Remediation Action Plan
Harpham Tank Battery
PADCO, LLC

SUMMARY:

PADCO (COGCC operator ID 24500) plugged the last well (Harpham #3 in August 2022) associated with the Harpham Tank Battery (COGCC facility ID 317064). PADCO has completed initial soil sampling per COGCC form 27 remediation project 25696. Based on the soil sample analyses there are exceedances of Table 915 thresholds at various sample points and depths for TPH (total petroleum hydrocarbon), SAR (sodium adsorption ratio), EC (electroconductivity), and other applicable Table 915 parameters.

The land use associated with the Harpham #3 offsite flowline and Harpham Tank Battery (Harpham TB) is a "dry farmed" agricultural field that historically is planted in corn or wheat. It is anticipated that with the remediation of the areas currently used by PADCO, the lands will be added into the existing agricultural field. A USDA soil survey (Attachment A) indicates the soil is the soil is a Weld Silt Loam with) to 3 percent slopes.

PADCO will remove soils with TPH (total petroleum hydrocarbon) above the Table 915-1 threshold of 500 ppm and haul them to an approved disposal site. PADCO is requesting approval for some sodic soils within Produced Water Pit #1 and Pit #2 to be left in place. The sodic soils PADCO is requesting approval to leave in place will be below the root depth for both corn and wheat of 60" bgs (below ground surface).

Below is the "remediation action plan" proposed for the closure of the Harpham TB and Harpham #3 off-site flowline.

Harpham #3 Off-site Flowline:

The Harpham #3 off-site flowline follows a straight line from the Harpham #3 well head (API 121-08090) approximately 1,850 feet to where it connected to the heater treater at the Harpham TB (COGCC facility ID 317064). The flowline crosses an agricultural field of dry farmed corn. A Form 44 was filed on November 17, 2022 (Form 44 doc# 403233396) indicating the flowline would be removed per COGCC Rule 1105.

Flowline integrity was known to be good during the operation of the well and there were no spills or releases associated with the flowline. During flowline abandonment any liquids evacuated from the flowline will be properly contained and disposed in compliance with Rule 905.

During excavation the flowline trench will be visually inspected for potential signs of contamination and photo documentation will be taken. Per Rule 913.h, soil samples will be taken from areas most likely impacted during the operation of the flowline. Soil samples will be taken at the wellhead riser, the riser to connect to the heater treater, at unions and/or connections or line type transitions found during excavation, and any points that are considered suspect due to visual observations.

Laboratory analysis results will be obtained and reviewed prior to any continued work associated with the flowline trench. If all analysis results meet Table 915-1 thresholds, the flowline excavation will be backfilled. If there are exceedances found, the extent of the contamination will be determined, the contaminated soil will be removed and hauled to disposal.

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Based on flowline depth, encountering groundwater during the flowline excavation is not anticipated but if encountered, PADCO will notify COGCC EPS, collect and analyze a groundwater sample for Table 915-1, and soil investigation will proceed using the Table 915-1 “Protection of Groundwater Soil Screening Level Concentrations”.

Harpham Storage Tank Area:

There were four (4) 400 bbl storage tanks inside an earthen berm at the Harpham TB. These tanks have now been removed. Soil samples were obtained at the midpoint of each tank location from a depth of approximately 6-12 inches. Laboratory analysis indicates Arsenic level of 4.65 mg/kg but no other exceedances of Table 915-1 standards (see Attachment B, Storage Tank Area Analysis Summary).

PADCO found the Arsenic exceedance in the detailed analysis performed at all the main areas of interest. PADCO believes this a natural background level of Arsenic in this region based on samples obtained from other facilities. PADCO will obtain a background sample to confirm this.

PADCO intends to remove the crushed gravel from the tank area and temporarily stockpile. Any excess clean soil from the tank berms and tank area will also be temporarily stockpiled to be used as fill in the produced water pit areas.

Harpham Heater Treater Area:

There is the flowline riser and concrete pad located where the Harpham vertical heater treater was located. An initial soil sample was taken (approximately 6-12 inches in depth). Laboratory analysis indicated a SAR (sodium adsorption ratio) of 7.44, which is slightly higher than the threshold of <6. A second soil sample was taken at a depth of approximately 36 inches and the SAR was 1.01 (see Attachment B, Harpham Heater Treater Analysis Summary).

PADCO plans to remove the concrete pad and remove the flowline riser (when removing the offsite flowline). Any gravel will be temporarily stockpiled with that from the tank area. PADCO will excavate approximately 1 cubic yard of slightly SAR impacted soil and stockpile. Closing samples will be taken from where the concrete pad was located and from the area where the contaminated soil was excavated.

Laboratory analysis results will be obtained and reviewed prior to any continued work. If all analysis results meet Table 915-1 thresholds, the heater treater area will be graded level with the surrounding terrain. If there are exceedances found, the extent of any additional contamination will be determined, the contaminated soil will be removed and hauled to disposal. Any excess clean soil from the heater treater berm and area will also be temporarily stockpiled to be used as fill in the produced water pit areas.

Produced Water Pit #1:

Produced Water Pit #1 (Pit #1) was the first produced water pit after the heater treater and is the Northern most produced water pit. It was sampled at various sample locations (see Attachment C for sample points) within the produced water pit area. During initial sampling both salt and hydrocarbon impacted soil was indicated. Additional sampling and analysis show soils are impacted to a depth of at least 96” below the bottom of the pit or 156” (13’) bgs. At this depth the analysis indicated TPH of 3,750 mg/kg, a SAR of 10.4, and pH of 9.73 (see Attachment B, Produced Water Pit #1 Analysis Summary). There were exceedances of naphthalene found in shallower soil samples (102”-132” bgs) but this soil will be removed and hauled to disposal. At sample point HP2 the Arsenic value was 3.24 mg/kg and is anticipated to be a natural background value. There was no indication of ground water observed during the sample excavations within Pit #1.

PADCO is proposing to excavate the North half of Pit #1 to about 15’ bgs and the South half to a depth of about 7’ bgs. With an approximate pit depth of 5-6 feet bgs, this would result in removing approximately 10 feet of soil from the North half and 2 feet from the South half of the pit area. The excavation of the North half is to remove TPH concentrations above Table 915-1 thresholds. Depending on the actual extent of the TPH concentrations, this could be around 2,500 to 3,000 cubic yards of soil being removed. PADCO also will remove soils from the North and South pit walls which show high TPH levels. PADCO will remove soils with TPH concentrations greater than 500 ppm (per Table 915-1). All TPH soils with a concentration of 500 ppm or more will be hauled to an approved disposal site. Sodic soils from the pit berms will be used in the deepest portions of the excavation and clean fill dirt will be hauled in for fill that is 60” or shallower below ground surface.

PADCO requests approval to leave in place sodic soils found at depths of 60” bgs (removing about 12” of sodic soil from the South half of Pit #1), resulting in about another 500 yards of soil being removed. Based on sample analysis the soil left in place would be estimated to have an EC level of <3, a SAR level of <10, Boron <2 mg/kg, and a pH of approximately 9. Pit #1’s surface area will become part of an existing “dry farmed” agricultural field which historically has a crop of corn or wheat. Reviewing literature on corn and wheat plant root depths, both crops appear to have maximum root depths of approximately 60” bgs (see attached article excerpts for documentation). PADCO requests approval to leave the sodic soils in place for these soils that are below crop root depth.

Produced Water Pit #2:

Produced Water Pit #2 is the second produced water pit and received effluent waters from Produced Water Pit #1. This pit was sampled at the points shown in Attachment C. No TPH exceedances were noted in Pit #2 but SAR, EC, Boron, and pH exceedances were noted from 0-12” of the pit bottom. At sample point HPP2 the Arsenic value was 2.55 mg/kg and is also expected to be a natural background value. Below 108” bgs or 48” from the pit bottom, the SAR ranged from 8-14 and pH raged from 9.6-10.1. There was no indication of ground water observed during the sample excavations within Pit #2.

PADCO requests approval to leave in place sodic soils found at depths of 72” bgs (removing about 12-24” of sodic soil from Pit #2), resulting in approximately 750-1,000 cubic yards of soil being removed. Based on sample analysis, the soil left in place would be estimated to have an EC level of <3.5, a SAR level of <14, Boron <2 mg/kg, and pH in the range of 9-10. Pit #2’s surface area will also become part of the existing “dry farmed” agricultural field which historically has a crop of corn or wheat. Based on the literature review, corn and wheat plant root depths would not exceed 60” bgs (see attached article excerpts for documentation). PADCO requests approval to leave the sodic soils in place for these soils that are below crop root depth.

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High sodic soils will be removed and hauled to disposal and clean fill dirt will be brought in for fill that is 60" or shallower below ground surface.

PADCO proposes to fill the excavation of both pits with soil (a mixture of berm soil and clean fill dirt) and the remaining ~36" of pit volume with clean topsoil.

Conclusions:

No Further Action (NFA) is proposed following the action plan on the following basis: The surface use of this pit area will be for non-irrigated agricultural purposes. Historically the crops grown in this field are wheat or corn. Based on agricultural studies of both crop types, the maximum root depth has been 5' (60") bgs. PADCO is proposing to excavate all contaminated soils with a TPH greater than 500 ppm and sodic soils shallower than 60" bgs from both Pit #1 and Pit #2. Some sodic soils will be used as fill for excavations deeper that 60" bgs, then clean fill dirt will be used to fill from 60" to 36" of depth. Top soil will be used to finish filling the pits to grade (~36" of top soil).

Attachment A

USDA Soil Survey

Prepared for:
PADCO LLC

Prepared by:
Lesair Environmental, Inc.
www.Lesair.com

United States Department of Agriculture

NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for Washington County, Colorado

Harpham Tank Battery (PADCO)

February 8, 2023

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (https://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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Contents

How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Soil Map


103° 10' 58" W
103° 10' 51" W
40° 9' 58" N
40° 9' 51" N
654750
654770
654790
654810
654830
654850
654870
654890
654910
4447790
4447770
4447750
4447730
4447710
4447690
4447670
4447650
4447630
4447610
4447590
4447570
Court Road Dd.5
78
Soil Map may not be valid at this scale.
Map Scale: 1:1,100 if printed on A portrait (8.5" x 11") sheet.
Meters
0 15 30 60 90
Feet
0 50 100 200 300
N
Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 13N WGS84

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Unit Polygons

Soil Map Unit Lines

Soil Map Unit Points

Special Point Features

Blowout

Borrow Pit

Clay Spot

Closed Depression

Gravel Pit

Gravelly Spot

Landfill

Lava Flow

Marsh or swamp

Mine or Quarry

Miscellaneous Water

Perennial Water

Rock Outcrop

Saline Spot

Sandy Spot

Severely Eroded Spot

Sinkhole

Slide or Slip

Sodic Spot

Spoil Area

Stony Spot

Very Stony Spot

Wet Spot

Other

Special Line Features

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Washington County, Colorado
Survey Area Data: Version 24, Sep 1, 2022

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Apr 14, 2022—Jun 15, 2022

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
78	Weld silt loam, 0 to 3 percent slopes	2.7	100.0%
Totals for Area of Interest		**2.7**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

Washington County, Colorado

78—Weld silt loam, 0 to 3 percent slopes

Map Unit Setting

National map unit symbol: 2x0hx
Elevation: 3,600 to 6,000 feet
Mean annual precipitation: 12 to 18 inches
Mean annual air temperature: 46 to 54 degrees F
Frost-free period: 115 to 155 days
Farmland classification: Prime farmland if irrigated

Map Unit Composition

Weld and similar soils: 80 percent
Minor components: 20 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Weld

Setting

Landform: Interfluves
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Calcareous loess

Typical profile

Ap - 0 to 3 inches: silt loam
Bt1 - 3 to 11 inches: silty clay
Bt2 - 11 to 15 inches: silty clay
Btk - 15 to 21 inches: silty clay
Bk - 21 to 31 inches: silt loam
C - 31 to 80 inches: silt loam

Properties and qualities

Slope: 0 to 3 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum content: 14 percent
Maximum salinity: Nonsaline to very slightly saline (0.1 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: High (about 11.7 inches)

Interpretive groups

Land capability classification (irrigated): 2e
Land capability classification (nonirrigated): 3c
Hydrologic Soil Group: C
Ecological site: R067BY002CO - Loamy Plains

Hydric soil rating: No

Minor Components

Colby

Percent of map unit: 7 percent
Landform: Hillslopes
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Convex
Across-slope shape: Convex
Ecological site: R067BY002CO - Loamy Plains
Hydric soil rating: No

Keith

Percent of map unit: 5 percent
Landform: Interfluves
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: R067BY002CO - Loamy Plains
Hydric soil rating: No

Adena

Percent of map unit: 5 percent
Landform: Interfluves
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve
Down-slope shape: Convex
Across-slope shape: Convex
Ecological site: R067BY002CO - Loamy Plains
Hydric soil rating: No

Rago, rarely flooded

Percent of map unit: 2 percent
Landform: Drainageways
Down-slope shape: Linear
Across-slope shape: Concave
Ecological site: R067BY036CO - Overflow
Hydric soil rating: No

Pleasant, ponded

Percent of map unit: 1 percent
Landform: Playas, closed depressions
Down-slope shape: Concave
Across-slope shape: Concave
Ecological site: R067BY010CO - Closed Upland Depression
Hydric soil rating: Yes

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Attachment B

Soil Analysis Summary Tables

Prepared for:
PADCO LLC

Prepared by:
Lesair Environmental, Inc.
www.Lesair.com

Harpham P&A Project
Storage Tank Area
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	GRO (mg/kg)	DRO (mg/kg)	ORO (mg/kg)	TPH (mg/kg)	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-Benzene (mg/kg)	Xylene (mg/kg)	1,2,4-Tri methyl benzene (mg/kg)	1,3,5-Tri methyl benzene (mg/kg)	Naph-thlene (mg/kg)	pH
---	---	Table 915	---	---	---	---	---	---	500	1.2	490	5.8	58	30	27	2	6-8.3
9/9/2022	Lesair	HT1	2209221-01	Tank #1 (center)	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.63
9/9/2022	Lesair	HT2	2209221-02	Tank #2 (center)	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.40
9/9/2022	Lesair	HT3	2209221-03	Tank #3 (center)	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.98
9/9/2022	Lesair	HT4	2209221-04	Tank #4 (center)	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.64

NOTES:

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Sodium Adsorption Ratio (SAR)	Specific Conductance (EC) (mmhos/cm)	% Solids	Boron (mg/l)	pH
---	---	Table 915	---	---	---	<6	<4	---	2	6-8.3
9/9/2022	Lesair	HT1	2209221-01	Tank #1 (center)	~6-12"	1.64	0.28	78.2	0.17	7.63
9/9/2022	Lesair	HT2	2209221-02	Tank #2 (center)	~6-12"	0.86	0.22	77.6	0.13	7.40
9/9/2022	Lesair	HT3	2209221-03	Tank #3 (center)	~6-12"	0.89	2.63	78.3	0.16	7.98
9/9/2022	Lesair	HT4	2209221-04	Tank #4 (center)	~6-12"	1.56	0.17	75.8	0.27	7.64

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Arsenic (mg/kg)	Barium (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (kg/mg)	Lead (kg/mg)	Nickel (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Zinc (mg/kg)	pH
---	---	Table 915	---	---	---	0.68	15,000	71	0.3	3,100	400	1,500	390	390	23,000	6-8.3
9/9/2022	Lesair	HT2	2209221-02	Tank #2 (center)	~6-12"	4.65	146.0	ND	ND	10.7	11.9	12.0	1.7	0.088	40.8	7.40

February 15, 2023

Harpham P&A Project
Heater Treater Area
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	GRO (mg/kg)	DRO (mg/kg)	ORO (mg/kg)	TPH (mg/kg)	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-Benzene (mg/kg)	Xylene (mg/kg)	1,2,4-Tri methyl benzene (mg/kg)	1,3,5-Tri methyl benzene (mg/kg)	Naph-thlene (mg/kg)	pH
---	---	Table 915	---	---	---	---	---	---	500	1.2	490	5.8	58	30	27	2	6-8.3
9/9/2022	Lesair	HH1	2209219-01	Heater Treater	~6-12"	ND	250	160	410	ND	ND	ND	ND	ND	ND	ND	7.75

NOTES:

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Sodium Adsorption Ratio (SAR)	Specific Conductance (EC) (mmhos/cm)	% Solids	Boron (mg/l)	pH
---	---	Table 915	---	---	---	<6	<4	---	2	6-8.3
9/9/2022	Lesair	HH1	2209219-01	Heater Treater	~6-12"	7.44	0.90	89.3	0.88	7.75
11/21/2022	Lesair	HH1a	2211387-01	Heater Treater	~36"	1.01	0.65	90.0	0.19	8.25

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Arsenic (mg/kg)	Barium (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (kg/mg)	Lead (kg/mg)	Nickel (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Zinc (mg/kg)	pH
---	---	Table 915	---	---	---	0.68	15,000	71	0.3	3,100	400	1,500	390	390	23,000	6-8.3

Harpham P&A Project
Produced Water Pit #1
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	GRO (mg/kg)	DRO (mg/kg)	ORO (mg/kg)	TPH (mg/kg)	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-Benzene (mg/kg)	Xylene (mg/kg)	1,2,4-Tri methyl benzene (mg/kg)	1,3,5-Tri methyl benzene (mg/kg)	Naph-thlene (mg/kg)	pH
---	---	**Table 915**	---	---	---	---	---	---	**500**	**1.2**	**490**	**5.8**	**58**	**30**	**27**	**2**	**6-8.3**
9/9/2022	Lesair	HP1	2209218-01	PW Pit#1	~6-12"	2	ND	ND	2	0.0430	ND	0.0190	0.0140	ND	ND	0.0110	8.43
11/21/2022	Lesair	HP1a	2211371-01	PW Pit#1	~42"	8,800	6,000	3,000	17,800	0.7700	ND	10.00	28.00	0.69	ND	13.00	8.68
11/21/2022	Lesair	HP1b	2211371-02	PW Pit#1	~66"	5,400	8,300	4,300	18,000	0.3400	ND	5.50	13.00	3.30	ND	9.70	9.66
11/21/2022	Lesair	HP1c	2211372-03	PW Pit#1	~84"	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	HP1d	2211372-04	PW Pit#1	~96"	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	HP1e	2211372-05	PW Pit#1	~108"	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	HP1f	2211372-06	PW Pit#1	~132"	---	---	---	---	---	---	---	---	---	---	---	---
9/9/2022	Lesair	HP2	2209218-02	PW Pit#1	~6-12"	1,400	3,800	470	5,670	ND	ND	0.65	3.90	ND	ND	4.10	8.38
11/21/2022	Lesair	HP2a	2211371-03	PW Pit#1	~60"	4,500	18,000	10,000	32,500	ND	ND	3.80	11.00	ND	ND	6.20	9.85
11/21/2022	Lesair	HP2b	2211371-04	PW Pit#1	~72"	4,100	18,000	11,000	33,100	ND	ND	5.70	22.00	ND	ND	12.00	9.84
11/21/2022	Lesair	HP2c	2211371-05	PW Pit#1	~96"	790	2,000	960	3,750	0.0037	ND	0.068	0.190	ND	ND	0.0099	9.73
9/9/2022	Lesair	HP3	2209218-03	PW Pit#1	~6-12"	5	1,200	290	1,495	ND	ND	0.012	0.060	ND	ND	0.0068	8.36
9/9/2022	Lesair	HP4	2209218-04	PW Pit#1	~6-12"	7	ND	ND	7	ND	ND	ND	ND	ND	ND	ND	8.51
9/9/2022	Lesair	HP5	2209218-05	PW Pit#1	~6-12"	17	ND	ND	17	0.0260	ND	0.040	0.047	ND	ND	0.0150	8.51
9/9/2022	Lesair	HP6	2209218-06	Pit#1 East Sidewall	~12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.35
9/9/2022	Lesair	HP7	2209218-07	Pit#1 North Sidewall	~12"	13	1,300	360	1,673	ND	ND	ND	ND	ND	ND	ND	8.34
9/9/2022	Lesair	HP8	2209218-08	Pit#1 West Sidewall	~12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.92
9/9/2022	Lesair	HP9	2209218-09	Pit#1 South Sidewall	~12"	2	9,000	2,600	11,602	ND	ND	ND	ND	ND	ND	ND	7.61
11/21/2022	Lesair	HP9a	2211371-06	Pit#1 South Sidewall	~48" x ~18"	5	1,400	860	2,265	ND	ND	ND	ND	ND	ND	0.0078	9.67

NOTES:

Harpham P&A Project
Produced Water Pit #1
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Sodium Adsorption Ratio (SAR)	Specific Conductance (EC) (mmhos/cm)	% Solids	Boron (mg/l)	pH
---	---	Table 915	---	---	---	<6	<4	---	2	6-8.3
9/9/2022	Lesair	HP1	2209218-01	PW Pit#1	~6-12"	71.20	13.70	51.7	4.24	8.43
11/21/2022	Lesair	HP1a	2211372-01	PW Pit#1	~42"	---	---	---	---	---
11/21/2022	Lesair	HP1b	2211372-02	PW Pit#1	~66"	7.90	2.12	83.8	0.53	9.27
11/21/2022	Lesair	HP1c	2211372-03	PW Pit#1	~84"	---	---	---	---	---
11/21/2022	Lesair	HP1d	2211372-04	PW Pit#1	~96"	10.20	2.40	84.5	0.77	9.24
11/21/2022	Lesair	HP1e	2211372-05	PW Pit#1	~108"	---	---	---	---	---
11/21/2022	Lesair	HP1f	2211372-06	PW Pit#1	~132"	8.60	2.19	85.9	0.77	9.57
9/9/2022	Lesair	HP2	2209218-02	PW Pit#1	~6-12"	35.10	13.20	52.6	2.48	8.38
11/21/2022	Lesair	HP2a	2211375-01	PW Pit#1	~60"	---	---	---	---	---
11/21/2022	Lesair	HP2b	2211375-02	PW Pit#1	~72"	9.77	2.62	84.7	1.04	9.44
11/21/2022	Lesair	HP2c	2211375-03	PW Pit#1	~96"	10.40	3.15	85.9	1.07	9.30
9/9/2022	Lesair	HP3	2209218-03	PW Pit#1	~6-12"	26.20	12.60	76.8	2.31	8.36
9/9/2022	Lesair	HP4	2209218-04	PW Pit#1	~6-12"	48.30	12.30	62.9	3.50	8.51
9/9/2022	Lesair	HP5	2209218-05	PW Pit#1	~6-12"	18.80	4.69	59.3	4.49	8.51
9/9/2022	Lesair	HP6	2209218-06	Pit#1 East Sidewall	~12"	13.20	0.57	82.1	2.41	8.35
9/9/2022	Lesair	HP7	2209218-07	Pit#1 North Sidewall	~12"	26.30	1.53	80.2	1.60	8.34
9/9/2022	Lesair	HP8	2209218-08	Pit#1 West Sidewall	~12"	5.59	0.29	83.5	3.34	7.92
9/9/2022	Lesair	HP9	2209218-09	Pit#1 South Sidewall	~12"	3.13	2.26	83.1	1.98	7.61
11/21/2022	Lesair	HP9a	2211376-01	Pit#1 South Sidewall	~48" x ~18"	7.24	2.43	83.4	0.71	8.74

Harpham P&A Project
Produced Water Pit #1
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Arsenic (mg/kg)	Barium (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (kg/mg)	Lead (kg/mg)	Nickel (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Zinc (mg/kg)	pH
---	**---**	**Table 915**	**---**	**---**	**---**	**0.68**	**15,000**	**71**	**0.3**	**3,100**	**400**	**1,500**	**390**	**390**	**23,000**	**6-8.3**
9/9/2022	Lesair	HP2	2209218-02		~6-12"	3.24	239.0	ND	ND	41.3	121.0	11.1	1.2	0.062	96.7	8.38

Harpham P&A Project
Produced Water Pit #2
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	GRO (mg/kg)	DRO (mg/kg)	ORO (mg/kg)	TPH (mg/kg)	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-Benzene (mg/kg)	Xylene (mg/kg)	1,2,4-Tri methyl benzene (mg/kg)	1,3,5-Tri methyl benzene (mg/kg)	Naph-thlene (mg/kg)	pH
---	---	Table 915	---	---	---	---	---	---	500	1.2	490	5.8	58	30	27	2	6-8.3
9/9/2022	Lesair	HPP1	2209217-01	PW Pit#2	~6-12"	28	55	ND	83	ND	ND	ND	0.0110	0.0240	ND	0.0050	8.54
11/21/2022	Lesair	HPP1a	2211377-01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	HPP1b	2211377-02	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	HPP1c	2211377-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---
9/9/2022	Lesair	HPP2	2209217-02	PW Pit#2	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.64
9/9/2022	Lesair	HPP3	2209217-03	PW Pit#2	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.97
9/9/2022	Lesair	HPP4	2209217-04	PW Pit#2	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.14
9/9/2022	Lesair	HPP5	2209217-05	PW Pit#2	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.34
11/21/2022	Lesair	HPP5a	2211377-04	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	HPP5b	2211377-05	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	HPP5c	2211377-06	---	---	---	---	---	---	---	---	---	---	---	---	---	---
9/9/2022	Lesair	HPP6	2209217-06	Pit#2 East Sidewall	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.45
11/21/2022	Lesair	HPP6a	2211374-01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	HPP6b	2211374-02	---	---	---	---	---	---	---	---	---	---	---	---	---	---
9/9/2022	Lesair	HPP7	2209217-07	Pit#2 North Sidewall	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.75
9/9/2022	Lesair	HPP8	2209217-08	Pit#2 West Sidewall	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.44
9/9/2022	Lesair	HPP9	2209217-09	Pit#2 South Sidewall	~6-12"	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.05
11/21/2022	Lesair	HPP9a	2211374-03	---	---	---	---	---	---	---	---	---	---	---	---	---	---

NOTES:

Harpham P&A Project
Produced Water Pit #2
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Sodium Adsorption Ratio (SAR)	Specific Conductance (EC) (mmhos/cm)	% Solids	Boron (mg/l)	pH
---	---	Table 915	---	---	---	<6	<4	---	2	6-8.3
9/9/2022	Lesair	HPP1	2209217-01	PW Pit#2	~6-12"	40.20	11.70	56.5	3.05	8.54
11/21/2022	Lesair	HPP1a	2211377-01	PW Pit#2	~48"	8.76	2.55	81.5	0.87	9.90
11/21/2022	Lesair	HPP1b	2211377-02	PW Pit#2	~72"	11.70	3.51	84.4	1.20	10.10
11/21/2022	Lesair	HPP1c	2211377-03	PW Pit#2	~96"	10.80	2.33	83.0	1.47	9.71
9/9/2022	Lesair	HPP2	2209217-02	PW Pit#2	~6-12"	36.80	11.10	52.6	3.59	8.64
9/9/2022	Lesair	HPP3	2209217-03	PW Pit#2	~6-12"	11.70	34.90	50.2	3.92	8.97
9/9/2022	Lesair	HPP4	2209217-04	PW Pit#2	~6-12"	18.10	22.30	80.2	2.03	9.14
9/9/2022	Lesair	HPP5	2209217-05	PW Pit#2	~6-12"	14.50	34.20	86.1	2.70	9.34
11/21/2022	Lesair	HPP5a	2211377-04	PW Pit#2	~60"	13.90	3.13	83.7	0.86	9.70
11/21/2022	Lesair	HPP5b	2211377-05	PW Pit#2	~72"	13.30	3.13	84.0	0.86	9.66
11/21/2022	Lesair	HPP5c	2211377-06	PW Pit#2	~84"	11.60	2.85	84.1	1.05	9.69
9/9/2022	Lesair	HPP6	2209217-06	Pit#2 East Sidewall	~6-12"	30.40	11.90	79.5	2.22	8.45
11/21/2022	Lesair	HPP6a	2211374-01	Pit#2 East Sidewall		36.60	2.76	78.1	2.32	9.16
11/21/2022	Lesair	HPP6b	2211374-02	Pit#2 East Sidewall		11.10	2.27	79.3	1.63	9.40
9/9/2022	Lesair	HPP7	2209217-07	Pit#2 North Sidewall	~6-12"	47.70	13.20	85.2	1.55	8.75
9/9/2022	Lesair	HPP8	2209217-08	Pit#2 West Sidewall	~6-12"	27.60	11.70	83.5	1.51	8.44
9/9/2022	Lesair	HPP9	2209217-09	Pit#2 South Sidewall	~6-12"	20.20	12.70	87.9	1.76	8.05
11/21/2022	Lesair	HPP9a	2211374-03	Pit#2 South Sidewall		13.50	3.01	89.0	0.73	9.58

February 15, 2023

Harpham P&A Project
Produced Water Pit #2
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Arsenic (mg/kg)	Barium (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (kg/mg)	Lead (kg/mg)	Nickel (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Zinc (mg/kg)	pH
---	**---**	**Table 915**	**---**	**---**	**---**	**0.68**	**15,000**	**71**	**0.3**	**3,100**	**400**	**1,500**	**390**	**390**	**23,000**	**6-8.3**
9/9/2022	Lesair	HPP2	2209217-02	PW Pit#2	~6-12"	2.55	493.0	0.402	ND	17.3	14.9	17.1	1.8	0.096	59.2	8.64

February 15, 2023

Harpham P&A Project
Pit Berm Soil Analysis
PADCO LLC
Analytical Results of Hydrocarbon and Produced Water Impacted Soil

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	GRO (mg/kg)	DRO (mg/kg)	ORO (mg/kg)	TPH (mg/kg)	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-Benzene (mg/kg)	Xylene (mg/kg)	1,2,4-Tri methyl benzene (mg/kg)	1,3,5-Tri methyl benzene (mg/kg)	Naph-thlene (mg/kg)	pH
---	**---**	**Table 915**	**---**	**---**	**---**	**---**	**---**	**---**	**500**	**1.2**	**490**	**5.8**	**58**	**30**	**27**	**2**	**6-8.3**
11/21/2022	Lesair	PB	2211373-01	North Pit#1 Berm	---	---	---	---	---	---	---	---	---	---	---	---	---
11/21/2022	Lesair	PPB	2211373-02	North Pit#2 Berm	---	---	---	---	---	---	---	---	---	---	---	---	---

NOTES:

Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Sodium Adsorption Ratio (SAR)	Specific Conductance (EC) (mmhos/cm)	% Solids	Boron (mg/l)	pH
---	**---**	**Table 915**	**---**	**---**	**---**	**<6**	**<4**	**---**	**2**	**6-8.3**
11/21/2022	Lesair	PB	2211373-01	North Pit#1 Berm	~18"	110.0	8.19	87.4	0.81	8.72
11/21/2022	Lesair	PPB	2211373-02	North Pit#2 Berm	~18"	18.2	2.82	86.6	1.03	8.86

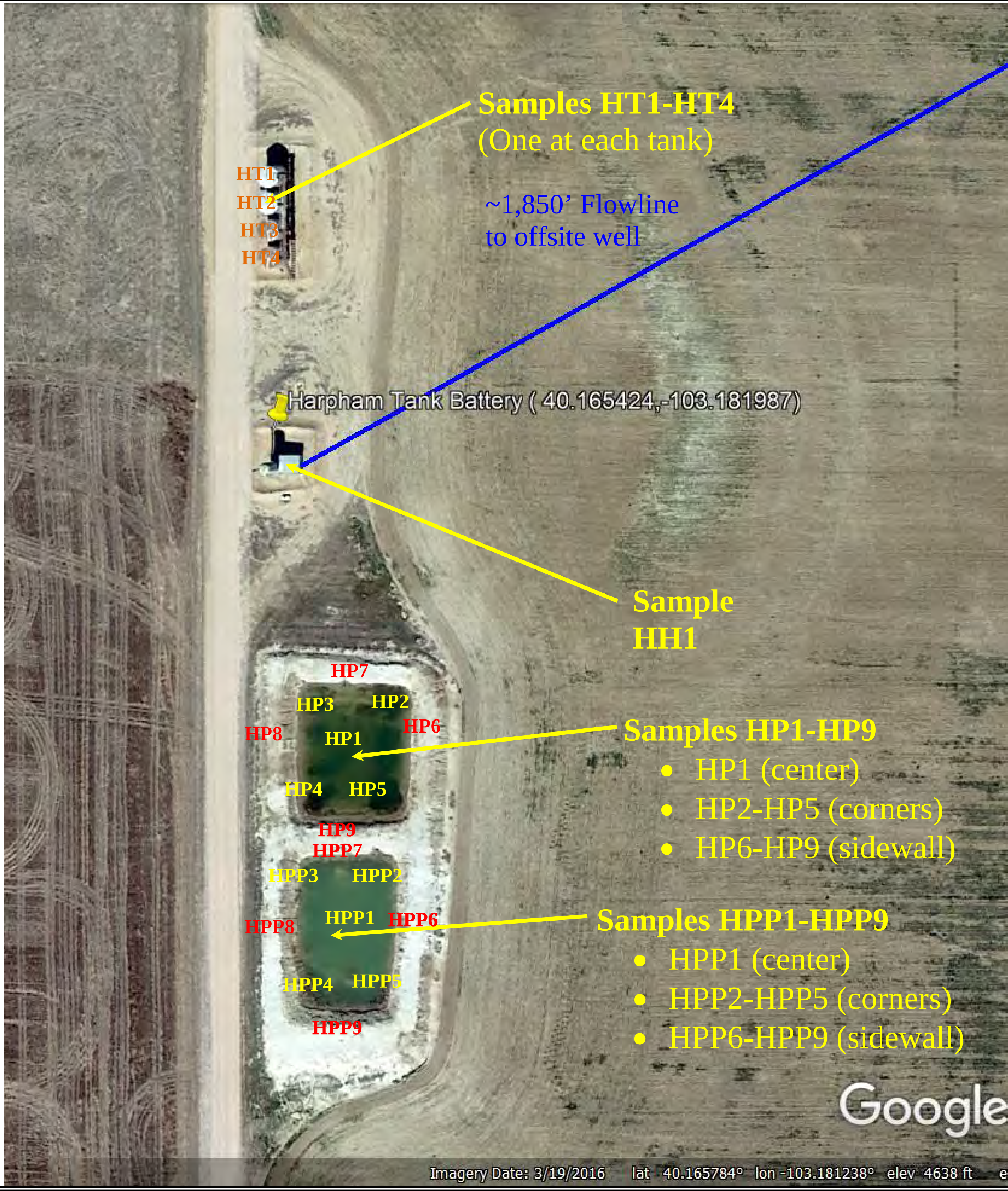
Sample Date	Sampled By	Soil Sample	Lab ID	Location	Sample Depth (inches)	Arsenic (mg/kg)	Barium (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (kg/mg)	Lead (kg/mg)	Nickel (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Zinc (mg/kg)	pH
---	**---**	**Table 915**	**---**	**---**	**---**	**0.68**	**15,000**	**71**	**0.3**	**3,100**	**400**	**1,500**	**390**	**390**	**23,000**	**6-8.3**

Attachment C

Sample Locations

Prepared for:
PADCO LLC

Prepared by:
Lesair Environmental, Inc.
www.Lesair.com



PADCO, LLC

Facility: Harpham Tank Battery
Facility No.: 317064
Location: SESW Section 3, Township 2N, Range 52W
40.165424, -103.181987

Date: August 1, 2022

LESAIR ENVIRONMENTAL, INC.
11786 Shaffer Place, Unit 210
Littleton, CO 80127
Office: (303) 904-2525

Attachment D

Root Depth Supporting Documents

WHEAT:

1. Getting to the Root of the Matter by Les Henry, JUN 9, 2017, "GrainNews"
2. Root Development of Field Crops by John E. Weaver, 1926

CORN:

1. How Deep Do Corn Roots Grow? Online Article
2. Rooting Characteristics by Lundstrum, 1988
3. How Fast and deep Do Corn roots Grow in Iowa? By Dr. Sotirios Archontoulis/Dr. Mark Licht, June 14, 2017

Prepared for:
PADCO LLC

Prepared by:
Lesair Environmental, Inc.
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Getting to the root of the matter

In the third of a three-part series, Les Henry looks at roots of field and garden crops

By
Les Henry
Published: June 9, 2017
Columns, **Crops**

In my asparagus patch, September, 2012. Planting date was May 2002. *Photo: Kathy Kuitschera*

This is the final of a three-part series. In part 1 (April 11, 2017) I talked about the folks that provided very detailed diagrams of many plant roots to the depth needed to get the complete picture. Part 2 (April 25, 2017) was perennial pasture and hay crops and weeds and part 3 is field and garden crops.

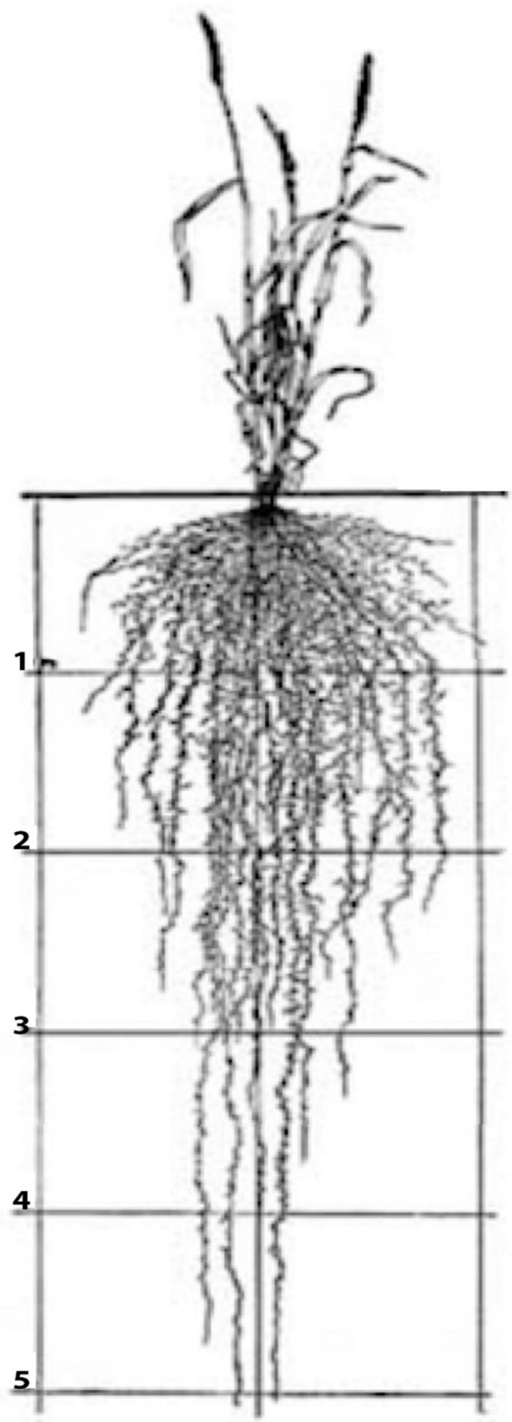
Excerpt from online article Part 3: Getting to the Root of the Matter, by Les Henry published June 9, 2017 in "GrainNews" assembled by Lesair Environmental from the original article.

Getting to the root of the matter

In the third of a three-part series, Les Henry looks at roots of field and garden crops

Wheat

Wheat was the crop that built our farming base and is still an important crop. Many still think that wheat roots end at a foot or two. Not so —more like five feet (See figure 1 below).



Excerpt from online article Part 3: Getting to the Root of the Matter, by Les Henry published June 9, 2017 in "GrainNews" assembled by Lesair Environmental from the original article.

Getting to the root of the matter

In the third of a three-part series, Les Henry looks at roots of field and garden crops

Weaver went on to explain that the root system at harvest showed no great change from that at flowering. In my many years of soil probing, I've found that a wheat crop is done extracting soil water by late July when flowering is complete. From then on it is a matter of redistributing what is in the plant to the seed in the head. Many times we hear about a late rain being good for "crop filling" but late in the season, wheat's water use is from depth, not the soil surface.

Winter wheat was found to have a well-developed root system to a depth of 3.5 feet when 55 days old so it goes in to winter all set to "suck from the deep" when spring growth starts.

ABOUT THE AUTHOR

Les Henry
Columnist

J.L.(Les) Henry is a former professor and extension specialist at the University of Saskatchewan. He farms at Dundurn, Sask.He recently finished a second printing of "Henry's Handbook of Soil and Water," a book that mixes the basics and practicalaspects of soil, fertilizer and farming. Les will cover the shipping and GST for "Grainews" readers. Simply send a cheque for$50 to Henry Perspectives, 143 Tucker Cres., Saskatoon, Sask., S7H 3H7, and he will dispatch a signed book.

Excerpt from online article Part 3: Getting to the Root of the Matter, by Les Henry published June 9, 2017 in "GrainNews" assembled by Lesair Environmental from the original article.

ROOT DEVELOPMENT
OF
FIELD CROPS

BY

JOHN E. WEAVER
Professor of Plant Ecology, University of Nebraska

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1926

TO MY DAUGHTER
CORNELIA

PREFACE

During the past twelve years, the writer has spent much time investigating the greatly neglected field of root habits of plants. Such a wide interest has been manifested in this work that it was deemed advisable to bring together into a single volume the more important results of these studies. In dealing with the various cultivated plants, the rather meager data from other investigations have been added to present, so far as possible, a general view of the root development of crops in the United States. No attempt has been made to include root studies other than those made in America, as this would have extended the work far beyond the scope of this volume. For an introduction to the more recent foreign investigations, the student is referred to the works of Rotmistrov, Schulze, Vorob'ev, and Osvald, in Europe, and the extensive work of Howard, in India.

The materials for this book, except the first three and last two chapters, have been taken largely from the following publications issued by the Carnegie Institution of Washington: "Ecological Relations of Roots," *Publication* 286; "Root

CHAPTER V

ROOT HABITS OF WHEAT

Wheat (*Triticum*) is an annual. But under our climate and cultural conditions, there are two seasonal forms, *viz.,* spring wheat, which is a summer annual, and fall or winter wheat, a winter annual. Both have a fibrous root system which penetrates deeply into the subsoil. That of winter wheat, perhaps because of the longer season for growth, is more extensive. Upon germination of the grain, the primary root takes the lead, but very, soon, two other roots appear on opposite sides of the first. To this whorl of three, still others may be added, and together they constitute the *primary root system.* In some cases, there may be as many as eight roots. 160 Early in the development of the plant, roots of the secondary root system grow from nodes above the primary one. The first whorl of roots of the secondary root system always develops within an inch or two of the soil surface. The number of roots increases somewhat in proportion to the number of tillers.

SPRING WHEAT

The development of Marquis spring wheat (*Triticum aestivum*) has been studied in detail both in upland and lowland silt loam soil in eastern Nebraska.

Early Development.--On May 1, a month after planting and when the second leaf was half grown, a typical root system wasdrawn (Fig. 56). The number of roots varied from three to eight. Lateral roots were fairly abundant but entirely unbranched. The greatest lateral spread was 5 inches and the working depth or working level (*i.e.,* a depth to which many roots penetrate and to which depth considerable absorption must take place), 6.5 inches. Compared with the shoot development, the plant had made an excellent growth underground.

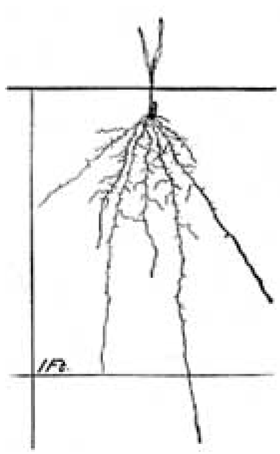


Fig. 56.--Marquis spring wheat 31 days old.

A plant 45 days old is shown in Fig. 57. During the 15-day interval since the first examination, two tillers and four or five new roots had developed on most of the plants. Young roots only 1 to 2 inches long were frequent. Thus, the balance between transpiration and absorption was well maintained. Lateral spread had increased 4 inches and working level about 3.5 inches. Moreover, lateral branches were much longer and secondary branches were beginning to appear. The slow rate of growth is shown by the fact that wheat planted in the same field on May 5 had a more advanced growth when only 25 days old.

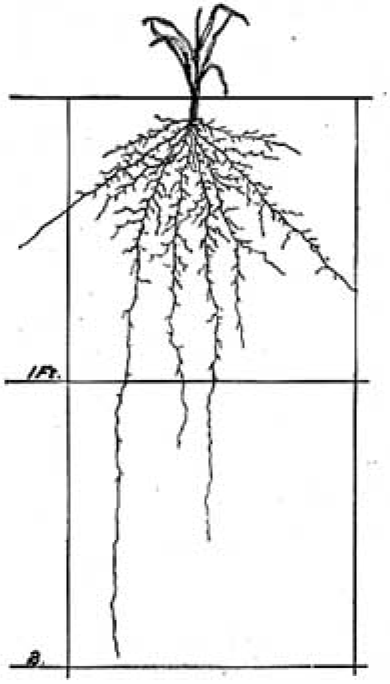


Fig. 57.--Wheat 45 days old.

Half-grown Plants.--Fifteen days later when the plants were 2 months old, the root habit was again examined (Fig. 58). The crop was now 8 inches high and the parent stalks had four to six leaves. Tillering had increased, and about five new roots, on an average, had been added to the secondary root system. The lateral spread had increased but slightly. Many roots had penetrated deeper, however, and others had spread obliquely downward and, with the increase both in number and length of laterals, had begun to fill in the soil volume already delimited at the earlier stage. The roots had deepened the working level to 1.5 feet, an increase in depth of about 10 inches.

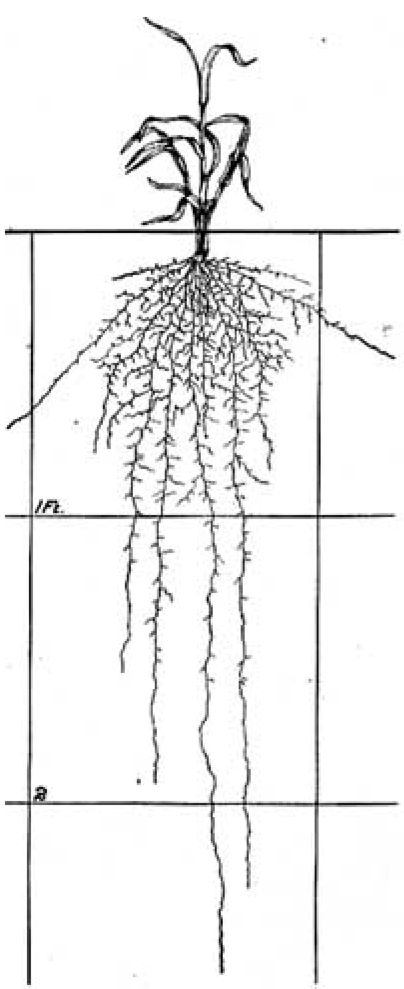
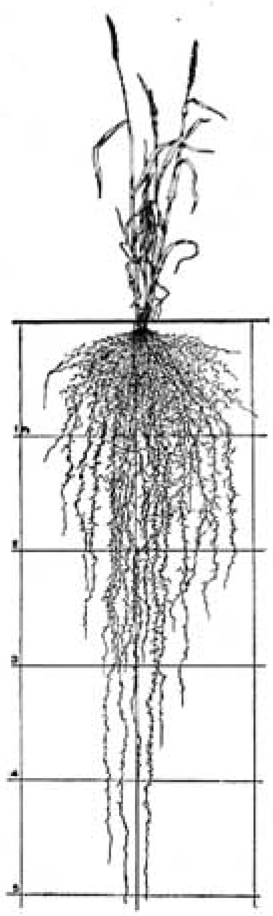


Fig. 58.--Wheat 60 days old.

Mature Root System.--Further studies on June 20, when the crop was in blossom, revealed marked differences. The plants were 2.2 feet tall, but the root system reached a maximum depth (4.8 feet) which was more than twice as great as the height of the shoot. During these last 20 days, there had occurred a marked development of roots (Fig. 59). The working level was at 3 feet; the lateral spread had increased to a maximum of 12 inches. A vast network of rebranched laterals occupied a volume of soil extending approximately 10 inches on all sides of the plant and to a depth of 2 to 3 feet. The total number of roots varied from 20 to 25 according to the number of tillers. Many of these were more superficially placed than those in the earlier stages of development, running rather horizontally or obliquely and ending in the surface 3 to 8 inches of soil. In the surface 2 feet especially, laterals were exceedingly abundant, usually 5 to 9 occurring on an inch of root length. Many of these were short, and few exceeded a length of 4 inches. Secondary laterals were not abundant. In the second foot, the branches were mostly less than 1 inch in length. Below 2 feet, branching was somewhat less pronounced, and in the fourth and fifth foot, numerous roots were characterized by unbranched, very short laterals. The fact that some root ends were without branches for a distance of several inches from the tips showed that growth was not yet complete.



60" root depth (blue text added by Lesair for clarity)

Fig. 59.--Wheat at the time of blossoming.

A final examination, a few days after harvesting on July 15, showed no great change in root development. The roots, except the deepest ones, were somewhat shrivelled and more brittle. Depth and lateral spread had increased only slightly. The crop on the lowland was 4 inches taller and better developed than that on the upland and the working level of the roots 6 inches deeper. No marked differences were found in the branching habit or extent of lateral spread. As a whole, the root system of wheat is a little finer and somewhat more extensive than that of oats (*See* Chapter VII).

Root Variations under Different Soils and Climates.--A crop from the same lot of seed was grown in mellow, fine sandy loam soil at Phillipsburg, in north central Kansas. Here, the annual precipitation is only 23 inches. But probably owing to 11 inches excess precipitation the preceding year, the mellow loess subsoil was quite moist beyond the maximum root penetration, 5.8 feet. The working level, lateral spread, degree of branching, etc., were about the same as described for Lincoln, in eastern Nebraska. The following season, both working level and maximum penetration were somewhat less.

Wheat was also grown in the hard, fine sandy loam soil of the short-grass plains at Burlington, Colo. Here, the 17 inches of annual precipitation moistens the soil to a depth seldom greater than 2.5 feet. Moreover, cold nights in early spring delay crop development, while later drought dwarfs the plants. Marquis spring wheat, grown on land that had been broken for 2 years, reached a height of only 1.7 feet, notwithstanding that the season was unusually favorable for crop growth. The mature root system was confined entirely to the first 2.7 feet of soil, since no available water occurred deeper. Not infrequently, roots extended laterally 10 to 12 inches only 6 inches below the 'surface. The maximum lateral spread exceeded that of plants grown further east, and the entire root system was more profusely branched. Thus, the roots, although more shallow than normal, were well adapted to extract water and solutes from these surface soil layers of low water content. The marked difference in the degree of branching here and in eastern Nebraska is shown in Fig. 60. During the next season, these findings were confirmed, the root system being slightly less extensive.

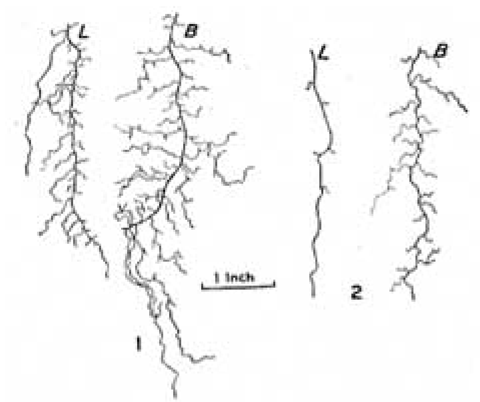


Fig. 60.--Wheat roots showing normal differences in branching at Lincoln, *L;* and Burlington, *B;* 1, at depth of 1.5 feet; 2, root ends.

Investigations at Limon, Colo., another station in the shortgrass plains, gave similar results. The dry soil, watered by light showers, stimulated the development of an intricately branched and extensive surface-absorbing system at the expense of depth of penetration. In this widely spreading, surface-rooting habit, the crop behaved like the native grama and buffalo grasses.

A variety of red spring wheat on the short-grass plains at Flagler, Colo., was found to have a root system almost identical with that of the Marquis variety. The tops were 2.5 feet tall. The roots extended to a similar depth, where dry soil prevented their further development. Lateral spread was marked and branching was profuse.

In the mellow loess soil along the Missouri River at Peru, Nebr., the shallower portion of the root system of Marquis wheat was not highly developed. But the part fitted to absorb in the deeper soil made a vigorous growth, having a working level of 4 feet. Many roots penetrated deeper, a few to 6.7 feet..

Durum wheat (*Triticum durum*) was also grown at Peru. Compared to other cereals, it has a rather meager surface-feeding system at maturity. Usually, this consisted of six to eight (rarely more) roots that extended out in an almost horizontal direction from 2 to 14 inches. They usually ended only 4 to 7 inches below the soil surface. The primary roots, accompanied by others, however, ran vertically downward or downward and outward, pursuing a more or less zigzag course. The soil was especially well filled with roots to the fourth foot, many also occurred in the fifth and sixth foot, and several extended even deeper. Maximum penetration was 7.4 feet. Examinations at several periods during its growth showed clearly that the root system developed in correlation with the aboveground parts, for it was only in this way that the increasing demands of the developing shoot for water and nutrients could be met.

Variations in Root Habit under Irrigation.--Marquis spring wheat was grown in dry land and in irrigated soil at Greeley, Colo. [104] Since the precipitation is only 13 inches annually, irrigation is widely practiced. The fine sandy loam soil in the several plots was of very similar physical and chemical composition. The wheat plots were treated alike as regards seed-bed preparation, time and rate of seeding, etc., except that the irrigated plots had been fertilized uniformly with 5 tons of barnyard manure per acre.

Early Development.--Root development on May 10, when the crop was about 6 weeks I old and in the fourth leaf stage, is shown in Fig. 61. The roots in irrigated soil developed quite normally. In the dry land, the available water in the second foot of soil was almost exhausted. Hence, the roots were mostly confined in their distribution to the surface 12-inch layer. The number of roots and branches was about the same in both cases, but the branches averaged considerably longer in the dry land.

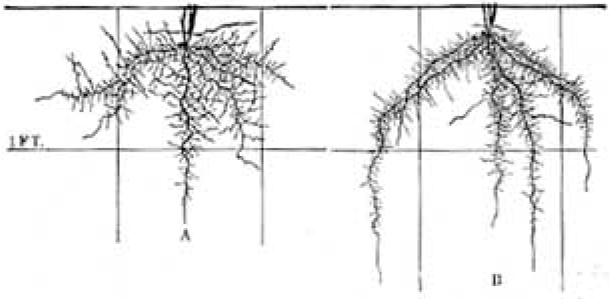


Fig. 61.--Root system of Marquis spring wheat 6 weeks old: A, in dry land; B, under irrigation.

Half-grown Plants.--A month later, although a small amount of water was available in the second foot of soil, the dry-land crop was only 13 inches high and showed distinct signs of suffering from drought. The plants had only one or two tillers each. The irrigated plants were 21 inches tall and had about twice as many tillers. Differences in root habit were very striking (Fig. 62). The wider spread, longer primary branches, and the much greater number of secondary and tertiary laterals in the drier soil are clearly evident. The network of roots just beneath the soil surface afforded an efficient means of securing water furnished by light showers. But many of these roots had died from drought, and growth was greatly retarded. Under irrigation, lateral spread was much less developed, but the root system extended very much deeper. Maximum penetration in the two cases was 31 and 65 inches, respectively.

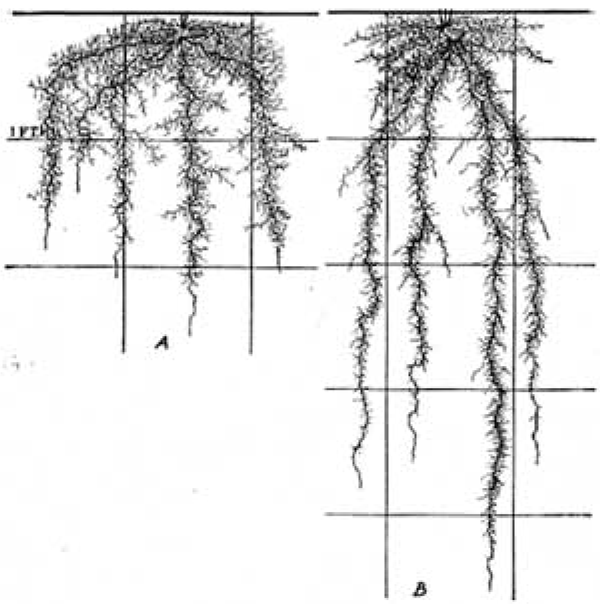


Fig. 62.--Roots of wheat plants 2.5 months old: *A,* in dry land; *B,* in irrigated soil.

Mature Root Systems.--A final examination was made when the crop was nearly ripe. The very meager rainfall during the interval since the last examination was entirely dissipated in several light showers, and the soil in the dry land had become progressively drier. Here, the wheat was only 15 inches tall.

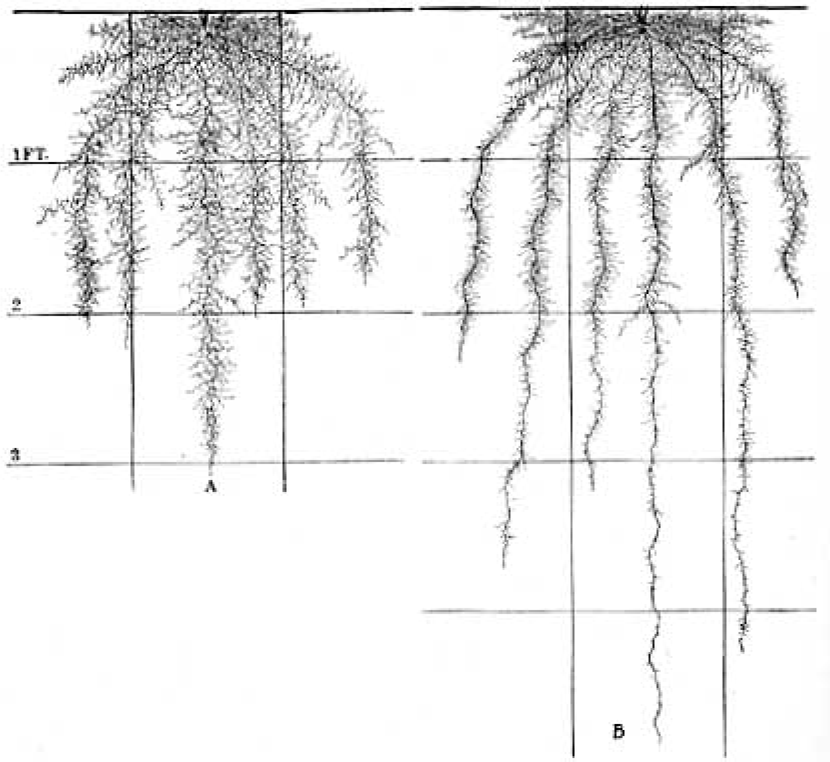


Fig. 63.--Roots of mature wheat plants: *A,* in dry land; *B,* in irrigated soil.

Only about half of the plants were furnished with a tiller, very few of which had headed. The yield was scarcely 3 bushels per acre. A fine crop, 43 inches tall and yielding at the rate of 29 bushels per acre, had developed under irrigation. Differences in root habit were quite as marked as before. A comparison of Figs. 62 and 63 shows that the roots in the dry land had grown relatively little. The chief differences were a more thorough occupation of the second and, to a slight extent, the third foot of soil. The working depth was 24 inches as compared with 52 in the irrigated plots. In the same sequence, maximum penetration was 37 and 75 inches. The furrow slice in both plots was thoroughly occupied by a large number of remarkably branched superficial roots. Probably owing to the death by drought of many of these in the drier land and to continued growth under irrigation, they were now more abundant and also longer in the watered soil. These, with the profusely branched older roots, formed a wonderfully efficient absorbing system. The greater length and degree of branching of laterals were, as before, very conspicuous in the drier soils.

Root Development under Increased Rainfall.--The following season, when the soils were equally moist, due to increased rainfall, the first examination revealed no differences in root habit. Later, the area occupied by the root system of the dry-land crop was much greater than during the preceding season, owing to a better shoot development, more tillers, and a subsoil with available moisture in which none of the roots died. The lateral spread was as great as formerly, and the working depth was over a foot deeper. In fact, the root habit was more nearly like that in the irrigated soil than that in dry land. The crop was 3 feet high and the yield 25 bushels per acre. Root development in the irrigated soil was approximately the same as the preceding year. A third plot, where light irrigation was practiced both years, gave results intermediate to those just described.

WINTER WHEAT

Development of winter wheat under measured environmental conditions has been thoroughly studied at Lincoln, Nebr.[226] A strain of Turkey Red winter wheat (*Triticum aestivum*), known as Kanred, was grown. It was drilled 2 inches deep in fertile silt loam soil on Sept. 20, and the growth both above and belowground recorded at 10- or 15-day intervals. Growth conditions were very favorable during both years of the experiment, and the crop developed normally.

Early Development.--Ten days after sowing, when the second leaf was about half grown, the roots were excavated (Fig. 64). The number of roots varied from two to five, but nearly all of the plants had three. The primary roots were deepest, extending to maximum depths of 8 to 9 inches. While these roots took a rather vertically downward course, the others usually ran obliquely outward, often later turning downward. The fairly abundant supply of laterals was scattered quite irregularly, the best-branched portions of the root giving rise to 12 or more per inch.

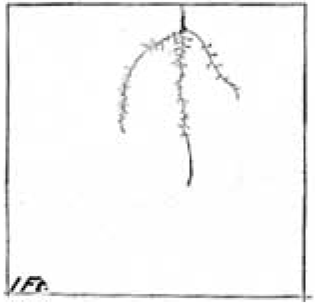


Fig. 64.--Primary root system of 10-day-old plant of winter wheat.

Ten days later, the plants had four leaves, and nearly all had one tiller extending an inch or more from the axil of the first leaf. The leaves were rapidly losing their vertical position, some already being nearly horizontal. A second tiller, originating either from the axil of the second leaf or more commonly belowground near the grain, was also found on most plants. Nearly every plant had a new root in addition to those of the primary root system. These roots of the secondary system were about a millimeter thick, turgid, white, and entirely unbranched but densely clothed with root hairs. They originated from the stem near the grain and ran mostly in a horizontal position or turned only a little downward. None exceeded 2.5 inches in length. The roots of the primary system had extended into the second foot of soil, elongating at the rate of over half an inch per day (Fig. 65). They were more frequently branched, and the branches were longer than before, but no laterals of the second order had appeared.

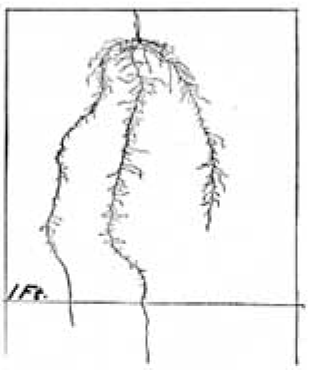


Fig. 65.--Wheat plant 20 days old. The first root of the secondary system has appeared.

When 30 days old (Oct. 20), most of the parent plants had the fifth leaf about half developed. Each was furnished on an average with four tillers. The largest of these had three leaves and stood as high as the parent plant. The prostrate habit, due to the outward curving of the short stems, was well initiated, the plants having a spread of 3.5 inches on each side of the drill row. This rapid growth of tops was correlated with a pronounced root development. The primary root system had reached a working level of 16 inches and a maximum penetration of 2.8 feet was attained by some plants (Fig. 66). The long, thick, unbranched root ends indicated rapid growth. Not only was the lateral spread greater, but the branches were much longer, and the older portions of the roots possessed many more of them. Branohes of the second order were found only on the oldest laterals from the main roots, but here they were abundant.

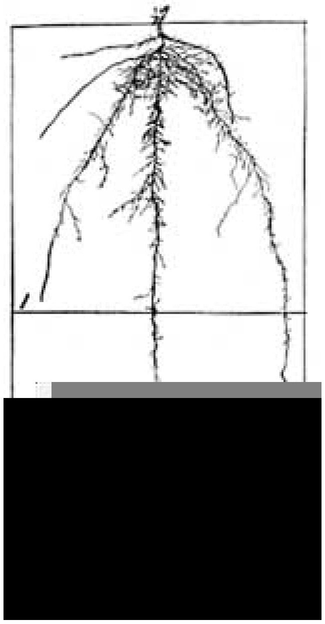


Fig. 66.--Wheat plant 30 days old. The secondary root system now furnished 18 per cent of the absorbing area.

The secondary root system, moreover, had made a marked growth. Each plant now had a total of 4 to 10 roots, an average of 4 in addition to the seminal ones. They varied from 1/8 inch to 6 inches in length and turned downward from horizontal to nearly vertical. They had about twice the diameter (1 millimeter) of the seminal roots in the surface soil, and only in the deeper layers was the diameter of the latter equal to that of the roots of the secondary system. All were densely clothed with root hairs, and short laterals occurred on the older roots.

Fig. 67.--A view in the wheat field on October 30, forty days after planting.

The next 10-day period revealed a marked growth. The number of tillers had increased to 7 per plant. These were so well developed that a plant of average size had a total of 20 leaves, more than half of which were fully grown (Fig. 67). To provide water and nutrients for such a large shoot, an extensive root system was imperative. An examination of the latter showed that the roots of the secondary root system averaged 9 per plant. While some were only a small fraction of an inch long, others had a length of 19 inches. In general, they ran rather obliquely outward and downward with an average spread of about 5 inches from the base of the plant (Fig. 68). A few extended into the second foot of soil. The older and longer ones were irregularly branched with short laterals at the rate of 5 to 10 per inch. All the main roots were so densely clothed with root hairs, to, which the soil clung tenaciously, that the smooth, white, root ends .stood out in marked contrast. The primary root system had increased both in working depth (now about 1.7 feet) and maximum extent, a few of the deepest roots having penetrated to 3 feet. The oldest portions of the roots, especially the first foot of the deeper ones, appeared shriveled, and microscopic examination showed a deterioration of the cortex. But the abundant root hairs on the deeper main roots and their branches, together with their bright, turgid appearance, showed plainly that they were functioning vigorously as absorbing organs. Primary branches were longer than before, and on some, secondary laterals were much more abundant. Thus, the efficiency of this portion of the root system was greatly increased.

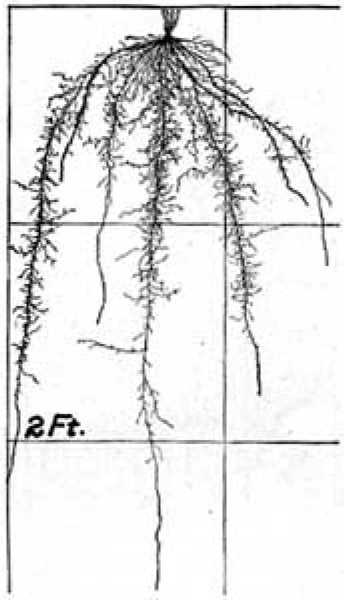


Fig. 68.--Root system of 40-day-old wheat plant.

Late Autumn Development.--After a 15-day interval, further examinations were made, the crop now being 55 days old. Growth had been very good so that, although the drill rows were 8 inches apart, over much of the field the soil was practically concealed by the plants. The height was only 3 inches, owing to strong curving of the short stems which gave the plants their favorable prostrate winter habit. Tillers had increased rapidly from 7 per plant, 15 days earlier, to 11. On an average, each plant now had 32 leaves, an increase of 11. The photosynthetic area showed a gain of 141 per cent, and dry weight of tops, 160 per cent during the 15-day interval. The extensive tops furnished abundant food for the growth of an elaborate root system.

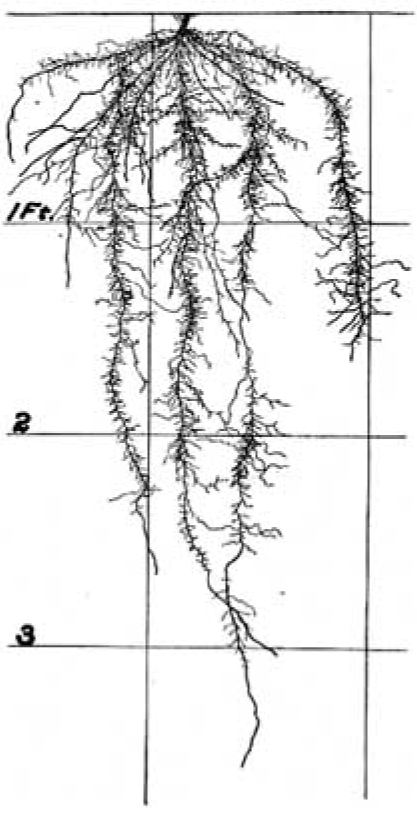


Fig. 69.--Root ystem of 55-day-old wheat plant.

Roots of the primary system often reached depths of over 3 feet, and a few were found at the 4-foot level (Fig. 69). Branching habit of the primary system had changed but little in the surface 2 feet except that the branches were somewhat longer. The younger portions, as the roots deepened, became clothed with laterals similar in number and in secondary branching to the older parts above. An average of 10 roots of the secondary system was found. They ran almost horizontally or so slightly obliquely downward that few or none occupied the area under the plant where the roots of the primary root system were absorbing. The working level was at 8 inches, but some of the longer roots penetrated to a depth of 20 inches.

About half were unbranched or nearly so; others were profusely branched throughout with laterals averaging an inch in length. Moreover, a few secondary branches were beginning to appear.

An examination on Nov. 29, the interval again being 15 days, revealed approximately the condition in which the roots passed the winter. Although some of the tips of the older leaves were frozen, the plants had made a good growth. Tillers had increased to 14 per plant, and the total number of leaves, to about 40. The height and spread of tops had not changed measurably. The primary root system now occupied the soil to a depth of 3 feet (Fig. 70). A few roots reached 4 feet. Thus, some growth in depth had occurred, and branching had increased considerably. Only the stele of these roots remained intact in the surface foot.

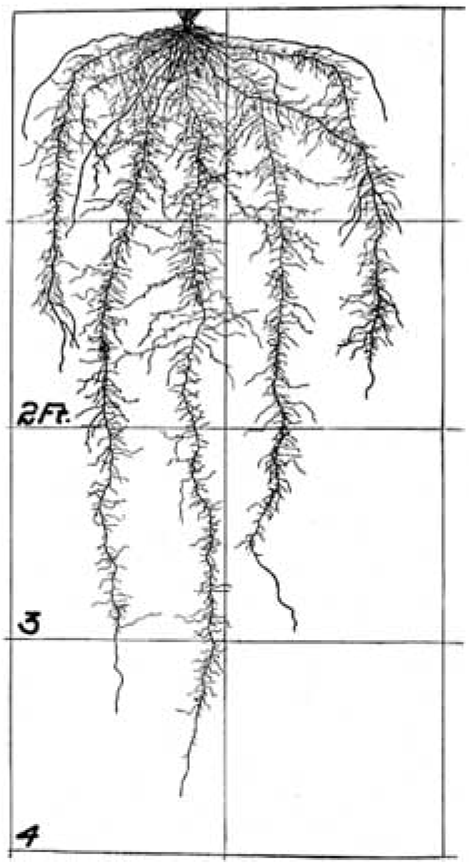


Fig. 70.--Root system of wheat 70 days old, showing the extent of root growth before the period of winter dormancy.

Early deterioration of the cortex was probably due to low water content of soil. In number, the secondary roots had increased from 10 to 11, the chief development being in the elongation of those already formed. A comparison of Figs. 69 and 70 shows the considerable increase in branching and the much more thorough occupation of the soil.

Relations of the Development of Roots and Tops.--The relative growth of the tops, including photosynthetic area and dry weight, at the end of the several intervals is shown in Table 6. Here, also, is given the growth of both the primary and secondary root systems. The table includes measurements throughout the period of winter dormancy until growth was resumed in the spring. These data can best be interpreted when plotted with the temperature (Fig. 71), since temperature was the limiting factor to growth, soil moisture and other conditions being quite favorable.

TABLE 6.--GROWTH OF WHEAT FROM SEPT. 20, 1921, TO MAR. 29, 1922

Date	Number of leaves	Number of tillers	Photosynthetic area, sq. cm.	Dry weight, shoots, grams	Working depth primary root system, inches	Number roots, secondary system	Average length, roots, secondary system, inches
Sept. 30	1.5	0.0	8.28	0.013	6.01	0.0	0.0
Oct. 10	3.5	1.6	21.50	0.046	11.0	0.8	0.7
Oct. 20	13.0	4.4	59.46	0.146	16.0	3.9	1.8
Oct. 30	20.6	7.2	93.98	0.239	20.0	8.7	2.1
Nov. 14	31.5	10.5	226.39	0.621	30.0	10.0	4.7

Nov. 29	39.7	13.8	0.835	36.0	11.0	5.4
Dec. 14	42.5	15.1	0.882	36.0	11.0	7.0
Jan. 13	40.0		0.697			
Feb. 12	40.5	14.8	0.556			
Mar. 14	45.0	15.3	0.490			
Mar. 29	61.0	17.7	0.727	36.0		

It may be noted that tiller production started about 15 days after planting and was kept up continuously until the middle of December. Leaf output paralleled the growth of tillers, and growth rate, based on dry weight, was very similar. Table 6 shows that the primary root system increased its working level quite uniformly. This was at the rate of 0.55 inch per day during the first 55 days, the extent of branching correlating with root elongation. The secondary root system began to develop simultaneously with the appearance of tillers. On an average, a new root and a new tiller appeared every 4 or 5 days until the middle of November, after which the rate of tillering exceeded that of root production. However, the increase in length and branching of the secondary root system continued with the formation and growth of tillers and at an undiminished rate until the middle of December. Here, growth both above and belowground ended abruptly when the air temperatures averaged almost continuously below freezing and the soil was frozen to a depth of several inches. The number of leaves and tillers decreased slightly due to repeated freezing and thawing, wind whipping, etc., and consequently, the dry weight of tops also decreased. The greater decrease in the latter (44 per cent) was due to the fact that many of the leaves were only partly injured, causing a marked decrease in dry weight but not in numbers. But the root system, even that part subjected to the greatest temperature changes, was apparently uninjured.

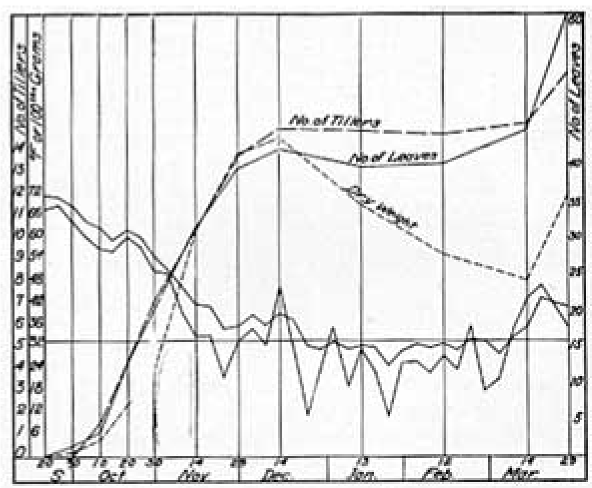


Fig. 71.--Graphs showing the growth rate of winter wheat and the temperature of soil and air. The upper temperature line is that of the soil at 6 inches depth, the lower one that of the air temperature.

During the second week in March, both roots and shoots resumed growth. Frost disappeared from the soil as the air temperature became higher (Fig. 71), and the plants developed slowly at an average temperature of 40°F. Rains replenished the water content of the surface soil, and with increasing temperature, the crop made a steady growth. The primary root system was apparently functioning as in late fall. Many new roots of the secondary system appeared. The culms began to grow 'erect and the spikes to develop. In less than 2 weeks, at an average temperature of 42°F., the crop regained 60 per cent of the loss in dry weight which had occurred during the 90 days of winter dormancy. This vigorous early spring growth was due largely to the well-developed root system and culms stored with food.

Absorbing and Transpiring Areas.--Determinations were also made of the relation of the actual absorbing area (exclusive of root hairs) to that of the transpiring area of leaves and stems. The work was done during the following season when conditions for growth were very similar' to those described. This was accomplished by carefully washing the soil from the roots with a gentle water spray, thus securing the root systems in their entirety and floating them in shallow trays of water while measurements were being made. These data are given in Table 7.

TABLE 7.--LENGTH AND ABSORBING AREA OF ROOT SYSTEM (EXCLUSIVE OF ROOT HAIRS) AND PHOTOSYNTHETIc AREA OF TOPS, 1922

Date	Area primary root system, sq. cm.	Area secondary system, sq. cm.	Total area of root system, sq. cm.	Photosynthetic area tops, sq. cm.	Length primary root system, cm.	Length of secondary root system, cm.	Total length of roots, cm.

Sep. 30	9.63	0.00	9.615	7.68	95.05	0.00	95.05
Oct. 10	31.02	0.37	31.39	22.50	323.87	1.50	325.37
Oct. 20	50.31	11.20	61.51	50.50	490.40	40.70	531.10
Oct. 30	62.80	42.32	105.12	88.98	632.70	207.45	840.15
Nov' 14	115.97	121.54	237.51	215.30	1,509.70	1,171.80	2,681.50
Nov. 29	151.76	157.92	309.68	280.00	2,004.70	1,234.70	3,239.40

The absorbing area of roots increased progressively with that of tops and was uniformly 10 to 35 per cent greater in extent (Fig. 72). Since microscopic examination indicated that practically all of the roots and their branches were clothed with functioning root hairs, except at the growing tips and on the oldest parts of the primary roots, the absorbing area was actually probably eight to ten times greater than the transpiring area. Deterioration of the cortex on the oldest portions of the roots of the primary root system began about the middle of November. By the end of the month, the epidermis on about the first 10 inches was either destitute of root hairs or sloughed off with the cortex, leaving only the stele intact. This reduced the absorbing root area, however, by less than 1 per cent. On Oct. 20, the secondary root system already furnished 18 per cent of the total absorbing area. This had increased to 40 per cent 10 days later, and by the middle of November, it was 51 per cent, notwithstanding the great increase of the area of the primary root system. Owing to the relatively finer roots of the primary system coupled with more profuse branching, its total length exceeded that of the secondary root system. On Nov. 29, it made up 62 per cent of the 32 meters of root length possessed by an average-sized plant. The absorbing area of the roots, exclusive of root hairs, exceeded the photosynthetic area, which was actually about the size of this page, by nearly 30 square, centimeters. The striking parallelism of the graphs of areas of roots and tops, together with the constantly greater area of the former (10 to 35 per cent) shows clearly the great importance of extensive root development in the economy of the plant.

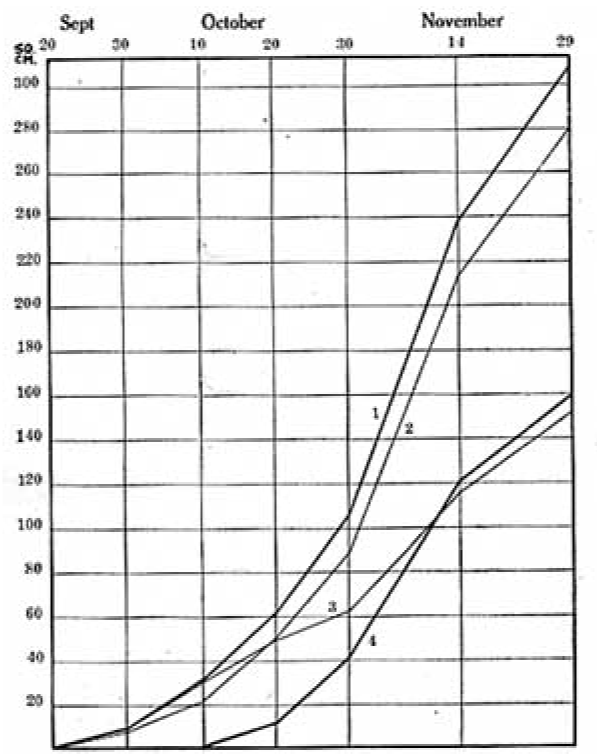


Fig. 72.--Graph showing: 1, the absorbing area of winter wheat (exclusive of root hairs); 2, photosynthetic and transpiring area; 3, the absorbing area of the Pnmary root system; 4, the absorbing area of, the secondary root system.

Mature Root System.--At maturity, winter wheat has a very extensive root system. As with other cereals, the abundance of roots, lateral spread, and amount and length of branching, as well as the depth of penetration, are quite variable in different kinds of soil and under different climates. A representative specimen of the Turkey Red variety is shown in Fig. 73. It was grown in moist, rich, silt loam soil near Lincoln. The tops were 3.8 feet high and the heads were well filled. Most of the numerous thread-like roots penetrated rather vertically downward, others ran obliquely downward but seldom reached a greater spread than 6 to 8 inches from the base of the plant. Still others ran out parallel with the soil surface for short distances before turning downward. The working depth was found at approximately 4.4 feet, and the maximum root depth was 6.2 feet. Beginning just below the surface and extending to a depth of 4 feet, numerous profusely branched laterals filled the soil. These light-colored roots showed very plainly in the black earth. They were covered with dense mats of root hairs, the rootlets intercrossing in the jointed subsoil in such a manner as to give a cobwebby appearance. It is quite impossible to show these finer roots and all their branches in the most detailed drawing. Below 4 feet, the roots were less abundant but still well branched and supplied with root hairs.' The last 6 inches of the deeper ones were poorly branched with laterals which were only a few millimeters in length.

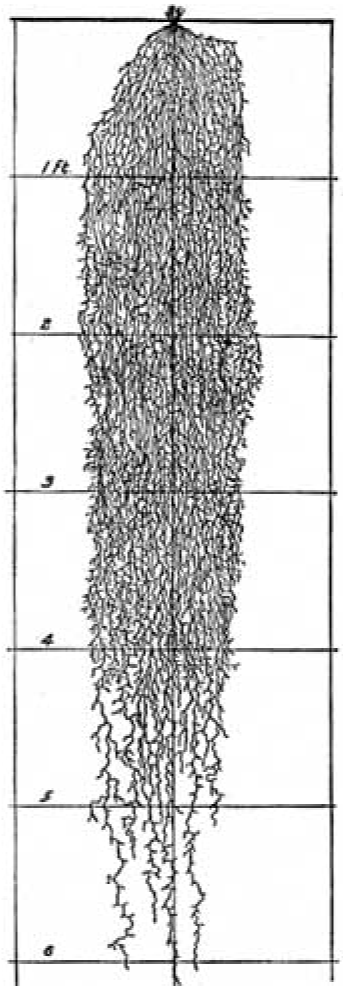


Fig. 73.--Mature root system of winter wheat.

Root Variations under Different Soils and Climates.--A field only 2 miles distant from that last mentioned, where silt loam intergraded at a depth of 2.3 feet into a very hard tenacious subsoil of clay intermixed with streaks and spots of chalk, gave marked differences in root extent. The crop was 3.3 feet high and of excellent quality. The working depth was only 3.2 feet and the maximum root penetration 4.7 feet, depths approximately 12 to 18 inches less than in the deep silt loam soil. However, in a third field, an equal distance from the first and also examined the same season, much greater root extent was found. Here, the silt, loam soil gradually gave way at a depth of about 1.5 feet to a very deep, rather mellow, loess subsoil. Like that in the other fields, it was moist to great depths. The mature crop was 3.5 feet high. The lateral spread was similar to that described, but roots were fairly abundant to the working level at 4.9 feet. Not a few penetrated to 7 feet, and a maximum depth of 7.3 feet was attained.

Quite in contrast to this excellent growth was that on the short-grass plains. At Flagler, Colo., a field of the Turkey Red variety was rooted entirely in the surface 16 inches of soil. The roots were developed very much as if grown in a large flowerpot, because the soil was moist only to a depth of 15 inches where a very tenacious hardpan, 7 inches thick, occurred. Below this, the soil was less compact but very dry. Such a limited root development was correlated with a poor growth of tops which scarcely exceeded a foot in height.

Relation of Roots to Tops under Different Climates.--Data on the development of roots and tops of wheat at many stations throughout a wide range of climatic and edaphic conditions are tabulated in Table 8. Even a casual examination of the table shows clearly the close correlation between the growth of tops and roots and the better development of both under an increased water content of soil and the presence of moisture in the subsoil as well as a more humid atmosphere. These relations are clearly shown in Fig. 74.

TARLE 8.--DEVELOPMENT OF WHEAT AT VARIOUS STATIONS IN THE GRASS LAND FORMATION

Variety	Soil	Height	Work	Maxi-

Station	of crop		of tops, feet	ing depth, feet	mum depth feet
Short-grass plains:					
Yuma, Colo.:	Turkey Red	Very fine sandy loam	2.1	2.1	2.3
Sterling, Colo	Turkey Red	Very fine sandy loam	2.0	2.7	2.8
Flagler, Colo	Red Spring	Very fine sandy loam	2.5	2.5	2.8
Flagler, Colo	Turkey Red	Very fine sandy loam	1.0	1.4	1.5
Burlington, Colo	Turkey Red	Very fine sandy loam	2.5	3.8	5.4
Colby, Kan	Kanred	Very fine sandy loam	3.2	2.0	2.3
Limon, Colo	Turkey Red	Very fine sandy loam	1.8	2.0	2.8
Limon, Colo	Spring	Very fine sandy loam	1.7	2.0	2.0
Averages			2.1	2.3	2.7
Mixed prairie:					
Union, Colo	Turkey Red	Very sandy loam	1.8	3.0	4.0
Ardmore, S. Dak	Turkey Red	Pierre clay	2.6	3.3	4.1
Phillipsb'g, Kan	Turkey Red	Very fine sandy loam	3.8	4.8	5.7
Mankato, Kan	Turkey Red	Very fine sandy loam	2.8	3.2	3.7
Averages			2.8	3.6	4.4
Tall-grass prairie:					
Lincoln, Nebr	Turkey Red	Silt loam	3.3	3.2	4.7
Lincoln, Nebr	Turkey Red	Alluvial silt loam	3.8	4.4	6.2
Lincoln, Nebr	Turkey Red	Silt loam	3.5	4.9	7.3
Fairbury, Nebr	Turkey Red	Clay loam	3.0	3.0	4.1
Wahoo, Nebr	Turkey Red	Silt loam	3.0	3.6	5.0
Wahoo, Nebr	Turkey Red	Silt loam	3.0	3.8	5.0
Averages			3.3	3.8	5.4

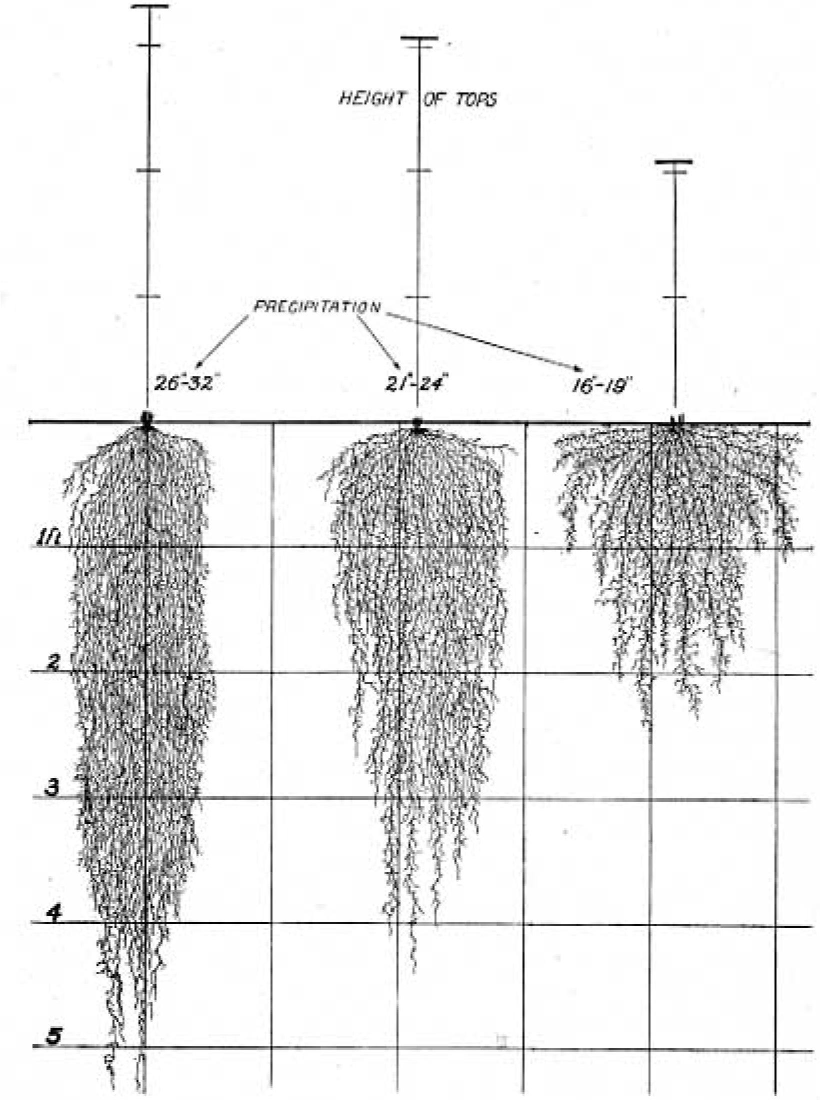


Fig. 74.--Diagram showing the growth of roots and shoots of winter wheat in rich silt loam or very fine sandy loam under different climates.

OTHER INVESTIGATIONS ON THE ROOT HABITS OF WHEAT

At St. Paul, Minn., isolated clumps of spring wheat were found to have roots which spread throughout a radius of 16 inches and had a depth of penetration of more than 4 feet. [82] Scotch Fife, a spring variety grown at Fargo, N. D., had many main roots, most of which ran almost vertically downward, sending out numerous small feeders, which practically occupied the soil to a depth of 4 feet, many roots presumably penetrating a foot or two deeper. A lateral spread of 9 inches was found. [202] Red winter wheat at Manhattan, Kan., has been shown to form a network of fine fibrous roots quite to the surface of the ground. The roots were recovered to a depth of 4 feet, although they probably extended deeper. [204]

In root studies of cereals on the Coastal Plain soils of New Jersey, it was found that very little root growth extended beyond a depth of about 8 inches, root development of these crops being almost invariably confined to the area above subsoil. [144] In unproductive, heavy, very poorly aerated clay soils at the Rothamsted Experiment Station, England, few roots of wheat or barley penetrated below the surface 2 to 4 inches and none appeared below the 6-inch level. Where applications of barnyard manure had improved the soil structure, the roots were well branched and several penetrated to a depth of 9 inches. [19]

RELATION OF ROOT HABITS TO CULTURAL PRACTICE

A well-prepared, firm seed bed is essential in growing the smaller cereals. It not only furnishes better conditions for water absorption by the seed but also gives the young roots better soil contact and thus promotes their efficiency in absorbing water. and nutrients. Grain that is drilled at a uniform depth in a firm seed bed that is well compacted beneath will germinate better, and the roots will have a more favorable environment I for growth than grain that is broadcast and worked into a loose soil. A loose crumbly surface soil, however, is best for retaining the water about the roots. Extremely adverse physical conditions, such as packing of the soil by heavy rains or drying and crusting of the surface, may prevent or delay the development of the secondary root system.[130] It has been fully demonstrated that early fall plowing for wheat promotes nitrification and thus furnishes a greater supply of nitrates to the wheat seedlings.[28] This results in increased yields.

A root system that is well established before the beginning of winter is better able to withstand the tearing or breaking of roots sometimes resulting from alternate thawing and freezing and heaving of the soil. It would seem equally important to sow spring grain early enough so that it may develop a deep root system before the advent of the hot dry weather which frequently occurs during the last few weeks before the crop matures. Even casual examination of the root system shows clearly that all of the surface soil is fully occupied with the roots of the crop and that there is no room for weeds. Their roots come into direct competition for water and nutrients with those of the cereal, and if weeds are permitted to grow, the yield of grain will be reduced.

The addition of fertilizers has a marked effect. Nitrogen promotes root branching and retards elongation. In New South Wales, where roots of spring wheat regularly penetrate to depths of about 4 feet, the effect of adding superphosphates is marked. In addition to other useful effects, they encourage rapid growth and deep root penetration, thus enabling the crop to draw upon moisture and nutrient supplies from deeper layers of the subsoil than in the case of land receiving no fertilizer.[53] In one experiment, an increased depth of 8.5 inches was ascertained; and in another the depth of penetration was almost doubled.[217, 128]

SUMMARY

Both spring and winter wheat are annuals with deeply penetrating, widely spreading, and profusely branching, fine, fibrous roots. Probably because of their shorter period of growth, the roots of the spring varieties are less extensive. The primary root system, consisting usually of a whorl of three roots with their branches, originates from the embryo and is the first to appear. But soon a secondary root system develops from the nodes above, the number and branching of roots increasing in correlation with the number of tillers. Root elongation, under favorable conditions, is very rapid; sometimes, a growth rate of over half an inch a day is maintained for 6.0 to 70 days in the primary root system of winter wheat. Although there is apparently some variation among varieties, the primary root system of spring wheat rather regularly reaches depths of 4 to 5 feet. Roots of the secondary system ramify the soil near the surface 6 to 9 inches on all sides and, likewise, fill the 2 to 3 feet below this area with a network of well-branched roots. Winter varieties are similar in general habit but more deeply rooted. Crops planted early during seasons favorable for growth form a secondary root system which rather thoroughly fills the surface 12 to 20 inches of soil, while the primary roots extend well into the third and fourth foot. The mature root system has a working level of 3.5 to 4 feet and a maximum depth of 5 to 7 feet. Pronounced modifications in root habit occur under different soil environments. Where the subsoil is dry, root depth is greatly abbreviated, and lateral spread, degree of branching, and absorption from surface soils are greatly increased. These differences occur in the same kind of soil. if one portion is irrigated and the other unwatered. Variation in depth and degree of branching also occurs in response to fertilizers. Moreover, in stiff clay soils where aeration is very poor, roots do not penetrate so deeply.

Gardening

How Deep Do Corn Roots Grow?

Most corn roots will grow to a maximum depth of 5 feet (1.5 meters) deep. There have been a few cases of corn roots growing deeper than this, up to 6–7 feet deep (2 meters), but this is rare. In fact, it's rare for corn roots to even reach the 5-foot depth. Most corn roots will reach only half this depth due to environmental factors. Sweet corn roots can be encouraged to grow deeper under ideal growing conditions.

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Does Corn Have Shallow or Deep Roots?

Corn falls in between a deep and shallow root system. This is because roots can develop up to 5 feet (1.5 meters) deep but most actual development only happens in the upper 3 feet (90 cm) of soil. Thus, most corn has shallow roots with the potential for growing deeper roots in optimal conditions.

- Corn roots can grow deep roots but soil conditions typically only allow for corn roots to grow to a depth of 3 feet (90 cm).
- Encourage corn roots to grow to a deeper depth by providing ideal growing conditions and fertilizer.
- Loose, well-tilled soil encourages deeper corn roots.

You can encourage your corn to grow deep roots by providing ideal growing conditions, like providing the right amount of sunlight. Deep root systems often have trouble developing in wet soil. You can solve this growing corn in well-draining, sandy soil. Adequate drainage will help ensure your corn gets the necessary amount of water and has the proper soil moisture for root growth.

Feeding corn with a balanced fertilizer is another great way to encourage the growth of deep corn taproots. Corn is a heavy feeder so it needs a serious amount of fertilizer to reach its ideal growth. Use this organic fertilizer to get your sweet corn the nutrients it needs.

Down to Earth Organic Bio-Fish Fertilizer Mix 7-7-2, 5 lb

Buy Now

We earn a commission if you click this link and make a purchase at no additional cost to you.

Does Corn Have Invasive Roots?

Corn does not have invasive roots and is not an invasive species of plant. Corn plants are actually considered a fairly stable crop because they grow fairly easily but not aggressively. You can manage the propagation of your corn patch with minimal effort.

How Wide Do Corn Roots Grow?

Corn roots do not grow very wide, mainly experiencing a spread of 4–5 inches (10–13 cm) from the stalk in all directions. This gives your corn roots a maximum diameter of 8–10 inches (20–25 cm). This lack of width is usually made up for by a deeper main root. However, this deeper root can fail to develop an ideal depth in poor soil conditions. From this main root, root hairs will spread out horizontally to the maximum width.

- The maximum diameter for corn roots is 8–10 inches (20–25 cm).
- Corn roots extend in a circle about 5 inches (13 cm) from the central stalk.

- Corn stalks tend to grow roots that are deep instead of wide.

Corn roots tend to grow at a steady but slow rate of 2.75 inches (7 cm) per leaf stage. This means that it will take a fair while for the maximum root depth to be achieved. However, maximum root width will be achieved remarkably quickly.

How Far Apart Should Corn Be Planted?

Plant corn seeds 8–10 inches (20–25 cm) apart. This will allow corn plants to reach their maximum root width without tangling with other corn roots. A simple trick to gauging planting distance is to use your arm to measure. Plant seeds just about as far apart as the distance from your elbow to your fingertips

- 8–10 inches (20–25 cm) is a perfect distance between corn plants.
- Providing correct spacing between corn plants prevents tangled roots.
- When growing corn from seed, thin rows so mature plants are at the proper distance.

When planting your corn patch, be sure to test that the soil drains well enough for your corn. Soil that is not well-draining will cause far more problems than corn that is planted too close together.

How Deep Does the Soil Need to Be for Corn?

Ideally, the soil should be at least 5 feet (1.5 meters) deep for corn. However, corn requires soil up to 8 feet (2.4 meters) deep in rare instances. When planting corn seeds, you'll want at least a 6-inch (15 cm) soil depth for your seedlings. This is because you need a soil depth of 1.5–3 inches (3–7.5 cm) for the corn seed, plus some room for initial root development. Any deeper than this and your seedlings won't develop healthy roots. Corn seedlings can then be transplanted to outdoor cornfields with several feet of soil depth.

- Corn seeds can be started in as little as 6 inches (15 cm) of soil.
- Mature corn plants need up to 8 feet (2.4 meters) of soil depth.
- Corn is a heavy feeder that needs fertile soil.

In addition to significant soil depth, corn prefers cool soil temperatures around 50℉ (10℃). Fertile, well-drained soils are best. This is because corn is a heavy feeder and needs a lot of nutrients for growth.

Is Corn a Deep-Rooted Plant?

While corn roots can grow deep, they often don't grow as deep as they could due to environmental factors. Having the wrong soil and not enough nutrients can stunt plant roots. Due to this, you need to take great care if you want your corn roots to hit the ideal target depth. Here are some key tips to remember about corn roots:

- Corn roots can grow to 5 feet (1.5 meters) deep but often develop to only half this depth.
- Corn roots grow to a maximum diameter of 8–10 inches (10–15 cm).

- Corn and its roots are not considered invasive.
- Corn seeds should be planted 8–10 inches apart (10–15 cm).
- Corn seeds should be planted 1.5–3 inches (3–7.5 cm) deep.
- You can start corn seeds in 6 inches (15 cm) of soil, then transplant them to deep soil.

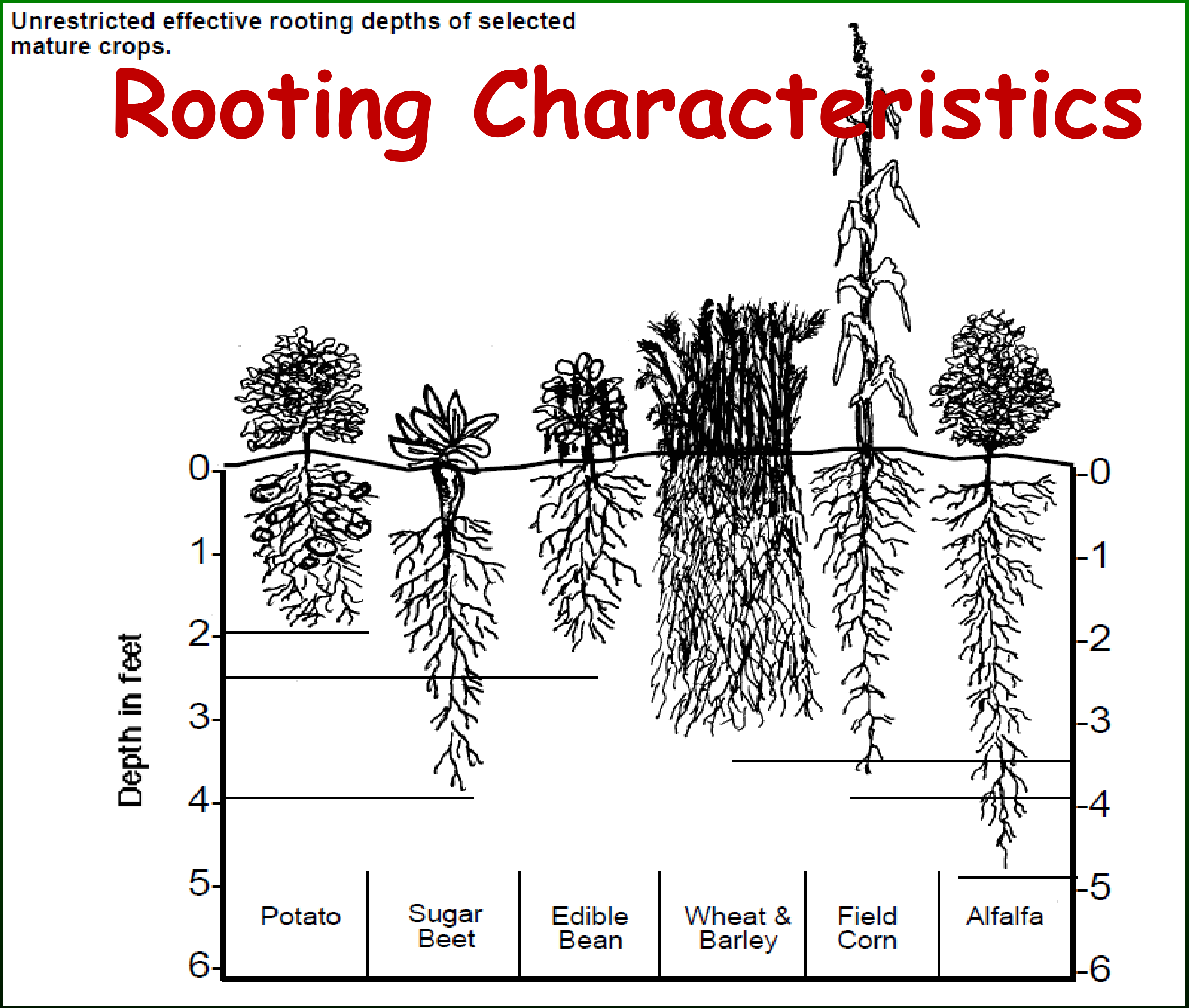
By providing your corn plants with deep soil, you'll encourage them to develop healthy roots. Deeply-rooted corn will be able to pull more water and nutrients from the soil. This leads to stronger, hassle-free plants that provide a large harvest of sweet corn.

#CORN #VEGETABLES

Gardening

How Deep Do Asparagus Roots Grow?

Rooting Characteristics



Lundstrom, 1988

NDSU

How Fast and Deep do Corn Roots Grow in Iowa?

June 14, 2017

Corn roots grow rapidly starting at the 4th-leaf stage and continue throughout vegetative development. This typically occurs from June to early July. Several factors affect root growth, but temperature and soil moisture are the most relevant factors in the absence of soil constraints. Well-developed, deep root systems are essential to support water and nutrient uptake and thus high yield potential. Hot and dry weather results in a depletion of moisture in the top 6-inch soil layer. This occurred in June of 2016 and also during the first two weeks of June 2017. Crop stress was evident in light soils or where root development was restricted. Should you be concerned about this? Maybe, maybe not. It is known that plant roots cannot grow in dry or saturated soil conditions. However, at this time it is unlikely that water is limiting root growth below a 6-inch soil depth.

In 2016, the FACTS team collected root depth measurements at critical crop stages in six corn fields across Iowa. Measurements were taken on the row and at the center of two 30-inch rows. These fields had different treatments such as planting date and tile drainage. Results indicated that root depth increased over time consistently across sites and treatments. On average, corn roots grew about 2.75 inches per leaf stage to a maximum depth of 60 inches (Figure 1). Going into more specifics, corn roots initially increased at a slow rate (0.29 in./day) up to 5th-leaf and from then on with a rate of 1.22 in./day until silking stage when maximum depth is reached.

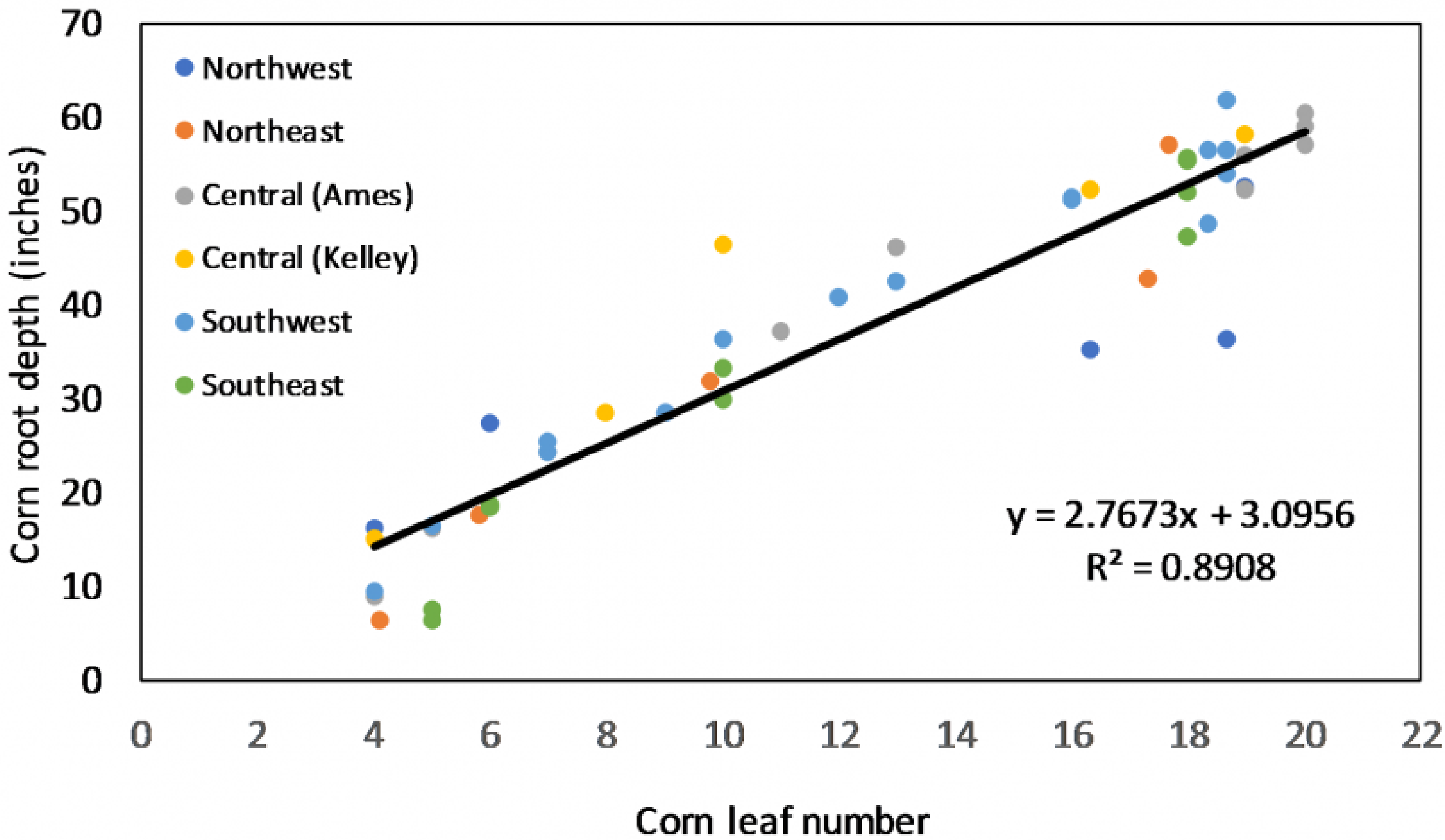


Figure 1. Corn root growth progression from the 4th- to 20th-leaf stage at the in-row sampling location at six field locations across Iowa. Each point represents an average of three replications.

Other important findings from this work are:

1. Roots merge between the two 30-inch rows at approximately the 6th-leaf stage.
2. Maximum rooting depth is largely determined by the depth of the groundwater table, root growth stops when it reaches a water table.

These findings match closely with information in Corn Growth and Development where it is stated that corn roots grow at a rate of approximately one inch per day, meet in 30-inch row centers at approximately the 3rd-leaf stage, and reach maximum depths of six feet or greater near the blister to milk stage (Abendroth et al. 2011). Differences can occur due to geographic location, hybrid characteristics, and climate conditions. Additionally, accurately detecting rooting depth is difficult because root biomass is much less at deeper depths compared to those in the surface 6-inches.

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Category: Crop Production

Crop:

Corn

Tags: Corn root growth

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