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THE ORIGIN AND PROPERTIES OF ALKALINE RAW HUMUS

by

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Table of Contents

	Page
Introduction.	1
Review of Literature.	2
General Description of the Area of Occurrence	5
Experimental.	9
Summary	14

Introduction

Forest litter and products of its decomposition, or "humus" in the broad sense of this word (Waksman, 27), is an important factor not only in development of the soil profile but in practical silviculture as well.

To a great extent independent of climate, the biological and chemical properties of organic remains determine the processes of soil genesis, such as leaching of podzols and gray forest soils, maintenance of the equilibrium of soluble salts in the brown earths and accumulation of iron and aluminum sesquioxides in laterites. Different forms of forest humus essentially modify the rate of natural reproduction of forest stands and thus greatly influence the technique of selective logging. Last but not least, forest humus plays an important part in the maintenance of fertility of permanent forest nurseries, being a source of useful organisms, balanced nutrients, buffering colloids, growth hormones and other substances essential in the preparation of inoculation media, liquid humates and composts, (Wilde, 29, 31, 32).

Undoubtedly anyone of these phases of the influence of forest humus in itself justifies the detailed study of the organic layers of forest soil profiles.

This paper deals with the investigation of the chemical and biological properties of a little-known type of forest humus, namely alkaline raw humus, occurring on calcareous rock outcrops in the podzol region of Wisconsin.

Review of Literature

The first classification of organic layers of forest soils is accredited to the German forester Emeis (8), who in 1875 described three types of forest humus. Emeis' classification clearly indicated the existence of two distinct types of forest humus: one consisting of well decomposed organic matter largely incorporated with mineral soil, and containing nitrogen in the form of "nitric acid"; the other comprising free, slightly decomposed or "raw" organic remains. This subdivision has formed the basis of all later schemes of classification. P. E. Müller (16) of Denmark in 1879 was the first to look upon forest humus layers as naturally occurring, biological units. He subdivided the humus layers of forest soils into two types or groups, mull and mor. According to Müller the most typical representative of the mull groups is the earthworm mull, a porous, loose, friable mass with a crumbly structure and consisting of an intimate mixture of humus with mineral soil. The organic matter content of the mixture is low. The deposit is inhabited by large earthworms, such as Lumbricus terrestris. It supports a rich vegetation of geophytes including Asperula odorata, Mercurialis perennis, Milium effusum, Melica uniflora, Stellaria nemorum, Oxalis acetosella and Anemone nemorosa.

The mor or raw humus group of Müller comprises matted humus layers usually very high in organic matter and lying like a carpet on top of the mineral soil. The deposit is more or less tough or compact, not porous and friable like the mull. The vegetation is strikingly different from that on the mull

type and includes Aira flexuosa, Trientalis europaea, Maianthemum bifolium, Melampyrum pratense, Potentilla tormentilla and the mosses Hypnum triquetrum, H. cupressiforme, Polytrichum formosum, Dicranum scoparium, Leucobryum vulgare and Ceratodon purpureus.

Following the original work of Müller, during the past 60 years there have been numerous attempts to broaden the classification of forest humus and to correlate such with the requirements of silvicultural practice, (Ramann, 17; Ebermayer, 6; Hesselman, 12; Leiningen, 15; Vater, 24; Albert, 1; Ekstrom, 7; Frosterus and Tamm, 9; Juncker, 13; Tschermak, 23; Bornebusch, 3; Romell and Heiberg, 18; Bornebusch and Heiberg, 4). The various classifications have recognized the following forms of the mull group: insect mull, surface mull, crumb mull, detritus mull, grain mull, twin mull, earth mull, coarse mull, fine mull, and firm mull. The mor or raw humus group has been divided into such forms as mosamylla, poorly humified humus, amorphous humus, fibrous humus, leaf mor, granular mor, greasy mor, root mor and fibrous mor.

Throughout all of these classifications there has been the general assumption that acidity regulates the rate of decomposition of humus. Acid humus types were usually considered to have a slow rate of decomposition and raw humus was often referred to as "sour humus." On the other hand, slightly acid to alkaline types were assumed to have a rapid decomposition rate. As recent studies have indicated (Romell and Heiberg, 18; Albert, 1; Wilde, 31), there are strongly acid types of mull with reaction below pH 5.0 as well as alkaline types of mor with

reaction as high as pH 8.0. Wilde gives the following range of reaction values for the principal forest humus layers of the Lake States region.

	pH
Acid earth mull	5.0 - 5.7
Slightly acid earth mull	5.8 - 7.0
Alkaline earth mull	7.0 - 8.0
Acid leaf mull	4.8 - 5.7
Slightly acid leaf mull	5.8 - 6.8
Strongly acid raw humus	3.7 - 4.7
Acid raw humus	4.8 - 5.5
Alkaline raw humus	7.3 - 8.0

Although numerous varieties of acid raw humus have been described in great detail, there have been but a few mentions pertaining to a raw humus of alkaline nature.

Ebermayer (6) as early as 1888 drew attention to an alkaline raw humus type of rather advanced decomposition which he calls alpen humus. This type was described by Ramann (17) in 1911. It is formed in the Eibsee region on dolomitic portions of the Bavarian Alps under the action of lime bearing seepage water which percolates down from the mountain sides. It is the product of a cool, moist climate, as found at elevations of 4500 feet near Hollental and 3300 feet near Obertsdorf. The humus develops on a limestone substratum. It is very dark in color and of fine, nearly amorphous structure. The decomposition is arrested at a certain stage by a high moisture content. Lang (14) has lately reported the occurrence of an alkaline raw humus type formed from the litter of ericaceous plants at elevations above timber line in dolomitic portions of the Alps. Here the effect of lime, as well as the slow action of micro-organisms under an average yearly temperature of about 0° C have

resulted in the development of a mat of calcareous raw humus above the limestone rock. This raw humus supports cranberry, sweet broom and bilberry which in warmer climates are characteristic of acid, base poor soils. Wilde (31) reported an occurrence of alkaline raw humus, formed under coniferous forests on dolomitic limestone outcrops of Door Peninsula in northeastern Wisconsin, the detailed investigation of which is the object of this study.

General Description of the Area of Occurrence

Door Peninsula forms a portion of the Niagara cuesta, an extensive upland bordering Lake Michigan. The peninsula is approximately 70 miles in length and from 5 to 20 miles in width, extending northeasterly into Lake Michigan. It is underlain by thick beds of hard Niagara limestone which show a slight dip to the east. The Labrador ice sheet, in advancing over this formation, removed nearly all of the residual soil from the higher portions and left deposits of glacial till composed chiefly of limestone material. Lacustrine clays were laid down during interglacial periods in the southern portion of the peninsula. In patches are found small areas of calcareous outwash sand.

Elevations on the peninsula range from about 580 to 800 feet above sea level. Topographically, the most striking feature is the long line of rugged bluffs bordering Green Bay and extending almost unbroken from a short distance north of Sturgeon Bay to the northeast point of the peninsula. In the interior of the peninsula the topography is rolling and marked by numer-

ous rock outcrops and escarpments. It is typically glacial in character with swamps, depressions and a few lakes scattered throughout the rolling upland. There are but a few short streams in the northern section.

Records of climate are available for 32 year period at the Sturgeon Bay station of the United States Weather Bureau. This station is located at an elevation of 656 feet and lies at approximately $44^{\circ}50'$ N. latitude and $87^{\circ}25'$ W. longitude. The mean annual temperature is 42.8 degrees while the mean annual precipitation averages 30.3 inches and is very well distributed throughout the year. An average of 56 inches of snow falls each year occurring largely from November through March. The growing season averages about 150 days in length usually beginning about May 15 and extending to the middle of October. The mean temperature of this period is about 60 degrees F. while the highest temperature on record is 100 degrees F. On an average 16 inches of precipitation is received during the growing season. Precipitation is well distributed through this period with some rainfall being received on an average of one day out of three. Prevailing winds occur from the northwest during the period of October to March while in April and May they shift to the northeast and finally around to the south during the remainder of the year. Relative humidity data are available only at Green Bay which is about 60 miles southwest of the area studied. The average relative humidity at this station is 75 per cent on the basis of morning and evening readings. Along the shores of Green Bay and Lake Michigan the relative humidity undoubtedly averages higher.

The predominant soil on the peninsula is a light brown fine sandy loam with a mull type of humus. The profile shows signs of podzolization. The A₂ horizon has a platy structure which breaks easily into fine crumbs. The B horizon is nut structured and contains remnants of limestone fragments. The profile is usually shallow and numerous limestone outcrops, with characteristics of typical skeletal soils, are found (Stebutt, 21). This soil supports a forest growth of hard maple, basswood, beech, elm, white ash, red oak and occasionally some hemlock. The ground vegetation includes plants common on mull soils, such as Adiantum pedatum, Uvularia grandiflora, Geranium Robertianum, Geum canadense and Smilax spp. Distinct loam podzols have developed on the limestone drift in some localities. These soils are characterized by a matted raw humus layer and a deep dark gray leached horizon grading into a reddish brown, tough, fractured clay horizon. The profile is usually deeper than the mull loam. The forest cover includes hard maple, beech, hemlock, balsam fir, with some white spruce and white pine. In the shrub layer are found leatherwood and round leaved dogwood while the ground vegetation is characterized by the presence of Maianthemum canadense, Cornus canadensis and other raw humus plants.

On areas of sandy outwash, the podzol profile is well developed. The profile consists of a 3 to 4 inch layer of matted raw humus underlain by a two inch humic horizon and a two to four inch strongly leached, ashy-gray layer. A strongly cemented hardpan layer occurs at about 14 to 16 inches and grades at various depths into calcareous sandy outwash material. The

forest growth consists of a dense stand of hemlock and balsam fir with some inferior hardwood associates. The ground cover is a typical podzol-hemlock association (Wilde, 29).

The low areas are covered with woody peat of nearly neutral reaction. The forest cover consists of American elm, black ash, red maple and northern white cedar. The forest is characterized by a rather slow rate of growth. The shrubs include elderberry, tag alder, gooseberry, raspberry and red osier. The ground cover is abundant and is characterized by such species as Urtica dioica, Galium triflorum, Aralia nudicaulis, Aspidium spinulosum, Psedera quinquefolia, and several moss species.

The well drained calcareous rock outcrops have but a very shallow layer of weathered material, sometimes less than one inch in thickness. The mineral soil is covered with a layer of raw humus of alkaline reaction, approximately four inches in thickness. The upper portion is dark brown and matted, consisting of leaves, needles and wood remains grading into a layer of nearly black, fine, powdery material. The forest stands on these sites are composed of northern white cedar, balsam fir and some white pine. The understory is composed chiefly of the shrub Juniperus communis depressa. No characteristic ground cover was observed on the sample plots studied. In transitions from upper to lower slopes the alkaline raw humus becomes deeper and sometimes grades into woody peat.

method (10). The results Experimental nutrient determinations

Alkaline raw humus samples were collected under stands of northern white cedar and balsam fir on calcareous rock outcrops near the town of Sister Bay, Door County, Wisconsin. Some samples were also taken from a one foot deep layer of alkaline raw humus formed under stands of northern white cedar, American elm and red maple on the edge of a woody peat swamp near Red Banks, Door County. For the purposes of comparison in the laboratory studies, samples of several of the principal humus types of the Lake States were collected as follows: crumb mull humus, formed under stands of sugar maple, basswood and elm on Colby silt loam near Marshfield, Wisconsin; root duff under stands of American elm, ash and oak on shallow Miami loam near Brussels, Door County, Wisconsin; hardwood-hemlock duff from Vilas sandy loam at Clear Lake, near Woodruff, Wisconsin; acid raw humus formed under hemlock stands on a fine sandy loam soil near Dukes, Michigan.

As the first step in the laboratory study, reaction, base exchange properties, total and available nutrients and total carbon were determined on these materials using the following procedures: reaction was determined electrometrically (20); base exchange capacity, total and replaceable bases by a modification of the Chapman and Kelley ammonium acetate method (5); total nitrogen by the standard Kjeldahl procedure (2); total and available phosphorus by the Truog method (22); total and available potash by the Volk-Truog procedure (25); and total carbon by the Heck modification of the chromic acid combustion

method (10). The results of the total nutrient determinations are given in Table 1.

In order to determine the fertilizing value of alkaline raw humus and to compare it in this respect to the other types of organic remains used in this study, a pot culture experiment was conducted in the greenhouse. The humus materials were ground and mixed with pure quartz sand at the rate of $4\frac{1}{2}$ per cent by weight. Four replications were made with each humus material. This mixture was placed in half gallon glass jars in each of which 20 seeds of Imperial Wisconsin rye were planted. After germination the seedlings were thinned out so as to leave only 10 in each jar. After 17 days of growth the seedlings were carefully removed, washed free from sand, dried in an oven at 60° C and weighed. The weight of the average seedling is included with the fertilizing values of the various organic materials in Table 2.

A previous study (34) reports the fertilizing values of organic materials of different origin, occurring on a few widely distributed soil types under normally developed forest stands of advanced age. Table 3, taken from this paper, is included here to illustrate the wide range in the nutrient content and fertilizing values of various morphological varieties of forest organic layers.

The degree of decomposition of humus is revealed by the analysis of a number of organic constituents. Waksman and Stevens (26, 27) have proposed methods of proximate analyses for peats and for soil organic matter by which a greater portion

Table 1

Total Nutrient Content of Various Types of Organic Remains as Determined
by Chemical Analysis

No.	Types of organic remains	Carbon %	Nitrogen %	C/N Ratio	Phosphorus %	Potash %	Calcium %	Magnesium %
1	Alkaline raw humus	31.4	1.31	22.9	0.125	0.115	5.882	7.642
2	Deep, alkaline raw humus	37.8	3.04	12.7	0.161	0.138	4.295	2.429
3	Crumb mull	7.38	0.51	14.4	0.054	0.265	0.498	0.284
4	Root duff	22.6	1.24	18.3	0.125	0.072	5.034	3.821
5	Hardwood-hemlock duff	22.8	1.37	16.7	0.109	0.290	0.932	0.668
6	Acid raw humus	39.2	2.06	19.0	0.123	0.135	0.723	0.634

Table 2

Available Nutrients and Productivity of Various Types of Organic Remains as
Determined by the Growth of Rye in the Greenhouse

No.	Types of organic remains	Reaction: pH	Base exchange: per 100 gms. m. e.	Total N %	Re- place- able Calcium %	Re- placeable Magnesium %	Available Phosphorus %	Avail- able Potash %	Ave. wt. of 17 day old seedling mgm.
1	Alkaline raw humus	7.5	123.0	1.31	2.140	0.281	0.004	0.038	66
2	Deep alkaline raw humus	6.4	167.5	3.04	1.225	0.230	0.005	0.042	59
3	Crumb mull	4.8	24.0	0.51	0.118	0.081	0.003	0.023	60
4	Root duff	6.7	85.2	1.24	1.480	0.247	0.004	0.008	62
5	Hardwood-hemlock duff	5.6	58.0	1.37	0.600	0.071	0.021	0.079	96
6	Acid raw humus	4.5	66.7	2.06	0.630	0.112	0.034	0.046	51

Table 3

Productivity of Different Types of Organic Remains as Determined by the Growth
of Norway Spruce in the Greenhouse

No.	Types of organic remains*	Reaction:	Base exchange: per 100 gms.	Total N	Avail-able P	Avail-able K ₂ O	Re-placeable Ca	Re-placeable Mg	Ave. weight of a 2-year old seedling
		pH	m. e.	%	%	%	%	%	mgm.
1	Norway pine duff	5.5	24.0	0.54	0.006	0.054	0.186	0.043	354
2	White pine duff	4.9	48.6	0.70	0.011	0.071	0.306	0.046	445
3	Hemlock duff	4.8	51.9	1.44	0.009	0.049	0.656	0.048	597
4	Hemlock duff	5.5	78.0	1.56	0.008	0.051	0.460	0.062	623
5	Hardwood-hemlock duff	4.9	55.3	1.44	0.012	0.079	0.562	0.031	793
6	Hardwood-hemlock duff	5.5	85.7	1.90	0.016	0.089	1.178	0.176	859
7	Hardwood-hemlock duff	5.5	76.0	1.42	0.015	0.087	1.060	0.191	876
8	Hardwood leaf mull	6.9	66.0	1.10	0.018	0.078	0.940	0.073	675
9	Hardwood crumb mull	5.0	25.8	0.69	0.003	0.046	0.348	0.048	391
10	Hardwood grain mull	6.4	13.2	0.196	0.004	0.036	0.234	0.048	283
11	Hemlock litter	3.9	84.9	0.73	0.003	0.017	0.166	0.010	305
12	White cedar duff	7.8	82.5	1.05	0.012	0.051	1.224	0.261	221

* Types of soil and locations: 1, Vilas sand, Goodnow; 2, Vilas sandy loam, Minocqua; 3 and 4, Kennan fine sandy loam, Clam Lake; 5, Vilas sandy loam, Lac du Flambeau; 6, and 7, Kennan fine sandy loam, Clam Lake; 8, Antigo silt loam, Rice Lake; 9, Colby silt loam, Marshfield; 10, Antigo silt loam, St. Croix; 11, Kennan fine sandy loam, Clam Lake (poorly humified duff); 12, calcareous rock outcrops, Sturgeon Bay.

of the organic material may be accounted for in the form of definite chemical compounds. In this study, the method of peat analysis (26) was used for the estimation of these compounds in the duff and raw humus samples and the method of soil organic matter analysis (27) was used for their estimation in the crumb mull sample. The results of this fractionation analysis of organic materials are presented in Table 4.

As a measure of the relative biological activity and the rate of decomposition of the various organic materials, the carbon dioxide evolution was determined according to the standard method modified by Heck (10). The organic materials were passed through a large mesh sieve to exclude pieces of wood, twigs and leaves. A portion of material of such size as to contain from 5 to 20 grains of carbon was placed in a 500 cc. Erlenmeyer flask and distilled water was added until suitable moisture conditions were obtained. The materials were then allowed to "compost" for a period of two weeks after which the moisture content was again adjusted. The carbon dioxide was absorbed in 0.5 N sodium hydroxide and determined at 48 hour intervals, after precipitation with neutral 2 N barium chloride, by titration with 0.5 N hydrochloric acid. The determinations were continued for six 48 hour periods. Figure 1 illustrates the relative biological activity of several types of forest organic remains as based on the milligrams of carbon dioxide released per gram of carbon contained in the original sample.

Summary

The origin and properties of alkaline raw humus developed upon limestone outcrops in the podzol region of Wisconsin

Table 4

Proximate Chemical Composition of Different Types of Forest Organic Remains

(On per cent basis of oven-dry organic material free from soil mineral particles)

	: Alkaline:		: Root :	: Acid :	: Hardwood :	
	: raw :	: Deep alkaline:	: duff :	: raw :	: hemlock :	: Crumb
	: humus :	: raw humus :		: Humus :	: duff :	: mull*
Ether soluble fraction	: 0.47 :	: 0.14 :	: 0.21 :	: 0.72 :	: 0.40 :	: 0.40 :
Cold water soluble fraction	: 1.92 :	: 2.19 :	: 2.31 :	: 2.74 :	: 1.40 :	: 0.72 :
Hot water soluble fraction	: 0.48 :	: 1.03 :	: 0.65 :	: 4.93 :	: 2.70 :	: 0.73 :
Alcohol soluble fraction	: 2.71 :	: 2.24 :	: 2.02 :	: 4.94 :	: 3.94 :	: 2.72 :
Hemicelluloses	: 3.17 :	: 2.52 :	: 1.40 :	: 4.38 :	: 3.48 :	: 2.64 :
Celluloses	: 2.65 :	: 0.37 :	: 0.98 :	: 4.73 :	: 0.57 :	: 0.71 :
Lignin fraction	: 36.55 :	: 40.49 :	: 32.58 :	: 43.75 :	: 30.79 :	: 33.85 :
Crude protein fraction	: 9.91 :	: 19.43 :	: 12.41 :	: 11.72 :	: 11.42 :	: 25.68 :
Ash	: 17.03 :	: 11.89 :	: 15.30 :	: 4.55 :	: 6.75 :	: --- :
Total accounted for	: 74.89 :	: 80.30 :	: 67.86 :	: 82.46 :	: 61.45 :	: 67.45 :

* On basis of organic matter content of sample (Cx1.72)

Figure 1. Relative Biological Activity of Different Humus Materials as Measured by Carbon Dioxide Evolution

were investigated in the field, laboratory and greenhouse.

The accumulation of raw organic remains in this region is attributed to high humidity, high content of calcium and magnesium carbonates, and the deficiency of a weathered soil layer, that is, to conditions unfavorable to the growth of micro-organisms. The humus develops under mixed hardwood-coniferous stands with a predominance of northern white cedar and balsam fir. The duff layer varies from 3 inches to one foot in thickness and is made up of dark brown, matted, little decomposed wood and leaf remains. The lower portion of this layer is highly dispersed, of dark color and amorphous consistency, being plastic when wet. The pH of the organic portion varies from 6.4 - 8.0 whereas the mineral substratum invariably has a reaction of pH 8.0.

The total analysis of alkaline raw humus, in comparison with other types, shows a high content of calcium and magnesium oxides and consequently is low in silica. The carbon-nitrogen ratio of this humus is wider than that of any humus studied. The content of phosphorus and nitrogen is comparable to that of other raw humus types, whereas the content of potash is below the average. Although the alkaline humus is high in base exchange capacity and in some available elements, the nutrient ratio is not well balanced as shown by analysis as well as by the poor growth of rye and Norway spruce seedlings in the greenhouse.

The amounts of water and alcohol soluble material, and of cellulose and lignin are considerably lower in the alkaline raw humus as compared with acid raw humus. The lignin content of deep alkaline raw humus, averaging about 40 per cent, is

approximately the same as that of the acid raw humus but distinctly higher than that of the mull varieties. The crude protein fraction of the deep alkaline humus is high, approximating that of the crumb mull humus.

The biological activity of alkaline raw humus, as determined by the carbon dioxide evolution method, is higher than that of acid raw humus and about the same as that of the true crumb mull developed under hardwood stands. In all cases, however, the activity is less than 50 per cent as great as that of biologically active hardwood-hemlock duffs.

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Plate 1. Thin bedded Niagara limestone exposed in a road cut, Door Peninsula, Wisconsin. Shows the characteristic thin soil mantle occurring above bedrock.

Plate 2. Forest growth on exposed limestone strata, Door Peninsula, Wisconsin: northern white cedar and balsam fir with an understory of Juniperus communis depressa.

Plate 3. Monoliths showing the morphological characteristics of three types of humus. From left to right: crumb mull with a thin layer of litter and deep layer of incorporated humus; acid raw humus of matted structure on a podzol soil with ortstein layer; alkaline raw humus grading into limestone bedrock. The monoliths represent a 15 inch deep section.

ORIGIN AND PROPERTIES OF ALKALINE RAW HUMUS¹

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As early as 1888, Ebermayer (2) directed attention to the existence of "Alpenhumus," characterized by an accumulation of free organic remains and an alkaline reaction. At a later date, Ramann (6) described a similar type of humus, formed on calcareous outcrops in the Bavarian Alps at an elevation of about 4,000 feet. Ramann attributed the development of this type to the influence of a cool and moist climate and to the action of lime-bearing seepage water. Lang (4) has reported the occurrence of an alkaline raw humus originating from the litter of ericaceous plants above timber line in the dolomitic Alps. In spite of an alkaline reaction, this type supports cranberry, sweet broom, bilberry, and other plants found ordinarily on strongly acid soils. Wilde³ recently pointed out the occurrence of a somewhat similar type of alkaline raw humus on dolomitic limestone outcrops of Door Peninsula in northern Wisconsin. The results of a detailed investigation of this humus type are reported in this paper.

AREA OF HUMUS OCCURRENCE

Door Peninsula forms a part of the Niagara cuesta, an extensive upland bordering Lake Michigan. The Labrador ice sheet, in advancing over this formation, removed nearly all the residual soil from the higher portions and left deposits of glacial till composed chiefly of limestone material. Lacustrine clays were laid down during interglacial periods in the southern part of the peninsula. Outwash of calcareous sand was deposited in small areas.

The elevation of the peninsula ranges from about 580 to 800 feet above sea level. The topography is rolling and is marked by numerous rock outcrops, escarpments, swamps, and a few lakes.

Records of climate are available for a 32-year period at the Sturgeon Bay Station of the U. S. Weather Bureau. The mean annual temperature is

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³ Wilde, S. A. 1937 Selection of litter, duff and humus for use in forest nurseries. Wis. Agr. Col. in cooperation with Wis. Dept. Conserv. Mimeo. Tech. Notes No. 16, Madison, Wisconsin.

42.8°F., and the mean annual precipitation is 30.3 inches. About 50 inches of snow falls from November until April. The growing season averages nearly 150 days. The mean temperature of this period is 60°F. An average of 16 inches of precipitation is well distributed during the growing season. The mean annual relative humidity at the Green Bay Station is 75 per cent. Along the shores of Green Bay and Lake Michigan the relative humidity undoubtedly averages higher, but no data for these localities are available.

The predominant soil type on the peninsula is a podzolic fine sandy loam with a mull humus (5). True podzols with a matted raw humus and a strongly cemented hardpan have developed on areas of sandy outwash. Deposits of woody peat occur in depressions. The calcareous rock outcrops have a very shallow layer of weathered material covered with raw humus of alkaline reaction, or alkaline "mor" (1).

The forest cover includes hard maple, basswood, beech, elm, white ash, red oak, balsam fir, white spruce, white cedar, and some white pine, red pine, and hemlock. The composition of forest stands and the ground cover on mull soils and podzols are typical of the Lake States region (10).

Plate 1 shows profiles of the principal types of humus occurring within the area.

MORPHOLOGICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF ALKALINE RAW HUMUS

The forest cover contributing to the development of alkaline raw humus is composed chiefly of northern white cedar (*Thuja occidentalis*) with some balsam fir (*Abies balsamea*) and incidental hardwoods. Common juniper (*Juniperus communis depressa*) occurs in openings. The ground cover is limited to the sporadic occurrence of saprophytic raw humus plants, such as *Maianthemum canadense* and *Cornus canadensis*.

A thin layer of litter is sharply delineated from the duff layer (F + H). The latter consists of dark brown matted remains of needles, leaves, and wood, chiefly those of white cedar. The total thickness of the duff varies from 4 inches on upland areas to approximately 10 inches on the lower slopes or in depressions of microrelief. In the lower portion the duff horizon grades into a narrow strip of nearly black, highly dispersed organic matter, powdery when dry and sticky when wet. This material is incorporated to some extent with weathered particles of limestone (A₁) and is underlain by an unconsolidated rock substratum.

In sampling, the undecomposed litter was removed, care being exercised to obtain the purely organic portion of the humus. The number of samples used in different analyses varied from 2 to 10, but no attempt was made to accumulate data sufficient for a statistical analysis.

The reaction, determined by means of a glass electrode, showed a variation from pH 6.7 to pH 8.0 with pH 7.5 as the weighted average. Base-exchange capacity, determined by the ammonium acetate method, varied from 98 to

TABLE 1

Average contents of phosphorus and bases in duff layer of alkaline raw humus

Per cent of oven-dry material

	P	K ₂ O	CaO	MgO
Total analysis.....	.125	.115	5.882	2.642
Soluble or replaceable fraction.....	.004	.038	2.140	0.281

TABLE 2

Proximate chemical composition of duff layers in alkaline and acid raw humus types

Per cent of dry material

CONSTITUENTS	ALKALINE RAW HUMUS	ACID RAW HUMUS
Ether-soluble fraction.....	0.31	3.63
Hot water soluble fraction.....	2.81	5.67
Alcohol-soluble fraction.....	2.47	4.94
Hemicelluloses.....	9.22	7.26
Cellulose.....	2.65	6.37
Lignin.....	38.52	43.75
Crude protein.....	14.67	11.72
Ash.....	14.46	4.55
Total accounted for.....	85.11	87.89

FIG. 1. RELATIVE BIOLOGICAL ACTIVITY OF DIFFERENT HUMUS TYPES AS DETERMINED BY CARBON DIOXIDE EVOLUTION

1, Mull; 2, Alkaline raw humus; 3, Acid raw humus

123 m.e. per 100 gm. Base saturation as a rule approached 100 per cent, but in some instances the content of replaceable bases exceeded base-exchange capacity because of free carbonates present in the form of calcareous dust.

The percentages of total carbon and total nitrogen averaged 34.6 and 2.17, respectively, giving a C/N ratio of 15.9.

The contents of total phosphorus, total bases, soluble phosphorus, and replaceable bases are given in table 1.

The degree of decomposition of alkaline raw humus was compared with that of an acid, hemlock raw humus (pH 4.5), collected near Chatham, Michigan. The results of fractionation analysis, according to Waksman and Stevens' methods (8, 9), are reported in table 2. The low contents of ether-soluble material and cellulose in alkaline raw humus indicate that this type occupies an intermediate position between acid raw humus and lowmoor peat (7).

As a measure of the biological activity, the carbon dioxide evolution was determined according to Heck (3) on alkaline raw humus, hardwood-hemlock duff of a mull nature, and acid raw humus. The determinations were continued for six 48-hour periods. Figure 1 illustrates the relative biological activity of these types based on the milligrams of carbon dioxide released per gram of carbon contained in the original sample.

The value of alkaline raw humus as a fertilizer has been previously reported (11).

SUMMARY

A rare type of alkaline raw humus was found on calcareous outcrops of Door Peninsula in the podzol belt of Wisconsin. This type originates chiefly from the remains of white cedar, balsam fir, and ground vegetation ordinarily associated with strongly acid soils. The dark brown, matted, peat-like duff layer varies in thickness from 4 to 10 inches. It grades into highly dispersed black organic matter, mixed with particles of limestone and underlain by a somewhat weathered rock substratum.

The chemical composition of the duff horizon is characterized by an average reaction of pH 7.5, exchange capacity of about 110 m.e. per 100 gm. with base saturation approaching 100 per cent, and a C/N ratio of 15.9. A high content of total CaO (5.9 per cent) and a low content of available phosphorus (0.004 per cent) stand out among other analytical data.

The results of fractionation analysis showed low contents of the ether-, water-, and alcohol-soluble materials and a very low content of cellulose (2.65 per cent), but rather high contents of hemicelluloses (9.22 per cent) and lignin (38.52 per cent). These data suggest that, genetically, alkaline raw humus occupies an intermediate position between acid raw humus and lowmoor peat.

In respect to biological activity, as determined by the carbon dioxide evolution method, the alkaline raw humus lies between the acid hemlock raw humus and slightly acid hardwood-hemlock duff of a mull nature.

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PLATE 1

PROFILE CHARACTERISTICS OF THREE HUMUS TYPES FOUND IN DOOR
PENINSULA, WISCONSIN

1. Crumb mull on a slightly podzolized silt loam; 2. Acid raw humus on a podzol sandy loam with ortstein horizon; 3. Alkaline raw humus underlain by limestone bedrock. The monoliths represent sections 20 inches deep.

1

2

3

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