/93	4	74	92	90	23.3	33.3	32.2	10.0	29.6
01/08/93	4	74	92	90	23.3	33.3	32.2	8.0	29.6
01/09/93	4	75	91	89	23.9	32.8	31.7	4.0	29.4
01/10/93	4	75	90	89	23.9	32.2	31.7	4.0	29.3
01/11/93	4	74	89	88	23.3	31.7	31.1	4.0	28.7
01/12/93	4	73	87	86	22.8	30.6	30.0	7.0	27.8
01/13/93	4	69	83	83	20.6	28.3	28.3	16.0	25.7
01/15/93	4	70	83	84	21.1	28.3	28.9	2.0	26.1
01/16/93	4	63	78	76	17.2	25.6	24.4	6.0	22.4
01/17/93	4	64	78	76	17.8	25.6	24.4	6.0	22.6
01/18/93	4	65	77	79	18.3	25.0	26.1	2.0	23.1
01/19/93	4	66	79	79	18.9	26.1	26.1	-2.0	23.7
01/20/93	4	63	76	77	17.2	24.4	25.0	8.0	22.2
01/22/93	4	61	74	75	16.1	23.3	23.9	11.0	21.1
01/23/93	4	60	72	73	15.6	22.2	22.8	20.0	20.2
01/27/93	4	61	72	74	16.1	22.2	23.3	9.0	20.6
01/28/93	4	60	73	71	15.6	22.8	21.7	11.0	20.0
01/29/93	4	58	78	70	14.4	25.6	21.1	9.0	20.4
02/01/93	4	58	67	69	14.4	19.4	20.6	7.0	18.1
02/02/93	4	53	73	71	11.7	22.8	21.7	0.0	18.7
02/03/93	4	65	66	67	18.3	18.9	19.4	7.0	18.9

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
02/04/93	4	65	67	68	18.3	19.4	20.0	11.0	19.3
02/06/93	4	55	64	65	12.8	17.8	18.3	2.0	16.3
02/07/93	4	55	63	65	12.8	17.2	18.3	18.0	16.1
02/10/93	4	56	63	64	13.3	17.2	17.8	21.0	16.1
02/11/93	4	54	61	62	12.2	16.1	16.7	14.0	15.0
02/17/93	4	53	56	56	11.7	13.3	13.3	4.0	12.8
02/18/93	4	57	61	59	13.9	16.1	15.0	2.0	15.0
02/19/93	4	57	63	41	13.9	17.2	5.0	1.0	12.0
02/22/93	4	53	59	60	11.7	15.0	15.6	12.0	14.1
02/25/93	4	56	61	40	13.3	16.1	4.4	2.0	11.3
03/01/93	4	54	49	40	12.2	9.4	4.4	14.0	8.7
03/29/93	4	52	53	51	11.1	11.7	11.0	12.0	11.1
04/07/93	4	68	55	57	20.0	12.8	13.9	15.0	15.6
04/12/93	4	56	54	56	13.3	12.2	13.3	18.0	13.0
04/13/93	4	54	54	60	12.2	12.2	15.6	15.0	13.3
04/14/93	4	50	52	55	10.0	11.1	12.8	21.0	11.3
04/18/93	4	62	58	61	16.7	14.4	16.1	19.0	15.7
04/19/93	4	54	56	59	12.2	13.3	15.0	19.0	13.5
04/20/93	4	54	57	59	12.2	13.9	15.0	21.0	13.7
04/21/93	4	57	63	57	13.9	17.2	13.9	6.0	15.0
04/22/93	4	58	61	64	14.4	16.1	17.8	14.0	16.1
04/26/93	4	60	64	67	15.6	17.8	19.4	12.0	17.6
04/27/93	4	59	63	65	15.0	17.2	18.3	13.0	16.9
04/28/93	4	57	61	64	13.9	16.1	17.8	24.0	15.9

APPENDIX A6. TEMPERATURE- WINDROW LG-3

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
11/09/92	6	154	152	153	67.8	66.7	67.2	16.0	67.2
11/10/92	6	118	122	121	47.8	50.0	49.4	21.0	49.1
11/11/92	6	146	127	133	63.3	52.8	56.1	21.0	57.4
11/12/92	6	155	137	144	68.3	58.3	62.2	17.0	63.0
11/13/92	6	159	143	152	70.6	61.7	66.7	11.0	66.3
11/14/92	6	145	142	131	62.8	61.1	55.0	9.0	59.6
11/15/92	6	155	146	134	68.3	63.3	56.7	0.0	62.8
11/16/92	6	161	155	142	71.7	68.3	61.1	6.0	67.0
11/17/92	6	160	158	152	71.1	70.0	66.7	18.0	69.3
11/18/92	6	155	154	152	68.3	67.8	66.7	22.0	67.6
11/19/92	6	155	163	165	68.3	72.8	73.9	19.0	71.7
11/20/92	6	168	163	157	75.6	72.8	69.4	8.0	72.6
11/22/92	6	127	159	157	52.8	70.6	69.4	19.0	64.3
11/23/92	6	133	162	167	56.1	72.2	75.0	17.0	67.8
11/24/92	6	128	156	158	53.3	68.9	70.0	11.0	64.1
11/25/92	6	154	159	154	67.8	70.6	67.8	13.0	68.7
11/26/92	6	159	161	153	70.6	71.7	67.2	13.0	69.8
11/27/92	6	158	163	154	70.0	72.8	67.8	11.0	70.2
11/28/92	6	123	142	106	50.6	61.1	41.1	11.0	50.9
11/29/92	6	148	151	146	64.4	66.1	63.3	5.0	64.6
11/30/92	6	151	155	154	66.1	68.3	67.8	8.0	67.4
12/01/92	6	145	149	146	62.8	65.0	63.3	4.0	63.7
12/02/92	6	124	152	145	51.1	66.7	62.8	2.0	60.2
12/03/92	6	162	155	165	72.2	68.3	73.9	5.0	71.5
12/04/92	6	147	142	137	63.9	61.1	58.3	4.0	61.1
12/06/92	6	143	154	171	61.7	67.8	77.2	3.0	68.9
12/07/92	6	142	151	171	61.1	66.1	77.2	3.0	68.1
12/08/92	6	127	140	100	52.8	60.0	37.8	0.0	50.2
12/09/92	6	126	152	142	52.2	66.7	61.1	4.0	60.0
12/10/92	6	118	132	124	47.8	55.6	51.1	2.0	51.5
12/11/92	6	125	138	127	51.7	58.9	52.8	2.0	54.4
12/12/92	6	132	143	130	55.6	61.7	54.4	7.0	57.2
12/13/92	6	149	157	150	65.0	69.4	65.6	8.0	66.7
12/14/92	6	154	161	153	67.8	71.7	67.2	4.0	68.9
12/15/92	6	107	144	128	41.7	62.2	53.3	7.0	52.4
12/16/92	6	119	141	125	48.3	60.6	51.7	11.0	53.5
12/17/92	6	137	143	124	58.3	61.7	51.1	14.0	57.0
12/18/92	6	156	144	132	68.9	62.2	55.6	7.0	62.2
12/20/92	6	138	146	137	58.9	63.3	58.3	11.0	60.2
12/21/92	6	137	151	141	58.3	66.1	60.6	5.0	61.7
12/22/92	6	133	140	134	56.1	60.0	56.7	9.0	57.6
12/23/92	6	136	146	139	57.8	63.3	59.4	13.0	60.2
12/24/92	6	141	150	141	60.6	65.6	60.6	-2.0	62.2
12/25/92	6	143	153	140	61.7	67.2	60.0	1.0	63.0
12/27/92	6	141	149	140	60.6	65.0	60.0	2.0	61.9
12/28/92	6	137	148	137	58.3	64.4	58.3	2.0	60.4
12/29/92	6	127	141	102	52.8	60.6	38.9	8.0	50.7

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
12/30/92	6	137	144	133	58.3	62.2	56.1	17.0	58.9
12/31/92	6	137	145	106	58.3	62.8	41.1	17.0	54.1
01/01/93	6	140	149	114	60.0	65.0	45.6	4.0	56.9
01/02/93	6	138	147	127	58.9	63.9	52.8	5.0	58.5
01/03/93	6	132	146	125	55.6	63.3	51.7	12.0	56.9
01/04/93	6	134	144	125	56.7	62.2	51.7	15.0	56.9
01/05/93	6	135	146	127	57.2	63.3	52.8	13.0	57.8
01/06/93	6	134	146	125	56.7	63.3	51.7	9.0	57.2
01/07/93	6	134	146	124	56.7	63.3	51.1	10.0	57.0
01/08/93	6	133	145	124	56.1	62.8	51.1	8.0	56.7
01/09/93	6	126	139	115	52.2	59.4	46.1	4.0	52.6
01/10/93	6	124	136	110	51.1	57.8	43.3	4.0	50.7
01/11/93	6	127	133	109	52.8	56.1	42.8	4.0	50.6
01/12/93	6	127	133	108	52.8	56.1	42.2	7.0	50.4
01/13/93	6	126	132	105	52.2	55.6	40.6	16.0	49.4
01/15/93	6	127	130	105	52.8	54.4	40.6	2.0	49.3
01/16/93	6	126	135	106	52.2	57.2	41.1	6.0	50.2
01/17/93	6	125	135	106	51.7	57.2	41.1	6.0	50.0
01/18/93	6	135	127	105	57.2	52.8	40.6	2.0	50.2
01/19/93	6	124	136	105	51.1	57.8	40.6	-2.0	49.8
01/20/93	6	121	134	102	49.4	56.7	38.9	8.0	48.3
01/22/93	6	117	129	104	47.2	53.9	40.0	11.0	47.0
01/23/93	6	119	129	92	48.3	53.9	33.3	20.0	45.2
01/27/93	6	117	128	84	47.2	53.3	28.9	9.0	43.1
01/28/93	6	115	124	83	46.1	51.1	28.3	11.0	41.9
01/29/93	6	112	123	80	44.4	50.6	26.7	9.0	40.6
02/01/93	6	111	123	80	43.9	50.6	26.7	7.0	40.4
02/02/93	6	105	123	81	40.6	50.6	27.2	0.0	39.4
02/03/93	6	104	119	78	40.0	48.3	25.6	7.0	38.0
02/04/93	6	103	119	78	39.4	48.3	25.6	11.0	37.8
02/06/93	6	98	115	74	36.7	46.1	23.3	2.0	35.4
02/07/93	6	98	114	74	36.7	45.6	23.3	18.0	35.2
02/10/93	6	97	113	73	36.1	45.0	22.8	21.0	34.6
02/11/93	6	95	110	70	35.0	43.3	21.1	14.0	33.1
02/17/93	6	95	107	72	35.0	41.7	22.2	4.0	33.0
02/18/93	6	96	104	71	35.6	40.0	21.7	2.0	32.4
02/19/93	6	75	91	55	23.9	32.8	12.8	1.0	23.1
02/22/93	6	69	83	54	20.6	28.3	12.2	12.0	20.4
02/25/93	6	95	63	43	35.0	17.2	6.1	2.0	19.4
03/01/93	6	85	94		29.4	34.4		14.0	31.9
03/29/93	6	57	56		13.9	13.3		12.0	13.6
04/07/93	6	60	59		15.6	15.0		15.0	15.3
04/12/93	6	58	58		14.4	14.4		18.0	14.4
04/13/93	6	61	61		16.1	16.1		15.0	16.1
04/14/93	6	57	57		13.9	13.9		21.0	13.9
04/16/93	6	61		61	16.1		16.1	20.0	16.1
04/18/93	6	65		66	18.3		18.9	19.0	18.6
04/19/93	6	64		64	17.8		17.8	19.0	17.8
04/20/93	6	65		65	18.3		18.3	21.0	18.3

04/21/93	6	72		72	22.2		22.2	6.0	22.2
04/22/93	6	70		69	21.1		20.6	14.0	20.8
04/26/93	6	75		73	23.9		22.8	12.0	23.3
04/27/93	6	72		73	22.2		22.8	13.0	22.5
04/28/93	6	74		72	23.3		22.2	24.0	22.8

APPENDIX A2. TEMPERATURE- WINDROW CG-1

09/24/92	2	115	110	141	46.1	43.3	60.6		50.0
09/25/92	2	147	138	157	63.9	58.9	69.4	18.0	64.1
09/26/92	2	152	141	161	66.7	60.6	71.7	26.0	66.3
09/27/92	2	153	151	167	67.2	66.1	75.0	20.0	69.4
09/28/92	2	154	152	168	67.8	66.7	75.6	17.0	70.0
09/29/92	2	152	151	162	66.7	66.1	72.2	12.0	68.3
09/30/92	2	155	149	140	68.3	65.0	60.0	21.0	64.4
10/01/92	2	110	113	126	43.3	45.0	52.2	23.0	46.9
10/02/92	2	142	132	149	61.1	55.6	65.0	20.0	60.6
10/03/92	2	142	139	150	61.1	59.4	65.6	25.0	62.0
10/04/92	2	118	134	142	47.8	56.7	61.1	12.0	55.2
10/06/92	2	116	115	133	46.7	46.1	56.1	18.0	49.6
10/07/92	2	99	65	129	37.2	18.3	53.9	21.0	36.5
10/08/92	2	122	89	136	50.0	31.7	57.8	21.0	46.5
10/09/92	2	131	113	140	55.0	45.0	60.0	26.0	53.3
10/10/92	2	128	110	128	53.3	43.3	53.3	21.0	50.0
10/11/92	2	135	118	141	57.2	47.8	60.6	21.0	55.2
10/12/92	2	136	129	142	57.8	53.9	61.1	23.0	57.6
10/13/92	2	140	133	141	60.0	56.1	60.6	22.0	58.9
10/14/92	2	139	134	141	59.4	56.7	60.6	24.0	58.9
10/15/92	2	138	133	141	58.9	56.1	60.6	27.0	58.5
10/16/92	2	139	133	141	59.4	56.1	60.6	26.0	58.7
10/17/92	2	135	124	141	57.2	51.1	60.6	11.0	56.3
10/18/92	2	117	126	134	47.2	52.2	56.7	7.0	52.0
10/19/92	2	110	126	132	43.3	52.2	55.6	7.0	50.4
10/20/92	2	121	131	116	49.4	55.0	46.7	8.0	50.4
10/21/92	2	118	127	113	47.8	52.8	45.0	20.0	48.5
10/22/92	2	92	101	62	33.3	38.3	16.7	21.0	29.4
10/23/92	2	92	107	87	33.3	41.7	30.6	21.0	35.2
10/24/92	2	97	120	94	36.1	48.9	34.4	21.0	39.8
10/26/92	2	99	117	89	37.2	47.2	31.7	24.0	38.7
10/27/92	2	98	116	89	36.7	46.7	31.7	17.0	38.3
10/28/92	2	97	112	87	36.1	44.4	30.6	22.0	37.0
10/29/92	2	85	81	106	29.4	27.2	41.1	22.0	32.6
10/30/92	2	104	105	130	40.0	40.6	54.4	17.0	45.0
11/02/92	2	120	110	142	48.9	43.3	61.1	16.0	51.1
11/03/92	2	122	113	142	50.0	45.0	61.1	22.0	52.0
11/05/92	2	119	103	116	48.3	39.4	46.7	17.0	44.8
11/06/92	2	120	106	121	48.9	41.1	49.4	1.0	46.5
11/07/92	2	122	106	126	50.0	41.1	52.2	6.0	47.8
11/09/92	2	118	101	123	47.8	38.3	50.6	16.0	45.6
11/10/92	2	114	96	120	45.6	35.6	48.9	21.0	43.3
11/11/92	2	112	93	117	44.4	33.9	47.2	21.0	41.9
11/12/92	2	115	96	121	46.1	35.6	49.4	17.0	43.7
11/13/92	2	118	99	122	47.8	37.2	50.0	11.0	45.0
11/14/92	2	117	99	120	47.2	37.2	48.9	9.0	44.4
11/15/92	2	116	99	119	46.7	37.2	48.3	0.0	44.1
11/16/92	2	115	98	117	46.1	36.7	47.2	6.0	43.3

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
11/17/92	2	81	80	119	27.2	26.7	48.3	18.0	34.1
11/18/92	2	94	89	114	34.4	31.7	45.6	22.0	37.2
11/19/92	2	96	99	101	35.6	37.2	38.3	19.0	37.0
11/20/92	2	88	89	105	31.1	31.7	40.6	8.0	34.4
11/22/92	2	88	86	93	31.1	30.0	33.9	19.0	31.7
11/23/92	2	93	90	93	33.9	32.2	33.9	17.0	33.3
11/24/92	2	70	76	83	21.1	24.4	28.3	11.0	24.6
11/25/92	2	71	83	84	21.7	28.3	28.9		26.3
11/26/92	2	76	90	85	24.4	32.2	29.4	13.0	28.7
11/27/92	2	81	95	88	27.2	35.0	31.1	11.0	31.1
11/28/92	2	84	99	86	28.9	37.2	30.0	11.0	32.0
11/29/92	2	87	103	94	30.6	39.4	34.4	5.0	34.8
11/30/92	2	90	106	96	32.2	41.1	35.6	8.0	36.3
12/01/92	2	92	110	98	33.3	43.3	36.7	4.0	37.8
12/02/92	2	92	112	98	33.3	44.4	36.7	2.0	38.1
12/03/92	2	93	113	97	33.9	45.0	36.1	5.0	38.3
12/04/92	2	90	113	96	32.2	45.0	35.6	4.0	37.6
12/06/92	2	87	111	91	30.6	43.9	32.8	3.0	35.7
12/07/92	2	87	113	93	30.6	45.0	33.9	3.0	36.5
12/08/92	2	86	114	93	30.0	45.6	33.9	0.0	36.5
12/09/92	2	81	110	89	27.2	43.3	31.7	4.0	34.1
12/10/92	2	68	104	83	20.0	40.0	28.3	2.0	29.4
12/11/92	2	72	106	75	22.2	41.1	23.9	2.0	29.1
12/12/92	2	75	102	96	23.9	38.9	35.6	7.0	32.8
12/13/92	2	71	99	96	21.7	37.2	35.6	8.0	31.5
12/14/92	2	71	100	99	21.7	37.8	37.2	4.0	32.2
12/15/92	2	72	104	80	22.2	40.0	26.7	7.0	29.6
12/16/92	2	70	101	77	21.1	38.3	25.0	11.0	28.1
12/17/92	2	72	103	79	22.2	39.4	26.1	14.0	29.3
12/18/92	2	86	105	82	30.0	40.6	27.8	7.0	32.8
12/20/92	2	77	105	81	25.0	40.6	27.2	11.0	30.9
12/21/92	2	79	105	82	26.1	40.6	27.8	5.0	31.5
12/22/92	2	80	107	82	26.7	41.7	27.8	9.0	32.0
12/23/92	2	82	102	84	27.8	38.9	28.9	13.0	31.9
12/24/92	2	85	111	87	29.4	43.9	30.6	-2.0	34.6
12/25/92	2	84.0001	89	81	28.9	31.7	27.2	1.0	29.3
12/27/92	2	75	75	79	23.9	23.9	26.1	2.0	24.6
12/28/92	2	75	101	76	23.9	38.3	24.4	2.0	28.9
12/29/92	2	74	102	77	23.3	38.9	25.0	8.0	29.1
12/30/92	2	82	113	88	27.8	45.0	31.1	17.0	34.6
12/31/92	2	92	113	88	33.3	45.0	31.1	17.0	36.5
01/01/93	2	93	115	90	33.9	46.1	32.2	4.0	37.4
01/02/93	2	92	113	88	33.3	45.0	31.1	5.0	36.5
01/03/93	2	89	108	86	31.7	42.2	30.0	12.0	34.6
01/04/93	2	91	108	87	32.8	42.2	30.6	15.0	35.2
01/05/93	2	94	109	88	34.4	42.8	31.1	13.0	36.1
01/06/93	2	94	110	89	34.4	43.3	31.7	9.0	36.5
01/07/93	2	94	102	89	34.4	38.9	31.7	10.0	35.0
01/08/93	2	94	89	89	34.4	31.7	31.7	8.0	32.6

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
01/09/93	2	87	103	86	30.6	39.4	30.0	4.0	33.3
01/10/93	2.0005	83	79	82	28.3	26.1	27.8	4.0	27.4
01/11/93	2	83	81	81	28.3	27.2	27.2	4.0	27.6
01/12/93	2	83	79	81	28.3	26.1	27.2	7.0	27.2
01/13/93	2	82	96	79	27.8	35.6	26.1	16.0	29.8
01/15/93	2	87	92	83	30.6	33.3	28.3	2.0	30.7
01/16/93	2	75	94	69	23.9	34.4	20.6	6.0	26.3
01/17/93	2	79	101	70	26.1	38.3	21.1	6.0	28.5
01/18/93	2	82	103	72	27.8	39.4	22.2	2.0	29.8
01/19/93	2	78	100	73	25.6	37.8	22.8	-2.0	28.7
01/20/93	2	72	95	71	22.2	35.0	21.7	8.0	26.3
01/22/93	2	68	90	70	20.0	32.2	21.1	11.0	24.4
01/23/93	2	70	90	69	21.1	32.2	20.6	20.0	24.6
01/27/93	2	73	86	61	22.8	30.0	16.1	9.0	23.0
01/28/93	2	73	86	65	22.8	30.0	18.3	11.0	23.7
01/29/93	2	74	87		23.3	30.6		9.0	26.9
02/01/93	2	79	84		26.1	28.9		7.0	27.5
02/02/93	2	84	83		28.9	28.3		0.0	28.6
02/03/93	2	75	81		23.9	27.2		7.0	25.6
02/04/93	2	75	75		23.9	23.9		11.0	23.9
02/06/93	2	72	75		22.2	23.9		2.0	23.1
02/07/93	2	73	81		22.8	27.2		18.0	25.0
02/10/93	2	72	80		22.2	26.7		21.0	24.4
02/11/93	2	71	80		21.7	26.7		14.0	24.2
02/17/93	2	72	82		22.2	27.8		4.0	25.0
02/18/93	2	72	84		22.2	28.9		2.0	25.6
02/19/93	2	73	87		22.8	30.6		1.0	26.7
02/22/93	2	69	68		20.6	32.2		12.0	20.3
02/25/93	2	71	88		21.7	31.1		2.0	26.4
03/01/93	2	69	78		20.6	25.6		14.0	23.1
03/29/93	2	69	93		20.6	33.9		12.0	27.2
04/07/93	2	78	97		25.6	36.1		15.0	30.8
04/12/93	2	83	92		28.3	33.3		18.0	30.8
04/13/93	2	65	69		18.3	20.6		15.0	19.4
04/14/93	2	78	83		25.6	28.3		21.0	26.9
04/18/93	2	91	85		32.8	29.4		19.0	31.1
04/19/93	2	89	86		31.7	30.0		19.0	30.8
04/20/93	2	84	86		28.9	30.0		21.0	29.4
04/22/93	2	97	102		36.1	38.9		14.0	37.5
04/26/93	2	101	104		38.3	40.0		12.0	39.2
04/27/93	2	99	104		37.2	40.0		13.0	38.6
04/28/93	2	97	101		36.1	38.3		24.0	37.2

APPENDIX A3. TEMPERATURE- WINDROW CG-2

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
10/14/92	3	123	107	108	50.6	41.7	42.2	24.0	44.8
10/15/92	3	136	137	141	57.8	58.3	60.6	27.0	58.9
10/16/92	3	136	142	145	57.8	61.1	62.8	26.0	60.6
10/17/92	3	143	143	143	61.7	61.7	61.7	11.0	61.7
10/18/92	3	136	149	120	57.8	65.0	48.9	7.0	57.2
10/19/92	3	135	146	127	57.2	63.3	52.8	7.0	57.8
10/20/92	3	137	139	132	58.3	59.4	55.6	8.0	57.8
10/21/92	3	135	136	130	57.2	57.8	54.4	20.0	56.5
10/22/92	3	136	136	139	57.8	57.8	59.4	21.0	58.3
10/23/92	3	136	135	135	57.8	57.2	57.2	21.0	57.4
10/24/92	3	131	144	130	55.0	62.2	54.4	21.0	57.2
10/26/92	3	133	148	139	56.1	64.4	59.4	24.0	60.0
10/27/92	3	127	142	133	52.8	61.1	56.1	17.0	56.7
10/28/92	3	130	143	137	54.4	61.7	58.3	22.0	58.1
10/29/92	3	132	154	135	55.6	67.8	57.2	22.0	60.2
10/30/92	3	133	153	136	56.1	67.2	57.8	17.0	60.4
11/02/92	3	128	140	125	53.3	60.0	51.7	16.0	55.0
11/03/92	3	128	141	127	53.3	60.6	52.8	22.0	55.6
11/05/92	3	120	154	130	48.9	67.8	54.4	17.0	57.0
11/06/92	3	114	148	130	45.6	64.4	54.4	1.0	54.8
11/07/92	3	107	146	129	41.7	63.3	53.9	6.0	53.0
11/09/92	3	100	142	125	37.8	61.1	51.7	16.0	50.2
11/10/92	3	93	136	120	33.9	57.8	48.9	21.0	46.9
11/11/92	3	89	133	114	31.7	56.1	45.6	21.0	44.4
11/12/92	3	115	96	121	46.1	35.6	49.4	17.0	43.7
11/13/92	3	99	139	118	37.2	59.4	47.8	11.0	48.1
11/14/92	3	100	136	115	37.8	57.8	46.1	9.0	47.2
11/15/92	3	97	132	111	36.1	55.6	43.9	0.0	45.2
11/16/92	3	94	127	108	34.4	52.8	42.2	6.0	43.1
11/17/92	3	94	128	101	34.4	53.3	38.3	18.0	42.0
11/18/92	3	104	127	100	40.0	52.8	37.8	22.0	43.5
11/19/92	3	98	124	97	36.7	51.1	36.1	19.0	41.3
11/20/92	3	88	115	98	31.1	46.1	36.7	8.0	38.0
11/22/92	3	75	99	72	23.9	37.2	22.2	19.0	27.8
11/22/92	3	83	102	92	28.3	38.9	33.3	17.0	33.5
11/24/92	3	73	93	75	22.8	33.9	23.9	11.0	26.9
11/25/92	3	66	91	83	18.9	32.8	28.3	13.0	26.7
11/26/92	3	74	105	89	23.3	40.6	31.7	13.0	31.9
11/27/92	3	81	111	92	27.2	43.9	33.3	11.0	34.8
11/28/92	3	84	116	93	28.9	46.7	33.9	11.0	36.5
11/29/92	3	91		96	32.8		35.6	5.0	34.2
11/30/92	3	95		95	35.0		35.0	8.0	35.0
12/01/92	3	98	120	96	36.7	48.9	35.6	4.0	40.4
12/02/92	3	98	113	97	36.7	45.0	36.1	2.0	39.3
12/03/92	3	98	113	98	36.7	45.0	36.7	5.0	39.4
12/04/92	3	97	112	96	36.1	44.4	35.6	4.0	38.7
12/06/92	3	94	110	94	34.4	43.3	34.4	3.0	37.4

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
03/20/93	3	95	112	95	35.0	44.4	35.0	3.0	38.1
12/08/92	3	83	112	96	28.3	44.4	35.6	0.0	36.1
12/09/92	3	86	109	93	30.0	42.8	33.9	4.0	35.6
12/10/92	3	67	100	90	19.4	37.8	32.2	2.0	29.8
12/11/92	3	76	101	95	24.4	38.3	35.0	2.0	32.6
12/12/92	3	74	102	96	23.3	38.9	35.6	7.0	32.6
12/13/92	3	71	99	96	21.7	37.2	35.6	8.0	31.5
12/14/92	3	71	100	99	21.7	37.8	37.2	4.0	32.2
12/15/92	3	70	98	101	21.1	36.7	38.3	7.0	32.0
12/16/92	3	66	93	102	18.9	33.9	38.9	11.0	30.6
12/17/92	3	66	97	104	18.9	36.1	40.0	14.0	31.7
12/18/92	3	72	98	108	22.2	36.7	42.2	7.0	33.7
12/20/92	3	73	94	110	22.8	34.4	43.3	11.0	33.5
12/21/92	3	76	94	112	24.4	34.4	44.4	5.0	34.4
12/22/92	3	77	93	112	25.0	33.9	44.4	9.0	34.4
12/23/92	3	80	94	114	26.7	34.4	45.6	13.0	35.6
12/24/92	3	85	97	116	29.4	36.1	46.7	-2.0	37.4
12/25/92	3	81	90	115	27.2	32.2	46.1	1.0	35.2
12/27/92	3	78	82	112	25.6	27.8	44.4	2.0	32.6
12/28/92	3	72	78	102	22.2	25.6	38.9	2.0	28.9
12/29/92	3	71	78	109	21.7	25.6	42.8	8.0	30.0
12/30/92	3	77	81	103	25.0	27.2	39.4	16.7	30.6
12/31/92	3	76	40	102	24.4	4.4	38.9	17.2	22.6
01/01/93	3	80	83	104	26.7	28.3	40.0	4.4	31.7
01/02/93	3	78	80	101	25.6	26.7	38.3	5.0	30.2
01/03/93	3	76	79	102	24.4	26.1	38.9	12.0	29.8
01/04/93	3	76	79	101	24.4	26.1	38.3	15.0	29.6
01/05/93	3	78	80	101	25.6	26.7	38.3	13.0	30.2
01/06/93	3	81	82	103	27.2	27.8	39.4	9.0	31.5
01/07/93	3	82	82	106	27.8	27.8	41.1	10.0	32.2
01/08/93	3	82	82	107	27.8	27.8	41.7	8.0	32.4
01/09/93	3	77	77	108	25.0	25.0	42.2	4.0	30.7
01/10/93	3	71	74	107	21.7	23.3	41.7	4.0	28.9
01/11/93	3	70	74	107	21.1	23.3	41.7	4.0	28.7
01/12/93	3	69	73	107	20.6	22.8	41.7	7.0	28.3
01/13/93	3	66	71	107	18.9	21.7	41.7	16.0	27.4
01/15/93	3	71	76	110	21.7	24.4	43.3	2.0	29.8
01/16/93	3	70	78	101	21.1	25.6	38.3	6.0	28.3
01/17/93	3	72	82	108	22.2	27.8	42.2	6.0	30.7
01/18/93	3	74	86	112	23.3	30.0	44.4	2.0	32.6
01/14/93	3	78	87	114	25.6	30.6	45.6	-2.0	33.9
01/20/93	3	67	85	115	19.4	29.4	46.1	8.0	31.7
01/22/93	3	68	82	114	20.0	27.8	45.6	11.0	31.1
01/23/93	3	61	84	116	16.1	28.9	46.7	20.0	30.6
01/27/93	3	66	93	117	18.9	33.9	47.2	9.0	33.3
01/28/93	3	65	92	115	18.3	33.3	46.1	11.0	32.6
01/29/93	3	66	93	113	19.0	33.9	45.0	9.0	32.6
02/01/93	3	71	96	112	21.7	35.6	44.4	7.0	33.9
02/02/93	3	82	93	111	27.8	33.9	43.9	0.0	35.2

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
02/03/93	3	80	91	107	26.7	32.8	41.7	7.0	33.7
02/04/93	3	81	92	107	27.2	33.3	41.7	11.0	34.1
02/06/93	3	80	90	106	26.7	32.2	41.1	2.0	33.3
02/07/93	3	81	91	106	27.2	32.8	41.1	18.0	33.7
02/10/93	3	81	91	105	27.2	32.8	40.6	21.0	33.5
02/11/93	3	81	91	104	27.2	32.8	40.0	14.0	33.3
02/17/93	3	82	94	104	27.8	34.4	40.0	4.0	34.1
02/18/93	3	82	95	104	27.8	35.0	40.0	2.0	34.3
02/19/93	3	81	95	102	27.2	35.0	38.9	1.0	33.7
02/22/93	3	80	91	96	26.7	32.8	35.6	12.0	31.7
02/25/93	3	80	92	93	26.7	33.3	33.9	2.0	31.3
03/01/93	3	79	86	90	26.1	30.0	32.2	14.0	29.4
03/29/93	3	72	73	66	22.2	22.8	18.9	12.0	21.3
04/07/93	3	83	83	74	28.3	28.3	23.3	15.0	26.7
04/12/93	3	88	90	71	31.1	32.2	21.7	18.0	28.3
04/13/93	3	82	70	67	27.8	21.1	19.4	15.0	22.8
04/14/93	3	70	86	70	21.1	30.0	21.1	21.0	24.1
04/18/93	3	92	110	80	33.3	43.3	26.7	19.0	34.4
04/19/93	3	88	110	87	31.1	43.3	30.6	19.0	35.0
04/20/93	3	87	113	82	30.6	45.0	27.8	21.0	34.4
04/21/93	3	106	123	95	41.1	50.6	35.0	6.0	42.2
04/22/93	3	126	120	90	52.2	48.9	32.2	14.0	44.4
04/26/93	3	95	121	106	35.0	49.4	41.1	12.0	41.9
04/27/93	3	95	122	106	35.0	50.0	41.1	13.0	42.0
04/28/93	3	96	120	95	35.6	48.9	35.0	24.0	39.8

APPENDIX A8. TEMPERATURE- WINDROW CG-3

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
12/24/92	8	78	51	54	25.6	10.6	12.2	-2.0	16.1
12/25/92	8	89	69	74	31.7	20.6	23.3	1.0	25.2
12/27/92	8	112	78	82	44.4	25.6	27.8	2.0	32.6
12/28/92	8	141	115	101	60.6	46.1	38.3	2.0	48.3
12/29/92	8	151	134	118	66.1	56.7	47.8	8.0	56.9
12/30/92	8	147	138	138	63.9	58.9	58.9	17.0	60.6
12/31/92	8	144	138	144	62.2	58.9	62.2	17.0	61.1
01/01/93	8	105	89	70	40.6	31.7	21.1	4.0	31.1
01/02/93	8	105	88	68	40.6	31.1	20.0	5.0	30.6
01/03/93	8	122	93	124	50.0	33.9	51.1	12.0	45.0
01/04/93	8	120	85	122	48.9	29.4	50.0	15.0	42.8
01/05/93	8	112	84	121	44.4	28.9	49.4	13.0	40.9
01/06/93	8	113	95	123	45.0	35.0	50.6	9.0	43.5
01/07/93	8	122	101	127	50.0	38.3	52.8	10.0	47.0
01/08/93	8	94	75	69	34.4	23.9	20.6	8.0	26.3
01/09/93	8	99	82	79	37.2	27.8	26.1	4.0	30.4
01/10/93	8	92	93	95	33.3	33.9	35.0	4.0	34.1
01/11/93	8	88	101	86	31.1	38.3	30.0	4.0	33.1
01/12/93	8	88	106	92	31.1	41.1	33.3	7.0	35.2
01/13/93	8	89	76	71	31.7	24.4	21.7	16.0	25.9
01/15/93	8	80	75	72	26.7	23.9	22.2	2.0	24.3
01/16/93	8	101	116	117	38.3	46.7	47.2	6.0	44.1
01/17/93	8	118	118	98	47.8	47.8	36.7	6.0	44.1
01/18/93	8	66	65	69	18.9	18.3	20.6	2.0	19.3
01/19/93	8	64	48	57	17.8	8.9	13.9	-2.0	13.5
01/20/93	8	66	56	63	18.9	13.3	17.2	8.0	16.5
01/22/93	8	68	57	54	20.0	13.9	12.2	11.0	15.4
01/23/93	8	42	53	47	5.6	11.7	8.3	20.0	8.5
01/27/93	8	42	50	60	5.6	10.0	15.6	9.0	10.4
01/28/93	8	40	53	56	4.4	11.7	13.3	11.0	9.8
01/29/93	8	40	55	53	4.4	12.8	11.7	9.0	9.6
02/01/93	8	39	45	40	3.9	7.2	4.4	7.0	5.2
02/02/93	8	41	59	47	5.0	15.0	8.3	0.0	9.4
02/03/93	8	52	48	58	11.1	8.9	14.4	7.0	11.5
02/04/93	8	50	56	46	10.0	13.3	7.8	11.0	10.4
02/06/93	8	57	68	55	13.9	20.0	12.8	2.0	15.6
02/07/93	8	54	68	55	12.2	20.0	12.8	18.0	15.0
02/10/93	8	60	78	61	15.6	25.6	16.1	21.0	19.1
02/11/93	8	64	83	62	17.8	28.3	16.7	14.0	20.9
02/17/93	8	47	64	48	8.3	17.8	8.9	4.0	11.7
02/18/93	8	46	64	49	7.8	17.8	9.4	2.0	11.7
02/19/93	8	36	41	42	2.2	5.0	5.6	1.0	4.3
02/22/93	8	42	48	47	5.6	8.9	8.3	12.0	7.6
02/25/93	8	42	45	44	5.6	7.2	6.7	2.0	6.5
03/01/93	8	44	46	44	6.7	7.8	6.7	14.0	7.0
03/29/93	8	69	68	69	20.6	20.0	20.6	12.0	20.4
04/07/93	8	83	76	76	28.3	24.4	24.4	15.0	25.7

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
04/12/93	8	70	62	78	21.1	16.7	25.6	18.0	21.1
04/13/93	8	71	71	68	21.7	21.7	20.0	15.0	21.1
04/14/93	8	69	70	69	20.6	21.1	20.6	21.0	20.7
04/16/93	8	66	87	69	18.9	30.6	20.6	20.0	23.3
04/18/93	8	68	87	76	20.0	30.6	24.4	19.0	25.0
04/19/93	8	66	84	75	18.9	28.9	23.9	19.0	23.9
04/20/93	8	62	84	74	16.7	28.9	23.3	21.0	23.0
04/21/93	8	74	88	84	23.3	31.1	28.9	6.0	27.8
04/22/93	8	70	83	79	21.1	28.3	26.1	14.0	25.2
04/26/93	8	67	84	79	19.4	28.9	26.1	12.0	24.8
04/27/93	8	72	82	83	22.2	27.8	28.3	13.0	26.1
04/28/93	8	71	87	82	21.7	30.6	27.8	24.0	26.7

APPENDIX A5. TEMPERATURE- WINDROW LV-1

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
11/09/92	5	145	148	148	62.8	64.4	64.4	16.0	63.9
11/10/92	5	115	87	68	46.1	30.6	20.0	21.0	32.2
11/11/92	5	121	132	101	49.4	55.6	38.3	21.0	47.8
11/12/92	5	131	139	115	55.0	59.4	46.1	17.0	53.5
11/13/92	5	133	141	121	58.0	60.6	49.4	11.0	55.4
11/14/92	5	131	136	118	55.0	57.8	47.8	9.0	53.5
11/15/92	5	129	133	115	53.9	56.1	46.1	0.0	52.0
11/16/92	5	128	131	114	53.3	55.0	45.6	6.0	51.3
11/17/92	5	126	128	111	52.2	53.3	43.9	18.0	49.8
11/18/92	5	140	140	131	60.0	60.0	55.0	22.0	58.3
11/19/92	5	131	149	141	55.0	65.0	60.6	19.0	60.2
11/20/92	5	103	136	139	39.4	57.8	59.4	8.0	52.2
11/22/92	5	146	135	134	63.3	57.2	56.7	19.0	59.1
11/22/92	5	145	138	138	62.8	58.9	58.9	17.0	60.2
11/24/92	5	83	101	95	28.3	38.3	35.0	11.0	33.9
11/25/92	5	97	105	98	36.1	40.6	36.7	13.0	37.8
11/26/92	5	111	115	90	43.9	46.1	32.2	13.0	40.7
11/27/92	5	122	122	92	50.0	50.0	33.3	11.0	44.4
11/28/92	5	123	125	93	50.6	51.7	33.9	11.0	45.4
11/29/92	5	144	127	99	62.2	52.8	37.2	5.0	50.7
11/30/92	5	150	133	109	65.6	56.1	42.8	8.0	54.8
12/01/92	5	149	134	110	65.0	56.7	43.3	4.0	55.0
12/02/92	5	148	135	111	64.4	57.2	43.9	2.0	55.2
12/03/92	5	147	135	111	63.9	57.2	43.9	5.0	55.0
12/04/92	5	145	133	110	62.8	56.1	43.3	4.0	54.1
12/06/92	5	142	132	111	61.1	55.6	43.9	3.0	53.5
12/07/92	5	142	132	110	61.1	55.6	43.3	13.0	53.3
12/08/92	5	141	134	116	60.6	56.7	46.7	0.0	54.6
12/09/92	5	137	131	113	58.3	55.0	46.0	4.0	52.8
12/10/92	5	127	124	114	52.8	51.1	45.6	2.0	49.8
12/11/92	5	127	123	115	52.8	50.6	46.1	2.0	49.8
12/12/92	5	124	125	112	51.1	51.7	44.4	7.0	49.1
12/13/92	5	117	122	110	47.2	50.0	43.3	8.0	46.9
12/14/92	5	115	124	112	46.1	51.1	44.4	4.0	47.2
12/15/92	5	110	124	113	43.3	51.1	45.0	7.0	46.5
12/16/92	5	106	123	111	41.1	50.6	43.9	11.0	45.2
12/17/92	5	106	124	111	41.1	51.1	43.9	14.0	45.4
12/18/92	5	107	126	114	41.7	52.2	45.6	7.0	46.5
12/20/92	5	106	125	114	41.1	51.7	45.6	11.0	46.1
12/21/92	5	106	126	119	41.1	52.2	48.3	5.0	47.2
12/22/92	5	108	124	119	42.2	51.6	48.3	9.0	47.2
12/23/92	5	112	127	114	44.4	52.8	45.6	13.0	47.6
12/24/92	5	113	119	116	45.0	48.3	46.7	-2.0	46.7
12/25/92	5	120	120	115	48.9	48.9	46.1	1.0	48.0
12/27/92	5	122	123	113	50.0	50.6	45.0	2.0	48.5
12/28/92	5	119	119	112	48.3	48.3	44.4	2.0	47.0
12/29/92	5	120	118	112	48.9	47.8	44.4	8.0	47.0

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
12/30/92	5	117	131	113	47.2	55.0	45.0	17.0	49.1
12/31/92	5	121	132	121	49.4	55.6	49.4	17.0	51.5
01/01/93	5	128	138	125	53.3	58.9	51.7	4.0	54.6
01/02/93	5	129	137	124	53.9	58.3	51.1	5.0	54.4
01/03/93	5	127	135	124	52.8	57.2	51.1	12.0	53.7
01/04/93	5	129	135	124	53.9	57.2	51.1	15.0	54.1
01/05/93	5	122	137	126	50.0	58.3	52.2	13.0	53.5
01/06/93	5	134	139	128	56.7	59.4	53.3	9.0	56.5
01/07/93	5	135	139	129	57.2	59.4	53.9	10.0	56.9
01/08/93	5	124	138	130	51.1	58.9	54.4	8.0	54.8
01/09/93	5	128	135	130	53.3	57.2	54.4	4.0	55.0
01/10/93	5	123	132	130	50.6	55.6	54.4	4.0	53.5
01/11/93	5	122	130	129	50.0	54.4	53.9	4.0	52.8
01/12/93	5	122	130	129	50.0	54.4	53.9	7.0	52.8
01/13/93	5	122	128	127	50.0	53.3	52.8	16.0	52.0
01/15/93	5	128	132	130	53.3	55.6	54.4	2.0	54.4
01/16/93	5	117	124	111	47.2	51.1	43.9	6.0	47.4
01/17/93	5	127	125		52.8	51.7		6.0	52.2
01/18/93	5	133	132	139	56.1	55.6	59.4	2.0	57.0
01/19/93	5	139	128	141	59.4	53.3	60.6	-2.0	57.8
01/20/93	5	138	123	138	58.9	50.6	58.9	8.0	56.1
01/22/93	5	137	115	135	58.3	46.1	57.2	11.0	53.9
01/23/93	5	93	83	120	33.9	28.3	48.9	20.0	37.0
01/27/93	5	104	113	127	40.0	45.0	52.8	9.0	45.9
01/28/93	5	104	114	126	40.0	45.6	52.2	11.0	45.9
01/29/93	5	102	116	125	38.9	46.7	51.7	9.0	45.7
02/01/93	5	107	121	127	41.7	49.4	52.8	7.0	48.0
02/02/93	5	112	122	124	44.4	50.0	51.1	0.0	48.5
02/03/93	5	109	120	121	42.8	48.9	49.4	7.0	47.0
02/04/93	5	111	123	121	43.9	50.6	49.4	11.0	48.0
02/06/93	5	107	121	123	41.7	49.4	50.6	2.0	47.2
02/07/93	5	108	123	120	42.2	50.6	48.9	18.0	47.2
02/10/93	5	108	124	121	42.2	51.1	49.4	21.0	47.6
02/11/93	5	107	122	119	41.7	50.0	48.3	14.0	46.7
02/17/93	5	110	125	120	43.3	51.7	48.9	4.0	48.0
02/18/93	5	110	126	121	43.3	52.2	49.4	2.0	48.3
02/19/93	5	110	129	114	43.3	53.9	45.6	1.0	47.6
02/22/93	5	106	123	99	41.1	50.6	37.2	12.0	43.0
02/25/93	5	108	133	116	42.2	56.1	46.7	2.0	48.3
03/01/93	5	108	128	108	42.2	53.3	42.2	14.0	45.9
03/29/93	5	94	99	76	34.4	37.2	24.4	12.0	32.0
04/07/93	5	104	102	77	40.0	38.9	25.0	15.0	34.6
04/12/93	5	106	102	76	41.1	38.9	24.4	18.0	34.8
04/13/93	5	108	106	79	42.2	41.1	26.1	15.0	36.5
04/14/93	5	102	104	75	38.9	40.0	23.9	21.0	34.3
04/16/93	5	81	64	67	27.2	17.8	19.4	20.0	21.5
04/18/93	5	100	89	73	37.8	31.7	22.8	19.0	30.7
04/19/93	5	100	87	71	37.8	30.6	21.7	19.0	30.0
04/20/93	5	107	87	74	41.7	30.6	23.3	21.0	31.9

04/21/93	5	119	98	93	48.3	36.7	33.9	6.0	39.6
04/22/93	5	120	96	82	48.9	35.6	27.8	14.0	37.4
04/26/93	5	125	100	88	51.7	37.8	31.1		40.2
04/27/93	5	99	123	87	37.2	50.6	30.6	13.0	39.4
04/28/93	5	97	121	87	36.1	49.4	30.6	24.0	38.7

APPENDIX A7. TEMPERATURE- WINDROW LV-2

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
11/09/92	7	143	139	138	61.7	59.4	58.9	16.0	60.0
11/10/92	7	146	148	69	63.3	64.4	20.6	21.0	49.4
11/11/92	7	143	140	117	61.7	60.0	47.2	21.0	56.3
11/12/92	7	130	156	143	54.4	68.9	61.7	17.0	61.7
11/13/92	7	141	153	133	60.6	67.2	56.1	11.0	61.3
11/14/92	7	105	140	117	40.6	60.0	47.2	9.0	49.3
11/15/92	7	103	140	120	39.4	60.0	48.9	0.0	49.4
11/16/92	7	107	140	129	41.7	60.0	53.9	6.0	51.9
11/17/92	7	93	138	132	33.9	58.9	55.6	18.0	49.4
11/18/92	7	98	136	127	36.7	57.8	52.8	22.0	49.1
11/19/92	7	101	135	121	38.3	57.2	49.4	19.0	48.3
11/20/92	7	120	138	135	48.9	58.9	57.2	8.0	55.0
11/22/92	7	94	137	134	34.4	58.3	56.7	19.0	49.8
11/23/92	7	81	92	118	27.2	33.3	47.8	17.0	36.1
11/24/92	7	98	121	128	36.7	49.4	53.3	11.0	46.5
11/25/92	7	111	139	132	43.9	59.4	55.6	13.0	53.0
11/26/92	7	118	141	136	47.8	60.6	57.8	13.0	55.4
11/27/92	7	122	142	136	50.0	61.1	57.8	11.0	56.3
11/28/92	7	124	143	137	51.1	61.7	58.3	11.0	57.0
11/29/92	7	119	139	133	48.3	59.4	56.1	5.0	54.6
11/30/92	7	118	137	139	47.8	58.3	59.4	8.0	55.2
12/01/92	7	113	136	130	45.0	57.8	54.4	4.0	52.4
12/02/92	7	114	132	139	45.6	55.6	59.4	2.0	53.5
12/03/92	7	111	133	129	43.9	56.1	53.9	5.0	51.3
12/04/92	7	112	136	129	44.4	57.8	53.9	4.0	52.0
12/06/92	7	104	133	128	40.0	56.1	53.3	3.0	49.8
12/07/92	7	102	133	129	38.9	56.1	53.9	3.0	49.6
12/08/92	7	104	135	129	40.0	57.2	53.9	0.0	50.4
12/09/92	7	105	135	127	40.6	57.2	52.8	4.0	50.2
12/10/92	7	107	131	129	41.7	55.0	53.9	2.0	50.2
12/11/92	7	103	123	127	39.4	50.6	52.8	2.0	47.6
12/12/92	7	97	118	121	36.1	47.8	49.4	7.0	44.4
12/13/92	7	94	118	116	34.4	47.8	46.7	8.0	43.0
12/14/92	7	99	123	119	37.2	50.6	48.3	4.0	45.4
12/15/92	7	102	122	118	38.9	50.0	47.8	7.0	45.6
12/16/92	7	107	124	101	41.7	51.1	38.3	11.0	43.7
12/17/92	7	100	120	122	37.8	48.9	50.0	14.0	45.6
12/18/92	7	102	119	122	38.9	48.3	50.0	7.0	45.7
12/20/92	7	107	119	121	41.7	48.3	49.4	11.0	46.5
12/21/92	7	110	117	121	43.3	47.2	49.4	5.0	46.7
12/22/92	7	108	117	118	42.2	47.2	47.8	9.0	45.7
12/23/92	7	107	120	116	41.7	48.9	46.7	13.0	45.7
12/24/92	7	107	118	111	41.7	47.8	43.9	-2.0	44.4
12/25/92	7	109	115	110	42.8	46.1	43.3	1.0	44.1
12/27/92	7	110	118	112	43.3	47.8	44.4	2.0	45.2
12/28/92	7	108	119	113	42.2	48.3	45.0	2.0	45.2
12/29/92	7	109	121	114	42.8	49.4	45.6	8.0	45.9

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
12/30/92	7	137	144	133	58.3	62.2	56.1	17.0	58.9
12/31/92	7	124	126	112	51.1	52.2	44.4	17.0	49.3
01/01/93	7	127	129	116	52.8	53.9	46.7	4.0	51.1
01/02/93	7	127	127	114	52.8	52.8	45.6	5.0	50.4
01/03/93	7	127	126	114	52.8	52.2	45.6	12.0	50.2
01/04/93	7	126	126	115	52.2	52.2	46.1	15.0	50.2
01/05/93	7	124	127	115	51.1	52.8	46.1	13.0	50.0
01/06/93	7	125	126	114	51.7	52.2	45.6	9.0	49.8
01/07/93	7	128	125	119	53.3	51.7	48.3	10.0	51.1
01/08/93	7	128	125	119	53.3	51.7	48.3	8.0	51.1
01/09/93	7	128	124	118	53.3	51.1	47.8	4.0	50.7
01/10/93	7	131	124	119	55.0	51.1	48.3	4.0	51.5
01/11/93	7	131	123	118	55.0	50.6	47.8	4.0	51.1
01/12/93	7	130	122	118	54.4	50.0	47.8	7.0	50.7
01/13/93	7	96	100	94	35.6	37.8	34.4	16.0	35.9
01/15/93	7	102	116	117	38.9	46.7	47.2	2.0	44.3
01/16/93	7	101	116	117	38.3	46.7	47.2	6.0	44.1
01/17/93	7	118	118	98	47.8	47.8	36.7	6.0	44.1
01/18/93	7	119	122	129	48.3	50.0	53.9	2.0	50.7
01/19/93	7	122	124	129	50.0	51.1	53.9	-2.0	51.7
01/20/93	7	120	121	124	48.9	49.4	51.1	8.0	49.8
01/22/93	7	123	122	126	50.6	50.0	52.2	11.0	50.9
01/23/93	7	117	121	127	47.2	49.4	52.8	20.0	49.8
01/27/93	7	117	120	127	47.2	48.9	52.8	9.0	49.6
01/28/93	7	115	120	126	46.1	48.9	52.2	11.0	49.1
01/29/93	7	115	118	127	46.1	47.8	52.8	9.0	48.9
02/01/93	7	109	118	128	42.8	47.8	53.3	7.0	48.0
02/02/93	7	112	119	127	44.4	48.3	52.8	0.0	48.5
02/03/93	7	111	116	123	43.9	46.7	50.6	7.0	47.0
02/04/93	7	101	116	123	38.3	46.7	50.6	11.0	45.2
02/06/93	7	114	116	121	45.6	46.7	49.4	2.0	47.2
02/07/93	7	111	112	116	43.9	44.4	46.7	18.0	45.0
02/10/93	7	112	111	116	44.4	43.9	46.7	21.0	45.0
02/11/93	7	114	114	116	45.6	45.6	46.7	14.0	45.9
02/17/93	7	112	117	124	44.4	47.2	51.1	4.0	47.6
02/18/93	7	111	117	125	43.9	47.2	51.7	2.0	47.6
02/19/93	7	61	88	95	16.1	31.1	35.0	1.0	27.4
02/22/93	7	56	75	90	13.3	23.9	32.2	12.0	23.1
02/25/93	7	74	111	100	23.3	43.9	37.8	2.0	35.0
03/01/93	7	69	104	99	20.6	40.0	37.2	14.0	32.6
03/29/93	7	69	100	89	20.6	37.8	31.7	12.0	30.0
04/07/93	7	91	99	77	32.8	37.2	25.0	15.0	31.7
04/12/93	7	85	98	71	29.4	36.7	21.7	18.0	29.3
04/13/93	7	87	99	73	30.6	37.2	22.8	15.0	30.2
04/14/93	7	70	95	75	21.1	35.0	23.9	21.0	26.7
04/16/93	7	75	91	69	23.9	32.8	20.6	20.0	25.7
04/18/93	7	84	103	79	28.9	39.4	26.1	19.0	31.5
04/19/93	7	83	98	77	28.3	36.7	25.0	19.0	30.0
04/20/93	7	85	100	77	29.4	37.8	25.0	21.0	30.7

04/21/93	7	92	106	84	33.3	41.1	28.9	6.0	34.4
04/22/93	7	90	104	82	32.2	40.0	27.8	14.0	33.3
04/26/93	7	99	107	86	37.2	41.7	30.0	12.0	36.3
04/27/93	7	92	103	85	33.3	39.4	29.4	13.0	34.1
04/28/93	7	94	102	84	34.4	38.9	28.9	24.0	34.1

APPENDIX A9. TEMPERATURE- WINDROW LV-3

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
12/30/92	9	73		79	22.8		26.1	17.0	24.4
12/31/92	9	82		90	27.8		32.2	17.0	30.0
01/01/93	9	93		112	33.9		44.4	4.0	39.2
01/02/93	9	99	142	124	37.2	61.1	51.1	5.0	49.8
01/03/93	9	136	150	136	57.8	65.6	57.8	12.0	60.4
01/04/93	9	135	150	139	57.2	65.6	59.4	15.0	60.7
01/05/93	9	140	148	133	60.0	64.4	56.1	13.0	60.2
01/06/93	9	134	148	139	56.7	64.4	59.4	9.0	60.2
01/07/93	9	72	140	83	22.2	60.0	28.3	10.0	36.9
01/08/93	9	113	132	105	45.0	55.6	40.6	8.0	47.0
01/09/93	9	120	131	114	48.9	55.0	45.6	4.0	49.8
01/10/93	9	120	142	130	48.9	61.1	54.4	4.0	54.8
01/11/93	9	122	142	137	50.0	61.1	58.3	4.0	56.5
01/12/93	9	123	140	134	50.6	60.0	56.7	7.0	55.7
01/13/93	9	128	142	128	53.3	61.1	53.3	16.0	55.9
01/15/93	9	121	140	127	49.4	60.0	52.8	2.0	54.1
01/16/93	9	119	136	125	48.3	57.8	51.7	6.0	52.6
01/17/93	9	119	135	122	48.3	57.2	50.0	6.0	51.9
01/18/93	9	119	136	123	48.3	57.8	50.6	2.0	52.2
01/19/93	9	119	132	121	48.3	55.6	49.4	-2.0	51.1
01/20/93	9	114	116	127	45.6	46.7	52.8	8.0	48.3
01/22/93	9	112	127	113	44.4	52.8	45.0	11.0	47.4
01/23/93	9	110	121	108	43.3	49.4	42.2	20.0	45.0
01/27/93	9	106	116	104	41.1	46.7	40.0	9.0	42.6
01/28/93	9	106	116	104	41.1	46.7	40.0	11.0	42.6
01/29/93	9	104	112	102	40.0	44.4	38.9	9.0	41.1
02/01/93	9	97	108	99	36.1	42.2	37.2	7.0	38.5
02/02/93	9	97	108	100	36.1	42.2	37.8	0.0	38.7
02/03/93	9	96	108	98	35.6	42.2	36.7	7.0	38.1
02/04/93	9	96	108	98	35.6	42.2	36.7	11.0	38.1
02/06/93	9	99	109	98	37.2	42.8	36.7	2.0	38.9
02/07/93	9	95	110	95	35.0	43.3	35.0	18.0	37.8
02/10/93	9	98	112	96	36.7	44.4	35.6	21.0	38.9
02/11/93	9	101	110	98	38.3	43.3	36.7	14.0	39.4
02/17/93	9	99	105	100	37.2	40.6	37.8	4.0	38.5
02/18/93	9	99	105	101	37.2	40.6	38.3	2.0	38.7
02/19/93	9	67	80	98	19.4	26.7	36.7	1.0	27.6
02/22/93	9	64	80	89	17.8	26.7	31.7	12.0	25.4
02/25/93	9	65	82	84	18.3	27.8	28.9	2.0	25.0
03/01/93	9	66	80	69	18.9	26.7	20.6	14.0	22.0
03/29/93	9	60	64	62	15.6	17.8	16.7	12.0	16.7
04/07/93	9	65	70	60	18.3	21.1	15.6	15.0	18.3
04/12/93	9	66	70	61	18.9	21.1	16.1	18.0	18.7
04/13/93	9	68	70	72	20.0	21.1	22.2	15.0	21.1
04/14/93	9	65	70	60	18.3	21.1	15.6	21.0	18.3
04/16/93	9	60	54		15.6	12.2		20.0	13.9
04/18/93	9	74	70	68	23.3	21.1	20.0	19.0	21.5

date	w'row	temp1	temp2	temp3	degC1	degC2	degC3	ambient	tempavg
04/19/93	9	72	70	66	22.2	21.1	18.9	19.0	20.7
04/20/93	9	68	70	73	20.0	21.1	22.8	21.0	21.3
04/21/93	9		68	74		20.0	23.3	6.0	21.7
04/22/93	9		68	70		20.0	21.1	14.0	20.6
04/26/93	9		68	70		20.0	21.1	12.0	20.6
04/27/93	9		68	76		20.0	24.4	13.0	22.2
04/28/93	9		68	75		20.0	23.9	24.0	21.9

APPENDIX B. CARBON AND NITROGEN DATA

sample # and descrip.	%C (1)	%C (2)	%C (3)	%C avg.	%N (1)	%N (2)	%N avg.	C/N
Windrow LG-1								
leaves: LG-1	57.91	55.02	56.87	56.60	1.51	1.32	1.42	39.85
grass: LG-1	44.09	44.10	43.42	43.65	2.78	3.04	2.91	15.00
LG-1: 10/16	35.89	33.57	34.08	34.51	1.08	1.05	1.07	32.40
LG-1: 10/21	29.89	28.97	31.05	29.97	1.29	1.28	1.29	23.32
LG-1: 10/28	31.89	29.52	31.66	31.02	1.64	1.53	1.59	19.57
LG-1: 11/6	31.80	33.50	31.27	32.19	1.44	1.41	1.43	22.59
LG-1: 11/14	36.59	36.11	37.21	36.64	1.72	1.80	1.76	20.82
LG-1: 11/18	28.32	29.12	28.43	28.62	1.51	1.56	1.54	18.64
LG-1: 11/28	33.32	34.25	32.98	33.52	1.76	1.38	1.57	21.35
LG-1: 12/3	35.23	32.87	34.69	34.26	1.36	1.52	1.44	23.79
LG-1: 4/14	29.57	30.61	29.19	29.79	1.77	1.56	1.67	17.89
Windrow LG-2								
grass: LG-2	43.59	44.17	45.08	44.28	2.60	2.51	2.56	17.33
leaves: LG-2	43.12	42.85	41.38	42.45	1.94	2.04	1.99	20.96
LG-2: 10/21	36.74	38.12	36.41	37.09	1.33	1.36	1.35	27.58
LG-2: 10/28	37.25	38.44	37.19	37.63	2.12	2.07	2.10	17.96

sample # and descrip.	%C (1)	%C (2)	%C (3)	%C avg.	%N (1)	%N (2)	%N avg.	C/N
LG-2: 11/14	37.47	37.63	38.31	37.80	1.57	1.56	1.57	24.15
LG-2: 11/6	35.95	37.26	37.25	36.82	1.36	1.61	1.49	24.79
LG-2: 11/28	36.57	36.25	37.24	36.69	1.78	1.68	1.73	21.21
LG-2: 12/3	33.70	33.65	35.31	34.22	1.38	1.31	1.35	25.35
LG-2: 4/14	30.48	32.43	30.26	31.06	1.56	1.73	1.65	18.88
Windrow LG-3								
leaves: LG-3	48.74	48.63	49.43	48.93	1.24	1.19	1.22	40.11
grass: LG-3	36.80	36.54	35.88	36.41	3.38	3.51	3.45	10.27
LG-3: 11/14	39.00	40.40	40.00	39.80	1.85	1.61	1.73	23.01
LG-3: 11/18	46.53	48.13	48.10	47.59	1.44	1.46	1.45	32.82
LG-3: 11/28	37.66	39.76	37.92	38.45	1.73	1.73	1.73	22.23
LG-3: 12/3	40.22		40.39	40.30	1.57	1.58	1.58	25.51
LG-3: 3/2	36.45	36.27	36.58	36.43	1.89	1.81	1.86	19.64
LG-3: 4/7	31.45	35.17	35.98	34.20	1.45	1.40	1.43	23.92

sample # and descrip.	%C (1)	%C (2)	%C (3)	%C avg.	%N (1)	%N (2)	%N avg.	C/N
Windrow CG-1								
grass: CG-1				43.65	2.78	3.04	2.91	15.00
chips: CG-1				49.82	0.26	0.21	0.24	207.58
CG-1: 10/16	43.59	44.05	42.90	43.51	0.49	0.42	0.46	95.63
CG-1: 10/21	42.74	42.35	44.30	43.13	0.70	0.38	0.54	79.87
CG-1: 10/28	37.51	38.41	39.38	38.43	1.04	1.01	1.03	37.49
CG-1: 11/14	43.83	42.85	45.44	44.04	1.40	1.68	1.54	28.60
CG-1: 11/6	43.18	45.30	45.04	44.51	0.72	0.60	0.66	67.44
CG-1: 11/18	39.53	46.37	41.95	40.95	0.77	0.78	0.78	52.84
CG-1: 11/28	42.62	43.06	44.22	43.30	0.63	0.55	0.59	73.39
CG-1: 12/3	39.78	41.32		40.55	0.75	0.72	0.74	54.80
CG-1: 4/14	41.75	43.77	42.28	42.60	0.66	0.64	0.65	65.54
Windrow CG-2								
chips: CG-2	46.13	46.93	47.60	46.89	0.15	0.17	0.16	293.06
grass CG-2	43.59	44.17	45.08	44.28	2.60	2.51	2.55	17.33
CG-2: 10/21	38.67	40.02	40.62	39.77	0.44	0.42	0.43	92.49
CG-2: 10/28	37.19	46.22	40.32	41.24	1.07	0.97	1.02	40.43

sample # and descrip.	%C (1)	%C (2)	%C (3)	%C avg.	%N (1)	%N (2)	%N avg.	C/N
CG-2: 11/6	44.79	46.18	43.46	44.81	0.73	1.00	0.87	51.80
CG-2: 11/14	47.16	47.40	48.03	47.53	0.70	0.78	0.74	64.23
CG-2: 11/18	42.35	43.41	43.26	43.01	0.91	0.94	0.93	46.50
CG-2: 11/28	42.05	45.39	44.43	43.96	0.97	0.81	0.89	49.39
CG-2: 12/3	41.45	43.06	40.37	41.63	0.58	0.56	0.57	73.03
CG-2: 4/14	42.44	42.67	42.42	42.51	0.65	0.61	0.63	67.48
Windrow CG-3								
CG-3: 3/2	45.10	46.14	45.56	45.60	0.24	0.57	0.41	111.22
CG-3: 4/7	45.08	44.59	44.49	44.72	0.69	0.82	0.76	59.23
Windrow LV-1								
leaves: LV-1	48.74	48.63	49.84	48.74	1.24	1.19	1.22	40.11
LV-1: 11/14	48.79	50.21	48.49	49.16	1.53	1.50	1.52	32.45
LV-1: 11/18	44.75	45.97	46.53	45.75	0.91	0.86	0.89	51.69
LV-1: 11/28	42.73	42.79	43.04	42.85	0.94	0.94	0.94	45.58
LV-1: 12/3	43.09	42.47		42.78	0.70	0.74	0.72	59.42
LV-1: 3/2/93	44.64	44.19	42.83	43.89	1.22	1.37	1.29	34.02
LV-1: 4/7	42.20	41.26	41.96	41.81	1.39	1.34	1.37	30.63

sample # and descrip.	%C (1)	%C (2)	%C (3)	%C avg.	%N (1)	%N (2)	%N avg.	C/N
Windrow LV-2								
leaves: LV-2	48.74	48.63	48.84	48.74	1.19	1.24	1.21	40.28
LV-2: 11/14/92	48.88	44.72	46.36	46.65	1.13	1.12	1.13	41.47
LV-2: 11/18	45.78	44.83	46.00	45.54	1.06	1.00	1.03	44.21
LV-2: 11/28	44.67	44.68	44.27	44.54	1.04	1.01	1.03	43.24
LV-2: 12/3	43.31	43.12	43.06	43.17	1.08	1.02	1.05	41.11
LV-2: 3/2/93	44.61	43.54	44.36	44.17	1.34	1.23	1.29	34.24
LV-2: 4/7	41.40	42.79		42.09	1.38	1.27	1.33	31.77
Windrow LV-3								
LV-3: 2/15/93	46.17	46.49	46.21	46.29	0.83	0.85	0.84	55.44
LV-3: 3/2	43.86	47.01	46.90	45.92	0.58	0.55	0.57	80.56
LV-3: 4/7	38.88	38.57	40.65	39.37	0.80	0.89	0.85	46.59

APPENDIX C. GAS DATA. Units are moles/l

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-1					
9/29/92	ch4	1.57e-03	2.34e-03	1.48e-03	1.80e-03
10/3/92	ch4	3.72e-04	5.09e-04	6.59e-04	5.13e-04
10/6/92	ch4	0.00e+00	2.00e-05	1.62e-04	6.07e-05
10/12/92	ch4	0.00e+00	2.03e-05	1.68e-04	6.28e-05
10/14/92	ch4	1.62e-05	2.72e-05	4.74e-04	1.72e-04
9/26/92	ch4	0.00e+00	2.93e-04	8.05e-04	3.66e-04
10/9/92	ch4				
10/16/92	ch4		1.06e-04	9.10e-05	9.85e-05
10/19/92	ch4	7.00e-05	1.24e-05	0.00e+00	2.75e-05
10/26/92	ch4	0.00e+00	9.35e-03	4.54e-04	3.27e-03
10/28/92	ch4	2.26e-04	3.26e-05	1.79e-04	1.46e-04
10/30/92	ch4	7.87e-05	5.64e-05	1.13e-04	8.27e-05
11/3/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/6/92	ch4	0.00e+00	2.72e-05	0.00e+00	9.10e-06
11/9/92	ch4	0.00e+00	1.13e-05	0.00e+00	3.77e-06
11/17/92	ch4	1.13e-05	0.00e+00	0.00e+00	3.77e-06
11/18/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/20/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Windrow LG-1					
11/23/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/28/92	ch4	2.47e-04	8.52e-05	0.00e+00	1.11e-04
12/5/92	ch4				0.00e+00
12/9/92	ch4				0.00e+00
12/12/92	ch4	0.00e+00	0.00e+00		0.00e+00
12/29/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/6/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/14/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
9/26/92	co2	4.09e-03	2.43e-03	6.04e-03	4.19e-03
9/29/92	co2	6.22e-03	6.65e-03	4.30e-03	5.72e-03
10/3/92	co2	3.52e-04	4.34e-03	4.86e-03	3.18e-03
10/6/92	co2	2.26e-03	2.94e-03	4.03e-03	3.08e-03
10/12/92	co2	2.36e-03	3.13e-03	3.84e-03	3.11e-03
10/14/92	co2	4.80e-03	3.88e-03	5.66e-03	4.78e-03
10/16/92	co2		5.14e-03	3.16e-03	4.15e-03
10/19/92	co2	3.46e-03	2.27e-03	1.02e-03	2.25e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-1					
10/26/92	co2	4.04e-03	9.90e-03	1.68e-04	4.70e-03
10/28/92	co2	4.69e-03	9.20e-04	4.61e-03	3.41e-03
10/30/92	co2	4.76e-03	4.58e-03	4.78e-03	4.71e-03
11/3/92	co2	2.49e-04	2.16e-04	1.12e-04	6.90e-03
11/6/92	co2	2.73e-03	4.30e-03	2.64e-03	3.22e-03
11/9/92	co2	1.80e-03	4.12e-03	2.69e-03	2.87e-03
11/17/92	co2	3.98e-03	2.30e-03	2.34e-03	2.87e-03
11/18/92	co2	9.02e-05	7.29e-05	9.43e-04	3.69e-04
11/20/92	co2	2.37e-03	1.00e-03	1.24e-03	1.54e-03
11/23/92	co2	1.57e-04	6.28e-04	1.02e-03	6.02e-04
11/28/92	co2	1.47e-02	9.64e-03	1.29e-03	8.54e-03
12/12/92	co2	2.56e-04	4.52e-05		1.51e-04
12/29/92	co2	7.07e-05	6.40e-05	0.00e+00	4.49e-05
1/2/93	co2	7.17e-05	8.13e-04	5.58e-05	3.14e-04
1/6/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	co2	7.64e-05	6.59e-05	5.80e-05	6.68e-05
4/14/93	co2	5.65e-04	3.86e-04	3.89e-05	3.30e-04
9/29/92	o2	4.07e-03	5.32e-04	4.69e-04	1.69e-03
10/3/92	o2	4.13e-03	2.90e-03	4.50e-03	3.84e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-1					
10/6/92	o2	6.72e-03	5.79e-03	4.85e-03	5.79e-03
10/12/92	o2	4.23e-03	3.64e-03	4.58e-03	4.15e-03
10/9/92	o2		3.31e-03	2.90e-03	3.11e-03
10/14/92	o2	4.04e-03	3.44e-03	2.86e-03	3.45e-03
10/16/92	o2	2.98e-03		3.83e-03	3.41e-03
10/19/92	o2	2.36e-04	5.30e-03	6.23e-03	3.92e-03
10/23/92	o2	5.63e-03	4.73e-03	3.28e-03	4.55e-03
10/26/92	o2	6.23e-03	3.94e-03	8.31e-03	6.16e-03
10/28/92	o2	6.36e-03	4.79e-03	8.28e-03	6.48e-03
11/3/92	o2	7.73e-03	6.35e-03	8.38e-03	7.49e-03
11/6/92	o2	6.32e-03	4.07e-03	6.20e-03	5.53e-03
11/9/92	o2	6.51e-03	3.54e-03	4.07e-03	4.71e-03
11/17/92	o2	5.47e-03	7.67e-03	2.90e-03	5.35e-03
11/18/92	o2	8.22e-03	8.11e-03	7.95e-03	8.09e-03
11/23/92	o2	7.44e-03	8.75e-03	7.21e-03	7.80e-03
11/28/92	o2	3.26e-03	3.93e-03	5.22e-03	4.14e-03
12/5/92	o2	9.15e-03	8.18e-03	5.74e-03	7.69e-03
12/9/92	o2	6.39e-03	7.83e-03	8.40e-03	7.54e-03
12/29/92	o2	9.19e-03	9.28e-03	8.92e-03	9.13e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-1					
1/6/93	o2	8.20e-03	8.02e-03	8.47e-03	8.23e-03
1/18/93	o2	9.20e-03	8.05e-03	8.69e-03	8.65e-03
4/14/93	o2	6.01e-03	7.49e-03	9.04e-03	7.51e-03
Windrow LG-2					
10/19/92	ch4	9.80e-06	3.66e-04	2.77e-05	1.35e-04
10/26/92	ch4	0.00e+00	0.00e+00	1.66e-05	5.53e-06
10/28/92	ch4	0.00e+00	4.53e-04	1.66e-04	2.06e-04
10/30/92	ch4	0.00e+00	2.85e-04	3.13e-04	1.99e-04
11/3/92	ch4	0.00e+00	1.16e-05	6.53e-05	2.56e-05
11/6/92	ch4	2.82e-05	2.20e-05	0.00e+00	1.67e-05
11/9/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/17/92	ch4	0.00e+00	3.60e-05	1.84e-05	1.81e-05
11/18/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/20/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/23/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/28/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/5/92	ch4				0.00e+00
12/12/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-1					
Windrow LG-2					
12/29/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/6/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/14/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/19/92	co2	4.86e-03	6.00e-03	4.65e-03	5.17e-03
10/26/92	co2	6.81e-03	5.31e-04	4.24e-03	3.86e-03
10/28/92	co2	3.32e-03	3.78e-03	1.90e-03	3.00e-03
10/30/92	co2	1.89e-03	7.49e-03	5.33e-03	4.90e-03
11/3/92	co2	2.93e-03	3.72e-03	5.36e-03	4.00e-03
11/6/92	co2	4.55e-03	3.05e-03	1.23e-03	2.94e-03
11/9/92	co2	3.11e-03	6.91e-04	4.74e-04	1.43e-03
11/17/92	co2	1.40e-03	4.10e-03	2.07e-03	2.52e-03
11/18/92	co2	4.93e-05	1.46e-04	6.36e-05	8.63e-05

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-2					
11/20/92	co2	1.56e-04	1.24e-04	2.92e-03	1.07e-03
11/23/92	co2	9.73e-05	9.80e-05	1.00e-04	9.84e-05
11/28/92	co2	5.24e-04	7.83e-05	0.00e+00	3.01e-04
12/12/92	co2	4.46e-05	3.68e-05	3.81e-05	3.98e-05
12/29/92	co2	5.92e-05	5.65e-05	5.44e-05	5.67e-05
1/2/93	co2	5.60e-05	5.69e-05	6.99e-05	6.09e-05
1/6/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	co2	0.00e+00	7.46e-05	6.99e-05	4.82e-05
4/14/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/19/92	o2	2.75e-03	3.29e-03	1.16e-03	2.40e-03
10/26/92	o2	4.87e-03	7.26e-04	3.12e-03	2.91e-03
10/28/92	o2	5.23e-03	5.09e-03	8.05e-03	6.12e-03
11/3/92	o2	4.45e-03	4.59e-03	3.76e-03	4.27e-03
11/6/92	o2	4.76e-03	6.64e-03	4.95e-03	5.45e-03
11/9/92	o2	3.95e-03	4.54e-03	8.31e-03	5.60e-03
11/17/92	o2	2.38e-03	3.97e-03	3.62e-03	3.32e-03
11/18/92	o2	5.41e-03	5.02e-03	5.60e-03	5.34e-03
11/28/92	o2	7.63e-03	7.83e-03	8.18e-03	7.88e-03
12/5/92	o2	6.37e-03	7.71e-04	7.01e-03	4.72e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-2					
12/12/92	o2	7.14e-03	7.74e-03	9.35e-03	8.08e-03
12/29/92	o2	8.91e-03	9.39e-03	9.55e-03	9.28e-03
1/2/93	o2	8.07e-03	9.06e-03	9.01e-03	8.71e-03
1/6/93	o2	8.26e-03	8.59e-03	5.50e-03	7.45e-03
1/18/93	o2	8.53e-03	8.62e-03	7.81e-03	8.32e-03
4/14/93	o2	6.31e-03	5.72e-03	4.13e-03	5.39e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-3					
11/9/92	ch4	1.60e-09	2.52e-09	0.00e+00	1.37e-09
11/17/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/18/92	ch4	0.00e+00	5.85e-09	0.00e+00	1.95e-09
11/20/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/23/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/28/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/5/92	ch4				0.00e+00
12/12/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/17/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/21/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/29/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/6/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/11/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/14/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/27/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/4/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Windrow LG-3					
2/10/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/12/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/15/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/23/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/5/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/7/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/9/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/28/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/9/92	co2	5.93e-03	6.20e-03	5.34e-03	5.82e-03
11/17/92	co2	1.44e-04	1.50e-04	1.09e-04	1.34e-04
11/18/92	co2	1.05e-03	3.60e-03	1.58e-03	2.08e-03
11/20/92	co2	1.14e-03	4.86e-03	4.21e-03	3.40e-03
11/23/92	co2	9.10e-03	5.64e-03	3.12e-04	5.02e-03
11/28/92	co2	1.65e-04	0.00e+00	6.74e-05	7.75e-05
12/12/92	co2	3.48e-04	3.37e-03	2.66e-03	2.13e-03
12/17/92	co2	1.23e-04	1.47e-04	3.34e-03	1.20e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-3					
12/21/92	co2	3.98e-03	4.00e-03	5.32e-03	4.43e-03
12/29/92	co2	1.32e-03	1.32e-04	7.75e-05	5.10e-04
1/2/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/6/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/11/93	co2	5.40e-05	8.43e-05	4.56e-05	6.13e-05
1/14/93	co2	6.05e-05	1.10e-04	5.01e-05	7.35e-05
1/18/93	co2	6.29e-05	5.45e-05	7.18e-05	6.31e-05
1/22/93	co2	4.32e-05	0.00e+00	0.00e+00	1.44e-05
1/27/93	co2	6.17e-05	8.18e-05	4.02e-05	6.12e-05
2/4/93	co2	4.89e-05	0.00e+00	0.00e+00	1.63e-05
2/10/93	co2	0.00e+00	3.44e-05	3.72e-05	2.39e-05
2/12/93	co2	3.63e-05	4.29e-05	3.83e-05	3.92e-05
2/15/93	co2	4.65e-05	4.87e-05	3.32e-05	4.28e-05
1/18/93	co2	4.50e-05	4.38e-05	4.41e-05	4.43e-05
1/22/93	co2	5.09e-05	4.43e-05	0.00e+00	4.76e-05
1/27/93	co2	3.42e-05	3.55e-05	0.00e+00	3.17e-05
2/4/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/10/93	co2	5.85e-05	8.82e-05	4.60e-05	6.42e-05
2/12/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-3					
2/15/93	co2	7.57e-04	8.88e-04	5.32e-04	7.26e-04
2/23/93	co2	3.41e-03	1.81e-03	1.51e-04	1.79e-03
3/2/93	o2	4.27e-03	3.77e-03	4.72e-03	4.25e-03
3/5/93	o2	8.20e-03	1.10e-02	9.65e-03	9.62e-03
4/2/93	o2	6.76e-03	3.36e-03	5.18e-03	5.10e-03
4/7/93	o2	5.07e-03	4.24e-03	5.65e-03	4.99e-03
4/9/93	o2	9.41e-03	5.39e-03	4.55e-03	6.45e-03
4/22/93	o2	4.36e-03	4.31e-03	3.06e-03	3.91e-03
4/28/93	o2	1.14e-02	8.55e-03	1.38e-02	1.13e-02
11/9/92	o2	8.28e-03	8.99e-03	7.24e-03	8.17e-03
11/17/92	o2	7.00e-03	7.15e-03	7.11e-03	7.09e-03
11/18/92	o2	8.68e-03	8.98e-03	8.86e-03	8.84e-03
11/20/92	o2	9.43e-03	9.04e-03	9.43e-03	9.30e-03
11/23/92	o2	8.95e-03	8.60e-03	8.00e-03	8.52e-03
11/28/92	o2	8.89e-03	8.82e-03	8.98e-03	8.90e-03
12/12/92	o2	8.48e-03	8.56e-03	8.75e-03	8.60e-03
12/17/92	o2	8.26e-03	8.48e-03	8.90e-03	8.55e-03
1/22/93	o2	8.84e-03	8.56e-03	9.27e-03	8.89e-03
1/27/93	o2	6.83e-03	8.81e-03	8.50e-03	8.05e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-3					
2/4/93	o2	8.54e-03	7.86e-03	8.73e-03	8.38e-03
2/10/93	o2	8.99e-03	8.57e-03	7.60e-03	8.39e-03
2/12/93	o2	7.21e-03	7.66e-03	7.82e-03	7.56e-03
2/15/93	o2	8.39e-03	8.99e-03	8.66e-03	8.68e-03
2/23/93	o2	8.92e-03	9.02e-03	8.99e-03	8.98e-03
3/2/93	o2	9.44e-03	9.84e-03	9.00e-03	9.43e-03
3/5/93	o2	8.44e-03	7.81e-03		8.13e-03
4/2/93	o2	9.97e-03	9.28e-03	9.36e-03	9.54e-03
4/7/93	o2	8.08e-03	9.38e-03	9.21e-03	8.89e-03
4/9/93	o2	8.52e-03	1.00e-02	9.39e-03	9.30e-03
4/22/93	o2	8.83e-03	7.66e-03	7.90e-03	8.13e-03
4/28/93	o2	6.02e-03	6.64e-03	9.10e-03	7.25e-03
Windrow CG-1					
9/29/92	ch4	2.60e-05	0.00e+00	0.00e+00	8.67e-06
9/30/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
9/26/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/3/92	ch4	4.14e-05	0.00e+00	0.00e+00	1.38e-05
10/6/92	ch4	7.80e-06	0.00e+00	0.00e+00	2.60e-06

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LG-3					
Windrow CG-1					
10/12/92	ch4	12:00 am	0.00e+00	7.95e-06	9.52e-06
10/14/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/16/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/19/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/23/92	ch4				

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-1					
10/26/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/28/92	ch4	1.05e-05	0.00e+00	0.00e+00	3.50e-06
10/30/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/3/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/6/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/9/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/17/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/18/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/20/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/23/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/28/92	ch4	0.00e+00	0.00e+00	1.40e-05	4.67e-06
12/5/92	ch4				0.00e+00
12/9/92	ch4				0.00e+00
12/12/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/14/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
9/26/92	co2	2.22e-03	1.29e-03	1.41e-03	1.64e-03
9/29/92	co2	1.02e-03	8.75e-04	9.12e-04	9.36e-04

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-1					
9/30/92	co2	1.17e-03	5.03e-04	1.15e-04	5.96e-04
10/3/92	co2	8.17e-04	1.34e-03	1.36e-03	1.17e-03
10/6/92	co2	3.68e-04	9.89e-05	3.18e-04	2.62e-04
10/12/92	co2	6.77e-04	1.30e-03	2.13e-03	1.37e-03
10/14/92	co2	8.21e-04	4.49e-04	1.51e-03	9.27e-04
10/16/92	co2	1.06e-03		1.23e-03	1.15e-03
10/19/92	co2	5.03e-04	9.42e-04	4.69e-04	6.38e-04
10/26/92	co2	3.68e-04	8.17e-04	8.40e-04	6.75e-04
10/28/92	co2	1.07e-03	5.82e-04	1.82e-03	1.16e-03
10/30/92	co2	9.56e-04	6.45e-04	1.64e-03	1.08e-03
11/3/92	co2	1.48e-04	1.87e-04	7.37e-04	3.57e-04
11/6/92	co2	6.08e-04	1.72e-04	2.80e-04	3.53e-04
11/17/92	co2	3.65e-04	4.70e-04	3.77e-04	4.04e-04
11/18/92	co2	3.80e-05	4.64e-05	3.80e-05	4.08e-05
11/20/92	co2	6.54e-04	1.09e-04	8.95e-05	2.84e-04
11/23/92	co2	1.05e-04	7.50e-05	6.92e-05	8.31e-05
11/28/92	co2	1.47e-04	1.97e-03	3.41e-03	1.84e-03
12/12/92	co2	3.92e-05	4.06e-05	5.32e-05	4.43e-05
1/2/93	co2	6.65e-05		4.63e-05	5.64e-05

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-1					
1/18/93	co2	6.48e-05	5.88e-05	5.54e-05	5.97e-05
4/14/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
9/29/92	o2	8.51e-03	8.63e-03	7.65e-03	8.26e-03
9/30/92	o2	7.27e-03	7.87e-03	4.92e-03	6.69e-03
10/3/92	o2	7.11e-03	6.66e-03	7.34e-03	7.04e-03
10/6/92	o2	7.48e-03	7.90e-03	7.90e-03	7.76e-03
10/9/92	o2	9.99e-03	8.60e-03	7.59e-03	8.73e-03
10/12/92	o2	6.89e-03	5.94e-03	5.39e-03	6.07e-03
10/14/92	o2	5.91e-03	6.09e-03		6.00e-03
10/16/92	o2	6.89e-03		6.44e-03	6.67e-03
10/19/92	o2	5.00e-03	6.19e-03	4.62e-03	5.27e-03
10/23/92	o2	7.70e-03		5.50e-03	6.60e-03
10/26/92	o2	8.22e-03	8.47e-03	5.98e-03	7.56e-03
10/28/92	o2	8.62e-03	8.96e-03	7.31e-03	8.30e-03
11/3/92	o2	1.47e-02	1.35e-02	1.06e-02	1.29e-02
11/6/92	o2	7.79e-03	8.52e-03	7.91e-03	8.07e-03
11/9/92	o2	8.25e-03	5.14e-03	8.52e-03	7.30e-03
11/17/92	o2	8.44e-03	5.36e-03	8.23e-03	7.34e-03
11/18/92	o2	8.04e-03	7.88e-03	8.92e-03	8.28e-03
Windrow CG-1					
11/23/92	o2	4.78e-03	5.52e-03	4.82e-03	5.04e-03
11/28/92	o2	4.52e-03	4.20e-03	5.97e-03	4.90e-03
12/5/92	o2	9.16e-03	5.58e-03	7.63e-03	7.46e-03
12/9/92	o2	1.13e-02	6.50e-03	5.05e-03	7.62e-03
1/18/93	o2	5.10e-03	8.92e-03	8.63e-03	7.55e-03
4/14/93	o2	7.61e-03	7.39e-03	6.04e-03	7.01e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-2					
10/16/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/19/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/23/92	ch4				0.00e+00
10/26/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/28/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/30/92	ch4	3.53e-05	0.00e+00	0.00e+00	1.18e-05
11/3/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/6/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/9/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/17/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/18/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/20/92	ch4	0.00e+00			0.00e+00
11/23/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/28/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/5/92	ch4				0.00e+00
12/9/92	ch4				0.00e+00
12/12/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/29/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-2					
1/6/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/14/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
10/16/92	co2	4.50e-04		5.90e-04	5.20e-04
10/19/92	co2	1.53e-03	8.67e-04	5.49e-04	9.82e-04
10/26/92	co2	2.03e-03	2.66e-04	7.04e-04	1.00e-03
10/28/92	co2	1.10e-03	1.78e-03	1.74e-03	1.54e-03
10/30/92	co2	1.75e-03	1.95e-03	2.51e-03	2.07e-03
11/3/92	co2	7.69e-04	1.10e-03	1.17e-03	1.01e-03
11/6/92	co2	1.01e-03	5.01e-04	1.12e-03	8.77e-04
11/9/92	co2	1.48e-04	3.90e-04	3.66e-04	3.01e-04
11/17/92	co2	6.54e-04	3.58e-04	3.62e-04	4.58e-04
11/18/92	co2	4.90e-05	1.21e-04	2.86e-05	6.62e-05
11/20/92	co2	8.93e-05	8.26e-05	8.85e-05	8.68e-05
11/23/92	co2	5.37e-05	1.09e-04	1.25e-03	4.71e-04
11/28/92	co2	9.93e-05	1.12e-03	1.35e-03	8.56e-04
12/12/92	co2	3.84e-04	4.10e-05	4.90e-05	1.58e-04
12/29/92	co2	1.22e-04	7.64e-05	3.47e-04	1.82e-04
1/2/93	co2	6.02e-05	5.34e-05	5.95e-05	5.77e-05

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-2					
1/6/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	co2	7.08e-05	5.24e-05	8.53e-05	6.95e-05
4/14/93	co2	3.23e-05	1.33e-04	0.00e+00	5.51e-05
10/16/92	o2	3.87e-03		7.47e-03	5.67e-03
10/19/92	o2	7.09e-03	6.00e-03	6.12e-03	6.40e-03
10/23/92	o2	5.78e-03	5.83e-03	1.40e-03	4.34e-03
10/26/92	o2	7.47e-03	6.89e-03	6.70e-03	7.02e-03
10/28/92	o2	8.23e-03	6.98e-03	7.75e-03	7.65e-03
11/3/92	o2	8.37e-03	6.33e-03	5.61e-03	6.77e-03
11/6/92	o2	8.22e-03	6.07e-03	7.43e-03	7.24e-03
11/9/92	o2	7.99e-03	5.78e-03	8.81e-03	7.53e-03
11/17/92	o2	8.06e-03	4.15e-03	6.01e-03	6.07e-03
11/18/92	o2	4.90e-03	8.40e-03	5.34e-03	6.21e-03
11/28/92	o2	4.69e-03	4.22e-03	6.37e-03	5.09e-03
12/5/92	o2	8.84e-03	7.55e-03	8.31e-03	8.23e-03
12/9/92	o2	7.54e-03	1.09e-02	0.00e+00	6.15e-03
12/12/92	o2	9.27e-03	1.11e-02	8.64e-03	9.67e-03
12/29/92	o2	8.98e-03	8.91e-03	9.00e-03	8.96e-03
1/2/93	o2	8.51e-03	8.73e-03	8.42e-03	8.55e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-2					
1/6/93	o2	6.30e-03	7.70e-03	8.34e-03	7.45e-03
1/18/93	o2	8.93e-03	8.99e-03	8.38e-03	8.77e-03
4/14/93	o2	7.88e-03	8.99e-03	8.56e-03	8.48e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-3					
12/29/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/6/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/11/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/14/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/27/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/1/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/4/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/10/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/12/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/15/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/23/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/5/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/7/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/9/93	ch4				0.00e+00

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-3					
4/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/28/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/29/92	co2	1.68e-04	8.99e-04	6.41e-04	5.69e-04
1/2/93	co2	5.41e-05		6.42e-05	5.92e-05
1/6/93	co2	0.00e+00	1.37e-03	1.96e-04	5.22e-04
1/11/93	co2	3.97e-05	1.23e-04	5.96e-05	7.41e-05
1/14/93	co2	5.56e-05	5.56e-05	4.45e-05	5.19e-05
1/18/93	co2	5.53e-05	5.29e-05	5.16e-05	5.33e-05
1/22/93	co2	0.00e+00	4.56e-05	4.86e-05	3.14e-05
1/27/93	co2		1.14e-04	9.81e-05	1.06e-04
2/1/93	co2	5.63e-05	4.10e-05	4.25e-05	4.66e-05
2/4/93	co2	1.85e-03	1.26e-04	6.53e-05	6.80e-04
2/10/93	co2	3.06e-04	1.03e-04	4.05e-05	1.50e-04
2/12/93	co2	6.15e-05	4.42e-05	0.00e+00	3.52e-05
2/15/93	co2	4.17e-05	4.06e-05		4.12e-05
2/23/93	co2	6.29e-05	4.61e-05	4.26e-05	5.05e-05
3/2/93	co2	4.54e-05	4.88e-05	5.12e-05	4.85e-05
3/5/93	co2	4.02e-05	0.00e+00	3.90e-05	2.64e-05

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-3					
4/2/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/7/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/9/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/22/93	co2	2.09e-04	0.00e+00	7.11e-05	9.33e-05
4/28/93	co2	1.10e-03	3.29e-04	9.01e-04	7.77e-04
12/29/92	o2	9.29e-03	8.28e-03	7.99e-03	8.52e-03
1/2/93	o2	9.40e-03	8.93e-03	7.86e-03	8.73e-03
1/6/93	o2	7.83e-03	7.03e-03	8.18e-03	7.68e-03
1/11/93	o2	9.52e-03	9.02e-03	9.95e-03	9.50e-03
1/14/93	o2	8.56e-03	9.16e-03	9.43e-03	9.05e-03
1/18/93	o2	8.26e-03	8.38e-03	8.37e-03	8.34e-03
1/22/93	o2	8.67e-03	8.68e-03	8.10e-03	8.48e-03
1/27/93	o2	7.27e-03	7.30e-03	6.47e-03	7.01e-03
2/1/93	o2	7.30e-03	8.10e-03	8.34e-03	7.91e-03
2/4/93	o2	8.77e-03	9.68e-03	9.43e-03	9.29e-03
2/10/93	o2	7.26e-03	6.99e-03	7.83e-03	7.36e-03
2/12/93	o2	7.94e-03	7.92e-03	7.65e-03	7.84e-03
2/15/93	o2	7.33e-03	8.77e-03	8.24e-03	8.11e-03
2/23/93	o2	7.76e-03	9.22e-03	8.60e-03	8.53e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow CG-3					
3/2/93	o2	7.80e-03	7.00e-03	8.03e-03	7.61e-03
3/5/93	o2	7.70e-03	7.53e-03		7.62e-03
4/2/93	o2	9.38e-03	9.55e-03	7.32e-03	8.75e-03
4/7/93	o2	9.08e-03	9.74e-03	9.63e-03	9.48e-03
4/9/93	o2	8.08e-03	8.33e-03	9.45e-03	8.62e-03
4/22/93	o2	9.17e-03	1.02e-02		9.69e-03
4/28/93	o2	7.11e-03	9.08e-03	8.37e-03	8.19e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-1					
11/9/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/17/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/18/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/20/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/23/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/28/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/5/92	ch4				0.00e+00
12/12/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/17/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/21/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/29/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/6/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/11/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/27/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/10/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/12/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-1					
2/15/93	ch4	3.60e-06	0.00e+00	0.00e+00	1.20e-06
2/23/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/5/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/2/93	ch4				0.00e+00
4/7/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/9/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/28/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/9/92	co2	1.34e-03	4.57e-04	5.42e-04	7.80e-04
11/17/92	co2	7.68e-05	5.67e-05	8.50e-05	7.28e-05
11/18/92	co2	3.22e-04	2.84e-05	2.92e-05	1.27e-04
11/20/92	co2	1.18e-03	2.94e-04	1.92e-04	5.55e-04
11/23/92	co2	9.44e-05	1.34e-04	1.63e-03	6.19e-04
11/28/92	co2	6.67e-05	4.73e-05		5.70e-05
12/12/92	co2	5.14e-04	1.42e-03	1.65e-04	7.00e-04
12/17/92	co2	8.85e-05	0.00e+00	2.83e-03	9.73e-04
12/21/92	co2	8.74e-04	1.19e-03	3.20e-04	7.95e-04
12/29/92	co2	7.01e-05	7.48e-05	6.40e-05	6.96e-05

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-1					
1/2/93	co2	5.50e-05	5.73e-05	5.60e-05	5.61e-05
1/6/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/11/93	co2	5.38e-05	5.91e-05	6.32e-05	5.87e-05
1/18/93	co2	6.89e-05	6.44e-05	5.33e-05	6.22e-05
1/22/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/27/93	co2	6.83e-05	0.00e+00	7.42e-05	4.75e-05
2/10/93	co2	3.43e-05	3.92e-05	3.84e-05	3.73e-05
2/12/93	co2	6.38e-05	0.00e+00	4.07e-05	3.48e-05
2/15/93	co2	6.50e-05	4.77e-05	5.53e-05	5.60e-05
2/23/93	co2	4.02e-05	3.77e-04	3.87e-04	2.68e-04
3/2/93	co2	5.35e-05	4.86e-05	5.56e-05	5.26e-05
3/5/93	co2	4.13e-05	3.82e-05	3.52e-05	3.82e-05
4/7/93	co2	6.40e-05	0.00e+00	7.29e-05	4.56e-05
4/9/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/22/93	co2	1.62e-03	9.79e-04	4.98e-04	1.03e-03
4/28/93	co2	6.41e-03	2.18e-04	3.74e-04	2.33e-03
11/9/92	o2	7.29e-03	6.06e-03	3.39e-03	5.58e-03
11/17/92	o2	8.44e-03	8.24e-03	6.13e-03	7.60e-03
11/18/92	o2	7.35e-03	8.45e-03	9.09e-03	8.30e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-1					
11/23/92	o2	6.74e-03	6.31e-03	4.40e-03	5.82e-03
11/28/92	o2	9.51e-03	6.50e-03	8.53e-03	8.18e-03
12/5/92	o2	5.11e-03	4.99e-03	5.08e-03	5.06e-03
12/12/92	o2	8.39e-03	1.27e-02	9.79e-03	1.03e-02
12/17/92	o2	7.98e-03	8.20e-03	7.31e-03	7.83e-03
12/21/92	o2	9.01e-03	8.47e-03	8.62e-03	8.70e-03
12/29/92	o2	9.42e-03	9.50e-03	9.42e-03	9.45e-03
1/2/93	o2	8.70e-03		8.41e-03	8.56e-03
1/6/93	o2	8.23e-03	8.33e-03	8.36e-03	8.31e-03
1/11/93	o2	8.40e-03	8.67e-03	8.52e-03	8.53e-03
1/18/93	o2	8.56e-03	9.31e-03	8.72e-03	8.86e-03
1/22/93	o2	9.09e-03	1.00e-02	1.01e-02	9.73e-03
1/27/93	o2	8.12e-03	8.77e-03	7.64e-03	8.18e-03
2/10/93	o2	8.42e-03	7.79e-03	7.43e-03	7.88e-03
2/12/93	o2	7.46e-03	8.13e-03	7.16e-03	7.58e-03
2/15/93	o2	8.98e-03	8.88e-03	9.57e-03	9.14e-03
2/23/93	o2	9.23e-03	8.06e-03	8.15e-03	8.48e-03
3/2/93	o2	8.61e-03	9.65e-03	9.40e-03	9.22e-03
3/5/93	o2	8.25e-03	8.31e-03		8.28e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-1					
4/2/93	o2	8.70e-03	9.57e-03	8.79e-03	9.02e-03
4/7/93	o2	7.77e-03	8.17e-03	8.02e-03	7.99e-03
4/9/93	o2	9.67e-03	1.05e-02	7.95e-03	9.37e-03
4/22/93	o2	8.01e-03	8.50e-03	8.42e-03	8.31e-03
4/28/93	o2	4.63e-03	7.00e-03	7.75e-03	6.46e-03
Windrow LV-2					
11/17/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/18/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/20/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/23/92	ch4	0.00e+00	2.34e-09	0.00e+00	7.80e-05
11/28/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/5/92	ch4				0.00e+00
12/12/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/17/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/21/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
12/29/92	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/1/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/6/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-1					
Windrow LV-2					
1/11/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/14/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/27/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/1/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/4/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/10/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/12/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/15/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/23/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-2					
3/5/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/7/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/9/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/28/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
11/17/92	co2	9.21e-04	4.43e-05	4.11e-05	3.35e-04
11/18/92	co2	1.06e-04	3.53e-04	1.81e-04	2.13e-04
11/20/92	co2	8.20e-04	6.63e-04	1.62e-03	1.03e-03
11/23/92	co2	8.57e-03	1.10e-02	1.13e-02	1.03e-02
11/28/92	co2	0.00e+00	0.00e+00	5.52e-05	1.84e-05
12/12/92	co2	1.07e-04	7.35e-05	1.61e-04	1.14e-04
12/17/92	co2	8.50e-04	1.15e-04	7.83e-05	3.48e-04
12/21/92	co2	3.45e-03	3.89e-03	3.99e-03	3.78e-03
12/29/92	co2	1.50e-03	1.65e-03	6.04e-03	3.06e-03
1/1/93	co2	0.00e+00	1.25e-04	8.97e-05	7.16e-04
1/6/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/11/93	co2	8.55e-05	6.08e-05	1.23e-04	8.98e-05
1/14/93	co2	4.89e-05	5.66e-05	4.23e-05	4.93e-05

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-2					
1/18/93	co2	0.00e+00	4.90e-05	0.00e+00	1.63e-05
1/22/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/27/93	co2	1.57e-03	2.94e-03	2.18e-03	2.23e-03
2/1/93	co2	8.34e-05	7.42e-05	7.84e-05	7.87e-05
2/4/93	co2	8.27e-05	6.38e-04	5.31e-04	4.17e-04
2/10/93	co2	4.05e-05	0.00e+00	3.98e-05	2.68e-05
2/12/93	co2	3.96e-05	3.84e-05	3.98e-05	3.93e-05
2/15/93	co2	4.26e-05	4.52e-05	5.14e-05	4.64e-05
2/23/93	co2	6.07e-05	5.16e-05	4.95e-05	5.39e-05
3/2/93	co2	0.00e+00	3.85e-05	4.31e-05	2.72e-05
3/5/93	co2	0.00e+00	6.48e-05	5.27e-04	1.97e-04
4/2/93	co2	0.00e+00	2.80e-05	0.00e+00	9.33e-05
4/7/93	co2	4.04e-05	5.08e-05		4.56e-05
4/9/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/22/93	co2	1.63e-03	2.00e-03	1.96e-03	1.86e-03
4/28/93	co2	6.10e-03	5.67e-03	3.54e-03	5.10e-03
11/17/92	o2	7.88e-03	8.24e-03	1.11e-02	9.07e-03
11/18/92	o2	8.73e-03	8.01e-03	4.55e-03	7.10e-03
11/23/92	o2	3.92e-03	5.07e-03	3.34e-03	4.11e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-2					
11/28/92	o2	4.81e-03	5.16e-03	8.04e-03	6.00e-03
12/5/92	o2	4.64e-03	6.35e-03	6.67e-03	5.89e-03
12/12/92	o2	7.42e-03	6.95e-03	8.07e-03	7.48e-03
12/17/92	o2	9.02e-03	1.14e-02	9.37e-03	9.93e-03
12/21/92	o2	6.06e-03	2.69e-03	5.51e-03	4.75e-03
12/29/92	o2	8.23e-03	8.58e-03	6.38e-03	7.73e-03
1/1/93	o2	7.23e-03	7.86e-03	8.97e-03	8.02e-03
1/6/93	o2	8.59e-03	7.69e-03	7.60e-03	7.96e-03
1/11/93	o2	9.04e-03	9.18e-03	1.05e-02	9.57e-03
1/14/93	o2	7.40e-03	8.75e-03	9.36e-03	8.50e-03
1/18/93	o2	8.39e-03	8.84e-03	8.28e-03	8.50e-03
1/22/93	o2	1.02e-02	9.29e-03	8.93e-03	9.47e-03
1/27/93	o2	2.22e-03	6.98e-03	6.85e-03	5.35e-03
2/1/93	o2	9.07e-03	7.86e-03	7.94e-03	8.29e-03
2/4/93	o2	8.31e-03	8.74e-03	8.98e-03	8.68e-03
2/10/93	o2	7.53e-03	7.30e-03	6.01e-03	6.95e-03
2/12/93	o2	8.57e-03	5.22e-03	8.05e-03	7.28e-03
2/15/93	o2	8.87e-03	8.73e-03	7.93e-03	8.51e-03
2/23/93	o2	7.97e-03	7.47e-03	7.12e-03	7.52e-03
3/2/93	o2	9.71e-03	9.19e-03	7.95e-03	8.95e-03
3/5/93	o2	7.58e-03	7.41e-03		7.50e-03
4/2/93	o2	9.07e-03	8.31e-03	9.31e-03	8.90e-03
4/7/93	o2	8.80e-03	9.59e-03	8.46e-03	8.95e-03
4/9/93	o2	8.02e-03	6.35e-03	7.67e-03	7.35e-03
4/22/93	o2	7.87e-03	6.92e-03	7.69e-03	7.49e-03
4/28/93	o2	5.13e-03	5.73e-03	6.80e-03	5.89e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-3					
1/6/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/11/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/14/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/18/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
1/27/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/1/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/4/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/10/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/12/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/15/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2/23/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
3/5/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/2/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/7/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/9/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/22/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/28/93	ch4	0.00e+00	0.00e+00	0.00e+00	0.00e+00

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-3					
1/6/93	co2	0.00e+00	0.00e+00	1.35e-03	4.50e-40
1/11/93	co2	1.21e-03	7.51e-05	8.92e-05	4.58e-04
1/14/93	co2	0.00e+00	5.33e-05	9.74e-05	5.02e-05
1/18/93	co2	1.06e-04	4.86e-05	6.61e-05	7.36e-05
1/22/93	co2	4.29e-05	0.00e+00	0.00e+00	1.43e-05
1/27/93	co2	1.76e-03	3.75e-03	2.87e-03	2.79e-03
2/1/93	co2	6.91e-05	4.11e-04	6.38e-05	1.81e-04
2/4/93	co2	7.69e-04	1.26e-03	8.97e-04	9.75e-04
2/10/93	co2	5.94e-04	1.05e-03	8.25e-04	8.23e-04
2/12/93	co2	5.64e-05	5.50e-05	5.98e-05	5.70e-05
2/15/93	co2	3.99e-05			3.99e-05
2/23/93	co2	5.05e-05	6.63e-05	4.17e-05	5.28e-05
3/2/93	co2	1.08e-04	1.31e-04	3.13e-04	1.84e-04
3/5/93	co2	3.14e-05	4.04e-05	3.90e-05	3.69e-05
4/2/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/7/93	co2	3.55e-05	6.10e-05	4.17e-05	4.61e-05
4/9/93	co2	0.00e+00	0.00e+00	0.00e+00	0.00e+00
4/22/93	co2	4.48e-04	1.05e-04	5.67e-04	3.73e-04
4/28/93	co2	1.23e-03	1.29e-03	2.48e-03	1.67e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-3					
1/6/93	o2	6.85e-03	8.24e-03	7.11e-03	7.40e-03
1/11/93	o2	7.59e-03	9.02e-03	8.61e-03	8.41e-03
1/14/93	o2	8.84e-03	9.21e-03	9.92e-03	9.32e-03
1/18/93	o2	7.97e-03	8.36e-03	6.82e-03	7.72e-03
1/22/93	o2	8.67e-03	8.51e-03	8.98e-03	8.72e-03
1/27/93	o2	5.66e-03	5.80e-03	5.91e-03	5.79e-03
2/1/93	o2	8.42e-03	7.51e-03	7.95e-03	7.96e-03
2/4/93	o2	8.98e-03	8.56e-03	9.53e-03	9.02e-03
2/10/93	o2	7.02e-03	6.42e-03	7.21e-03	6.88e-03
2/12/93	o2	7.90e-03	7.53e-03	6.78e-03	7.40e-03
2/15/93	o2	7.17e-03	8.43e-03	9.07e-03	8.22e-03
2/23/93	o2	9.17e-03	9.10e-03	8.48e-03	8.92e-03
3/2/93	o2	8.18e-03	9.52e-03	8.69e-03	8.80e-03
3/5/93	o2	6.83e-03	1.02e-02		8.52e-03
4/2/93	o2	8.64e-03	1.01e-02		9.37e-03
4/7/93	o2	8.00e-03	8.58e-03	8.91e-03	8.50e-03
4/9/93	o2		8.24e-03	8.04e-03	8.14e-03
4/22/93	o2	9.38e-03		9.19e-03	9.29e-03
4/28/93	o2	7.69e-03	8.46e-03	6.67e-03	7.61e-03

date	gas	meas1	meas2	meas3	mol/l-avg
Windrow LV-3					

APPENDIX D. LEACHATE DATA. All units are mg/l, except: TSS=g/l, pH=no units (hydrogen ion concentration)

date	plot	TSS	NO3	NH4	FTKN	TKN	OP	FTP	TP	pH	BOD
09/25/92	Ctrl-1	0.102	0.049	0.3	3.94	10.087	7.718	22.764	26.673	7.01	
09/29/92	Ctrl-1	0.088	0.09	0.239	8.977	16.703	10.503	11.453	11.287	7.32	
10/09/92	Ctrl-1	0.14	0.101	0.55	0.977	35.127	19.698	10.372	8.543	7.18	
10/12/92	Ctrl-1	0.1	0.145	0.562	5.672	31.285	15.894	22.016	21.6	7.49	
10/14/92	Ctrl-1	0.052	0.161	2.736	12.502	33.419	14.671	21.101	19.604		
10/16/92	Ctrl-1	0.08	0.168	1.837	18.052	21.285	13.176	19.687	17.275	8.09	52.2
10/28/92	Ctrl-1	0.112	0.22	0.865	26.162	35.127	11.753	12.451	11.37		
11/03/92	Ctrl-1									7.87	76.1
11/09/92	Ctrl-1	0.056	0.278	1.036	30.004	30.431	12.089	16.693	13.949	7.87	
11/14/92	Ctrl-1	0.092	0.293	0.669	38.372	41.383	13.939	17.203	22.072	7.79	28.4
11/20/92	Ctrl-1	0.028	4.322	1.282	41.684	41.684	10.348	1.991	1.558	8.11	17.2
11/29/92	Ctrl-1	0.096	0.202	3.715	18.018	22.173	11.399	17.513	19.29	7.81	61.2
12/05/92	Ctrl-1	0.062	0.189	0.436	19.724	35.771	3.116	4.869	6.722	8.04	
12/11/92	Ctrl-1	0.064	0.201	0.944	20.07	41.43	11.924	6.553	7.058	7.95	
04/16/93	Ctrl-1	0.056	0.048	2.856	6.386	8.788	0.04	0.575	1.251		
04/22/93	Ctrl-1	0.16	0.184	7.39	12.458	19.893	0.162	0.395	0.812		
09/25/92	1	0.124	0.134	2.924	35.127	67.143	14.263	17.101	19.438	7.02	
09/29/92	1	0.082	0.336	0.542	20.827	20.531	13.312	15.125	15.125	6.56	
10/09/92	1	0.096	0.203	0.87	45.725	52.839	12.188	13.503	16.065	7.49	

date	plot	TSS	NO3	NH4	FTKN	TKN	OP	FTP	TP	pH	BOD
10/12/92	1	0.138	0.228	2.692	41.872	57.581	10.816	14.015	15.979	7.6	
10/16/92	1	0.054	0.493	0.539	21.42	25.273	4.971	6.243	8.209	8.2	26.9
10/21/92	1	0.152	0.319	4.331	50.467	73.291	6.884	9.234	11.71	7.88	123.9
11/03/92	1	0.084	0.262	1.202	43.947	48.689	3.965	3.775	5.722	7.72	28.3
11/09/92	1	0.08	0.22	0.929	50.068	68.85	4.783	4.131	5.919	7.94	
11/14/92	1	0.084	3.965	0.71	45.898	49.812	3.761	5.074	5.321	7.96	41.0
11/20/92	1	0.014	0.926	0.301	35.362	36.566	1.608	2.014	2.254	8.35	26.9
11/29/92	1	0.39	0.168	6.041	24.581	44.393	3.924	5.105	9.476	8.04	83.6
12/05/92	1	0.106	0.093	1.316	18.907	47.404	5.748	6.301	4.89	8.27	
12/11/92	1	0.106	3.763	1.316	24.049	36.558	5.967	10.688	9.577	8.18	
01/18/93	1										33.1
02/05/93	1									8.47	34.8
03/06/93	1										36.3
04/02/93	1	0.121	0.618	0.202	21.77	24.673	2.811	5.242	4.894	7.60	
04/09/93	1	0.06	0.373	0.215	23.871	23.989	3.176	4.932	17.336		
04/22/93	1	0.256	2.487	0.604	21.628	29.418	2.96	4.529	6.233		
09/25/92	2	0.188	0.189	33.667	91.902	130.321	18.747	22.848	24.261	6.5	
09/29/92	2	0.088	0.174	0.804	18.752	27.941	13.16	15.125	16.15	7.16	
10/09/92	2	0.166	0.361	2.581	52.218	63.039	17.698	29.987	19.398	7.7	
10/12/92	2	0.166	0.349	1.477	37.135	39.43	13.283	15.913	16.047	7.75	

date	plot	TSS	NO3	NH4	FTKN	TKN	OP	FTP	TP	pH	BOD
10/14/92	2	0.09	0.285	2.644	33.2	41.725	10.244	13.969	12.629		
10/16/92	2	0.09	0.256	1.243	22.707	38.774	10.011	12.294	12.897	7.9	61.2
10/21/92	2	0.062	0.195	0.867	13.197	25.33	7.117	9.613	10.35	7.68	59.7
10/30/92	2	0.062	0.158	0.681	12.214	16.804	4.922	7.2	7.803		
11/03/92	2	0.05	0.2	1.073	13.853	26.642	7.203	8.54	9.345	7.55	37.2
11/09/92	2	0.042	0.169	0.676	38.969	44.091	6.78	7.96	6.796	7.8	
11/14/92	2	0.044	1.141	1.007	38.372	39.878	6.535	9.631	17.513	7.86	11.9
11/20/92	2	0.018	4.001	1.416	36.867	40.781	6.666	5.87	9.167	7.82	26.9
11/29/92	2	0.102	0.279	2.092	48.348	54.007	0.333	2.428	3.186	7.68	56.7
12/05/92	2	0.04	0.309	0.779	13.132	51.806	5.697	2.954	0.071	7.74	
12/11/92	2	0.066	1.905	0.353	23.926	35.942	4.901	9.577	8.928	7.97	
01/18/93	2										34.5
02/05/93	2									8.08	26.4
03/06/93	2										34.9
04/02/93	2	0.066	0.744	0.32	27.046	30.622	3.338	5.711	7.294	7.34	
04/03/93	2										13.9
04/09/93	2	0.04	0.353	0.445	28.754	28.479	2.987	4.449	5.366		
04/16/93	2	0.1	1.006	0.171	22.808	26.707	3.109	5.784	7.329		
04/22/93	2	0.162	0.249	6.391	27.541	41.922	3.784	4.39	7.398		
10/14/92	3	0.144	0.2	3.969	28.937	55.169	21.377	23.821	26.502		

date	plot	TSS	NO3	NH4	FTKN	TKN	OP	FTP	TP	pH	BOD
10/16/92	3	0.082	0.208	3.827	23.362	25.823	18.802	20.939	22.413	7.48	116.4
10/21/92	3	0.03	0.21	2.424	23.035	23.69	13.651	15.51	16.65	7.7	53.7
10/28/92	3	0.108	0.312	1.474	35.823	46.644	13.406	14.572	15.175	7.51	
11/03/92	3	0.082	0.296	1.092	25.658	26.314	9.668	11.221	10.685	7.54	41.8
11/09/92	3	0.084	0.306	1.318	51.348	47.933	15.894	20.269	66.3	7.91	
11/14/92	3	0.4	2.5	0.793	37.77	38.975	5.213	9.476	10.635	7.86	11.9
11/20/92	3	0.024	0.418	1.416	45.898	45.898	7.188	6.241	9.167	7.95	14.9
11/29/92	3	0.08	0.254	1.957	41.43	43.317	0.007	0.071	2.344	7.77	49.2
12/05/92	3	0.022	0.247	0.832	16.276	46.147	10.91	5.311	0.492	7.83	
12/11/92	3	0.05	0.361	0.751	19.671	21.953	4.323	9.577	7.909	7.98	
01/18/93	3										23.9
01/28/93	3									7.85	22.4
02/05/93	3									8.10	37.8
03/06/93	3										38.8
04/02/93	3	0.085	0.334	0.908	63.604	61.603	4.731	9.172	7.381	7.29	
04/03/93	3										16.4
04/09/93	3	0.014	0.303	0.587	29.542	30.448	3.595	5.656	5.511		
04/16/93	3	0.048	0.495	1.111	42.255	59.524	5.38	6.879	17.819		
04/22/93	3	0.034	0.3	0.677	24.39	24.142	2.406	4.146	3.607		
10/16/92	4	0.138	0.213	3.559	23.035	36.807	23.953	34.008	30.054	7.5	

date	plot	TSS	NO3	NH4	FTKN	TKN	OP	FTP	TP	pH	BOD
10/21/92	4	0.15	0.22	2.723	16.149	29.921	20.641	23.995	25.831	7.73	
10/28/92	4	0.186	0.454	3.811	60.088	76.483	19.292	23.285	26.636	7.57	
11/03/92	4	0.148	0.365		35.167	45.332	18.802	21.877	23.352	7.54	
11/09/92	4	0.038	0.267	0.9	50.495	69.277	5.19	18.689	19.687	7.99	
11/14/92	4	0.076	0.405	0.96	46.801	53.424	11.491	27.635	34.126	7.85	38.8
11/29/92	4	0.258	0.202	8.299	44.575	53.693	11.256	4.954	6.806	7.93	106.0
12/05/92	4	0.028	0.32	0.642	13.132	45.518	9.009	5.319	2.765	8.03	
12/11/92	4	0.076	0.418	0.917	24.512	34.092	8.817	13.282	13.282	7.93	
01/18/93	4										22.4
01/28/93	4									7.95	14.9
03/06/93	4										47.8
04/02/93.	4	0.039	0.121	0.228	13.799	14.733	0.581	3.294	1.969	7.52	
04/03/93	4										6.7
04/09/93	4	0.032	0.269	0.215	15.562	16.467	2.149	3.496	4.658		
04/16/93	4	0.098	3.271	0.129	17.413	22.539	0.419	5.237	4.545		
04/22/93	4	0.036	0.111	1.056	11.679	14.157	1.554	1.734	1.421		
11/14/92	Ctrl-2	0.066	0.364	1.145	36.265	41.383	18.346	27.635	30.031	7.55	52.2
11/20/92	Ctrl-2	0.046	0.402	1.321	36.867	41.383	17.693	30.572	39.844	7.9	23.9
11/29/92	Ctrl-2	0.038	0.15	0.657	17.492	19.064	3.065	5.122	5.627	7.93	56.7
12/5/92	Ctrl-2	0.038	0.115	0.746	9.359	36.085	13.061	2.175	6.89	7.84	

date	plot	TSS	NO3	NH4	FTKN	TKN	OP	FTP	TP	pH	BOD
12/11/92	Ctrl-2	0.064	0.124	0.917	17.112	20.812	14.345	17.543	19.766	8.1	
1/2/93	Ctrl-2									7.94	
1/18/93	Ctrl-2										28.3
1/28/93	Ctrl-2									7.89	35.8
2/5/93	Ctrl-2									8.15	37.8
3/6/93	Ctrl-2										64.7
04/02/93	Ctrl-2	0.011	0.4	0.187	4.916	5.978	1.608	0.178	0.169	7.34	
04/03/93	Ctrl-2										45.5
04/09/93	Ctrl-2	0.002	0.094	0.433	4.377	15.404	0.703	1.532	0.816		
04/16/93	Ctrl-2	0.024	0.109	0.824	6.894	7.261	0.743	1.114	0.334		
4/22/93	Ctrl-2	0.054	0.094	0.585	5.376	6.793	0.621	0.569	0.691		
11/20/92	5	0.084	0.27	0.427	17.717	41.383	11.491	24.003	36.831	7.39	186.6
11/29/92	5	0.024	0.116	3.052	16.297	20.353	3.039	3.206	4.595	7.6	88.1
12/05/92	5	0.012	0.103	2.431	17.177	18.97	2.744	2.794	5.122	7.29	
12/11/92	5	0.012	0.115	1.082	11.623	15.878	3.36	9.762	8.65	7.49	
1/2/93	5									7.66	
01/18/93	5										44.0
01/28/93	5									7.69	50.3
02/05/93	5									8.01	43.8
03/06/93	5										68.7

date	plot	TSS	NO3	NH4	FTKN	TKN	OP	FTP	TP	pH	BOD
04/02/93	5	0.033	0.215	0.403	13.591	14.653	1.013	0.665	0.839	7.48	
04/03/93	5										18.9
04/09/93	5	0.004	0.082	0.319	8.394	8.63	0.378	1.307	0.511		
04/16/93	5	0.026	0.184	0.907	11.899	13.061	0.527	0.961	0.575		
04/22/93	5	0.018	0.078	0.706	12.529	12.847	0.054	0.134	0.439		
11/20/92	7	0.332	0.218	0.791	23.136	44.995	8.657	16.044	22.999	6.18	
11/28/92	7	0.126	0.168	0.268	22.585	47.404	0.741	2.596	5.795	7.21	
12/05/92	7	0.078	0.106	0.217	18.812	47.404	6.146	0.492	4.28	7.32	
12/11/92	7	0.196	0.124	0.765	16.557	34.708	4.619	9.206	11.429	7.21	
1/2/93	7									8.25	
01/18/93	7									7.60	64.2
01/28/93	7									7.76	66.7
02/05/93	7									8.02	12.9
03/06/93	7										29.4
04/02/93	7	0.024	0.235	0.203	7.567	9.497	0.243	0.672	0.543	7.55	
04/03/93	7										5.0
04/09/93	7	0.002	0.08	0.21	11.86	12.135		1.428	0.1		
04/16/93	7	0.036	0.184	1.285	15.29	17.521	1.311	0.769	0.056		
04/22/93	7	0.032	0.072	0.474	12.352	13.662					
10/12/92	pond	0.031	0.868	0.068	2.438	7.922	1.046	0.274	0.77	8.92	

date	plot	TSS	NO3	NH4	FTKN	TKN	OP	FTP	TP	pH	BOD
10/16/92	pond	0.01	0.098	0.179	2.349	3.446	0.801	0.351	0.274	8.99	
10/21/92	pond	0.02	0.024	0.184	1.193	2.794	0.774	0.283	0.266	8.86	
10/28/92	pond	0.03	0.015	0.141	1.757	3.09	0.625	0.368	0.257	8.13	
11/03/92	pond	0.029	1.32	0.082	1.964	2.676	0.584	0.437	0.283	7.84	
11/9/93	pond									8.15	
11/14/92	pond		2.41	0.305	38.372	43.372	0.017	0.639	0.986	7.87	
11/28/92	pond	0.08	0.061	0.484	6.581	10.323	9.395	1.118	1.817	7.56	
04/02/93	pond	0.058	0.233	0.522	2.959	3.589		0.342	0.615	7.69	
04/03/93	pond										7.0
04/09/93	pond	0.02	0.068	0.454	3.826	3.708		0.197	0.672		
04/16/93	pond	0.094	0.075	0.681	8.28	9.271			1.169		
04/22/93	pond	0.134		0.403	6.828	6.509					

APPENDIX E. ELEMENTAL COMPOSITION

Samples analyzed by the VA Tech Soil Testing and Plant Analysis Laboratory.
Data reported as parts per million in solution.

Windrow	P	K	Ca	Mg	Mn	Fe	Pb
LG-1	48.47	181.2	1212	358.2	17.13	261.0	0.77
	51.83	195.1	1208	343.6	17.58	255.5	0.72
LG-2	55.43	171.1	1232	379.7	18.15	256.5	0.71
	51.17	156.7	1161	359.1	16.92	245.3	0.64
LG-3	36.62	209.8	807.7	310.1	14.37	324.4	0.46
	38.13	231.5	831.5	319.5	14.47	332.3	0.40
CG-1	35.75	171.1	526.7	227.9	7.508	318.8	0.70
	32.83	164.9	481.9	210.6	6.979	275.4	0.72
CG-2	24.74	130.9	446.0	185.9	7.083	188.9	0.52
	21.84	118.8	411.4	172.6	6.077	167.3	0.42
CG-3	13.98	62.09	240.4	93.16	3.514	97.78	0.20
	13.53	61.52	276.1	98.33	3.591	91.88	0.18
LV-1	34.49	139.3	892.1	180.61	13.14	83.52	0.53
	36.57	147.9	947.9	199.7	13.98	93.58	0.54
LV-2	33.46	129.2	892.6	206.0	16.96	62.90	0.15
	32.26	124.6	847.8	193.3	16.17	59.15	0.22
LV-3[1]	23.50	107.1	588.3	135.3	15.62	62.74	0.29
grass for LG-3							0.31
							0.35
all other raw mat'l samples							<0.1[2]

1 Two samples were digested for each windrow. The tube holding the second LV-3 sample broke in the oven.

2 The "<" indicates elemental concentrations below detection limit.

VITAE

Archer Harrison Christian was born in Lynchburg, Virginia. She attended Vanderbilt University in Nashville, Tennessee, from which she received a B.S. degree in Sociology, with a minor in Environmental Science in 1976. She subsequently undertook graduate studies in the University's Department of Environmental Engineering. Prior to returning to Virginia in 1980, Ms. Christian served as a sub-contractor to the Tennessee Environmental Council, delivering public education programs in energy conservation and co-developing and conducting construction workshops for residential attached solar greenhouses. Ms. Christian began her graduate studies in the Department of Crop and Soil Environmental Sciences at Virginia Tech in 1991, following 11 years of work in Virginia in the areas of energy conservation, brick manufacturing, and real estate investment and remodeling. Since June 1992, Ms. Christian has served as the Executive Director of the Virginia Association for Biological Farming, a non-profit, educational organization committed to the extension of biological agriculture in Virginia. Ms. Christian is employed as a Research Associate and Compost Specialist at Virginia Tech and lives in Christiansburg, Virginia.