TECHNICAL NOTES

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B. R. Bertramson prepared this paper for a talk to the Third Biennial Weed Control Course given at the University of Idaho, November 14-19, 1955. Ray Kent, Soil Conservationist, State Program Staff, in Washington secured permission to distribute it. I believe that soil conservationists will find that it contains many worthwhile ideas on the subject of a crop rotation as a conservation measure and as a way to achieve maximum production.

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PRINCIPLES OF CROP ROTATION 1/

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"Good crop rotations provide for systematic cropping of the land in a way that will stabilize the soil and maintain or improve fertility, increase yields, and improve the nutrient value of crops."3/ Big news of the 1730's in England's agriculture was Lauren Townshend's introduction of a new scheme of crop rotation which included wheat, turnips, barley and alfalfa or beans and was known as the "Norfolk rotation." Under this system the average yield of wheat in England was raised from about 8 bushels to around 20 bushels by 1840.

Rotations and religion enjoy about the same category of controversy among avid agriculturists. Let us review briefly some of the theories from the early to the modern that have had a bearing upon the acceptance of crop rotations.

The Fallow Theory. Soils either cultivated and uncropped or left to grow weeds gave higher yields in the subsequent crops. It was believed crop production was fatiquing and hence soils needed a rest. For the most part, the practice of resting the soil was a partial answer to a soil fertility problem later solved by soil science and fertilizer technology of our modern era.

The Toxin Theory. According to the toxin theory, the failure of some crops to grown well following others was explained by the fact that preceding crops in some way produced a toxin in the soil that was harmful to the following crop. For instance, cane or sorghums have been considered "hard on the soil" since they impaired the growth of the following crop. More recent theories have explained this on the basis of nitrogen tie-up and, where moisture is a limiting factor, on the greater depletion of moisture by this crop than some others.

1/ Presented in the Third Biennial Weed Control Course, University of Idaho, Moscow, Idaho, Nov. 14-19, 1955.
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3/ Uhland, R. E. Jour. Soil and Water Conservation, Vol. 4, p. 146-152, 1949.

Sanitation Theory. When crops were rotated, farmers seemed to avoid some of the troubles with disease which plagued them in fields where rotation of crops was not practiced. For example, continuous growing of potatoes on an area resulted in serious losses from scab. Continuous growing of corn increased smut damage. Livestock diseases and parasites have been partially controlled through moving the animals to fresh areas frequently. This fitted in well with the scheme of crop rotations.

The Pest Theory. Some crops seem to be associated with certain weed, insect, and rodent problems. For instance, oats were infested with wild oats, mustards, and other spring annuals as weeds. Pastures are contaminated with some of the perennial weeds, such as Canadian thistle. Winter wheat is infested with gromwell, tarweed, cheatgrass (downy brome) and other fall annuals. Rodents seem to prosper in perennial crops, such as pastures, alfalfa fields, etc. Wireworms thrive best in pastures. The alternation of crops tends to break up the happy homes of these pests and, therefore, results in better yields and less nuisance.

Conservation Theory. In conservation we need to think of "use without abuse." We are interested in the maximum sustained production, which means that we need to look carefully at the loss of topsoil. A crop rotation including perennial forages permits a sequence of crops with a minimum of time for the soil to be exposed and hence a minimum erosion hazard. The Soil Conservation Service and the Agronomy Department at Purdue University worked out a system of rotations that had a very practical slant, it seemed to me. They classified the soils according to degrees of erosion hazard inherent in their makeup. For instance, the steeper the slope, the greater the erosion hazard. Likewise, the finer the texture of the soil, the greater the erosion hazard. The formula for this classification was quite emperical; yet seasoned with practical experience, it worked fairly well. The rule in adapting a rotation, then, was: "The greater the erosion hazard, the more years of rotation would be devoted to a perennial forage crop." This recognizes the necessity for a compromise between exploitation and conservation. In this way the maximum profit over a period of 20 to 30 years conforms fairly well with a good system of rotation employing the forage crops. While this served well in those situations where livestock was used in the business enterprise, it was not too readily accepted by the cash crop farmers.

Taking the best out of these theories as they have grown, we could state these reasons underlying the crop rotation as applying generally: Crop rotations do provide a definite area for each crop. This introduces orderliness into the method of crop sequences. We also know that alternating crops with different root systems and different growth habits permits us to make maximum use of the fertility and water resources of the soil. For example, crops have different depths of root systems and different growth habits. Some make greater demands on the fertility of the soil than others. For instance, potatoes demand a much higher potash level than the cereals, which in turn require larger amounts of phosphorus. Clovers require much more lime in the soil than does corn or wheat. Crop sequence can be used to make the best use of the preceding crop. Potatoes grow best following a pasture legume like clover rather than following corn, and less erosion hazard results. A rotation, if it includes grasses and legumes, helps to maintain the organic matter supply. Where legumes are used, they add nitrogen ranging from surpluses beyond the needs of the legume to negl gible amounts. (In numerous instances today, it is cheaper to buy the nitrogen fertilizers than to produce them in legume crops.) Certainly the use of grasses and legumes in the rotation helps to restore the physical condition of the soil. It prevents erosion during the time the land is in these perennial crops and in general makes the land more resistant to erosion for some time following these sod crops. Deep-rooted legumes help open up the subsoil for better aeration and more rapid and deeper water penetration. Likewise, the use of rotation helps to prevent leaching, another source of deterioration of the soil, by utilizing the nutrients during the time when there is downward movement of water, either as a result of irrigation or through natural rainfall. Except where only nitrogen is a limiting factor, crop rotations are not a substitute for fertilizers. Crops remove fertility regardless of their sequence unless all of the crop is returned to the soil. Hence, the maximum benefits can be derived only from a good system of crop rotation supplemented by an adequate fertilizer program. Fertilizer, in general, is a supplement to a good crop rotation, not a substitute for it.

In order to exploit the benefits of a rotation, it is necessary to give some thought to the order of crops in the rotation. In general, long-growing-season crops should be followed by short-growing-season crops. It is desirable to alternate deep and shallow-rooted crops. It is desirable to alternate crops which furnish large amounts of crop residues with those which furnish scant residues and favor the rapid decomposition of organic matter. Green manure crops in the rotation may enhance the availability of soil phosphorus and potassium. It is desirable to arrange the crops in sequence to obtain the greatest returns from the soil. It is sometimes desirable to take into account the time interval between crops so that sufficient time is permitted for the accumulation of available nutrients for the next crop. For instance, the plowing under of a grass sod crop or a straw crop will result in considerable tie-up of nitrogen. Of course, nowadays we can correct this by supplementing the nutrients of the soil by a good fertilizer program. If too long a time interval between crops is permitted, we have excessive leaching and also a loss of productivity through the growing of weeds.

Controversies over rotations arise because the factors affecting rotations are constantly changing. Let us take a look at some of these factors.

Advances in chemical and mechanical technology. I suspect many of the benefits claimed for rotations in the era before chemical fertilizers may have been accounted for by the nitrogen fixed by the legume in the rotation. The thirty-year crop rotation studies at Purdue University showed that the continuous corn had declined to a yield of about 50 bushels to the acre. One would hardly recognize the crop of corn on this field in its 31st year. It has received 160 pounds of nitrogen to the acre and yielded around 120 bushels of corn to the acre. Obviously, the limiting factor in the production of corn under a system of continuous corn on that level land was nitrogen. In the rotation, this was provided by the legume.4/

4/ For detailed report see J. B. Peterson, Jour. Soil and Water Conservation 10:281-285. 1955

Continuous wheat at the Rothamsted Experiment Station for over 100 years yielded as well as the wheat in the rotation provided the continuous wheat was adequately fertilized. The average from either treatment was about 24 bushels per acre. Combining the rotation and the fertilizer treatments, however, gave a yield of over 32 bushels per acre--another 33% increase in yield. At Pullman, wheat in the continuous wheat plots with adequate nitrogen fertilizer added for 34 years yielded as well as wheat after fallow, also nitrogen fertilized.

New machines overcome some of the old problems that were best handled by rotations. Machines nowadays can harvest a crop quickly and get out of the field so that the land can be utilized for the next crop. New machines handle crop residues, improve the tilth of the soil, and prepare the seedbed more effectively than did the old horse-drawn machines of a few decades ago. Horsepower to do the job is no longer a limiting factor. In 1910 more than 20 million horses were used to till our soils. Today the figure is perhaps less than one million. In their place over 4 million tractors are doing the job better and faster. Even the passing of the horse introduced another factor in our concept of rotations. We no longer need the many acres of pasture and the many acres of oats and hay to keep these hay-burners going. (This is in part compensated for by the greater demands of our growing population for meat and dairy products.) The manure by-product from this original source of horsepower is no longer available, hence the need for added crop residues and fertilizers is greater.

Great advances in insecticides have made it possible to control the pests in a continuous crop quite well under some circumstances. The question remains whether it is cheaper to effect this control than it is to avoid the pests through a rotation. Whichever method of control nets the farmer the greater income in the long run is the one that will be accepted.

The new era of selective herbicides has made it possible in some instances to grow the same crop continuously year after year with no particular weed problem. Again, the economics of a rotation of crops versus a single cash crop with herbicides will decide which the farmer will follow in the long run.

Rodent control is receiving the attention of specialist with their new and mysterious chemicals. It has been called to my attention that one of the most pressing problems of farmers in some of the irrigated areas of Washington is the control of pocket gophers. It appears there are still some challenging problems for the biologists in the control of some of these animals. Also, it is well known by farmers that rotations are not an effective control of these pests in many instances.

Cheaper fertilizers in greater supply and comparatively higher prices for farm produce has decreased some of the dominant advantage that legumes earlier imparted in the rotation. We have also come to recognize that the growing of good crops whether they be legume or otherwise makes large demands on the fertility of the soil. Here, expressed in dollars, is the value of plant nutrients removed from soil per acre by various crops:

Corn (60 bu./acre)	$13.60
Soybeans (20 bu./acre)	17.00
Alfalfa (4 tons/ acre)	51.30

While the legumes do return some nitrogen to the soil or at least provide their major nitrogen needs, they are in general heavy feeders on potash and phosphorus. (Fertilizer Review, January, 1950, page 10.) Where the farmer finds it profitable to deviate from a rotation, whose principal advantage is providing the nitrogen, to one in which he is using nitrogen fertilizer, the change to the simpler rotation is inevitable. This trend is illustrated in the increased production of synthetic ammonia fertilizers; 1930, 160,000 tons; 1950, 1,600,000 tons; 1952, 2,200,000 tons--a fourteen-fold increase in 22 years.

New crops continue to come into the picture. For instance in the 30's wheat had been the dominant crop in the Great Plains area. But corn was grown extensively in this natural wheat area as the farmers began to shift from wheat production toward livestock. Now in these areas, the new sorghums are coming in to take the place of some of the surplus acres of wheat. In the Mid-west, soybeans have enjoyed a great rise in popularity within the last two or three decades. Presently, farmers in the West and the Pacific Northwest are looking at safflower as a possible alternative crop to take some of the acres presently devoted to wheat. Obviously, these new crops place new emphasis and requirements on the need for rotations.

Government regulations have a dominant effect upon the rotation system as it is actually practiced by farmers. Unfortunately, in many of our areas the program on acreage control and subsidies has discouraged rather than encouraged a good system of crop rotation. For instance, in the Great Plains the scheme had been two years of wheat followed by one year summer fallow. With the acreage limitation of the last two decades, the pattern was shifted to one year of wheat and one year of summer fallow. Acreage restrictions have resulted in a shift from annual cropping in areas of the Pacific Northwest well adapted to it. As a result, erosion has become more serious with the more extensive use of summer fallowing. Failure to give adequate creidt for legumes in a rotation so far as permitting a base for wheat is concerned has encouraged many farmers to refrain from rotation with legumes because of fear of losing their acreage base for wheat, which after all was the crop that brought in the cash.

Weather and weather cycles also have a dominant effect upon the outlook of farmers with regard to rotations--particularly in areas where droughts occur. For example, in the Pacific Northwest a great deal of interest was manifested in annual cropping in the lower rainfall areas during the recent very favorable years when moisture was adequate. The nitrogen needs of the crop were amply taken care of by fertilizer. It was indeed a profitable procedure. This last year's dry weather sort of dried up the enthusiasm of some people in the limited rainfall area for annual cropping, especially with the acreage limitations.

What has the research on rotations told us? Just about everything I have said previously can be proved or disproved by the research work on rotations, depending upon how the rotations were set up and what they were designed to demonstrate or prove. One must bear in mind that rotations require several years to complete a cycle. In order to determine the cumulative effects, one has to study several cycles. As one looks back through the literature, rotation studies can be found extending anywhere from the classical ones of Rothamsted of over 100 years down to such newcomers as 30 year rotations. Some of these have provided us with a great deal of very useful information. I have referred to some of this information already. However, scarcely any of these were developed prior to the time of our new concepts on field plot technique and use of statistics. Few if any, of these has adequate replications and none of them had all of the requirements for the application of our latest techniques and statistics in order to get reliable answers. Factors of soil variability were not appreciated in the setting up of many of these experiments. Present concepts of soil fertility and extensive use of fertilizer were unknown hence not adequately handled in these experiments. Other factors which are taken into consideration in the use of modern field plot techniques were also little understood and consequently neglected at that time. I have also indicated some of the trends and technologies that have changed our thinking through the years. These play havoc with the long-range experiments. As a result, many of the answers which are finally obtained are no longer applicable because new technologies, new crops, and entirely new situations are facing the farmers today.

New rotations set up withing the last decade following the dictates of good field plot technique should give usefull and reliable information. Admittedly, a portion of this may face obsolescence as the decades roll by and new technologies begin to appear.

In looking back over the various reasons I have cited for rotations and particularly for the use of grasses and legumes in the rotation, the one reason that stands out unchallenged is that of improving the soil structure and reducing erosion to a negligible factor. With the demands for more livestock products in our higher standard of living, the prospect for more forage crops in the rotations seems good. Likewise, the control of erosion following and during the growth of other crops in the rotation can probably be effected through improved technologies, in machinery, fertilizer usage, etc.

While advances in science have shown us what is wrong with some of our old experiments in the rotation, they have not permitted us to evaluate accurately the improvements in soil structure and physical conditions that we think the forages impart to the soil when used in a rotation. Our methods of soil structure evaluation are indeed crude and inadequate. Our aggregate analysis methods are much too severe. They might be compared to the use of a sledge hammer in determining the relative strength of egg shells.

Advocates of short rotations (leys) including forages extol the cumulative benefits from this system. Work the soil hard! Keep it covered, fertilize it adequately and keep the biological stress high. With several rounds of the rotations the advantages of all these intensive practices continue ot increase. I fully subscribe to this theory. I hope that modern rotation experiments will provide us with factual quantitative proof in its support.