ROOT SYSTEMS OF CERTAIN FORAGE CROPS IN RELATION TO THE MANAGEMENT OF AGRICULTURAL SOILS

by

Thomas Pavlychenko

A THESIS

Presented to the Faculty of

The Graduate College in the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Department of Botany

Lincoln, Nebraska

September, 1940

ACKNOWLEDGMENT

The author wishes to acknowledge great indebtedness to Dr. J. E. Weaver for his close cooperation in the work and his assistance in organizing the material, for partially financing the work on the species from the U. S. A., and for final revision of the manuscript.

He wishes also to express deep gratitude to Dr. L. E. Kirk, Dean of the College of Agriculture, University of Saskatchewan, for his manifold assistance, encouragement and suggestions. Special gratitude is due to the Carnegie Corporation of New York for financing a year's stay of the author in the U. S. A., thus enabling an inclusion of the prairie species in this study, and to the National Research Council of Canada, and to the Dominion Department of Agriculture for financing the project as a whole.

CONTENTS

ROOT SYSTEMS OF CERTAIN FORAGE CROPS IN RELATION TO THE MANAGEMENT OF AGRICULTURAL SOILS

INTRODUCTION

The economic value of agricultural soils is based upon their productivity. The productiveness of land, however, is not a constant quality. Even within the same soil type and under moderately uniform climatic conditions, it varies widely in accordance with the system of land utilization and soil management. Under defective management, it is not uncommon to see seriously eroded and weedy fields yielding poor crops in districts with good soils. Conversely, fields free from erosion and weeds frequently are observed producing good crops where land is only of fair quality. Differences in the productivity of land arising from improper management of soil are pronounced not only in areas with ample rainfall but especially in areas of low precipitation (2, 3, 4, 32).

Unfortunately, the fundamentals of soil management are neither clearly understood nor appreciated in practical farming. Agricultural lands, consequently, become extremely weedy (6, 8, 9, 10). Volunteer weeds appropriate large amounts of soil moisture and leave but small quantities for crops (1). Reductions in crop yields, due to weeds, usually range from 18 to 45 per cent, depending upon the species of weed, the degree of infestation, and

the effectiveness of the measures employed for their control (34). Damage may be as low as 4 per cent with light infestations and as high as 84 per cent under severe ones (37), in which case profitable farming is jeopardized even on good soils (13, 14, 21, 23, 27, 47, 50). Good soil management should achieve proper utilization of soil moisture throughout the growing season (11, 12), elimination of weeds, and preservation of natural soil structure as far as is consistent with necessary field operations (1, 17, 25).

Weed infestation and pulverization of soil arise from long, continuous use of land for annual crops. The amount and nature of soil-binding materials left by annual crops are not sufficient to offset pulverization in tillage operations (64, 65). The practice of annually removing plant cover after weeds have shattered their seed provides ideal conditions for increase of weed seed in the soil. Unless some practical method is found to supplement the quantity of root fiber produced by annual crops and to check accumulation of weed seeds, the menace of erosion and weed infestation to arid agricultural lands will become increasingly grave.

The fact that the newly broken sod of some perennial grasses does not drift for several years and only very gradually becomes reinfested with weeds, definitely indicates that the remedy may be found among the perennial forage crops. Such crops must be of high competitive

efficiency and capable of producing large quantities of strong roots. Root fiber binds pulverized soil into larger structural aggregates which in time become stabilized and exert considerable resistance to the action of wind and water (15, 18, 25). Detailed information concerning the underground parts of perennial grasses, annual grains, and weeds is, therefore, of primary importance for intelligent management of soil (55).

The writer has had the privilege of discussing the results herein presented with several leading plant ecologists, soil conservationists, and weed specialists. Their opinion was that the material should be published in full (26). Methods, therefore, will be described fully, and an abundance of data will be given. The "raw data" are appended for the benefit of those who may be interested in greater detail (Appendix, Table 1).

Terms used by different authors to designate the same root structures vary so widely in meaning that it seems advisable to define those used in this work (7, 16, 38, 43, 44, 45, 46, 51, 52, 63).

The roots arising directly from the grass seed will be designated as <u>seminal roots</u>. These roots are often called primary roots to differentiate them from those originating from the underground stems, which are termed the secondary roots (38). The term, primary root, is confusing in two ways. One group of scientists uses this term to

indicate only the first root arising from the seed, applying the term, laterals, to other seed roots (44). Another group uses this term to indicate any seminal or main crown root, and thereby differentiates them from branches which they call the secondary and tertiary roots. Since these terms are inconsistent and confusing it seemed advisable to call all roots arising from the seed seminal roots.

Roots originating from any node of the culm between the seed and the surface of the soil will be called crown roots. Roots produced by horizontal underground stems either from nodes or vegetative buds will be designated adventitious roots. Any seminal, crown, or adventitious root of monocotyledonous plants and the taproots of dicotyledonous species, which are always directly connected with stem tissue, will be referred to as main roots. This term will be used only to designate these basic root structures from their branches. Branches developing directly from any root previously mentioned will be listed as branches of the first order. Rootlets originating from branches of the first and higher orders will be classified as branches of the second, third, or fourth orders, respectively.

All seminal roots, together with their branches of the various orders, will be termed the seminal root system. Similarly, all crown roots with their respective branches will be termed the crown root system. The sum total of the

seminal and crown root systems will be known as the <u>entire root system</u>.

The weight in grams required to break a root or a root-branch will be known as its <u>tensile strength</u>. The total weight in grams required to break the roots and their branches passing through one cubic centimeter of soil will be termed the <u>soil-binding equivalent</u> of the species producing these root structures.

The volume of soil occupied by the root system where branches of the second and higher orders are found will be referred to as the main working area of the root system (54, 55 and 62). The volume of soil penetrated only by undifferentiated ends of branches of the first order and the branchless ends of the main root will be designated as the zone of primary absorption.

This study was pursued throughout a period of seven years (1933 to 1939, inclusive). It includes examination of the roots of <u>Agropyron cristatum</u> (L.) Beauv., <u>Agropyron pauciflorum</u> (Schwein.) Hitchc., and <u>Bromus inermis</u> Leyss. and a quantitative determination of the soil-binding qualities of the roots of certain native and cultivated grasses, and alfalfa. A study of the effect of root fiber of certain grasses upon soil structure was also made, and the use of perennial forage grasses in rotation with grain crops for control of common annual weeds was investigated. The three cultivated grasses were studied in Canada and the seven

native prairie grasses, winter wheat, and alfalfa in the United States.

ENVIRONMENT

The climate of Saskatoon, Saskatchewan, supports mixed prairie vegetation. Over 50 per cent of the average annual precipitation (13.5 inches) falls during the growing season. Temperature of the air fluctuates between -40° and 103°F. The mean temperature during the growing season (April to November) is 53.3°F., the average maximum 85.7°, and the average minimum temperature 25.4°. Winds are frequent, particularly in spring, and reach velocities of 30 or more miles per hour. This accelerates surface evaporation and transpiration by plants. Periods of severe drought occur frequently, causing low yields or failure of annual grain crops, and temporary dormancy of perennial native and cultivated grasses. Much sunshine from March to September promotes rapid growth of plants if other conditions are favorable. Thus, when precipitation is normal or above, yields of grain and forage are heavy.

The upper 12 to 14 inches of Saskatoon, dark brown, silt-loam soil are rich in humus and have a granular structure. Below this, to a depth of five feet, humus is less concentrated, and the color becomes much lighter. Here the structure is prismatic and the texture fine. A layer of sand, 6 to 10 inches in thickness, occurs about five

feet below the surface. Sometimes two such layers are found separated by 5 to 10 inches of silty clay.

The environment at Lincoln, Nebraska, where most of the native species herein described were studied, is also typically semi arid. Winters are moderately long and cold. The growing season is of 165 to 170 days duration and is characterized by hot summers. The season free of frosts injurious to vegetation generally extends from April 20 to October 10. Average day temperatures in summer reach 90°F. with maximum temperatures frequently rising to 100°F. or more. These high temperatures are detrimental to plants in very dry periods but accelerate development in years with sufficient moisture. Normally, average day temperatures vary from 75° to 85°F., these being 10° or more higher than those for the night. Minimum temperatures of 15° to 20°F. or more below zero occur in winter and the soil freezes to a depth of 6 to 24 inches (58, 60).

In March, April and May the prairie receives approximately 60 per cent of sunshine, but in June, July and August the number of clear days increases to 72 per cent or more. Wind movement is fairly constant and often high, causing high evaporation and low humidity, particularly during periods of drought.

The precipitation varies considerably at different stations in the prairie. At Lincoln the mean annual precipitation over a period of 50 years is 28 inches. From

76 to 79 per cent of the rainfall occurs between April 1 and September 30, which is very favorable to vegetation. Most of the precipitation in summer months occurs in storms accompanied by thunder and lightning. These frequently are of short duration but result in ~~from~~ 1 to 3 inches of rainfall at a time. During very heavy rains (4 to 6 inches in 24 hours) which occur infrequently, the soil is unable to absorb all the water as it falls and runoff is high. Periods of drought are liable to occur at any time, especially after midsummer.

The soils of the true-prairie association belong either to the Prairie or Chernozem groups. Both these great soil groups have dark colored A horizons, yellowish or brownish B horizons, and well developed granular structures. Both are relatively non-acid, unleached, and have ample stores of organic matter and mineral nutrients.

Available water content in the surface 6 inches of soil varies widely and rapidly, sometimes as much as 10 per cent or more during a single week. In deeper strata the fluctuation is much slower and only in very rare cases is the moisture reduced to the hygroscopic coefficient. In the lowland, the moisture content is generally from 3 to 10 per cent higher (58 and 60).

ROOT SYSTEMS OF AGROPYRON CRISTATUM, A. PAUCIFLORUM, AND BROMUS INERMIS

Methods

This study included an investigation of the number of seminal and crown roots per plant of three perennial forage grasses; a quantitative study of entire root systems of spaced plants excavated 5, 15, 30, 60, 90, 660, and 800 days after emergence; and a determination of the amount and distribution of root material produced in sods. All plants, except one lot, were grown under field conditions. This lot was grown in deep sand-boxes in the greenhouse and examined 5 days after emergence. Results thus procured were used only for supplementary information. As many as 78 plants per species were excavated and analyzed in early stages of growth, but only one or two representative specimens were examined during the second and third seasons of growth.

The entire root systems of these plants were exposed by the soil-block washing method (36) (Fig. 1). Roots were preserved in a four per cent solution of formaldehyde and later placed in a large, shallow tank for analysis. The number and extent of seminal and crown roots were recorded separately. Length of all main roots and their branches in smaller plants was determined by actual measurement. Number and length of branches of more mature

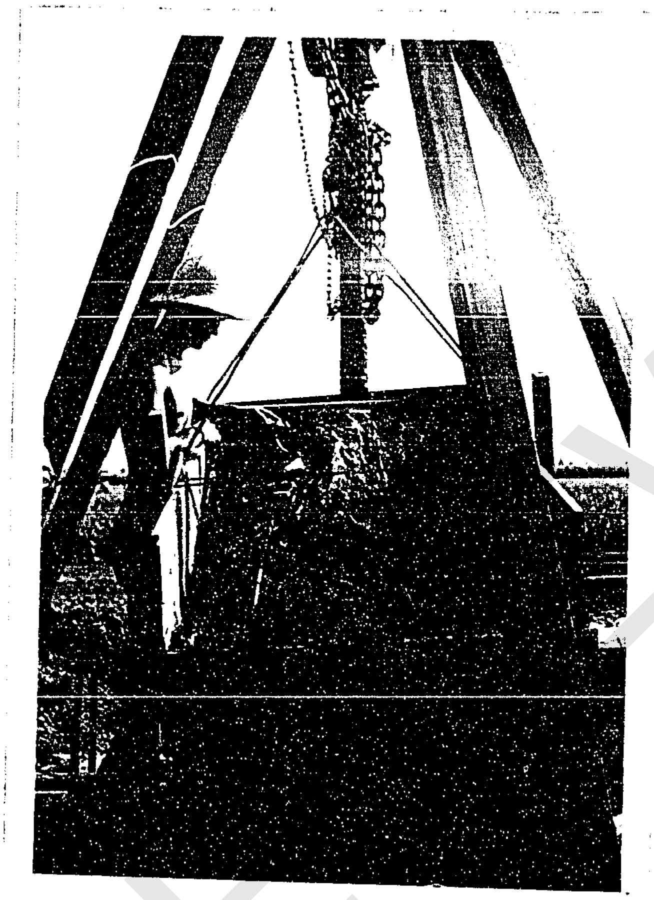

Fig. 1. Block of soil containing one complete root system undergoing washing operation with the fine spray from a fan nozzle. Six to ten days were required to free the roots from two to three tons of earth.

plants were computed from random sample counts and measurements. Beginning at the ground level, the root system was divided into horizontal strata, each 12.5 cm. deep, until the depth of greatest penetration was reached. The average frequency of branches of the first order per centimeter of main root was determined separately at each depth from 250 counts. Length of main roots multiplied by mean frequency of branches gave the number of branches at each depth. Average length of branches of the first order at all depths was determined on the basis of 250 measurements taken at each depth. By multiplying the number of branches at each depth by their respective mean lengths, the total length of all branches at each depth was obtained. The sum for all depths gave the total length of branches of the first order. The number and length of branches of the second and third orders were secured in a like manner, except that the number of branches of each order was computed from their respective mean frequencies and the length of branches of the order which immediately preceded them.

A number of plots, each one rod square, of crested wheat grass, slender wheat grass, and brome grass were seeded on May 20, at rates of 25, 35 and 30 pounds per acre, respectively, in 1933 and in 1935 in order to determine the amount and nature of root fiber deposited by these grasses when grown in sod. When the plots seeded

in 1933 were in their fourth season of growth and those of 1935 in their second season, blocks of sod 30.5 by 76 cm. in surface area but 15, 30.5, and 152 cm. deep, respectively were excavated in triplicate and carefully washed. The extent and nature of the root systems and the dry weights of underground materials were determined. Six-year-old plots of <u>Agropyron cristatum</u> and <u>Agropyron pauciflorum</u>, which had been established in 1927 and grown under similar conditions, were broken in 1934 and the land was sown to grain on May 1, 1937. Four random soil samples 30.5 cm. long by 30.5 cm. wide and 15 cm. deep and four others of the same length and breadth but 30.5 cm. deep were obtained from each sod on June 15 of the same year.

Dead root fiber was separated from the samples by the floatation method. Samples were soaked in water for 24 hours. They were then placed in boxes with sides and bottoms made of screen with .2 mm. mesh and submerged. Clay and silt were washed through the screen by gentle movement of the boxes. Dead fiber, as it rose to the surface, was collected with a large spoon made of similar screen. Larger granules and clods were transferred to similar boxes made of screen with 1 mm. mesh and the procedure repeated. This continued through increasingly larger screens until the last bits of root fiber were separated from the soil. The amount of vegetable matter in each sample was deter-

mined both in oven dry weight and in combustible material.

Seminal Root System

Seminal roots have been erroneously called temporary roots (63). Results obtained in this and similar studies over a period of nine years gave conclusive evidence that, in annual grasses in arid climates, seminal roots function throughout the entire growing season, and, what is more important, they are frequently the only roots supporting the plant from emergence to maturity (35).

The number of seminal roots per plant was generally small. It varied within narrow limits in each species, and apparently was governed by a definite genetic factor. In Avena fatua L., for instance, three seminal roots was the constant number. In Avena sativa L. the average number in different years varied from 3.1 to 3.5; in Triticum aestivum L., from 3.6 to 4.2; in Secale cereale L., from 4.5 to 5.3; and in Hordeum distichon L., from 6.5 to 8.5 (38). Annual grasses with higher numbers of seminal roots were more capable of normal development under adverse conditions than were those with lower numbers (35, 39).

The number of seminal roots per plant was lower in the perennial grasses studied than in the annual grain crops previously named. There were averages of 1.6, 2.6, and 2.4 seminal roots in Agropyron cristatum at 5, 15, and 30 days, respectively, and still fewer in A. pauciflorum (1.5, 1.2,

and 1.1 at the same respective ages). Bromus inermis gave averages of 2.3 in 5 days and 2 at each of the other stages (Table 1).

Table 1. Average number of seminal roots per plant in cultivated forage grasses.

Species	Agropyron cristatum			Agropyron pauciflorum			Bromus inermis		
Age of plants, days after emergence	5	15	30	5	15	30	5	15	30
Total No. plants studied	65	43	28	78	47	21	63	31	12
Average No. seminal roots per plant	1.6	2.6	2.4	1.5	1.2	1.1	2.3	2.0	2.0

Of the seedlings of Agropyron cristatum excavated at the 5-day stage, 55.5 per cent had only one seminal root, 33.8 per cent developed two roots, and 10.7 per cent had three roots (Table 2). Plants with one and two roots were normal, but those with three roots were very weak. At 15 days, most of the healthy plants had two roots. Those with one or three roots, and particularly those which later gained the fourth root, were weak. At 30 days, those with one root had disappeared, a few plants with three roots were gaining strength, and those with four roots were dying. Only the plants with two roots were vigorous.