The Decomposition of Organic Matter in Two Midgrass Prairies in Western South Dakota

Venance H. Lengkeek

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THE DECOMPOSITION OF ORGANIC MATTER
IN TWO MIDGRASS PRAIRIES IN WESTERN SOUTH DAKOTA

BY

VENANCE H. LENKEEKE

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Microbiology, South Dakota
State University

1974
This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.
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INTRODUCTION AND LITERATURE REVIEW

Through the millennia of time man has been fascinated by the world in which he was living. He has always wondered about the land, the water, the air and now even the reaches of outer space that surround him. Yet, it has been only recently that the study of ecology - the study of an organism and its relationship to the place in which it lives - has come into being. Ecology as defined by Dasmann (11) is the "study of ecosystems to determine their status and the ways in which they function". He further explains an ecosystem as "a combination of a biotic community with its physical environment". A biotic community is "an assemblage of species of plants and animals inhabiting a common area and having, therefore, effects upon one another". Smith (29) defines an ecosystem as the interactions of the biotic (living) and the abiotic (nonliving) factors in a biotic community.

All ecosystems have two basic biological components (29). One component is the autotrophic organisms which fix energy from the sun and use inorganic substances to create food. The other is the heterotrophic organisms which utilize the stored food of the autotrophs, rearrange it, and finally decompose the complex materials into simple inorganic compounds. The autotrophs, which are predominantly green plants, grow wherever the most sunlight is available, heterotrophs predominate wherever organic matter accumulates, primarily in the upper layer of the soil. Heterotrophs consist of consumers which feed on green plants and other
organisms. Decomposers, chiefly bacteria and fungi that break down the complex compounds of dead organic matter, utilize part of it, and also release some of the simple substances back into the ecosystem again (29).

For a biotic community or ecosystem to exist, there must be a supply of energy (11, 29). The ultimate source of this energy for the earth is sunlight. The green plants, through photosynthesis, utilize this energy and manufacture foodstuff. The energy stored as cell substance in the green plants is ultimately dissipated and recycled throughout the ecosystem by a complex system known as a food chain (11). The plants and animals in an ecosystem are "interlinked in a complex system by means of which the basic chemicals of life are constantly recycled" (2). As Allen (2) says, "each organism has its place and does its useful job in the cycling of nutrients through which life is sustained ... in an ecosystem".

The major role played by decomposer microorganisms is the breakdown and decay of dead organic matter and the consequent return of its chemical constituents to the soil or atmosphere for reuse by other organisms (11). Without the decay of organic matter, minerals would be tied up in the organic matter, and organic debris would eventually accumulate to such high levels that life would cease to exist. Decomposer organisms may also play another important role during the process of decomposition. Russell (28) holds the view that the CO₂ produced during
decomposition may be used by plants through their roots or absorbed by their leaves. The CO₂ produced during decomposition, instead of being released immediately to the atmosphere, is concentrated in the plant canopy and is available for immediate use by the plants. Under intensive farming a high level of organic matter would be beneficial since the CO₂ released would benefit plant growth.

Decomposition is actually a "burning" or oxidation process (2, 5). Carbon and hydrogen are the elements that are largely oxidized. The oxidation of most organic compounds in the soil can be expressed by the following equation (1, 5):

\[
C(H_2O)_x + O_2 \xrightarrow{\text{Enzymatic Oxidation}} CO_2 \uparrow + H_2O + \text{Energy}
\]

The microbes, during the process of decomposition, are breaking the organic matter down into simple inorganic compounds. During this process from 45% to 65% (1, 16, 20, 23) of the carbon is metabolized by the microbes for growth. The organic matter then is actually the microbes' food. The process of converting substrate to protoplasmic carbon is known as assimilation (1). Since only 45-65% of the organic matter is assimilated by the microbes, the remainder is given off as by-products of water (H₂O) and carbon dioxide (CO₂). The evolution of CO₂ as a by-product of decomposition is an important tool to the soil microbiologist. For more than a half century, the evolution of CO₂ has served as a measureable manifestation of the life processes which take place in the soil (36). Today, rates of CO₂ release from the soil are
the most frequently used indices of microbial activity in soil, and are generally accepted as a measure of metabolic activity of soil biota (6, 7, 12, 18, 32, 40). This "soil respiration" is also comprised of the CO₂ produced by both soil fauna and soil flora, and includes root respiration as well (32). It has been very difficult to separate the evolved CO₂ as originating from decomposition or from the flora, fauna and roots also respiring in the soil. Eventually, there will be a need to determine the role of each component of the population in total soil respiration. For now, the total soil respiration is sufficient to measure the activity and, thus, energy use of the decomposers in the ecosystem.

The early soil microbiologists were primarily interested in the identity and quantity of microbes in the soil and held microbial numbers as an important tool in the study of the decomposer activity (4). The trend today, however, is shifting away from the numbers and identification of soil microflora to the study of soil metabolism as a means of studying activities of the soil microflora (7).

The main method of observing the evolved CO₂ is by absorption of the CO₂ in a NaOH or KOH solution and back titrating with HCl (9, 27, 36). This method is explained in detail later in the paper and has been known to be very quantitative showing carbon output (CO₂) to be within 6% of the carbon input from litter and roots (8).
Decomposition in an ecosystem is dependent upon many things, but the factors most responsible are temperature, bacterial density, moisture, aeration, cultivation, pH, soil depth, and the stage of decay or litter age (1, 6, 24, 41). Vandecaveye and Katznelson (35) have found that seasons of the year also affect decomposition, with peaks of decomposition occurring in the spring (April) and in late fall and early winter. Minimum decomposition occurs in July, August and February.

The above factors not only influence the rate of decomposition carried out by the various soil microorganisms but also influence the number as well as the variety of microbes present (35). Vandecaveye and Katznelson (35) point out that differences in microbial numbers as well as specific groups are due to differences in moisture, pH and especially the nature of the organic food supply (ie. surface organic residue, nitrogen, C/N, H2SO4 and insoluble carbon). Microbe numbers also follow seasonal temperature and moisture changes, with large populations occurring in the spring and fall when temperature and moisture conditions are optimum.

The peak of decomposition does not necessarily mean that the microorganisms are present in their highest possible numbers (6, 7, 13, 14). Vandecaveye and Baker (34) have found that maximum microbial development occurred about 15 days later than maximum CO2 evolution, showing that CO2 evolution is not a true index of bacterial numbers.
However, when peaks of decomposition do occur, it is a good indication that all factors favor rapid increases of microorganism numbers (4).

Temperature is an important factor in affecting the rate of decomposition of organic matter in soil (1, 5, 20, 39, 41). All microorganisms have a temperature that is optimum for their growth, and at or near this temperature, as they grow, more energy is needed, and since the decomposers receive their energy from the breakdown of soil organic material, more decomposition occurs. The optimum temperature may vary from species to species of microorganism; but, in general, temperatures from 25-35°C are considered optimum for soil microorganism growth (1, 6). Any change in temperature will alter the species composition of the active flora and, at the same time, have a direct influence upon each organism within the population. Microbial metabolism and, hence, carbon mineralization is slower at low temperatures, and warming is associated with greater CO₂ release (1). Soulides and Allison (30) have found that bacteria can withstand low temperatures to a marked degree. A temperature of a few degrees below 0°C does have a harmful effect on microorganisms, whereas at higher temperatures, such as 2°C, a slow growth may take place. Sudden severe frosts, however, are reported to have eliminated most of the bacteria in exposed soils (30).

Witkamp (40) has found a positive relationship between temperature cycles and "soil respiration". The relationship seems
to indicate bursts of CO₂ during the afternoon, with low CO₂ evolution occurring prior to dawn. However, flushes of CO₂ may occur between midnight and dawn. These bursts or flushes of CO₂ are caused by convection of relatively warm soil air transporting CO₂ from deeper layers, which are usually rich in CO₂, to the surface. Bodily (4) has also reported the bursts of CO₂ caused by temperature, moisture and the quality of organic matter present. He says this burst of CO₂ is indicative of the "explosive" nature of the decomposition process.

Soulides and Allison (30) have also observed bursts of CO₂ following intermittent drying or freezing of the soil. The bursts are due primarily to the release of nutrients, especially energy sources, that can be rapidly oxidized by the soil flora. During the initial period of incubation, the CO₂ bursts are probably enhanced by the youthful state of the growing bacterial populations.

Water, too, must be adequate for decomposition to proceed (6, 21, 25, 31, 38, 41). As with temperature so too with soil water, microorganisms have an optimum for growth. Lockett (21) has found that decomposition is decreased in soils containing 9% soil water, but increased greatly in soils containing up to 18% water. In soils with a water content of 0-10%, deposition is limited because water is limiting for microorganism metabolism. At high water content, 25-30%, microbial activity is limited because of the hindering of the movement of air through the soil thus reducing the O₂ supply (1, 21).
Soullides and Allison (30) have found that drying of a soil is far more destructive to bacteria than is freezing. Prolonged drying reduces viable bacteria numbers to the extreme (30). When such soil is moistened, a burst of CO₂ occurs, due perhaps to not only the availability of nutrients, but also to the high biological activity of the young cells (3, 30). The surviving bacteria in the unwetted soil begin their growth from a state of "physiological youth", which is characterized by a high degree of metabolic activity at the close of the lag phase. The longer the soil is dried the more the activities of the microorganisms are stimulated on wetting (30).

The quantity and quality of organic matter is also an important factor to be considered when studying decomposition in an ecosystem (1, 3, 6, 7, 21, 30, 33, 34, 37).

The liberation of nitrogen in available forms during decomposition is also an important factor in decomposition. Thus, the importance of the chemical composition of plant material added to the soil, and the kinds of microorganisms taking part in decomposition of various plant complexes becomes important (21, 34).

Plants in the early stages of growth decompose more rapidly than mature plants. Where young plant material is decomposing in the soil the nitrogen is liberated rapidly as NH₄⁺ which is quickly oxidized to nitrate (21). Also, young plants have large amounts of water soluble organic matter and a higher protein content; older plants are rich in resistant organic substances and low in
protein. The younger plants decompose quite rapidly and because of the high protein content, or the narrow C/N ratio, the soils do not become deficient in nitrogen. The mature plants resist decay and because of the wide C/N ratio, the available nitrogen is insufficient to satisfy the nutritional needs of the microorganisms (21). Lohnis (22) has also found that mature leguminous plants stimulate activity to a greater extent than mature non-legumes, due probably to differences in chemical composition, such as nitrogen content.

The quality of the rhizosphere flora also differs with the species of host plant (21, 33, 37). Vandecaveye and Baker (34) have found that:

"any specific type of organic residue which is returned to the soil repeatedly at regular seasonal intervals during the course of soil development together with the particular temperature and moisture conditions under which it is decomposed should have a definite effect upon the type of soil microflora that will persist. The decomposition products that will result from the transformation of this organic residue by microbial activities will determine in larger measure not only the character of the soil humus formed, but also the character of the microbial habitat which has a powerful influence on the type of soil microflora that will survive."

For instance, organic debris high in cellulose will be broken down almost entirely by fungi. Wherever the dominant plant is high in cellulose, fungi will be the main decomposer organisms in the soil (1). Non-cellulitic material will favor a microbe population with higher bacterial numbers than fungal numbers.

The complexity of plant tissues also determines the resistance of that plant to decomposition. The compounds in plant tissue are
listed in terms of their ease of decomposition starting with the most easily decomposed (5, 17):

1. Sugars, starches and simple proteins
2. Crude Proteins
3. Hemicelluloses
4. Cellulose
5. Lignins, fat, waxes, etc.

Lockett (21) has found that as plants advance towards maturity, the percentage of ether and alcohol, soluble fractions, water soluble fractions, ash and crude protein decreases progressively and the percentage of hemicellulose, cellulose and lignin increase progressively. An abundance of $H_2O$-soluble constituents, a high protein content, low hemicellulose, cellulose and lignin content lead to a rapid disintegration of young plants, while mature plant debris decomposes slower.

Barratt (3) has found that the fibrosity of mature litter is also important in determining its rate of decomposition. Parenchymatous tissues are preferentially attacked; leaf mesophyll disappears before petioles and vascular ends.

The type of soil present in an ecosystem also has an effect on the decomposition that may occur. Clark (7) has found that individual soils have sharply dissimilar microflora, depending upon climate, soil physical and chemical properties, and the type and amount of plant cover.

The soil pH is very important in influencing the conservation
of soil organic matter (4). Soils with an acidic pH favor populations of fungi (4, 6), while soils with an alkaline pH favor bacteria and actinomycetes (4, 6). Bodily (4) has found that acidifying a soil favors fungi, while liming favors bacteria. Bodily has also found that in competition for food between groups of microorganisms a change in fertilizer and liming practices may favor one group or the other. Application of inorganic fertilizers such as \( \text{NH}_4\text{NO}_3 \) has great influence on fungi. Inorganic fertilizers increase soil acidity and thus favor fungi, since fungi can tolerate higher acidity than can bacteria (4).

Leaching also influences the pH of the soil and is directly related to the amount of precipitation and the quality of organic debris present (35). Changes in pH may also be due to organic matter decomposition itself. Rapid rates of decomposition seems to raise the pH slightly and slow rates of decomposition seems to lower pH (3), due to progressive accumulation of nitrate nitrogen (34).

Soil depth also plays an important part in decomposition of organic matter. Vandecaveye and Katznelson (35) have found that microbe numbers decreased sharply with soil depth. The microbe numbers in the surface 0.5 inch are 3-4 times larger than those in the 4-10 inch layers. One reason for the higher numbers in the surface is that plant residues decompose at or near the surface and the more soluble constituents move down the profile (7, 31). Clark (7) has found that microbe numbers are directly related to
the amount of organic matter present. Thus, where the organic debris is high in the top layers of the soil, so are microbe numbers. Most decomposition occurs in the top layers of the soil.

An ecosystem indeed is a very complex system, with all factors working together to recycle and use the energy present. Decomposition is only one part - but a very important part - of the system as a whole. Without decomposition all life processes would cease. In today's age of ecological awareness it is important to study all the relationships that interact and exist in an ecosystem. It is then important to study all factors that affect and are affected by decomposition. Clark (7) has pointed up the importance of the study of decomposition in an ecosystem when he states:

"There are a number of variables interacting to affect microbial numbers and activity in the soil that are difficult to separate and that make it difficult to determine which factor or combination of factors is controlling activity. A true understanding of what happens in a soil system will come about only by use of extensive field experiments in which the environmental parameters on all aspects of an ecosystem are carefully measured."

This paper concerns the role of the decomposers in the flow of energy through an ecosystem. The ecosystem is a grassland; the decomposers are the bacteria, actinomycetes and fungi of the soil; and, CO₂ evolution, during the process of organic matter decomposition, is closely paralleled with energy flows through an ecosystem.

The research for this paper was conducted in conjunction with the Grassland Study of the International Biological Program.
The Grassland Biome headquarters is located at Ft. Collins, Colorado. Their study is concerned with the energy flow that occurs in an ecosystem. The Grassland Biome sites are located at Hopland, California, Bison and Bridger, Montana, Dickinson, North Dakota, Cottonwood, South Dakota, Pawnee, Colorado, Hays, Kansas, Osage, Oklahoma, Pantex, Texas, and Jornada, New Mexico.

Each ecosystem is separated into three biological components, the producers, the consumers, and the decomposers.

The research, conducted at Cottonwood, South Dakota, for this paper was concerned with the decomposer component of the ecosystem. The method of collecting the data for decomposition was standardized throughout the biome, and all data was sent to the Natural Resource Ecology Laboratory at Ft. Collins. The data for the Net Primary Production (NPP) for Cottonwood, and for the Cottonwood site description was received from the International Biological Program.
DESCRIPTION OF STUDY AREA

Cottonwood - Midgrass Prairie

The Cottonwood study site is located in the central part of the midgrass prairie (15, 26). The major grasses are western wheatgrass (*Agropyron smithii* - Rydb), green needlegrass (*Stipa viridula* - Trin.), blue grama (*Bouteloua gracilis* - Lag), and buffalograss (*Buchloe dactyloides* - Englm). Forbs, especially scarlet globemallow (*Sphaeralcea copinea* - Rydb), fringed sagewort (*Artemisia frigida* - Weild), and dandelion (*Taraxacum officinale* - Weber) are very common. Many native legumes are also present, vetch (*Vicia spp.*) and milkvetch (*Astragalus spp.*) being most common. Under light or no grazing, the mid-grasses predominate. Where grazing is increased, short grasses are in majority and form a short grass sod.

The climate is a continental type with large variations in temperature from winter to summer. Temperatures may fluctuate greatly from day to day, and even in a few hours. The average annual temperature is 9°C. Summer highs reach 38°C or higher while winter lows may reach 30°C below zero or lower. Soil temperature at 8 cm averages 16.9°C throughout the growing season.

Precipitation averages 15.13 inches per year, 11.94 inches (79% of the total) fall during the growing season which consists of the months April - September. Soil water averages 15.1% throughout the growing season. Thunderstorms produce most of the
precipitation during the growing season, while snow provides the precipitation during the winter.

Sunshine is very predominant at Cottonwood, as this area receives about 2/3 of possible sunshine through the year. July and August receive the most sunshine, about 3/4 of possible. Due to the warm temperatures, high prevalence of sunshine and northwest winds averaging 11 MPH, evaporation is high. The maximum or potential evaporation is 55 inches per year, while the average annual lake evaporation is 39 inches. Water loss from soil is usually less since the soil water is often limiting.

Soil textures are predominantly silty clay. The landscape is rather gentle with long sloping hills.

The study area was divided into two areas, a permanent exclosure in high range condition and a temporary exclosure in low range condition. The permanent exclosure consists of about 5 acres of range in good condition. It is located on a gentle northeasterly slope with silty clay soils typical of the area. The temporary exclosure contains about two acres of range in fair condition. It has slope and soils similar to the permanent exclosure.

Each exclosure was divided into two replicates. Each replicate was divided into three transects, transect T1, T2 and T3. Two cylinders for CO₂ evolution experiments were set in each transect. This totaled 24 CO₂ samples collected per sample date, 12 CO₂ samples per condition. Two control cylinders were placed per condition. The 24 experimental cylinders plus the 4 control
cylinders were treated similarly and gave a total of 28 samples per trial.

**Gillette Prairie - Alpine Midgrass Prairie**

Gillette Prairie is an alpine meadow located in the central part of the Black Hills of South Dakota. Gillette Prairie is in a mountain region consisting of an ancient crystalline core surrounded by hogbacks of sedimentary structure. The elevation is quite high, around 6,500 feet above sea level.

The growing season consists of the months of May through August for an average length of 120 days. Freezing may occur during any month of the year and plays an important part in the maturation of the plants through the growing season. Predominant plant species are buffalograss (*Buchloe dactyloides* - Engelm), brome grass (*Bromis inermis* - Leyss), timothy (*Phleum pratense* - L), kentucky bluegrass (*Poa pratensis* - L), and many native as well as cultivated legumes. The predominant native legumes are species of *Astragalus*, *Thermopsis*, *Oxitropis* and *Vicia*. The chief cultivated legumes are alsike clover (*Trifolium hybridum* - L) and red clover (*Trifolium pratense* - L), and cicer vetch (*Astragalus cicer*). Some of the lower valley meadows are cultivated in oats, alfalfa and cicer vetch, while most of the higher meadows are cut for wild hay. In some sheltered areas, aspen have become established, and other shrubby plants also grow. The prairie consists of approximately 500 acres of rolling alpine meadow. The prairie
can be classified as a midgrass alpine prairie (15, 26). The prairie is surrounded on either side by a coniferous forest of pine, spruce and aspen.

The average temperature per year is 5.5 C. The average temperature for the growing season is 18.5 C. Soil temperature lags behind canopy temperature and averages 13.3 C at eight cm depth throughout the growing season.

Sunshine is predominant especially in the mornings. Thunderstorms are a common feature during the afternoons and occur frequently. They are caused by convection currents caused by the heating of the ground surface. The heated air rises and cools, and thunderstorms appear. Rainfall averages 22-24 inches per year and 12 inches during the growing season. Soil water averages 18.73% throughout the growing season.

The parent material of the soils consists of undifferentiated crystalline, metamorphic and sedimentary materials. These materials have been ground and eroded by nature until soil is formed deep enough to support various plant life. The soils in Gillete Prairie are very rocky, but the soils that are present are of a loamy texture. Soil depth is not great, ranging from 8 cm to 100 cm. Shallow soils are located on the hillsides and hilltops, while the deeper soils are found in the valleys. Soil coloration ranges from rust on the hills to dark brown in the valleys. Soil fertility is good with an average of 3.36 ppm total NO3-N throughout the growing season, 17.91 lbs./acre phosphorous and 5.96% organic matter.
Native leguminous plants are very prevalent in the prairie and come into anthesis at various times during the growing season. These plants are grazed by domestic livestock as well as by deer and grouse. These plants also play an important role in symbiotic nitrogen fixation.

Since Gillette Prairie encompasses such a large area, it was decided that an area of lesser size, having characteristics similar to that of the prairie as a whole, should be chosen for study of organic matter decomposition. The study area, approximately 5 acres, consists of a valley, hillside and hilltop. Major slopes for micro-climatic differences were also included. These were west-southwest, east and southeast slopes. This area was thus divided into six distinct regions with a sample station located in each.

Station 1 is located on an east slope sloping off into a gentle valley. Legumes are plentiful and heavily nodulated at this station. The soil is quite rocky, about 11%; organic matter is about 4.7%. This station is about 6,500 feet in elevation.

Station 2 is located in a valley, 500 ft. northwest and 50 ft. lower than station 1. This area has been cultivated and fertilized. Cicer vetch has also been planted for a hay and seed crop. Cicer is diminishing and quack grass (*Agropyron repens* - L) is replacing it. The cicer vetch is fairly heavily nodulated with what appear to be effective nodules. The soil at station 2 is deep, rich and free from rocks. Because of cultivation, organic
matter is low, about 4.1%. This area is located in a natural
drainage and receives run-off water, as well as soil carried by
erosion. The elevation of station 2 is about 6,500 ft.

Station 3 is located in the same drainage valley as station 2.
The major features are the same as station 2, except that this
area has not been cultivated. Native grasses and clover are cut
for hay each year. Organic matter is about 6.0%, and the ele­
vation is approximately 6,400 ft.

Station 4 is located on a west-southwest slope. This area is
on a very steep slope and drains into the valley where stations 2
and 3 are located. The soil consists of approximately 35% rocks
and is very shallow. Legumes, apparently effectively nodulated,
abound, and these seem to be the predominant plants. Organic
matter is about 6.8%.

Station 5 is under a small grove of aspen and other woody
plants. Legumes are almost entirely absent. Woody debris and
leaves are the major source of organic matter, which is present at
about 7.3%. Tree roots are very predominant in the soil and are
located throughout the area. The slope is quite gentle. This area
is screened from the wind, and shade is always present. Deer seem
to inhabit this area; deer pellets are scattered throughout. The
soil is very rich and deep.

Station 6 is located on the top of the ridge which runs
through Gillette Prairie. The slope is generally flat but does
slope slightly to the east. The soil is very shallow and rocky
(35%). Lichens and "mossy" type vegetation are predominant. Legumes are also present and are well nodulated. The ridgetop itself is flat and is the highest point on Gillette Prairie with an elevation of 6,500 ft. Organic matter is about 7.1%.
MATERIALS AND METHODS

Soil organic matter decomposition was determined by absorption of the evolved CO₂ in an excess of known strength alkali solution followed by back titration with a standard acid. This method is outlined by Coleman (8).

Canopies

Aluminum irrigation pipe was used to form a canopy to isolate the sample area, exclude atmospheric CO₂, and trap the evolved CO₂. The pipes had an inside diameter of 4 inches or 10.2 cm. Each canopy enclosed 78 cm² of sample area. The length of the pipes used at Cottonwood was 27 cm, and the length of those used at Gillette Prairie was 15 cm. Each pipe section was pushed into the soil to such a depth that 10 cm protruded above the soil to form a canopy in which the alkali could be placed. The cylinders were emplaced to a depth such that the maximum amount of microorganism activity would be inside the buried portion of the cylinder. Where the majority of organic matter is located in the soil is where the majority of the soil bacteria are located. Since the majority of the organic matter is contained in the A horizon of the soil, the majority of the soil bacteria will be there also (7). The A horizon of the soils at Cottonwood was approximately 8-12 cm in depth; thus, the cylinders were buried or emplaced 17 cm into the soil. The A horizon of the soils at Gillette Prairie was much shallower than the A horizon of the soils at Cottonwood. The
average depth of the A horizon of the soils at Gillete Prairie was from 3-5 cm. The cylinders were emplaced to a depth of 5 cm at Gillete Prairie.

Although the cylinders were driven into the soil to a different depth at Cottonwood than at Gillete Prairie, the canopy protruding above the soil was the same (10 cm) in both locations.

At both locations, the cylinders were emplaced early in the growing season, before much photosynthetic growth has appeared, to eliminate as much as possible the severing of plant material.

At Cottonwood, 24 cylinders were emplaced in the soil on April 8. There were 12 cylinders emplaced per condition. Four control cylinders, two controls per condition, were also emplaced to measure the atmospheric CO₂ inside the 10 cm canopy.

At Gillete Prairie, 26 canopies, four per station, were emplaced. Control cylinders were emplaced at stations 2 and 6. The control at station (C-2) was set in the valley, the one at station 6 (C-6) on the hilltop. The emplacement of the two controls at two different locations would take into account any difference in atmospheric CO₂ due to differences in altitude.

The controls were cylinders 10 cm in length. The cylinders were capped at both ends and were set on the ground adjacent to the emplaced cylinders. The area inside the control cylinders was the same as the area of the above ground canopy of the experimental cylinders. The atmospheric CO₂ contained in the control cylinders would then be equal to that of the experimental cylinders.
Before emplacement of the cylinders into the soil, all the photosynthesizing plant material was removed. Before each CO\textsubscript{2} trial, photosynthetic material was again removed to reduce the absorption of CO\textsubscript{2} by photosynthesis.

**KOH - Potassium Hydroxide**

The KOH solution was a commercially prepared reagent grade listed as CO\textsubscript{2} free. A 0.6 N KOH solution was used to absorb the CO\textsubscript{2} released during decomposition. Twenty ml of KOH was placed in 20 dram, plastic vials having a surface area of 12.6 cm\textsuperscript{2}. This area was 16\% of the total area within the canopy. The vials containing the 0.6 N KOH were then placed in the canopies to absorb the CO\textsubscript{2} resulting from decomposition. The canopies were quickly sealed with a flexible plastic cover and covered with aluminum foil to exclude atmospheric CO\textsubscript{2}.

**Barium Chloride (BaCl\textsubscript{2})**

Barium Chloride (BaCl\textsubscript{2}) was added to the 0.6 N KOH solution to precipitate the carbonate (K\textsubscript{2}CO\textsubscript{3}). The BaCl\textsubscript{2} solution used was also a 0.6 N solution.

**Hydrochloric Acid (HCl)**

Titration was run using 0.6 N HCl.

**Thymolphthalein**

Thymolphthalein was the indicator used.
Carbon Dioxide Absorption Procedure

The 0.6 N KOH was prepared the same day that CO2 samples were set out. Care was taken that the KOH was exposed to the atmosphere as little as possible to exclude CO2 absorption due to atmospheric CO2. The KOH solution was carefully poured into a 2000 ml Erlenmeyer flask. The flask was then sealed with Parafilm and taken to the study area. All green plant material was removed from the canopies. The KOH solution was carefully poured into a 5-ml Nalge pipetter. Twenty ml were added to each 20 dram vial and the vial was set in the canopy. The canopy was quickly capped with soft pliable plastic covers and covered with aluminum foil. The aluminum foil provided a heat shield and helped prevent atmospheric CO2 from entering the canopies. The vials were left in the canopies for 24 hours. Changes in barometric pressure, as well as sudden changes in temperature, may actually pull atmospheric CO2 out of the soil or push atmospheric CO2 into the soil. For this reason whenever sudden barometric changes occur, CO2 evolution should not be considered quantitative. After a period of 24 hours, the canopies were opened, and the KOH vials were capped, sealed with Parafilm and taken back to the laboratory for titration. Vials were taken up in the same sequence as they were emplaced.

All KOH, BaCl2 and HCl solutions were made up to a 0.6 N solution. Coleman (8) has found that a 0.6 N solution or any molarity in this range will quantitatively absorb the CO2 evolved. It is noted that both the BaCl2 and the HCl must be made up to the
same normality as the KOH solution.

**Titration Procedure**

1. Twenty ml of BaCl₂ were added to the KOH. (20 ml BaCl₂ to 20 ml KOH). A white precipitate resulted.

2. Ten drops of thymolphthalein were added to the solution of BaCl₂ and K₂CO₃ as an indicator. The white precipitate turned blue upon addition of the thymolphthalein indicator.

3. Titration was run using HCl. A buret was set up attached to a 2 liter Erlenmeyer flask containing the HCl. The vials were placed on a magnetic stirrer, and a flea magnet was placed in the vial to create a swirling action. The stirrer and vial were placed under the buret and titration run. Titration was carried out until the solution turned from blue to a clear color. The total number of ml of HCl used was recorded at the point where the solution turned from blue to clear.

**Calculation of Evolved CO₂**

1. The mean of the HCl used was found for the controls.

2. The experimental values were subtracted from the mean value of the controls.

3. The results obtained were multiplied by a mg CO₂ equivalent of 22 mg to obtain mg CO₂ per unit time (1 ml of 1.000 M HCl = 22 mg CO₂. This is determined by the formula: 2 KOH + CO₂ = K₂CO₃ + H₂O; therefore, 1 mM HCl = 1 mM KOH, but only ½ mM CO₂. The MW of CO₂ = 214; ½ mM CO₂ = 22 mg).
4. The mg CO₂ as determined by step 3 in converted to mg CO₂/24 hr/m² by taking the results of step 3 and multiplying by a conversion factor of 128.2 m² (\(\frac{10,000 \text{ cm}^2/m^2}{78 \text{ cm}^2/\text{cylinder}} = 128.2 \text{ m}^2\)).

This step will give a total result of mg CO₂/24 hr/m². These results can be further converted to g CO₂/24 hr/m². It should be noted that the vials must be left open in the canopies for a period of 24 hours. If not, a conversion factor of \(\frac{24}{X}\) (\(X\) being the time in hours the vials are in the canopies) must be multiplied times the mg CO₂/m².

5. Since 0.6 N HCl is used instead of 1 N HCl, the g CO₂/24 hr/m² must be multiplied by 0.6 to convert the data in terms of 1 N HCl.

See Table 1 for calculation of absorbed CO₂ into g CO₂/24 hr/m².

For CO₂ data to be quantitative, several factors must be taken into account.

1. Eighty percent of the alkali should be unneutralized at the end of the absorption period.
2. The surface of the KOH containing vials should be 15-20% of the total ground surface of the cylinder.
3. Any rainfall of 2-3 mm will flush the CO₂ into the ground and into the cylinders invalidating CO₂ evolution results.
4. Barometric pressure changes will also cause flux of CO₂. Any time a weather front is passing or barometric pressure is fluctuating greatly, CO₂ trials should not be run.
Table 1. Calculation of Absorbed CO₂ into \( \sqrt{\text{CO}_2/24 \text{ hr/m}^2} \)

<table>
<thead>
<tr>
<th>(a) Station</th>
<th>(b) ml HCl titr. Expr. Value</th>
<th>(c) Control Blank Value</th>
<th>(d) (c-b) Blank-Expr.</th>
<th>(e) mg CO₂/24 hr. ((d) \times 22)</th>
<th>(f) g CO₂/24 hr/m² ((e) \times 128.2 \times 0.6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.9</td>
<td>13.2</td>
<td>3.3</td>
<td>72.6</td>
<td>2.58</td>
</tr>
<tr>
<td>2</td>
<td>8.1</td>
<td>5.1</td>
<td></td>
<td>114.2</td>
<td>8.78</td>
</tr>
<tr>
<td>3</td>
<td>9.3</td>
<td>3.9</td>
<td></td>
<td>85.8</td>
<td>6.60</td>
</tr>
<tr>
<td>4</td>
<td>9.1</td>
<td>4.1</td>
<td></td>
<td>90.2</td>
<td>6.93</td>
</tr>
</tbody>
</table>

**TOTAL**: 24.89

\[
\frac{24.89 \text{ g CO}_2/24 \text{ hr/m}^2}{4} = 6.22 \text{ g CO}_2/24 \text{ hr/m}^2
\]
Temperature

1. Cottonwood

Temperature was measured at a soil depth of 8 cm and at ground level. The average temperature at the 8 cm soil depth and at ground level was recorded on each date that CO₂ evolution was tested.

2. Gillette Prairie

A temperature recorder was installed at Gillette Prairie that recorded soil temperature at 8-10 cm depth, ground level temperature and temperature at 2 meters. Table 2 shows the emplacement sites of the temperature probes at each station on Gillette Prairie. For the first period of the season (June 7 - June 25) the temperature recorder functioned well; but later as moisture and heat became factors, the recorder ceased working and temperatures were recorded manually.

Soil Water

Soil samples were taken to a depth of 8 cm on every CO₂ trial at both locations. A spade was used to extract the soil, then slices of soil were cut off to a depth of 8 cm. The slices of soil were mixed thoroughly and taken back to the laboratory for determination of soil water. Four samples were taken per condition at Cottonwood or per station at Gillette Prairie. Soil samples were placed in crucibles, weighed and the dried crucible weight was subtracted to give wet soil weight. The soil samples were then
Table 2. The Emplacement of Temperature Probes at Gillette Prairie.

<table>
<thead>
<tr>
<th>Station</th>
<th>Probe Number</th>
<th>Emplacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Air temp. (2m) ground level</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8-10 cm soil depth</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>8-10 cm soil depth</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>ground level</td>
</tr>
<tr>
<td>3</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>8-10 cm soil depth</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>ground level</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>8-10 cm soil depth</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>8-10 cm soil depth</td>
</tr>
</tbody>
</table>
oven-dried for 24 hours at 100°C and weighed again. Crucible weights were subtracted to give dry soil weight. The dry soil weight was subtracted from the wet soil weight to give the amount of water lost due to heating. Percentage soil water was then determined by the formula:

\[
\% \text{ soil } H_2O = \frac{\text{wet soil wt} - \text{dry soil wt}}{\text{dry soil wt}} \times 100
\]

Percentage soil water was determined and plotted for both the high range condition and low range condition at Cottonwood, and for each of the six stations at Gillette Prairie.

**Percentage Organic Matter**

Percentage organic matter was determined by the Soils Testing Laboratory at South Dakota State University at Brookings, South Dakota. Samples were taken from an area identical to the area of that covered by the canopies (78 cm²). A canopy was pressed into the soil just deep enough to leave a readily visible mark. The soil sample was taken from inside this marked area to a depth of 8 cm. Two samples were taken per station and mixed thoroughly.
RESULTS AND DISCUSSION

Cottonwood

The data on CO₂ production is expressed as grams CO₂ evolved per 24 hours per meter squared (g CO₂/24 hr/m²). Results are depicted graphically. Generally more CO₂ was evolved from the low range condition than from the high range condition. The low condition had more root biomass (1.67%) than did the high condition (0.73%). Root respiration as well as microbial respiration contributes to the CO₂ evolved from the soil so a higher root mass present in one condition than in the other would presumably increase the total CO₂ evolved.

The greater amount of CO₂ evolved from the low range condition may also be influenced by the level of organic matter in the soil. As of June 1, the low range condition had 20% organic matter and the high range condition 15%. Kucera (20) has found that the principal source of organic matter in the soil is roots and root material. The low condition soil had both a higher root biomass and a higher organic matter content explaining perhaps the higher amount of evolved CO₂. Figure 1 contains the results of CO₂ evolution, the soil water and the soil temperature for both conditions at Cottonwood.

For both conditions there is a peak of CO₂ evolution in May followed by a gradual decline. As organic matter, accumulated during the season, warms bacterial activity increases, and more
Fig. 1. CO₂ evolution from the High range condition and the Low range condition at Cottonwood. The standard deviation is also shown.
Fig. 1. (cont.) Soil temperature and soil water for the High and Low range condition at Cottonwood.
organic matter is available for decomposition. Clark (7) describes this phenomenon.

Total CO$_2$ production for the low range condition for the period 8 April through 27 October is 1166.45 grams CO$_2$ per meter squared. This equals 437.42 grams carbon per meter squared. The high range condition evolved 787.99 grams CO$_2$ per meter squared during this same period; or 233.97 grams of carbon per meter squared.

The Net Primary Productivity (NPP) for 1970 for the low range condition was 651 grams C/m$^2$. The NPP for the high range condition for 1970 was 908 grams C/m$^2$. Productivity during 1972 for the high range condition is 146 g C/m$^2$ for the above ground productivity and 198 g C/m$^2$ for the below ground productivity.

Soil water and soil temperature values are given in Figure 1. It seems there is no relationship between soil water and temperature with CO$_2$ evolution under our conditions.

Because there is little relationship between soil water and soil temperature with CO$_2$ evolution at Cottonwood, it is thought that perhaps the method used for CO$_2$ determination needs some improvement before it will be satisfactory for CO$_2$ determination at Gillette Prairie. It was first thought that the emplacement of the cylinders into the soil was severing the roots and that the CO$_2$ production was coming not so much from microbial activity on the natural mulch, but from the death and resulting decomposition of the severed roots. After completion of all CO$_2$ data at
Cottonwood, root samples were taken from inside the canopies and compared to those taken just adjacent to the cylinders. The results show very little difference in root biomass from inside the cylinders as compared to the root biomass outside the cylinders. The emplacement of the cylinders into the soil does sever some roots, but it seems that the quantity of roots severed probably does not greatly affect the evolution of CO₂.

It was then thought that the permanent emplacement of the cylinders into the soil would disturb the ecosystem such that CO₂ evolution would be indicative of the adjustment of the microbes to the cylinders and not the quantitative measurement of CO₂ for that ecosystem. Tests were run to determine any difference in CO₂ evolution between permanently emplaced cylinders and cylinders emplaced in the soil just prior to CO₂ collection. The tests showed no differences.

Since it appeared that the emplacement of cylinders into the soil was not responsible for the aberrant results obtained at Cottonwood, it was decided that perhaps CO₂ samples should be taken at greater frequency. Carbon dioxide collection at Cottonwood was taken at monthly intervals and after 0.05 or more inches of precipitation. If temperature or soil moisture should have a delayed action on CO₂ evolution then CO₂ measurement should be made more often, say once a week. It was decided to check the soil moisture and CO₂ evolution once every week or after every recorded precipitation of 0.05 inches or greater the following summer at
Gillette Prairie. Also, a temperature recorder was installed at Gillette Prairie to record daily temperatures. It was hoped that by increasing the frequency of CO₂ measurement we would better be able to see the relationship between soil moisture, soil temperature and CO₂ evolution.

**Gillette Prairie**

Carbon dioxide evolution was measured, whenever possible, at weekly intervals at Gillette Prairie. Soil moisture was determined on every date that CO₂ was sampled. Soil temperatures were recorded every hour for 24 hours a day by an installed temperature recorder with 9 temperature probes. The recorder proved to be less than satisfactory, and eventually failed. Whenever temperature was recorded for daily periods, the data is recorded on the graph of soil temperature.

All CO₂ is expressed as grams CO₂ per 24 hours per meter squared (g CO₂/24 hr/m²). Results of CO₂ evolution, soil water, soil temperature and soil organic matter for Gillette Prairie are shown in Figures 2, 3, 4, 5, 6, and 7.

Carbon dioxide evolution at Gillette Prairie seems to correspond closely with soil water. For all stations at Gillette Prairie, except station 3, CO₂ evolution is higher on the day of emplacement of the cylinders into the soil (June 7) than on the next CO₂ trial on June 11. The emplacement of the cylinders into the soil may be responsible for the difference in CO₂ evolution between the two dates. Precipitation is recorded on June 12. Soil moisture
Fig. 2. CO₂ evolution, with standard deviation, and soil water for station 1 at Gillete Prairie.
Fig. 2. (cont.) Soil temperature and soil organic matter for station 1 at Gillette Prairie. Solid dots represent temperature at CO₂ evolution sample dates; smaller dots represent temperatures at dates other than CO₂ sample dates.
Fig. 3. CO$_2$ evolution, with standard deviation, and soil water for station 2 at Gillette Prairie.
Fig. 3. (cont.) Soil temperature and soil organic matter for station 2 at Gillette Prairie. Solid dots represent temperature at CO₂ evolution sample dates; smaller dots represent temperatures at dates other than CO₂ sample dates.
Fig. 4. CO$_2$ evolution, with standard deviation, and soil water for station 3 at Gillette Prairie.
Fig. 4. (cont.) Soil temperature and soil organic matter for station 3 at Gillette Prairie. Solid dots represent temperature at CO₂ evolution sample dates; smaller dots represent temperatures at dates other than CO₂ sample dates.
Fig. 5. CO$_2$ evolution, with standard deviation, and soil water for station 4 at Gillete Prairie.
Fig. 5. (cont.) Soil temperature and soil organic matter for station 4 at Gillette Prairie. Solid dots represent temperature at CO₂ evolution sample dates; smaller dots represent temperatures at dates other than CO₂ sample dates.
Fig. 6. CO₂ evolution, with standard deviation, and soil water for station 5 at Gillette Prairie.
Fig. 6. (cont.) Soil temperature and soil organic matter for station 5 at Gillette Prairie. Solid dots represent temperature at CO2 evolution sample dates; smaller dots represent temperatures at dates other than CO2 sample dates.
**Fig. 7.** $\text{CO}_2$ evolution, with standard deviation, and soil water for station 6 at Gillete Prairie.
Fig. 7. (cont.) Soil temperature and soil organic matter for station 6 at Gillette Prairie. Solid dots represent temperature at CO₂ evolution sample dates; smaller dots represent temperatures at dates other than CO₂ sample dates.
was not determined on this date although 0.35 inches of precipitation was recorded. (See Table 3 for dates and amounts of precipitation.)

Precipitation also occurred each day from July 19-23 and again all stations recorded an increase of CO₂ evolution during this period. Temperatures fluctuated wildly during the period of June 7 through August 3. Freezing temperatures are recorded for all stations on June 18 and the high temperature for most of the stations occurred on July 6. For all stations, organic matter remained quite stationary.

Although CO₂ evolution, temperature, soil moisture and soil organic matter all differ somewhat from station to station, there are several factors which seem to be the same for each. These factors concern the relationship of soil water, temperature, and soil organic matter to CO₂ evolution. For each station there seems to be an immediate and direct effect of soil water upon CO₂ evolution. As soon as precipitation occurs or soil water increases, there is a burst of CO₂ production. Also, whenever soil water gradually increases or decreases, CO₂ evolution also seems to increase or decrease correlating directly with fluctuations in soil water.

Fluctuations of soil water seem to be the most important factor affecting decomposition under the present conditions at Gillette Prairie.

Temperature seems to be more indirectly important in
Table 3. Showing recorded precipitation at Gillette Prairie.

<table>
<thead>
<tr>
<th>Date</th>
<th>Amount (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 12</td>
<td>.35</td>
</tr>
<tr>
<td>June 13</td>
<td>.05</td>
</tr>
<tr>
<td>June 14</td>
<td>.90</td>
</tr>
<tr>
<td>June 18</td>
<td>.75 + 1 in. snow</td>
</tr>
<tr>
<td>June 21-22</td>
<td>.20</td>
</tr>
<tr>
<td>July 19-23</td>
<td>.20</td>
</tr>
<tr>
<td>July 25-August 2</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3.45 inches</strong></td>
</tr>
</tbody>
</table>
influencing decomposition at Gillette Prairie. The effect of temperature seems more important in its effect on soil moisture and organic matter. Temperatures may drop to freezing at any time during the year at Gillette Prairie, and may just as likely reach very high temperatures during the summer months. If freezing or low temperatures occur, the vegetation is set back or even killed. This killing of the vegetation by low temperatures increases organic matter accumulation. Higher temperatures also affect soil moisture. The soil at Gillette Prairie is shallow and as temperatures rise, evaporation also increases. As evaporation increases, soil water decreases, and as soil water decreases, so does CO₂ evolution.

A summary for the six stations at Gillette Prairie is shown in Table 4.
Table 4. Showing Ave. g CO₂/m², temperature, soil moisture, organic matter and total CO₂ and Carbon for Gillette Prairie.

<table>
<thead>
<tr>
<th>Station</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. CO₂ evolution</td>
<td>10.95</td>
<td>11.07</td>
<td>17.17</td>
<td>9.56</td>
<td>12.88</td>
<td>9.62</td>
</tr>
<tr>
<td>Ave. temperature</td>
<td>13°</td>
<td>15°</td>
<td>16°</td>
<td>14°</td>
<td>10°</td>
<td>14°</td>
</tr>
<tr>
<td>Ave. soil water</td>
<td>16%</td>
<td>18.5%</td>
<td>21%</td>
<td>16%</td>
<td>22%</td>
<td>18%</td>
</tr>
<tr>
<td>Ave. organic matter</td>
<td>4.3%</td>
<td>4.1%</td>
<td>5.7%</td>
<td>6.5%</td>
<td>8.5%</td>
<td>6.19%</td>
</tr>
<tr>
<td>Total CO₂/57 da.</td>
<td>624.15</td>
<td>630.99</td>
<td>978.69</td>
<td>544.82</td>
<td>734.16</td>
<td>548.34</td>
</tr>
<tr>
<td>Total C/57 da.</td>
<td>170.21</td>
<td>172.07</td>
<td>266.89</td>
<td>148.60</td>
<td>200.21</td>
<td>149.53</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The total amount of CO$_2$ evolution for the low range condition at Cottonwood is 1166.45 grams CO$_2$/m$^2$/season, which equals 437.42 grams carbon/m$^2$. The high range condition evolved 787.99 grams CO$_2$/m$^2$/season, or 233.97 grams carbon/m$^2$.

The total amount of CO$_2$ evolution at Gillette Prairie is 676.20 grams CO$_2$/m$^2$/season, which equals 184.58 grams carbon/m$^2$.

Macfadyen (23) and Golley (16) have found that 5-6% of the gross primary production is assimilated by decomposer organisms. Alexander (1) has found that from 20% to 40% of the substrate carbon is assimilated by microbes, while Kucera and Kirkham (20) have found that 45% of the carbon of organic matter is respired during decomposition. This means that the total grams of evolved carbon/m$^2$ for each grassland represent only 45% of the actual primary production. The 437.42 grams of evolved carbon/m$^2$ for the low range condition at Cottonwood is equal to 971.07 grams carbon produced/m$^2$/season; and the 233.97 grams of evolved carbon/m$^2$ for the high range condition at Cottonwood is equal to 519.41 grams carbon produced/m$^2$/season. The 184.58 grams of evolved carbon/m$^2$ for Gillette Prairie is equal to 409.77 grams carbon produced/m$^2$/season. Since Gillette Prairie is in high range condition, the productivity of the high range condition at Cottonwood will be compared to that of Gillette Prairie.

The total productivity in grams dry weight of material for
the high range condition at Cottonwood is 519.41 grams carbon/m²/season, that for Gillette Prairie is 409.77 grams carbon/m²/season.

The Net Primary Production (NPP) for the high range condition at Cottonwood is 146 grams carbon/m²/season for the above ground productivity, and 198 grams carbon/m²/season for the below ground productivity. The total NPP for the high range condition at Cottonwood is 344 grams carbon/m²/season.

Net Primary Production (NPP) figures for Gillette Prairie are not known, although it is known that 1,500 to 2,000 lbs. of hay are harvested per acre, equalling approximately 1/3 lb. of hay per square yard of 179.69 grams of hay per meter squared. Mueggler (25), in his study of alpine grasslands, found that total herbage was about 1,000 lbs./acre/season. Clark (7) has found that the values on the quantity of above ground litter observed on grassland in the Central and Northern Great Plains of the U. S. is within 100-1,000 grams/m². The figure of 179.69 grams of above ground litter seems to be in agreement with these two studies.

Roots also add organic matter to the soil. Kucera and Kirkham (20) found that roots are the principal source of organic matter in the soil. Dahlman and Kucera (10) estimate the 25% of the total root matter was turned over annually by decomposition and the figure may be as high as 55% (19). Vandecaveye and Katznelson (35) reported that roots and root debris account for as much as 50% of the organic matter in soil.
Root samples were taken at Gillette Prairie. Approximately 200 grams/m² of root material was found.

An estimation of NPP for Gillette Prairie, including both above ground and below ground litter, is 379.69 grams carbon/m²/season.

The amount of carbon/m² as determined by CO₂ evolution for the high range condition at Cottonwood is 519.41 grams carbon/m². The NPP for that condition is 344 grams carbon/m². There seems to be more carbon output in the system than carbon input by approximately 34%. This 34% difference observed between NPP and evolved CO₂ may be due to the respiration of CO₂ by the roots. Kucera and Kirkham (20) have found that in a Missouri grassland, roots are responsible for approximately 40% of the evolved CO₂.

For Gillette Prairie, the amount of carbon/m² as determined by CO₂ evolution is 409.77 grams carbon/m², while the NPP is 379.69 grams carbon/m². There is a 7.4% difference observed between NPP and evolved CO₂. This difference may also be due to root respiration.

The below ground biomass at Cottonwood is 198 grams carbon/m²; that at Gillette Prairie is 200 grams carbon/m². The 198 grams carbon/m² root biomass at Cottonwood "respired" 175.41 grams carbon/m²; whereas; the 200 grams carbon/m² biomass of roots at Gillette Prairie only "respired" 30.10 grams carbon/m². It seems that the carbon output at Gillette Prairie, as determined by CO₂ evolution using the KOH absorption method, is low. There are
several aspects of the CO₂ absorption method, as well as difficulty in determining NPP, that may account for the biased results.

The NPP figures for Cottonwood were received from the Grassland biome data bank at the Natural Resource Ecology Laboratory at Ft. Collins, Colo. Vegetation samples were taken on set sample dates. The samples include both above ground and below ground litter. The data was then sent to Ft. Collins for analysis.

The NPP figures for Gillette Prairie are an estimation. Since Gillette Prairie was not a part of the I.B.P. network, NPP figures are determined on a rough basis and need refining. It is important to be quantitative in determining NPP for an ecosystem before any CO₂ evolution data can be made useful. As of yet there seems to be some question as to a reliable method of measuring NPP.

There are also several aspects of the CO₂ evolution method for determination of decomposition that should be discussed, and perhaps need refining.

1. It seems that for the CO₂ absorption method of analysis for decomposition to be quantitative, sampling should be continuous, or at least done each day. When the sampling frequency of CO₂ evolution was increased, decomposition at Gillette Prairie seemed to correlate with soil water, soil temperature and soil organic matter.

2. All CO₂ samples were taken over an area of 78 cm². The results obtained from this area are then converted to terms of meters squared (m²). The sample error is too
great per sample area for the data to be representative of the area. The number of CO\textsubscript{2} sample sites per plot should be increased to reduce the large standard deviations.

3. Carbon dioxide evolution results are obtained for a particular date and no interpolation should be used for CO\textsubscript{2} evolution between dates.

The use of CO\textsubscript{2} evolution as a determination of decomposer activity is very useful. Although the CO\textsubscript{2} evolution, as determined by the method used at Cottonwood and Gillette Prairie, is an indication of the decomposition that occurs, refining the method of measuring CO\textsubscript{2} evolution by the factors mentioned above should give results that are very quantitative for detecting decomposition in an ecosystem.


