THESIS

on

NODAL ROOT DEVELOPMENT OF CERTAIN VARIETIES OF WHEAT AND THE EFFECT OF CULTURAL PRACTICES UPON THE DEPTH AT WHICH THEY FORM

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NODAL ROOT DEVELOPMENT OF CERTAIN VARIETIES OF WHEAT AND THE EFFECT OF CULTURAL PRACTICES UPON THE DEPTH AT WHICH THEY FORM

INTRODUCTION

The underground portion of plants, on the whole, has been grossly neglected in scientific research as compared with the tops or the easily examined parts of plants. In the words of Knight (11), "The progress which has been made in the investigation of the physiology of the root system of the plant is very slight when compared with the knowledge which we possess with reference to the rest of the plant. The reason is not far to seek. It is not that the importance of the root system is not recognized, but rather that the difficulties of manipulation are much more formidable when working with roots than in investigations of aerial parts. The presence of such a complex medium as the soil is always a disturbing factor, unless the plants are grown for example, in water-culture, and under these circumstances there may always be urged the objection that the behavior of a plant in water-culture is not necessarily a criterion of what its reaction would be under normal conditions of growth. It is doubtless due to such considerations as these that our knowledge of root physiology is so meagre." Until the work of Weaver (23,25) and others who followed his example, little or nothing was known concerning the parts of many plants below the surface of the ground. Most of the work, done thus far by any investigators working with root systems or root development, has been to determine the extent and perhaps the adaptability of various root systems.

Extensive work on the extent and variation in root systems of cultivated crops has been carried on during the last ten or twelve years. Much of the work has centered around the question of just how climatic factors vary the extent and type of roots and whether or not the plant will change its rooting habit to most profitably use the conditions presented to it. Do dry conditions increase, decrease, or change the horizontal or vertical extent of plant roots? What affect on root systems do different fertilizers have? Does soil texture or soil aeration have anything to do with root formation? How efficient are roots in drawing moisture from the soil? If above conditions vary the root systems of plants are the tops affected proportionally? These and many other questions have been studied and answered more or less satisfactorily. Considerable work of this type has been carried on with cereals.

Little is known of the early root formation while the cereal plant goes from the one leaf stage through the stooling period. It is well established that cereals first produce a temporary or seminal root system which forms at the seed and continues to function as the absorbing system until the secondary or permanent roots are developed when, in some cases, the secondary roots take up the burden of absorption while in other cases they merely share it with the roots already functioning.

It was observed by Superintendent D. E. Stephens and others at the Moro experiment station that spring wheat under extremely dry conditions often existing in the Columbia Basin, did not form permanent roots, but was able to produce part of a crop on seminal roots alone. Under conditions of adverse weather in the fall and a lack of moisture in the spring, even winter wheat occasionally matured with no secondary root formation. Usually under such conditions some varieties were able to form at least part of a secondary root system. This apparent varietal variation in formation of secondary roots was then temporarily associated with another observation, that of varietal variation in the depth at which these roots formed. If one variety sent its nodal or secondary roots out into the soil at a lower depth, it was possible that moisture conditions at this lower level would be such that normal root growth could take place.

With these two observations in mind and the possibility of a relation between them as well as a belief that many environmental factors had their influence upon permanent root development, these studies herein presented were undertaken in the spring of 1931. The purpose of these studies was first, to determine the variation of early secondary root development among certain wheat varieties especially the varietal variation of crown depth, and second, to determine the effect of some cultural and environmental factors upon the depth of the crown and the development of secondary roots in a few wheat varieties. The cultural factors studied were depth and date of planting. The environmental factors studied were temperature, as affected by date of planting, moisture and light.

These studies were started without knowledge of the fact that similar investigations had been made by Tavcar (21) and Friedberg (4) in Germany. Several factors, in addition to those studied by these workers, which influence the secondary root development in wheat were investigated. The results herein presented were obtained under different climatic and environmental conditions.

The secondary roots referred to in this study are the permanent, nodal or coronal roots which normally arise somewhere between the seed and the surface of the soil at a node which eventually becomes the crown of the wheat plant. This crown is the point at which tillers as well as nodal roots arise.

Throughout the investigation of this problem observations were made for which it was impossible to obtain substantiating data. These are presented only as observations and are brought into the discussion as possible explanations for some of the results obtained in these studies.

REVIEW OF LITERATURE

J. E. Weaver (23) in his extensive work on root systems of plants and particularly of cultivated crops gave us our first definite idea of the extent and variation in root systems. In elaborate and laborious studies in which he washed the soil from entire root systems with the aid of small picks, he was able to obtain the root systems of mature plants as they actually exist in the field for close examination and was able to make valuable photographs. In his work on cereal plants a few observations were made which have a direct bearing upon the present discussion. He established the fact that root development coincides with the development of above ground parts, and that secondary root development began with the appearance of tillers. He also emphasized the fact that varieties within a species varied in their root development and that root systems were able to adapt themselves to various environments.

Percival (16) has undoubtedly made one of the most extensive studies of the whole wheat plant and in his monograph, "The wheat plant", is probably the best illustrated description of this plant. Considerable study of the two root systems was made, and a discussion of factors influencing their formation and extent in the soil is given. Several workers have given us information concerning seminal root development and still others have studied the relation of the seminal or temporary root systems to the permanent root systems of cereal plants. Such observations are of interest since they have an indirect bearing upon the subject in hand. Janssen (10) found that all new roots in the spring developed from the crown of the plant and not from old roots as has been commonly assumed. He also believed that old roots may be cut away without greatly harming formation of new roots.

Cannon (2) in an extensive study on root growth found that aeration and temperature as well as soil depth, soil moisture and exposure of the plants greatly affected the extent of the roots in the soil.

Walworth and Smith (22) found that varieties of cereals differed to some extent in the number of temporary roots formed. They observed that within a variety of wheat the number of temporary roots varied from two to six and that between varieties the mean number of roots from 100 to 400 seedlings, varied from 2.2 to 3.6. Harris (9) in a study of seminal root development in barley and wheat found that varieties varied considerably as to the number of temporary or seminal roots produced. He also found differences within a variety depending upon the size of the seed. While the agreement was not exact, large kernels had a tendency to produce more plants with greater numbers of seminal roots than the small kernels. From his results with wheat he found that for the conditions under which he worked four to five seminal roots per plant was a closer average than three, as most investigators record. He found the greatest variation in the vulgare, durum and poulard wheats.

Wiggans (26) in an early study of the cereals gives the following description of their root formation:

"Seeds upon germination first send out what is known as the radicle and a very short time later the plumule appears. The plumule develops into the stem while the radicle is the first and most important temporary root. Next appears whatever other temporary roots that develop, the number varying from none to twelve. Later the permanent roots appear, forming a whorl at the first node, which is usually about an inch below the surface of the soil. The temporary roots during their short period of existence function in the same way as the permanent roots. As the permanent roots develop the temporary roots slowly disappear, as they no longer function in the development of the plant."

Wiggans found in his study of corn that different varieties varied in the number of seminal roots from a mean of 1.52 in flint corn to 6.07 in the dent corn. In einkorn and emmer wheat he found that the highest percentage of kernels produced five seminal roots instead of three as has often been reported.

Many investigators have stated or implied in their conclusions on root study that the seminal roots are only temporary, as the name by which they are often designated implies. However other investigators in this field, notably Krassousky (12) and Kravtsov (13), dispute this point emphatically and at some length as they believe that the temporary root system of cereals lives and functions until the death of the plant. In the words of Krassousky, "There seems to be full agreement among the investigators in this field that the primary root systems function only temporarily, and gradually die off when the nodal root systems develop. The question, however, is far from settled, especially in plants like corn and sorghum." She finds that nodal or permanent roots increase until the time of heading and flowering of the tillers. However, the seminal roots continue to function but their maximum activity is at a period somewhat in advance of that of the permanent roots. It was also determined for the first time by Miss Krassousky that salt absorption continued in the seminal roots throughout the vegetative period of wheat reaching its maximum near the time of heading when the main stem attains its maximum growth, and that maximum absorption by the nodal roots coincides with maximum growth of the tillers, implying that the seminal roots serve principally the main stem and the nodal roots the tillers. In further studies she found that if the seminal roots were cut from the plant the main stem suffered the most, whereas if the nodal roots were cut off the tillers were less in number and not so tall or vigorous in growth. Some adjustment was made by the plant, but neither could entirely replace the other. She also noted that while the removal of the seminal roots decreased the yield of grain, the removal of the nodal roots decreased principally the yield of straw.

Kravtsov (13) states that primary roots under natural conditions remain alive until growth ceases and may supply moisture to the whole plant during the ripening period when the upper soil layers are dry. Secondary root systems depend on the moisture of the surface soil for their appearance and development, and in years of drought the crop is produced essentially from the activity of the primary roots.

Such observations have also been made by the author in dry farm areas where spring wheat planted fairly deep would germinate during drying weather and by the time for normal permanent root formation the soil at the depth of the crown would be too dry, and even though a rain did not come later, a partial crop at least would be produced by the seminal roots. However, if rain came at any time later in the development of the plant rapid secondary root growth took place. Further observations of this type were made by Locke and Clarke (14) under abnormal conditions at Nephi, Utah and Woodward, Oklahoma, when the permanent roots did not form or were delayed in forming by dry crusts or dry surface soil. The crops were produced by seminal roots.

The common opinion among most investigators including Carleton (3), Robbins (19), Locke and Clarke (14) and Rabomnova (18) is that the secondary root system is formed at a certain depth below the surface no matter how deep the seed is planted. This is thought to be about one-half ($\frac{1}{2}$) to one inch below the surface at the ground. (In terms of the measurements used later in this paper about 12 to 24 millimeters). They believe that since seminal roots are formed at the seed, they will vary in depth according to depth of planting, but that permanent or coronal root formation is independent of depth of planting. Robbins states that permanent roots are formed at a depth of one inch below the surface. Locke and Clarke give this description of secondary root formation, "-----The second, the coronal or permanent roots, arise from the crown usually just below the surface of the ground. The distance between the seed and the crown varies with the depth of planting. When seeds are sown near the surface the crown is formed at or but little above the seed. When seeds are sown deeply, the plumule is pushed upward and the crown still is formed near the surface. That part of the plant between the seed and the crown is the mesocotyl, an underground stem which has been called the subcoronal internode. Under field conditions this may vary from less than one inch to three or four inches in length and has about the diameter of a pin." Percival (16) was unable to find a relation between depth of planting and depth of permanent root formation.

Contrary to the views of these and many other investigators is the view of Friedberg (4) and Tavcar (21), who believe that the depth of tillering varies with varieties as well as with differing environmental factors such as depth of planting, amount of light available to the plant and temperature. Friedberg says, "The current opinion that the tillering node of wheat varieties is formed at a uniform distance from the soil surface is erroenous. For a given variety the depth of the tillering node increases with the depth of planting; at an equal planting level different wheat varieties form their tillering node at different depths. The position of the node is a varietal character and is influenced by environmental conditions, particularly by the light during the early development of the plant."

Tavcar finds that the depth of the growing point is dependent on environmental factors as well as depth of planting. He also believes that the strength of light and the mean temperature modify the depth of the growing point. Bayles (1) in a preliminary study on the effect of temperature on depth of crown in some 30 spring and winter wheats, found that the warmer the temperature the shallower the crown. He also was able to find some relationship between depth of crown and winter hardiness. Govorov (6) in a study on characteristics of winter and spring forms of cereals in relation to winter hardiness found a connection between a greater hardiness in winter varieties and a deeper development of the tillering node below the soil surface. Friedberg (4) and Tavcar (21) also found in their studies that the depth of the crown or growing point of cereals determines to a certain extent the winter hardiness of the plant. Worzella (27) in a recent investigation on root development of hardy and non-hardy varieties of winter wheat, found that the more hardy varieties sent their roots obliquely or straight downward, while the more tender varieties rooted more horizontally.

Weaver and Himmel (24) and Maximov and Lebedincev (15) working on the effect of light on root development determined that longer day illumination or stronger light increased root development in cereals.

Weaver and Himmel (24) and Maximov and Lebedincev (15) in studies on the influence of light on root development found that root formation in most cases was much more extensive under long day illumination or under more intense light, although different plants varied considerably as to the way long and short illumination affected them. Tavcar (21) and Friedberg (4) both found that light intensity influenced the depth of crown in wheat plants. Friedberg says, "The position of the node is a varietal character and is influenced by environmental conditions, particularly by the light during the early development of the plant." Tavcar states, "The light stimulus of course has an influence on the position of the vegetative node. According to Schellenberg, the growth-arresting light stimulus affects the coleoptile in oats and the first foliage leaf in wheat, rye, and barley, and is transmitted to the basal portions of the axis. According to Kossowitsch, the plants tiller closer to the surface of the soil when the seed germinates in cloudy weather and deeper when it germinates in sunny weather." Tavcar in his own studies was able to substantiate the results of these investigators.

EXPERIMENTAL METHODS

These investigations did not entail elaborate and expensive apparatus, but as data were obtained it became apparent that several environmental factors must be taken into consideration in analyzing the results. Care and accuracy were of great importance throughout the whole study because of the fine measurements made and because of the small variation with which it was often necessary to work.

The equipment used in this work was, a sharp knife or pair of shears with which the tops of the plants were cut even with the ground, a garden spade to dig up the remainder of the plants, some paper bags in which to place the underground portion of the seedlings, and a short metric rule used to measure the depth of the crown and the seed below the surface of the ground.

The wheat plants used in this study were grown in the field and in small flats at Moro, Oregon, in 1931 and 1932, and in the field and the greenhouse at Corvallis, Oregon, in 1932 and 1933. The main varietal variation studies were made at Moro in 1931 and 1932 from the regular winter and spring wheat plat trials carried on at the experiment station. The environmental and cultural studies were also carried on at this time and continued at Corvallis in 1932 and 1933.

Varieties of spring and winter wheat were grown under different environmental conditions. Any time after secondary root formation, which takes place normally from two to four weeks after emergence, the plants were handled in the following manner: The tops were cut even with the ground with a sharp knife or pair of shears and the remainder of the plants were dug. If weather permitted, measurements were made in the field as the plants were dug. Often it was more convenient to place the plants in paper bags and make measurements and other observations later. Only the distance from the surface of the ground to the crown was measured at first, but later as it became apparent that depth of seeding varied the depth of this crown, the distance from the crown to the seed, the subcrown internode, was also measured. Measurements were made in millimeters. The average of at least 50 plants and usually many more was secured before any reliance was placed in the results. During these studies approximately 100,000 plants were handled in this manner.

In several trials the wheat was planted to an exact depth, but in the majority of cases the planting depth was only approximate. An examination of the depth of the seed and the depth at which the crown and permanent roots formed gave the relationship between depth of planting and depth of crown.

Severe winter killing took place in the winter of 1932-33 and most of the material planted in the field in the fall of 1932 was killed. Since that season was the last in which to obtain data for some phases of the problem, these are necessarily discussed with only a limited amount of supporting data.

The presentation of the data and the discussion of these studies cannot be clearly understood without a knowledge of some terms used therein. The temporary or seminal roots are those which form at the seed shortly after germination and carry the plant until the permanent roots begin to function. The secondary, permanent, nodal or coronal roots are those which form at a node somewhere between the seed and the surface of the ground. This node is called the crown or growing point of the wheat plant. The portion of the underground stem between the crown and the seed is called the mesocotyl or subcrown internode.

EXPERIMENTAL DATA

Varietal Variation in Depth and Time of Permanent Root Formation

Winter Wheat

In 1931 fifty plant lots were examined at nine different times from three sections of the winter wheat plats making in all a count of 450 plants for each of the 25 varieties. Table 1 gives the average for depth of the crown for each 50 plant lots as well as the maximum, minimum and average depth of the crown and the average depth of the seed for the 450 plants. Fortyfold sel. 43, a soft white winter wheat, had the deepest crown with an average of 54 millimeters or about $2\frac{1}{4}$ inches below the surface of the ground. Argentine and Oro, two turkey wheats, formed their crowns but little shallower with an average of 51 and 49 millimeters in depth respectively. Federation, a soft white spring wheat, often sown in the fall produced the shallowest crown by over 10 millimeters. It averaged only 24 mm. or less than one inch in depth. (Fig. 1) All of the turkey and the more winter hardy varieties of wheat produced their crowns or nodal roots at comparatively lower depths in the ground. More will be said later of the relative hardiness of these varieties. The last column of Table 1 gives the depth at which the seed was sown. While there is some slight variation in depth of planting the greatest difference, that between Argentine and Federation, is less than one-half inch.

The variation between the averages of the fifty plant counts may be due partly to the place in the long plats from which the plants were taken. Part of the counts were made from plants at one end of the plats

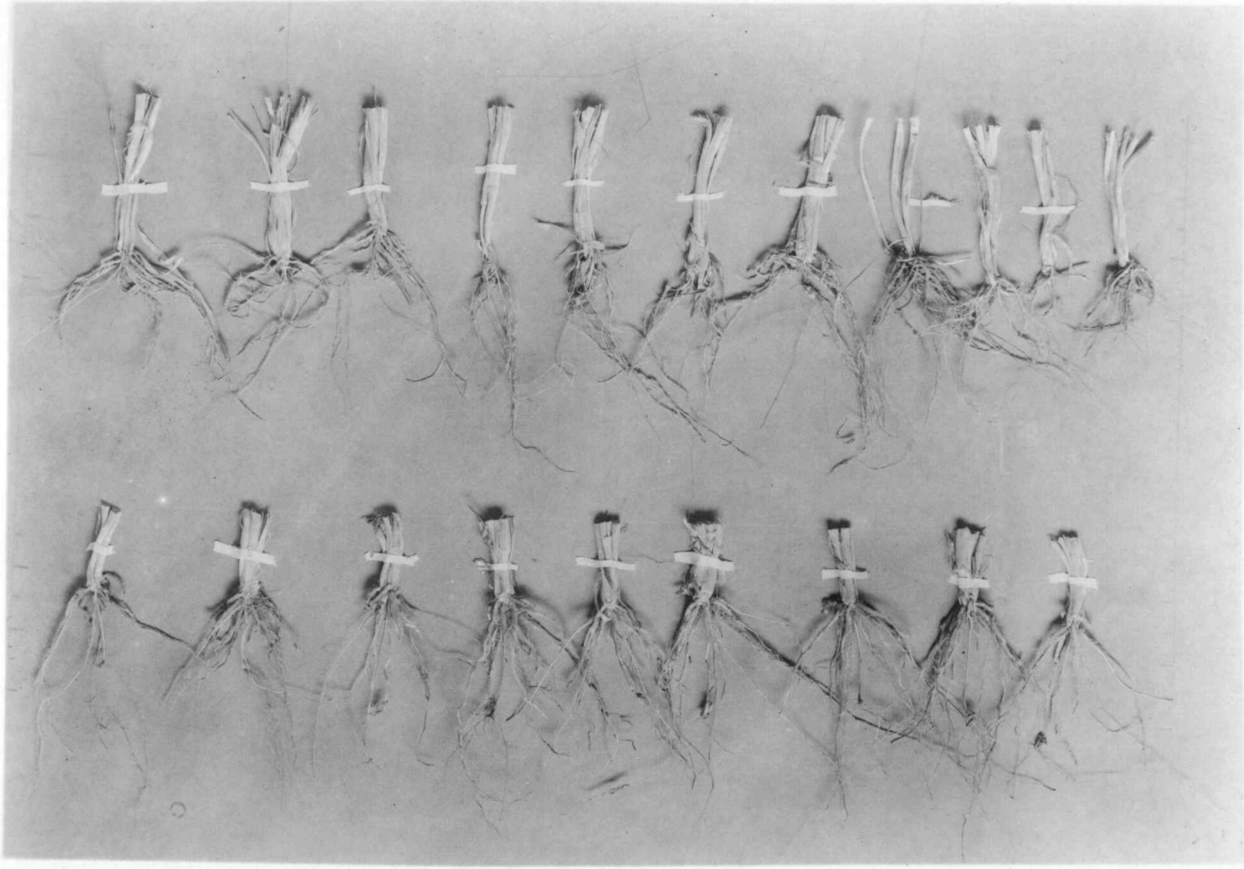

Fig. 1. Variation in crown depth of wheat varieties planted at approximately the same depth. Argentine at the top and Federation below.

Table 1. Depth of crown in millimeters in 25 winter wheat varieties at Moro, Oregon in 1931.

C.I. or		Ave. depth of crown for each 50 plant lot									Depth of crown for 450 plants			Depth of seed for
Nur.No.	Variety	1	2	3	4	5	6	7	8	9	Max.	Min.	Ave.	200 plants
10063	Fortyfold sel. 43	58	52	61	50	50	56	55	52	56	80	33	54	62
10061	Argentine	54	47	61	44	48	55	55	50	46	90	38	51	63
8220	Oro	49	46	54	47	43	50	49	54	46	80	30	49	60
4429	Turkey (local)	45	49	55	45	43	51	48	41	45	77	24	47	58
	Turkey (N. Powder)	49	42	53	41	41	49	47	51	49	78	25	47	60
8249	Kharkof	49	45	52	40	42	48	47	47	46	79	30	46	61
5146	Kanred	44	45	52	42	40	46	49	50	42	75	27	46	60
11424	Turkey sel.	42	39	49	42	44	49	48	48	52	75	25	46	60
5408	Triplet	51	43	49	44	42	46	49	44	46	71	27	46	55
10066	Hybrid 128 x Fortyfold	48	43	52	39	39	46	48	52	43	75	26	46	58
1571	Turkey	44	40	48	45	43	46	44	41	44	69	25	44	58
8246	Arco	46	34	50	41	41	41	45	45	42	76	20	43	58
1442	Kharkof	37	42	49	36	38	44	45	35	43	71	25	41	57
979	Arcadian x Hard Fed.	40	39	45	45	38	48	41	43	38	60	18	41	56
10062	Fortyfold sel. 29	39	39	47	33	37	41	45	42	44	65	25	41	61
10064	Fortyfold sel. 54	44	41	43	37	33	43	43	45	42	70	23	41	62
6703	Ridit	31	36	45	39	35	47	43	40	45	78	18	40	61
10065	White Odessa x Hard Fed.	38	34	41	35	39	44	39	44	43	60	20	40	60
4512	Hybrid 128	44	41	43	33	33	43	41	43	43	60	20	40	58
8247	Fortyfold x Federation	35	37	43	36	36	32	40	39	36	65	20	38	56
4655	White Odessa	36	33	45	34	32	38	40	40	38	65	17	37	57
930	Kanred x Marquis	38	33	39	29	32	44	39	40	39	69	21	37	61
964	Fortyfold x Hard Fed.	36	29	42	35	33	41	38	37	35	60	18	36	56
8244	P1068 x Preston	35	30	41	36	32	41	39	35	35	70	21	36	59
4734	Federation	21	21	22	27	27	25	24	25	24	35	8	24	52

which sloped gently to the south, others were made from the center of the plats where the ground is level and still other counts were made at the other end of the plats where there was a slight north slope to the land. Perhaps the difference in the temperature of the soil in these different places would account for some of the variation.

In the columns headed "max." and "min." in Table 1 are given the deepest and shallowest crown found in 450 plants for each variety. Plants were found with crowns formed 90 mm. or more than $3\frac{1}{2}$ inches below the surface of the ground; likewise, some plants were found with crowns nearly at the surface. Wide variation occurred within a variety. Some of this variation may be accounted for by the fact that the varieties were not pure lines nor hand selected seed, thus slight mixtures may have caused the wide variation in single plants.

The depth of the crown and the seed for 350 plants of each of these twenty-five varieties grown at Moro in 1932 is given in Table 2. The first thing that is noticed in comparing the 1931 and 1932 results is that none of the varieties produced their crowns as deep in 1932 as in 1931. The variety having the deepest crown in 1932 was Argentine which was next to the deepest in 1931. Its crown depth in 1932 was somewhat shallower than in 1931. While there are a few exceptions, on the whole, the varieties ranked in about the same relative order in 1932 with Federation again producing its crown and nodal roots closer to the surface of the ground than any other variety. The only difference in the weather about the time of nodal root formation between the two years was possibly the amount of sunshine. Cloudy weather was prevalent during the crown and root formation period of 1932, while clearer weather

Table 2. Depth of crown and seed from the surface in mm. of 25 winter wheat varieties grown at Moro, Oregon, in 1932.

C.I. or Nur. No.	Variety	Average of 350 plants Crown	Seed
		mm.	mm.
10061	Argentine	46	59
8220	Oro	43	60
	Turkey (N. Powder)	41	62
5146	Kanred	39	59
10063	Fortyfold sel. 43	39	60
10066	Hybrid 128 x Fortyfold	38	64
8249	Kharkof	38	60
4429	Local Turkey	37	64
6703	Ridit	36	61
8244	P 1068 x Preston	36	60
10064	Fortyfold sel. 54	36	56
1571	Turkey	36	60
5408	Triplet	35	62
1442	Kharkof	35	60
10065	White Odessa x Hard Federation	34	66
11424	Turkey sel.	34	63
8246	Arco	33	65
10062	Fortyfold sel. 29	33	64
4655	White Odessa	32	60
4512	Hybrid 128	32	57
8247	Fortyfold x Federation	31	57
979	Arcadian x Hard Federation	31	59
964	Fortyfold x Hard Federation	26	69
930	Kanred x Marquis	25	65
4734	Federation	22	60

was predominant during a like period in 1931.

Late in the fall of 1932 four wheat varieties were planted in the field at Corvallis. Crown and nodal root formation did not take place until in the winter of 1932-33. During this winter two of these varieties planted in the field. Table 3 shows that Oro and Fortyfold sel. 43 produced their crowns deeper than Hybrid 128 and Federation as was the case in 1931 and 1932. In the green house the varieties, due probably to the warm conditions, produced their crowns closer to the surface of the ground, but ranked in the same relative order as to depth of crown.

Subsequent to the 1931 winter wheat crop, it seemed impossible to get a planting of winter wheat that produced crowns and formed nodal roots so deep in the soil. It seemed that perhaps some unusual condition had existed which had caused the deep formation of the crown and the roots, but in a late fall planting in the field at Corvallis in 1932, similar results for one variety were obtained. Several varieties had been planted and had just about reached the stage for crown development when the cold weather of the winter of 1932-33 set in. The weather was so severe that most of the varieties froze out, but three plantings of Oro, a turkey wheat, survived and counts were obtained as to crown depth. In one planting the grain was sown too shallow and node and root formation took place at the seed. In another planting along with the first one for an average of 50 plants the crown formed at 54 mm. and the seed was 65 mm. in the ground. The other planting was under slightly different conditions and produced crowns at an average depth of 46 mm. with about one-fourth of the plants producing a second deeper node at 59 mm. The seed was planted at 62 mm.

Table 3. Depth of crown and seed in millimeters in wheat varieties grown in the field and in the greenhouse at Corvallis, Oregon, 1933.

C. I. No.	Variety	In field, depth in millimeters to: Crown, Per 50 plants			Crown, Ave.	Seed, Per 50 plants			Seed, Ave.	In greenhouse, depth in millimeters to: Crown, Per 50 plants			Crown, Ave.	Seed, Per 50 plants			Seed, Ave.
10063	Fortyfold sel. 43	38	41	40	40	61	58	58	59								
8220	Oro	37	42	40	40	59	56	62	59	33	29	26	29	63	57	58	59
4512	Hybrid 128	30	33	32	32	61	55	57	58								
4734	Federation	25	22	26	24	59	62	60	60	17	15	19	17	58	56	61	58

Spring Wheat

Seven different counts of fifty plants each were made of the thirteen spring wheat varieties grown in the plat trials at Moro in 1931. The counts were made at different times during the secondary root formation of these varieties and on the first five dates the number of plants that had well formed nodal roots was recorded. Those that had not started rooting yet had formed the node or crown so that its depth could be measured anyway. The node is usually apparent about six to eight days before the nodal roots commence to form.

Table 4 gives the depth of the crown and seed for seven counts of 350 plants and the per cent of plants having formed roots for the first five dates. The variation in depth of crown between spring wheat varieties is only slight and in all cases the crown was formed shallow, about 25 to 30 millimeters below the surface of the ground. The same varieties, except for Baart x Federation, C. I. No. 8252, which was dropped from the plat trials, were examined in 1932. Two hundred plants from each variety were measured for depth of crown and seed and a record made of their secondary root development. The data as presented in Table 5 show little variation in depth of crown in the 12 spring wheats. The average depth varied only from 22 to 27 millimeters.

Considerable difference in the rate at which permanent roots are formed in the spring wheats was found as is shown in Tables 4 and 5. Federation and Onas, two high yielding spring wheats, formed their roots somewhat earlier than other spring wheats in this trial. Of the 250 plants of each variety examined on five different dates in 1931, 90 per cent of the Federation plants and 82 per cent of the Onas plants

Table 4. Depth of crown and seed for 350 plants and per cent of plants having permanent roots on five dates in spring wheat varieties at Moro, Oregon, in 1931.

C. I. No.	Variety	Depth of crown in mm. per 50 plants								Ave.	% of plants with permanent roots per 50 plants*					
		5/2	5/5	5/6	5/8	5/22	6/17	6/19	Ave.	Depth Seed	5/2	5/5	5/6	5/8	5/22	Ave.
4733	Hard Federation	26	26	29	25	23	28	28	26	57	16	34	44	56	60	42
4981	White Federation	24	26	25	24	25	28	26	25	55	36	70	56	72	64	60
8255	Hard Federation sel. 31	27	28	27	28	26	27	27	27	58	28	56	66	66	70	57
8256	Hard Federation sel. 71	27	28	27	27	25	29	29	27	56	32	36	50	68	50	47
	Hard Federation sel. 79	24	28	30	28	22	30	27	27	57	28	40	58	68	62	51
	Hard Federation sel. 82	28	26	27	27	24	26	28	27	57	48	52	70	66	50	57
4734	Federation	27	28	27	29	24	26	25	27	57	88	88	92	94	88	90
6221	Onas	26	29	26	29	23	27	29	27	50	86	76	80	82	84	82
8254	Baart x Federation	27	27	29	27	26	28	29	28	52	28	58	74	68	66	59
1697	Baart	29	29	29	29	26	28	28	28	53	30	64	70	66	68	60
4158	Marquis	33	33	30	32	27	30	32	31	53	52	72	70	66	56	63
4067	Pacific Bluestem	30	28	32	31	29	28	31	30	54	40	72	76	70	78	67

*Roots counted only when well developed.

Table 5. Depth of crown and seed and the per cent of plants having permanent roots on four dates in spring wheat varieties in 1932.

C. I. No.	Variety	Depth of crown in mm. per 50 plants 5/3	5/5	5/9	5/11	Ave.	Ave. Depth of seed	% of plants with permanent roots per 50 plants 5/3	5/5	5/9	5/11	Ave.
4733	Hard Federation	26	22	22	21	23	60	23	71	80	62	59
4981	White Federation	24	23	20	21	22	61	37	46	82	89	64
8255	Hard Federation sel. 31	26	20	19	21	22	59	47	13	61	85	52
8256	Hard Federation sel. 71	24	21	20	21	22	57	11	32	71	62	44
	Hard Federation sel. 79	26	24	22	21	23	65	18	15	64	89	47
	Hard Federation sel. 82	25	24	20	21	23	57	22	29	62	85	50
4734	Federation	28	24	21	23	24	60	57	46	88	93	71
6221	Onas	26	26	22	23	24	59	60	47	89	83	70
8254	Baart x Federation	31	24	22	23	25	58	17	14	75	71	44
1697	Baart	28	26	21	23	25	58	31	36	63	37	42
4158	Marquis	29	30	25	22	27	58	31	26	57	79	48
4067	Pacific Bluestem	28	26	21	25	25	58	65	88	94	90	84

had formed their roots. The percentage of plants in these two varieties which had permanent roots on May 2 was already higher than was found in any other variety on May 22 as is shown in Table 4. Pacific Bluestem and a selection from a hybrid between Baart and Federation ranked next in order while Hard Federation had produced roots on only 42 per cent of the plants examined.

Similar results were obtained in 1932, Table 5, although not as conclusive as those of 1931. Pacific Bluestem produced 84 per cent, the highest percentage of plants with well developed nodal roots. Federation and Onas produced 71 and 70 per cent of their plants with nodal roots. An average for the two years of the 450 plants counted for the three varieties producing the highest percentage of well developed nodal roots is as follows: Federation 82 per cent, Onas 77 per cent, and Pacific Bluestem 75 per cent. For the other 9 varieties the percentage of plants with nodal roots for the two years averaged between 46 and 62 per cent.

The varietal variation in depth of crown for the two years for both winter and spring wheat varieties is summarized in Table 6. The average column in this table represents the depth of crown and seed in 800 plants for each fall sown wheat and 550 plants for each spring sown variety. The average depth of crown for the fall sown wheats varied from 23 millimeters for Federation to 49 millimeters for Argentine, a hardy turkey wheat. The average depth of crown for the spring sown wheats varied only from 24 millimeters for White Federation to 29 millimeters for Marquis. Except for Federation, a spring wheat often sown in the fall, all the winter varieties produced crowns

Table 6. Depth of crown and seed in 25 fall sown and 12 spring sown wheats grown at Moro, Oregon, in 1931 and 1932.

C.I. or Nur. No.	Variety	Results,1932 Depth in mm. Crown	Seed	Results,1933 Depth in mm. Crown	Seed	Average Depth in mm. Crown	Seed
Fall sown wheat							
10061	Argentine	51	63	46	59	49	61
10063	Fortyfold sel. 43	54	62	39	60	47	61
8220	Oro	49	60	43	60	46	60
	Turkey (N. Powder)	47	60	41	62	44	61
5146	Kanred	46	60	39	59	43	60
4429	Turkey (local)	47	58	37	64	42	61
8249	Kharkof	46	61	38	60	42	61
10066	Hybrid 128 x Fortyfold	46	58	38	64	42	61
5408	Triplet	46	55	35	62	41	59
11424	Turkey sel.	46	60	34	63	40	62
1571	Turkey	44	58	36	60	40	59
10064	Fortyfold sel. 54	41	62	36	56	39	59
1442	Kharkof	41	57	35	60	38	59
6703	Ridit	40	61	36	61	38	61
8246	Arco	43	58	33	65	38	62
10065	White Odessa x Hd. Fed.	40	60	34	63	37	62
10062	Fortyfold sel. 29	41	61	33	64	37	63
8244	P 1068 x Preston	36	59	36	60	36	60
4512	Hybrid 128	40	58	32	57	36	58
979	Arcadian x Hd. Fed.	41	56	31	59	35	58
4655	White Odessa	37	61	32	60	35	61
8247	Fortyfold x Federation	38	56	31	57	31	57
964	Fortyfold x Hd. Fed.	36	56	26	69	31	63
930	Kanred x Marquis	37	61	25	65	31	63
4734	Federation	24	52	22	60	23	56
Spring sown wheat							
4158	Marquis	31	53	27	58	29	56
4067	Pacific Bluestem	30	54	25	58	28	56
1697	Baart	28	53	25	58	27	56
8254	Baart x Federation	28	52	25	58	27	55
6221	Onas	27	50	24	59	26	55
4734	Federation	27	57	24	60	26	59
	Hd. Federation sel. 82	27	57	23	57	25	57
	Hd. Federation sel. 79	27	57	23	65	25	61
8256	Hd. Federation sel. 71	27	56	22	57	25	57
8255	Hd. Federation sel. 31	27	58	22	59	25	59
4733	Hard Federation	26	57	23	60	25	59
4981	White Federation	25	55	22	61	24	58

deeper in the ground. The more hardy varieties are at the top of the list which means that their crowns are formed deeper than the more tender varieties.

Crown Depth as Affected by Date of Seeding

The variation between the depth of the crown of winter and spring wheat thus far studied was from material planted at different dates. Although most of the winter wheat did not form its nodal roots until early in the spring, the date of planting and the conditions under which the grain germinates undoubtedly influences the crown depth. Field plats of Federation, C. I. No. 4734, fall planted, showed a shallower crown than did similar plantings made in the spring. In the spring of 1931, on May 14, two winter and three spring wheats were planted in small flats in which the grain was planted to a measured depth of three inches, or 76 millimeters. The plants were dug on June 24 and another planting made in these flats on July 1 which were dug on August 12. The spring was quite cool and the first planting in May behaved much as these varieties had in the earlier plantings in the field, while in the planting on July 1 a radical change took place and the crowns in all of the varieties were formed much nearer the surface of the ground. The results are presented in Table 7.

The two winter wheats, Argentine and Fortyfold sel. 43, produced their crowns much deeper in the ground than the three spring wheats. All the varieties formed shallower crowns from the July and from the May planting; more about this will be discussed under date of planting.

Table 7. Depth of crown and seed in millimeters of 5 wheat varieties grown at two dates in the late spring of 1931. *

C. I. No.	Variety	Planted May 14. Crown per 50 plants				Ave.	Ave. Seed Depth	Planted July 1 Average of 100 plants Crown	Seed
		mm.	mm.	mm.	mm.	mm.	mm.		
10061	Argentine	52	56	52	53	53	76	31	75
10063	Fortyfold sel.43	51	48	47	51	49	76	22	74
4734	Federation	31	31	31	31	31	76	12	76
1697	Baart	26	27	28	27	27	76	12	73
4733	Hd. Federation	22	21	22	22	22	76	8	72

* Grown in small flats under field conditions.

In a preliminary trial on the effect of date of planting, Baart and Federation were planted every six to eight days between March 14 and May 20, 1931. The two varieties were planted shallow and deep on each date. Observations on all dates were made and such measurements as were recorded are shown in the first four dates in Table 8. Permanent roots developed on the plants of all seedings up to April 24. Only a few permanent roots started on the plants from the sowing on that date and these soon stopped growing when the surface soil became too dry. Only the deeply seeded rows germinated normally in the next three plantings because of the low moisture content of the surface soil.

The wheat planted late in the spring produced no permanent roots until after a heavy June rain when they grew very rapidly. Permanent roots had grown as much as 2 inches in length 36 hours after the rain. Tables 8 and 9 give the results of planting different varieties of wheat at different dates upon the depth of the formation of the crown and nodal roots. Table 8 represents data obtained on Baart and Federation planted on the four dates already referred to and on four other dates during the spring and summer of 1931; the summer plantings were irrigated carefully in order to get as uniform distribution of the moisture and as uniform emergence of the plants as possible. Table 8 indicates that as the weather became warmer the crown formed nearer the surface. The plants from the first two plantings produced the deepest crowns while on the next two dates the crowns were somewhat shallower and on the dates in July and August the crowns were formed very close (about $\frac{1}{2}$ inch) to the surface of the ground. In the last planting the crowns were formed slightly lower than in the summer plantings. The average crown depth of Argentine, Fortyfold sel. 42 and Hard Federation planted on six dates during 1930 and 1931 are represented in Table 9. The crown depth for the three varieties is shallower for the summer plantings than for those in the fall and spring. The average crown depth for the three varieties planted on November 2 and on May 14, was 43 and 41 millimeters; when planted on August 5 the average was 18 millimeters. This further indicates that date of planting, due probably to variation in temperature and length of day influences the crown depth and therefore the depth at which the nodal roots develop in some wheat varieties.

Table 8. Depth of crown and seed in millimeters of two spring wheat varieties planted at two different depths on eight different dates during the spring and summer of 1931.

C. I. No.	Variety	Depth Planted	Depth in millimeters of crown and seed planted on: Mar. 14 Cr.	Mar. 14 Seed	April 6 Cr.	April 6 Seed	May 1 Cr.	May 1 Seed	May 12 Cr.	May 12 Seed	July 1 Cr.	July 1 Seed	Aug. 5 Cr.	Aug. 5 Seed	Aug. 16 Cr.	Aug. 16 Seed	Sept. 4 Cr.	Sept. 4 Seed	Av. Cr.	Av. Seed
1697	Baart	Shallow	25	33	30	45	20	58	23	47			12	37	13	42	18	40	20	43
1697	Baart	Deep	32	57	32	73	23	68	13	77	12	73	16	52	14	69	18	62	20	66
4734	Federation	Shallow	23	41	23	37	22	54	21	50			15	36	15	34	17	43	19	42
4734	Federation	Deep	39	64	34	74	23	73	17	60	12	76	20	59	17	48	21	72	23	66
	Av. depth of crown		30	49	30	57	22	63	19	59	12	75	16	46	15	48	19	54	20	56

Table 9. Depth of crown and seed in millimeters in three wheat varieties planted in 6 different dates in 1930 and 1931.

C. I. No.	Variety	Depth in millimeters of crown and seed planted on: Nov.2,1930 Crown	Seed	May 14,1931 Crown	Seed	July 1 Crown	Seed	Aug. 5 Crown	Seed	Aug. 16 Crown	Seed	Sept. 4 Crown	Seed	Average Crown	Seed
10061	Argentine	51	63	53	76	31	74	25	58	21	51	23	69	34	65
10063	Fortyfold sel. 43	54	62	49	76	22	75	18	40	21	60	26	67	32	63
4733	Hard Federation	24	59	22	76	8	72	12	55	14	56	18	68	16	64
	Av. depth of crown	43	61	41	76	20	74	18	51	19	56	23	68	27	64

<u>Crown Depth and Nodal Root Formation as Affected by Depth of Planting</u>

The depth at which wheat is planted affects the depth of permanent root formation, as has already been suggested in several places in the foregoing discussion. To determine the significance of depth of planting as a factor in influencing the depth of crown and nodal root formation has become instead of just an interesting side line, one of the main purposes of this investigation.

The first indication that depth of planting influenced the formation of permanent roots was observed in the spring of 1931. On several of the late plantings made that spring only the plants from the deep seedings formed permanent roots because of the dry condition of the surface soil. Later, during that season and parts of the next two years, plantings were made at different depths to determine just how much influence depth of planting had on the depth of the permanent root formation of wheat seedlings. Figure 2 shows the crown forming in shallow and deeply planted wheat.

In the spring of 1931 on April 12, Baart and Federation were planted at about $2\frac{1}{2}$ and $1\frac{1}{2}$ inches deep. Data from an examination of 250 plants are recorded in Table 10. Baart and Federation planted deeply, produced their nodal roots somewhat deeper in the ground than did the shallow plantings of these varieties. Baart and Federation planted shallow from a count of 200 plants produced their crown at an average of 25 and 23 millimeters in the ground respectively. Planted deep the average depth of crown was 30 mm. for Baart and 32 mm. for Federation.

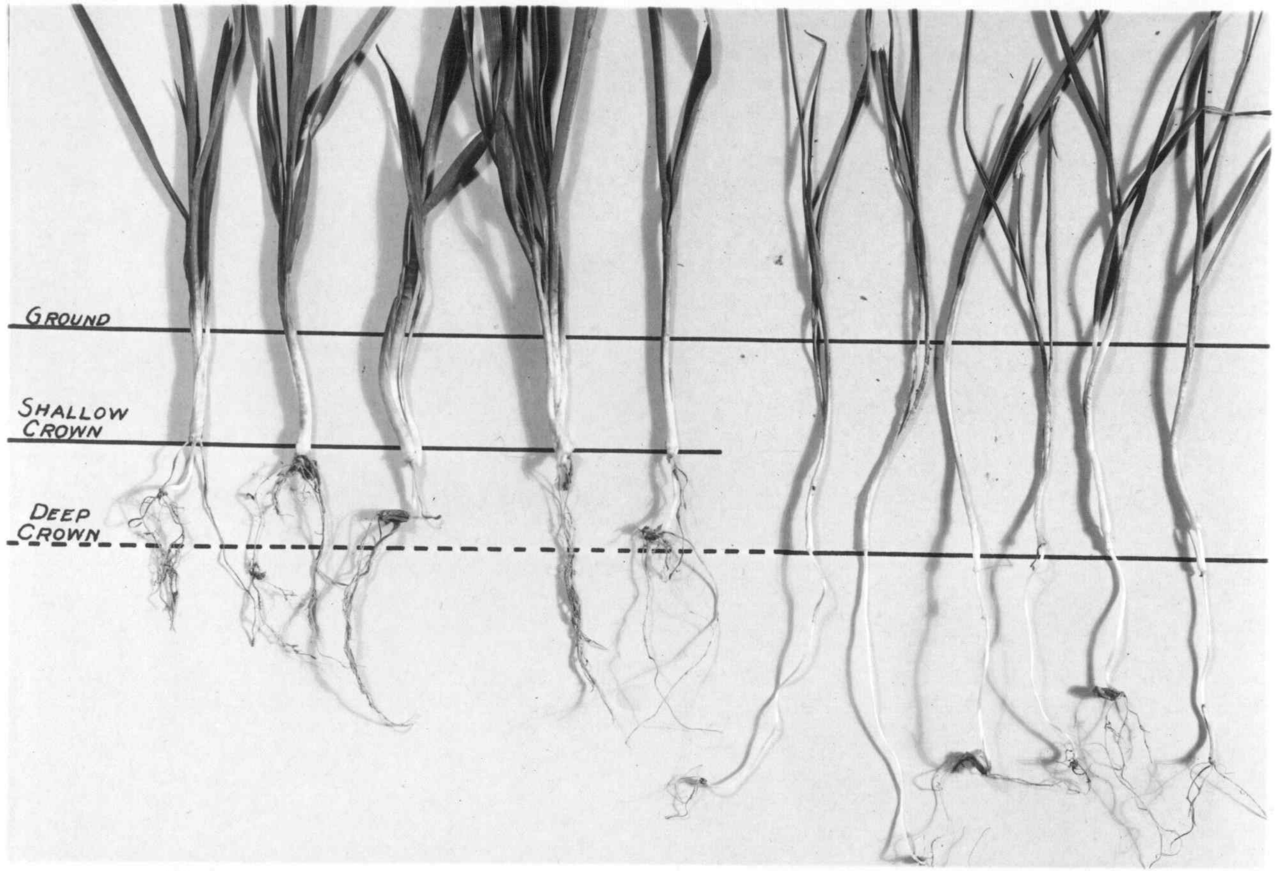

Fig. 2. Variation in crown depth between shallow plantings of Oro wheat, shown on the left, and deep plantings shown on the right.

Table 10. Depth of crown and seed for two spring wheats planted at two depths at Moro, Oregon, in 1931.

C. I. No.	Variety	Planted	Depth in millimeters to: Crown, Per 50 plants	Crown Av.	Seed, Per 50 plants	Seed Av.
1697	Baart	Shallow	25 28 20 27 26	25	45 58 33 45 38	44
1697	Baart	Deep	32 32 26 32 28	30	57 73 68 73 63	67
4734	Federation	Shallow	23 23 22 23 22	23	41 37 54 37 37	39
4734	Federation	Deep	36 34 29 34 28	32	64 74 73 74 55	68

During the summer of that year two winter and three spring wheat varieties were planted on July 1, August 5 and September 4 at approximately $2\frac{1}{2}$ and $1\frac{1}{2}$ inches deep. Data on crown depth from these plantings, given in Table 11 show that the depth of planting did not greatly influence the depth of the crown in this trial. Perhaps this can be explained as due to the fact that during the summer none of the varieties produce crowns very deep even though they are planted deeply.

Table 11. Depth of crown and seed for five wheat varieties planted at two depths at Moro, Oregon, during summer, 1931.

C. I. No.	Variety	Planted	Depth in millimeters to: Crown, Per 150 plants			Crown Av.	Seed, Per 150 plants			Seed Av.
4734	Federation	Shallow	15	15	17	16	36	34	43	38
4734	Federation	Deep	20	17	21	19	59	48	72	60
1697	Baart	Shallow	12	13	18	14	37	42	40	40
1697	Baart	Deep	16	14	18	16	52	69	62	61
4733	Hard Federation	Shallow	15	12	13	13	31	31	46	36
4733	Hard Federation	Deep	12	14	14	13	55	56	68	60
10063	Fortyfold sel. 43	Shallow	17	18	24	20	33	36	53	41
10063	Fortyfold sel. 43	Deep	18	21	26	22	40	60	67	56
10061	Argentine	Shallow	20	19	25	21	35	33	52	40
10061	Argentine	Deep	*	21	23	22	*	51	69	60

* No emergence

Av. deep seeding 18 mm
Av. shallow seeding 16 mm.

If they do form deep nodes usually conditions are such that a second shallower node is formed which becomes the crown. In this trial better than 10 per cent of the deeply planted seedlings out of 450 examined for each variety produced a second node very near to the surface of the ground. Under such conditions a wide variation in results would not be expected. More will be said of this condition under the next heading.

Further studies on the same varieties were carried on during the summer of 1932. Similar results were obtained and are presented in Table 12 in a different manner. For each variety and each depth of planting the 50 shallowest and the 50 deepest planted seedlings are averaged separately as to their depth of crown and seed. In all cases

Table 12. Depth of crown and seed of the 50 shallowest and the 50 deepest plants of each of five wheat varieties planted at two depths at Moro, Oregon, in 1932.

C. I. No.	Variety	Planted	50 shallowest plants Depth in mm. to Crown	50 shallowest plants Depth in mm. to Seed	50 deepest plants Depth in mm. to Crown	50 deepest plants Depth in mm. to Seed
4733	Hard Federation	Shallow	12	27	14	37
4733	Hard Federation	Deep	13	42	16	61
4734	Federation	Shallow	13	30	17	44
4734	Federation	Deep	16	41	20	57
10061	Argentine	Shallow	17	28	23	43
10061	Argentine	Deep	20	40	25	59
10063	Fortyfold sel. 43	Shallow	14	26	17	39
10063	Fortyfold sel. 43	Deep	17	35	20	51
1697	Baart	Shallow	13	24	16	36
1697	Baart	Deep	15	46	18	58

the 50 deepest planted seedlings produce their crowns slightly deeper than the 50 shallowest seeded plants, but the difference is not very great in any case.

Correlations were calculated from other data obtained in 1932 with the following results:

Variety	Planted	Correlation Coefficient Depth of planting/depth of crown	No. of Plants
Federation	Shallow	0.3067 ± 0.088	109
Federation	Deep	0.4590 ± 0.077	105
Argentine	Shallow	0.6707 ± 0.05	53
Argentine	Shallow and deep	0.5202 ± 0.049	228

The above list shows that the positive correlation between depth of planting and depth of crown or nodal root formation is higher in Argentine than in Federation. This is probably due to the fact that Argentine is one of the varieties that normally produces deep nodal roots and therefore would undoubtedly be more affected by depth of planting than Federation which has only a narrow range of crown depth under any circumstance.

Further correlations were worked out on part of the material grown in the field in 1933. This material was separated into two groups according to the normal depth of the crown. All measurements made on normally shallow crowning varieties, whether deep or shallow planted, were used in one correlation and all the counts from varieties which crown deeply were used in the other calculation. For 566 plants from varieties that normally crown shallow, the correlation between depth of planting and depth of crown was 0.7333 ± 0.013; for those plants that normally crown more deeply, 505 plants gave a correlation of 0.7854 ± 0.011.

These correlations are quite high and increase the evidence in favor of a direct relation between depth of seeding and depth of the formation of the crown.

In 1933 further depth of planting studies were carried on in the greenhouse and in the field at Corvallis, Oregon. In the fall of 1932 several plantings were made in the field but due to the severe freeze, only a limited amount of data is available from these trials. Four varieties of wheat were planted at three depths in three different places near Corvallis, but only one planting was early enough to provide any reliable data. Such observations as were made on the other two plantings indicated that these results would have been similar to results obtained from the one planting.

Table 13 indicates that for the conditions of this trial the deeper the seed is planted the deeper the crown and nodal roots are formed.

Table 13. Depth of crown and seed in four wheat varieties planted at three different depths at Corvallis, Oregon, in 1933.

C. I. No.	Variety	Planted	Depth in millimeters to: Crown Per 50 plants			Crown Av.	Seed Per 50 plants			Seed Av.
4734	Federation	Shallow	18	15	21	18	32	35	44	37
4734	Federation	Medium	25	24	22	24	60	56	57	58
4734	Federation	Deep	29	27	30	29	98	101	108	102
4512	Hybrid 128	Shallow	24	18	20	21	42	37	41	40
4512	Hybrid 128	Medium	30	30	27	29	57	60	56	58
4512	Hybrid 128	Deep	38	41	37	39	99	110	97	102
8220	Oro	Shallow	24	27	25	25	35	40	39	38
8220	Oro	Medium	27	29	30	29	56	58	58	57
8220	Oro	Deep	45	44	47	45	119	114	121	118
10063	Fortyfold sel. 43	Shallow	21	25	24	23	41	40	37	39
10063	Fortyfold sel. 43	Medium	28	31	26	28	61	64	57	61
10063	Fortyfold sel. 43	Deep	44	40	45	43	113	109	112	111

Average of all shallow seedings 22 mm.
Average of all medium seedings 27 mm.
Average of all deep seedings 39 mm.

Three countings of 50 plants each for each depth was obtained for each variety except Federation which froze out before the last counting was made. The deep plantings were made at about $4\frac{1}{2}$ inches, the medium at about $2\frac{1}{4}$ inches and the shallow plantings at approximately $1\frac{1}{2}$ inches. For all the plants examined of all varieties seeded shallow, medium and deep the average depth of the crown was 22, 27 and 39 millimeters respectively. The difference is not great, but seems to hold consistent for most cases. If the right conditions as regards temperature could be obtained or controlled greater differences would undoubtedly be obtained. This was shown by the results obtained in one planting during the winter of 1932 and 1933 when Oro was planted shallow, medium and deep with the following results:

Variety	Planted	Crown mm.	Seed mm.
Oro	Shallow	33 ($1\frac{1}{4}$ in.)	38 ($1\frac{1}{2}$ in.)
Oro	Medium	46 ($1\frac{3}{4}$ in.)	59 ($2\frac{1}{4}$ in.)
Oro	Deep	55 ($2\frac{1}{4}$ in.)	91 ($3\frac{1}{2}$ in.)

Root formation in this planting started just as the cold weather set in, which probably had its influence in producing the wide variation presented above. The equivalent in inches is only approximate, but shows that in this case there was an inch difference in the depth of crown due to depth of seeding the grain. In other words, Oro planted deeply formed crowns and permanent roots an inch deeper in the ground than the plants from the same variety planted shallow.

In most cases, when seeding wheat for results pertaining to depth of planting, the seed was planted at about $1\frac{1}{2}$, $2\frac{1}{4}$ and over $3\frac{1}{2}$ inches for shallow, medium and deep plantings respectively. One and one-half inches may not seem shallow for such a trial, but when it is considered that on the average some of the varieties used in this trial form their roots from one to two inches deep, it is apparent that in order to get a true comparison of the effect of depth of planting, the shallowest planting must be slightly deeper than the crowns will normally form under the given conditions. The crown and permanent roots cannot form lower than the seed is placed in the ground, so that if wheat were planted shallower than it would normally crown, the results obtained would not be the effect of depth of planting on the crown, but would be due to the fact that the crown was formed as deep as possible which is right at the seed. If such grain was planted slightly deeper, it would still probably form a crown just as deep as possible. In the trials here discussed only plants which had their crowns formed above the seed were considered. If shallower plantings had been made the depth of the crown would have been shallower in direct proportion in most cases, especially in the varieties which normally form their roots fairly deep under all circumstances.

During the winter and spring of 1933 several plantings were made in the greenhouse, and each variety was planted at two different depths. The first planting in the greenhouse was of Federation and Oro planted shallow and deep, the grains spaced at one-half, one and two inches. A planting board was used in order to get the spacing accurate. The results are presented in Table 14 which further substantiates the results of the field trials given above. An interesting variation due to spacing is noticed, about which more will be said later. The average depth of the crown of the deep seeded plants was a little more than double the depth of the crowns on the shallow seeded plants.

Table 14. Depth of crown and seed in two wheat varieties planted under various conditions in the greenhouse at Corvallis, Oregon, 1933.

C. I. No.	Variety	Spacing in in.	Depth of Planting	Depth in mm. from surface to: Crown Min.	Max.	Av.	Seed
4734	Federation	½	Shallow	3	33	13	40
4734	Federation	1	Shallow	3	30	13	39
4734	Federation	2	Shallow	4	27	16	32
4734	Federation	½	Deep	5	76	33	101
4734	Federation	1	Deep	4	53	30	86
4734	Federation	2	Deep	4	63	36	105
8220	Oro	½	Shallow	6	31	19	41
8220	Oro	1	Shallow	5	36	23	38
8220	Oro	2	Shallow	5	35	24	39
8220	Oro	½	Deep	4	70	33	111
8220	Oro	1	Deep	10	70	41	111
8220	Oro	2	Deep	22	125	49	112
Av.	Federation		Shallow			14	37
Av.	Federation		Deep			33	97
Av.	Oro		Shallow			20	39
Av.	Oro		Deep			41	111

Another greenhouse planting was made later in which Federation and Oro were planted at two depths and at three different rates. The grain was not spaced in this trial, but merely planted thin, normal or medium, and thick. Table 15 corroborates the results shown in Table 14 and offers further proof that depth of planting does influence depth of permanent root formation even when the temperature is quite constant and well regulated.

Table 15. Depth of crown and seed of two wheat varieties planted under various conditions in the greenhouse at Corvallis, Oregon, in 1933.

C. I. No.	Variety	Planting Depth	Planting Rate	Crown Per 50 plants	Crown Per 50 plants	Crown Av.	Seed Per 50 plants	Seed Per 50 plants	Seed Av.
4734	Federation	Shallow	Thick	11	12	12	43	42	43
4734	Federation	Shallow	Normal	10	12	11	39	39	39
4734	Federation	Shallow	Thin	12	12	12	38	40	39
4734	Federation	Deep	Thick	17	16	17	90	87	89
4734	Federation	Deep	Normal	17	17	17	84	88	86
4734	Federation	Deep	Thin	20	17	19	91	89	90
8220	Oro	Shallow	Thick	21	18	19	49	45	47
8220	Oro	Shallow	Normal	20	22	21	47	51	49
8220	Oro	Shallow	Thin	22	21	22	50	46	48
8220	Oro	Deep	Thick	27	29	28	82	86	84
8220	Oro	Deep	Normal	30	27	29	87	82	85
8220	Oro	Deep	Thin	34	29	32	94	91	93
	Federation	Shallow				12			40
	Federation	Deep				18			88
	Oro	Shallow				21			48
	Oro	Deep				30			87

Number of Nodes Per Plant

As already mentioned, while one node on a wheat plant usually predominates and becomes the crown of the plant, several nodes may form at different depths during its early growth. Data recorded in 1931 on the formation of additional nodes are presented in Tables 16 and 17. Five wheat varieties were planted in small flats on July 1,

Table 16. Average depth of the crown and additional nodes in five wheat varieties grown at Moro, Oregon, in 1931, planted July 1.

C. I. No.	Variety	No. of plants examined	Depth* of crown	Second Node No. of plants	Second Node Depth	Third Node No. of plants	Third Node Depth	Depth of seed
			mm.		mm.		mm.	mm.
10063	Fortyfold sel. 43	53	22	48	38	26	55	75
10061	Argentine	53	31	39	48	2	54	74
4734	Federation	53	12	48	28	7	38	76
4733	Hard Federation	51	8	38	25	2	28	72
1697	Baart	56	12	53	29	9	33	73

*All plants had the first node.

and when dug a record of the number of plants with two and three nodes and the depth of these nodes was made. Nearly all plants in all varieties produced two nodes and some in each variety produced three nodes, but only Fortyfold sel. 43 produced many plants with three nodes as shown in Table 16. The average depth for all varieties of the first, second and third nodes was 17, 34 and 42 millimeters respectively. In the three plantings represented in Table 17 the percentage of plants producing two nodes is not so high, but this may be due partly to the fact that the seed was not planted so deeply.

Table 17. Average depth of the crown, the second node and the seed, in 5 wheat varieties planted on three different dates in 1931.

C. I. No.	Variety	August 5: Depth of Crown	August 5: % 2nd Node	August 5: Depth 2nd Node	August 5: Depth of Seed	August 16: Depth of Crown	August 16: % 2nd Node	August 16: Depth 2nd Node	August 16: Depth of Seed	September 4: Depth of Crown	September 4: % 2nd Node	September 4: Depth 2nd Node	September 4: Depth of Seed
		mm.		mm.	mm.	mm.		mm.	mm.	mm.		mm.	mm.
4734	Federation	20	7	32	59	17	4	30	48	21	10	39	72
1697	Baart	16	5	27	52	14	4	37	69	18	4	28	62
4733	Hard Federation	12	20	20	55	14	6	22	56	14	9	29	68
10063	Fortyfold sel. 43	18	4	30	40	21	4	29	60	26	14	38	67
10061	Argentine	23	5	31	59	21	0	[illegible]	51	23	0		69

During these studies in 1932 and 1933 the tendency for plants to form second and third nodes has been observed in a few plants under nearly all conditions, but it seems that the more unnatural or out of the ordinary the conditions are the more this tendency becomes apparent.

Table 18. Average depth of the crown, the second and third node, and the seed in three wheat varieties grown at Corvallis, Oregon, in 1933.

C. I. No.	Variety	No. of plants examined	Depth of 1st node	Second Node		Third Node		Depth of seed
				No. of plants	Depth	No. of plants	Depth	
			mm.		mm.		mm.	
4734	@Federation	49	18	12	35	0		88
8220	Oro	53	45	12	68	0		119
8220	@ Oro	42	27	26	49	1	30*	102
10063	Fortyfold sel. 43	51	44	39	67	6	69	113

*One plant in this lot had 4 nodes at 10-20-30 and 46 mm. respectively.
@ Grown in greenhouse.

Table 18 gives data recorded in 1933 relative to second and third node formation. It is evident that Oro grown in the greenhouse under warm conditions produced a much higher percentage of plants with second nodes than Oro planted in the field. The depth of the nodes on the plants grown in the greenhouse are much shallower than the nodes on those grown in the field. Fortyfold sel. 43 produced the highest percentage of plants with second and third nodes as was the case in the results presented in Table 16.

Soil Moisture and Nodal Root Formation

During dry springs when permanent root formation often fails to take place and the crop must be matured by the seminal roots alone, the question is often asked, at just what soil moisture content the nodal roots will or will not form. Of course, this will vary decidedly with the soil under question, but in order to know a little better how to answer such a question for the soil on the Moro experiment station a pot experiment was devised to determine at what soil moisture content permanent roots would or would not form.

The available equipment was limited and means of controlling the moisture content were rather crude so conclusive information was not obtained. Ten cans about 18 inches in diameter and 16 inches deep were used with Federation planted in one half of each can and Hard Federation in the other half. Five sets of two cans each were filled to within 3 inches of the top with soil containing 15.5 per cent moisture upon which the seed was planted, then each of the five sets of cans were filled 2 inches more with soil of the following moisture contents: 5.6, 8, 11.8, 13.5 and 15.5 per cent. Each can was then covered with one half inch of dry sand as a mulch. Weights of the cans were recorded every 2 or 3 days, but due to difference in stand and vigor of growth, loss in weight from the pots was not uniform. Moisture loss from evaporation was apparently high because nodal roots formed only in the cans with the two highest moisture contents. Table 19 represents as near to the answer of the question as was approached by this study. Permanent roots did not form in the cans with initial moisture in surface soil of 11.8% and

Table 19. Percentage of soil* moisture in the surface 2 inches at beginning and end of experiment, a period of 35 days.

No. of Pot	Per cent moisture Beginning	End	Per cent moisture lost	Degree of permanent root formation
#2	8.0	4.3	3.7	None
#4	13.5	3.8	9.7	Medium
#5	15.5	3.6	11.9	Good

*A fine sandy loam soil was used.

only partially in those containing initial moisture of 13.5% while complete root formation took place in cans having 15.5% surface soil at the beginning of the trial. This root formation took place about 21 days after planting. From these results, it is impossible to state at just what moisture content the surface soil must be maintained in order to have permanent roots develop normally. However, from this experiment and from field observations, it seems apparent that permanent root development in grain varieties may be hindered or entirely prohibited by moisture deficiency in the surface soil. Figure 3 shows the wheat seedlings before and after a late rain during a dry spring.

DISCUSSION OF RESULTS

These studies as originally outlined increased in complexity as different factors were encountered which were found to bear some relation to the results already found. It was necessary in some cases to investigate these factors further in order to determine their exact bearing upon the problem. This was done in at least

Fig. 3. Effect of rain during a dry spring upon the secondary root development. Plants on the left before the rain with no secondary roots; those on the right dug 36 hours after the rain show well formed secondary roots.

some cases as has already been presented. The author wishes at this point to make clear that in many respects these studies are incomplete and that undoubtedly further study upon the secondary root development in wheat would greatly reward the investigator for his time as well as clear up many points which thus far have not been settled satisfactorily.

Having examined approximately 100,000 plants, it was natural that a good many observations and opinions were formed pertaining to various factors and phenomena connected with young wheat seedlings, particularly with root and crown formation. While most of these observations and opinions were not backed by enough data to warrant their inclusion in the discussion of experimental data, yet, they are of interest and may be suggestive of what further study would reveal. They are included here in this general discussion of results as possible explanation for some of the results obtained, but are only observations and opinions of the author to be taken for what they are worth.

From a rather extensive study covering three years' work, it seems safe to conclude that there is a varietal difference in the normal depth of the crown or growing point and that this variation is much more marked in wheats grown as winter wheats than is the case in the wheats normally grown in the spring. In the first year's results on varietal variation, which was most striking, the deepest crowned variety formed its nodal roots more than twice as deep in the ground as did the shallowest crowned variety. This tendency for some varieties to crown more deeply than others seemed to be correlated quite closely with winter hardiness of the varieties and as other investigators already suggested it seemed that the deeper crowned varieties were more winter hardy. Friedberg (4) makes the following statement, "---There would thus appear to be a certain correlation between a low tendency to elongation of the rhizome, i.e., a deeply situated tillering node, and frost resistance. Such a correlation seems reasonable since the deeper the tillering node the less will be the risk of damage to the growing point by frost. --- The tendency to produce a tiller from the coleoptyl, which is also a varietal character, allows of recovery after the growing point has been destroyed by frost, which explains how it is that varieties although susceptible to frost, recover better than other varieties of equal susceptibility but seldom developing tillers from the coleoptyl." Tavcar (21) found that the growing points of winter wheat, winter barley and winter oats were formed deeper in the ground than those of spring varieties sown in the fall and that the depth was in the order named, winter wheat having the deepest growing point. He further states, "--- From these investigations it will be seen that the genotypes of our cereal plants inherit the ability to react on the intensity of external factors in an individual manner, which is also the result of the individual position of the growing point. Within certain limits there is a certain connection between the differences in winter hardiness of individual winter cereal varieties. From this it follows that besides the well-known investigations of cell sap concentration, as well as of the single chemical compounds in the plant cells, the study of the depth of the growing point of individual breeding strains during the cold period may also represent factors of importance in the breeding of winter cereals for winter hardiness."

The same conclusion was made by the author from limited observation of the varieties with which he worked. The winter wheats in all cases produced their crowns deeper in the ground than the spring wheats. A little discussion of what is known of the relative hardiness of the 25 winter wheats experimented with, might be of interest. All of the turkey wheats are relatively hardy and all of them produced crowns considerably deeper than the more tender wheats. Except for Fortyfold sel. 43, the first seven wheats are turkey wheats which vary only slightly in their depth of crown. Why Fortyfold sel. 43 formed its crown so deeply is hard to determine, for it is not ordinarily as hardy as the turkey wheats, but from winter hardiness trials at Union, Oregon, and other eastern Oregon experiment stations, it appears to be much hardier than selections 29 and 54 from Fortyfold. It is known that the white wheat hybrids of Federation, Hard Federation and Arcadian are quite tender and in Table 6 they are near the bottom of the list. Federation is probably the most tender of the wheats grown as a winter wheat and is at the bottom of the list as to crown depth.

While depth of crown may not always correlate with winter hardiness, yet with varieties of the same type and with other factors fairly equal, plants with deeper crowns will probably survive colder weather than shallower crowned plants. In cold weather which is not accompanied by high winds, Bayles (1) found that small differences in depth made considerable difference in the temperature of the soil.

Another observation was made which may be related to winter hardiness in wheat varieties. This was similar to the observation made by Gladkii and Lykhvob (5) in Europe. They found that occasionally instead of tillering normally from the node above the seed (crown) winter wheat would often tiller from the seed and that injury to the crown or to the normal tillers increased the number of plants that would form tillers from the seed as well as increased the number of such tillers per plant. They also found that this tendency was more prevalent in winter wheats than in any of the other common cereals. Similar observations have also been made during the examination of material used in these studies, although only one planting of one variety produced many plants with a seed tiller. One planting of Oro made late in the fall of 1932 and examined the next spring had on the average about one plant with such a tiller out of every 10 to 15 plants examined. Other varieties of the same planting had perhaps one or two such plants per counting. This seed tiller or shoot is known as an axillary primordia of which there may be two, one originating from the axis on each side of the terminal primordium which is the normal plumule of the wheat seedling. Further study has been started along this line to determine if possible whether or not some varieties produce seed "shoots" or tillers to a greater extent than others and to determine under what conditions the largest percentage of these axillary primordia are formed. If winter wheats had the ability to produce tillers from the seed in case of injury or destruction of the crown, it might be quite a factor in winter hardiness.

Tavcar (21) in his conclusion says, "The depth of the growing point is conditioned through heredity, and, in case of the genotypes, the capacity to react to equal intensities of exertnal factors individually is inherited."

In the spring of 1931 a number of plants from several varieties were planted again after measurements had been made. Plants with crowns either deep or shallow were picked for this purpose. These were planted in pots or in the field and irrigated to get as much seed as possible. This was planted in 1932 in sections representing seed from one plant.

The plants from seed of parent stock that had crowned deeply had a tendency to crown deeper on the average than plants from parent stock that crowned shallow, but the wide variation between different plants of the same variety was not eliminated. The variation in crown depth from seed of deep and shallow plants of the same variety was not great and the results indicate that environmental factors probably have more to do with depth of crown in one variety than any tendency one way or another which might be inherited.

In varietal trials with spring wheats very little difference was found in their depth of crowning and root development, but some variation was found in the time or the rapidity at which different varieties formed their nodal roots. From data for two years it appears that Federation, Onas and Pacific Bluestem produce their nodal roots somewhat earlier than such varieties as Baart and the Hard Federation selections as is shown in Tables 4 and 5. Probably the only time such rapid root formation would be of special advantage, would be during extremely dry springs, and then only in case the earlier rooting varieties were able to establish their permanent roots, while the later varieties were obliged to wait till the next rain because of the dry surface soil. (Such cases have been noted in the past.) However, the mere ability to get their permanent roots out into the soil and functioning a few days earlier is probably of distinct advantage to such varieties as Federation and Onas, two high yielding spring wheats in the dry farm area of the Columbia Basin.

The depth of crown or nodal root development may vary considerably due to environmental conditions, but no matter what the conditions under which a group of wheats are grown, there is a tendency for some varieties to crown more deeply than others and a variety will rank in about the same relative order regardless of outside influences. It was found that date of planting affected the depth of crown due to the fact that summer plantings grew under much higher temperatures. High temperatures were found to produce shallower crowns, but even in the warmest weather the winter wheats crowned more deeply than the spring wheats.

In date of planting trials running from early spring through the summer and into the fall, the average depth of nodal root formation in all varieties used, gradually became shallower until the middle of the summer or shortly after as the weather cooled, when the nodal roots again form more deeply. Thus it appears that date of planting, due to temperature changes and day length affects the depth of crown and permanent root formation.

In most descriptions of permanent root formation, these roots are described as arising from a node or crown just below the surface of the ground and in most cases a statement is made to the effect that depth of planting does not vary the depth at which these roots form. Results of the study of this phase of the problem show that while in greenhouse plantings or in plantings made during warm weather there may be only slight correlation between depth of planting and depth of nodal root formation, under normal field conditions, in which wheat is planted in the fall or early in the spring, rather high correlations existed between depth of seeding and depth of permanent root development. Crowns two inches or more in depth can be produced by planting winter wheats three to four inches deep.

How deep should wheat be planted? This question is more complicated than at first appears; for two main factors must be taken into consideration. First, the seed must not be so deep that delayed emergence or poor germination takes place, which may be the case if the plumule must push up through too much soil; second, the seed should not be planted too shallow because it may not get into moist soil and if it does, the rooting system will be very shallow and lodging may occur. The proper depth to seed wheat will vary somewhat with the texture of the soil as discussed by Perkins and Spafford (17).

From the results of these studies it is suggested that the best depth to plant wheat is approximately the depth at which the nodal roots will form under a given set of conditions. At this depth the plant will be anchored as deeply as possible and at the least expense of energy to the young seedling. Also if depth of crown is correlated with winter hardiness, the plant will have the advantage of a deeper crown than would be the case if the seed were planted too shallow.

Plantings made during the warmer season or during seasons of changing soil temperature such as occur in the spring and fall have a tendency to form more than one node, perhaps due to the change of the level of optimum temperatures for nodal formation.

This tendency of plants to form two or more nodes is interesting and it is unquestionably connected with date and depth of planting. Tavcar (21) found that when he planted wheat one to eight cm. deep the crown formed deeper in the soil with increased depth of planting until the deeper plantings when the crown was again shallow. He explained this as due to the fact that more than one node was formed on seedlings planted very deeply. Table 8, which has already been discussed under date of planting, shows that in the planting of May 12 the shallow plants produced their crowns deeper than the deeply seeded plants. An explanation for this and also for the very shallow crowns in the deep plantings of July 1, may be found in the fact that when wheat is planted late in the spring or in the summer and at considerable depth (as it was in both of these cases) more than one node is formed on a large percentage of the plants. Therefore, the deeply planted seedlings of the May 12th planting, having two and sometimes three nodes, from which it is possible for both tillers and permanent roots to grow, likely had in many cases upper nodes which were shallower than the one node formed in the seedlings planted shallower. It is probably impossible to tell which node will be the predominant crown without growing the plants up to or a little beyond the stooling or tillering stage. Field observations indicate that either node may become the main crown according to the conditions present at the various nodes. If the soil around the shallow node becomes too dry, no nodal roots or tillers will form, or if already forming they will dry up and cease to grow, but others will form at the next lower node. Often the opposite has been observed. If the nodal roots begin to form at a lower node and then conditions change, and a node is formed at a higher level in the soil where conditions have become right for nodal formation, the roots from the lower node, while continuing to live, do not become nearly so extensive as those that form at the upper node. Under the latter condition the upper node becomes the crown.

From numerous observations in dry seasons, it is known that secondary roots often fail to form when the surface soil becomes too dry. The minimum soil moisture at which these roots form varies considerably with the soil. A partial wheat crop will mature from seminal roots alone, but the yields will be reduced. Even though the dry condition is relieved by late rains, the normal secondary root development is delayed and the crop suffers accordingly. Several cases of this kind are on record at the Moro experiment station.

Krassousky (12) found that the elimination of either the temporary or permanent roots in wheat reduced the yield.

Considerable work by different investigators has been done relative to tiller and root formation as affected by thickness of stand. Grantham (7 and 8) and Rabomnova (18) found that increased rate of planting decreased the number of tillers, but up to a certain rate increased the yield per acre. The more space a single plant had the more it would tiller. In greenhouse studies which have already been described wheat was planted at three different rates to determine whether or not thickness of stand influenced depth of crown. In each case the normal seeded plants produced deeper crowns. Perhaps the slight heat produced by the bunched plants during germination was enough to cause some difference in crown development, since warmer temperature tends to cause shallower crown formation. Competition for food, air or water may have been a factor.

Salmon (20) in an extensive investigation on the advantages of planting in furrows and on whether or not winter injury is reduced by so planting wheat, found that the temperature at the bottom of the furrow and where the grain was placed was always warmer than the top of the ground or the depth at which seed was usually planted. This may possibly explain the advantage of furrow drilling along with the protection afforded due to snow, and may also explain the fact that in preliminary trials the crown depth in furrows was shallower and more plants with several nodes were found. If the temperature in the furrow is warmer than that on the surface, the difference in temperature alone may be enough to account for the difference in crown depth.

Little attention in the past has been given to the nodal root formation or the depth at which these roots form in wheat. From a study of the limited investigations on this subject and from the results of the present studies, it appears that the formation and particularly the depth at which nodal roots form vary with the variety and environmental and cultural conditions under which the wheat is grown. Date and depth of planting and temperature and moisture of the soil are probably the most important factors influencing secondary root development. The light intensity and various methods of planting possibly have their influence as probably do other factors not thus far encountered.

SUMMARY AND CONCLUSIONS

Nodal root development in certain wheat varieties and factors affecting their development and particularly factors affecting the depth of the crown have been investigated in these studies. Wheat was planted under various conditions to determine the influence of variety, cultural practices and environmental factors upon secondary root development. Variations in date and depth of planting and soil moisture and temperature as they affect crown depth were studied. Observations and measurements were made on approximately 100,000 wheat plants in obtaining the data herein presented.

Considerable variation in depth of crown was found between varieties and within one variety. A correlation appeared to exist between depth of crown and winter hardiness. The more hardy winter wheats crowned more deeply than the tender winter wheats or the spring wheats.

Variation in the rate of secondary root formation was found in 12 spring wheats tested. Early root development may partly account for the high yields of Federation and Onas in the dry farm area of eastern Oregon.

Contrary to the common opinion of many investigators, data obtained in these studies show that date and depth of planting affect the crown depth in wheat. Crown depth is shallower in late spring or summer planted wheat than in plantings made in the fall or early spring due probably to higher temperature and length of day as well as light intensity. Deep crowning is correlated with deep seeding in normal fall sown wheat particularly and to a less extent in spring and summer planted wheat until other factors nullify the affect of depth of planting.

Wheat planted shallow during warm weather will often form secondary roots at or only slightly below the surface of the ground, while certain winter varieties planted deeply during cool weather may form roots two inches or more below the surface.

Moisture in the first two inches of soil greatly influences nodal root development. Too low moisture content in this region may eliminate their development.

Moisture and temperature conditions of the surface soil may cause the formation of several nodes if the wheat is deeply planted. Data indicate that warm or changing temperatures in the surface soil increase the tendency for more than one node to form.

Other factors which apparently influence secondary root development in wheat are: light intensity, rate of planting, and type of drill used. Numerous observations indicate that lack of sufficient light, heavy seeding and the use of a furrow drill produce shallow crowned plants.

LITERATURE CITED

1. Bayles, B. B. — Temperature in relation to depth of growing point in several wheat varieties. Unpublished 1928-32.

2. Cannon, W. A. — On the relation of root growth and development to the temperature and aeration of the soil. Amer. Jour. Bot. 2:211-24. 1915.

3. Carleton, M. A. — The small grains. MacMillan Co. 1924.

4. Friedberg, M. R. — Position of the tillering node and frost resistance. The Annales Agronomiques, Mar., April, 1932. (Abs. Monthly Bul. Agri. Sci. and Practice, July, 1932)

5. Gladkii, M. F. & Lykhveb, D. F. — Tillering below the crown at the seed in cereals. Nauch Agron. Zhur. (Jour. Landw. Wiss.) 4:355-69. Abs. Exp. Sta. Rec. 61:220. 1929.

6. Govorov, L. I. — The Characteristics of winter and spring forms of cereals in relation to winter hardiness. (Trans. title) Trudy Prikl. Bot. i i selek. (Bul. Appl. Bot. and Plant Breeding) 13:525-59. 1922-23. Abs. Exp. Sta. Rec. 53:231-2. 1925.

7. Grantham, A. E. — The tillering of winter wheat. Del. Agri. Exp. Sta. Bul. 117. 1917.

8. Grantham, A. E. — Tillering as a factor in determining the desirable qualities of winter wheats. Proc. Amer. Soc. Agron. 4:75-81. 1912.

9. Harris, L. E. — A study of secondary root development in winter and spring wheat and of seminal root number in wheat and barley species. Master Thesis, Oregon State Agri. College. 1932.

10. Janssen, George — Effect of date of seeding of winter wheat on plant development and its relation to winter hardiness. Jour. Amer. Soc. Agron. 21:444-66. 1929.

11. Knight, R. C. — The response of plants in soil and in water-culture to aeration of the roots. Ann. Bot. 38:305-25. 1924.

12. Krassousky, Irene — Physiological activity of seminal and nodal roots of crop plants. Soil Sci. 21:307-22. 1926.

13. Kravtsov, M. N. — Studies on the root system of spring wheat. Nauch. Agron. Zhur. (Jour. Landw. Wiss.) 5:80-93. 1928. Abs. Exp. Sta. Rec. 60:573. 1929.

14. Locke, L. F. & Clark, J. A. — Normal development of wheat plants from seminal roots. Jour. Amer. Soc. Agron. 16:261-8. 1924.

15. Maximov, N. A. & Lebedincev, E. — The influence of light relations on the development of root systems. (Ber Dent. Bot. Gesell. 41:292-27. 1923.) Abs. Exp. Sta. Rec. 61:424. 1929.

16. Percival, John — The wheat plant. London, Duckworth and Co. 1921.

17. Perkins, A. J. & Spafford, W. J. — Relating to the depth of sowing of some agricultural seeds. Jour. Dept. Agri. So. Aust. 15:208-16, 1907.

18. Rabomnova, O. D. — Spacing, depth of seeding, and tillering in spring wheat. Zhur. Opytn. Agron. (Russ. Jour. Expt. Landw) 15:371-94. 1914. Abs. Exp. Sta. Rec. 32:832. 1916.

19. Robbins, W. W. — The botany of crop plants. P. Blakiston's Son and Co. Philadelphia. 1917.

20. Salmon, S. C. — Seeding winter grains in furrows to prevent winter killing. Jour. Amer. Soc. Agron. 8:176-84. 1916.

21. Tavcar, Alvis — Relation of winter hardiness to the depth of the growing point in cereal plants. Ztschr. Pflanzenzucht. 15:63-74. 1930. (Trans. by Theo. Holm, 1931)

22. Walworth, E. H. & Smith, L. H. — Variation in the development of secondary rootlets in cereals. Jour. Amer. Soc. Agron. 10:32-35. 1918.

23. Weaver, J. E. — Root development of field crops. McGraw-Hill Book Co. New York. 1926.

24. ---- Himmel — Relation between the development of root system and shoot under long and short day illumination. Plant Phys. 4:435-57. 1929.

25. Weaver, J. E., Kramer, J. & Reed, M. Development of roots and shoots of winter wheat under field environment. Ecology 5:26-50. 1924.

26. Wiggans, R. G. The number of temporary roots in the cereals. Jour. Amer. Soc. Agron. 8:31-7. 1916.

27. Worzella, W. W. Root development in hardy and non-hardy winter wheat varieties. Jour. Amer. Soc. Agron. 24:626-37. 1932.