MERITS AND EQUIPMENT FOR DEEP PLACEMENT OF FERTILIZER

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INTRODUCTION

Deep Tillage Research in Perspective

The last fifty years of progress in crop production in the United States is largely indebted to research workers keenly interested in finding new combinations of the many inter-related variables of plants, soil, machines, and combinations which continue to reveal secrets that push yields per acre ever higher.

Since 1947 (70) a segment of this effort has devoted increasing attention to deep tillage in combination with chemical soil amendments designed to correct acidity and plant food deficiences that might inhibit peak crop production.

Recent investigators have reported high yield increases from deep fertilization over conventional fertilization tillage practices. However, some of these investigators (27) find it hard to justify the higher costs of machinery and fertilizer.

There are no reports appraising the cost of deep placement equipment in its total economic relationship, which would take into account that the practice could substitute for plowing or other initial tillage, and that the tractor would be used as a principle power source for many other farm functions.

At present there are few commercial subsoil-fertilization implements on the market, and these are single shank units capable of slow field production and a minimum of soil shattering or aeration.

Up until the present, all experiments have been accomplished with custom-built equipment. Tractor and equipment manufacturers and dealers have been generous in lending equipment and personnel to help fabricate or mount tools and fertilizer applicators specified by a specific research project.

Out of this backlog of close cooperation between industry and public sponsored research institutions, there currently is a wealth of experience concerning methods of incorporating soil amendments into profiles deeper than the conventional tillage operations, commonly defined as 7-to 8-inches deep. Very little has been published concerning the engineering and design of custom-built equipment in regard to the fertilizer metering, placement, and distribution. It appears that information is not sufficient to attempt a deep placement specification for fertilizer distribution patterns in relation to optimum root growth, plant growth or yield response.

A Statement of Purpose

It is the object of this report to review the concepts of deep tillage and deep fertilization methods and to review the availability and the status of the equipment to accomplish their applications.

This report will deal with the various principles of deep application and the distribution patterns of fertilizer that might be desirable. This report will also elaborate on timely applicator information previously unpublished or lightly mentioned in the literature.

From documented material there will be included herein reproductions only of deep applicators that exemplify the various principles of placement methods.

It is not intended that this report be controversial in attempting either to justify or to disprove the desirability of placing fertilizer deep. The existing research data is inconsistent; proponents both for and against the practice are prevalent.

In this age of specialization, an agricultural engineer, in designing deep application equipment is in the position of cooperating with agronomists, to function according to specifications furnished by them. These specifications might, for example, prescribe for a given situation the fertilizer quantity, type and analysis of fertilizer, the desirable pattern of distribution in the soil, the depth and degree of soil fracture needed, and the amount of soil profile mixing required. Until some agreement is reached on specifications, particularly in regard to deep fertilizer placement and physical forms of fertilizer used, the engineer will continue to have difficulty in producing acceptable tool designs.

The cost of tool design or the seeming practicality of any particular design to fit into commercial operations should not initially concern workers in basic deep fertilizer placement research. After basic beneficial relationships of agronomic principles have been established, then it is the responsibility of the engineer to redesign the tool for economical operation if possible. The final economic test will be acceptance of the application by the farmer.

Because of this defined engineering responsibility, merits for applying fertilizer deep should be considered for two main reasons:

1. The application must have benefits to justify concern for engineering design.
2. By reviewing applicator capabilities, weaknesses in previous

research procedures that failed to show encouragement, may come to light.

In 1956, Kohnke and Bertrand (29) of Purdue wrote, "It is to be hoped that the Agricultural implement industry will soon recognise the importance of this practice and provide machines for the requirements of various types of farming."

In a private letter dated January 17, 1963, the company Product Engineer for New Idea Division of Avco Corporation, Coldwater, Ohio, stated in part, that "actual engineering data on placing fertiliser deeper than the normal 7 inches in depth seems to be very limited."

In a letter of January 18, 1963, to the writer, Hulburt[1] wrote:

> There is not much reference material on this topic (referring to equipment for deep application of fertiliser)——However, the why of some spectacular responses has been quite a challenge for a good, dedicated research worker to get into this problem, and come up with good findings that will definitely be a benefit to the problem soils.

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[1] W. C. Hulburt, Head of Planting and Fertilizing Equipment and Practices Investigations, U. S. Dept. of Agriculture, Agricultural Research Service, Agricultural Engineering Research Division, Beltsville, Maryland.

A COMPOSITE REVIEW OF DEEP TILLAGE AND FERTILIZER PLACEMENT PRACTICES

Deep Tillage Considerations

It is recognized that deep placement of fertilizer by definition and by application is too inter-related with deep tillage to be separated. Currently, fertilizer and lime are incorporated into a soil profile only as a companion operation with deep tillage tools. Those factors of soil physical make-up directly affecting design of deep tillage equipment must also be considered in an appraisal of equipment to place chemical plant food into a soil profile below the surface 7-to 8-inch seedbed.

Three basic reasons for tilling the soil are (1) to change the soil structure, (2) to kill weeds, and (3) to manage crop residues.

It is often necessary to modify the soil structure to facilitate the intake, storage and transmission of water (47, 26). A good seedbed for seed germination and the deeper rootbed environment are associated with soil structure. A desirable rootbed is thought of in terms of a soil in which the structure has large stable pores extending throughout the vertical profile. Large pores help insure the intake of water and drainage of any water excess. In such a soil, aeration is good and plant roots are free to develop normally.

In general, compacted soils have high bulk density, small pore space, and the structure is said to be destroyed. The rate of water intake or movement is reduced, water storage capacity is restricted, and crop roots have difficulty in penetrating the dense soil profile. When crop roots are confined by a dense soil, this drastically restricts the amount of available water and soil nutrients in the root feeding zone, thus directly reducing crop yields (10,25,48,66,70).

Continuous row cropping over a period of years on medium and coarse textured soils presents a serious problem of soil compaction (23,34,45,55). The problem is found in many areas of the United States, particularly in the Mississippi River Valley.

Raney and colleagues (46) reviewed the status and progress of soil compaction research prior to 1955, and tried to define types of compaction and some of the reasons for the increasing interest in this subject. The reasons were:

> 1. With the rapid adoption of new fertilizer practices, new insecticides, crop varieties, etc., productivity is more frequently limited by soil physical properties than was the case prior to the adoption of such practices.
>
> 2. An increasing number of farmers have access to power units and tillage tools that enable them to 'do something about' soil compaction problems.
>
> 3. It appears that many soils are actually becoming more compact under the continuing influence of present day systems of management.

In addition to the more recent review by Raney, et.al., (46) two complete reviews (34,69) are available concerning soil compaction problems.

There are two general conditions of soil compaction restricting root penetration which influence subsoil tool design and tractor draft requirements. These conditions were ably defined by Raney, et. al. (46).

1. <u>Induced Pans</u>. Soils where the horizon or layer limiting water and root penetration is apparently the result of a recently applied compaction force such as implement traffic or trampling upon a soil that had, under virgin conditions, physical properties favorable to the penetration of roots and water.

2. Genetic or Natural Pans. Soils where the horizon limiting root and water penetration has developed in the profile through the slow, but long continued action of soil genetic processes. This group is further subdivided according to the nature of the horizon most restrictive to root and water penetration into (a) soils with claypan horizons, (b) soils with fragipan or siltpan horizons, (c) soils with indurated hardpans, (d) soils with impervious zones where the colloids are dispersed due to adsorbed alkali cations, and (e) soils with compact, but unconsolidated C or D horizons.

At times, one soil may fall into more than one type, i.e., it may have a restrictive layer formed as a result of a recently applied compacting force superimposed upon a profile with a genetically developed restrictive horizon. There is even evidence that horizons compacted through an applied force may, if left undisturbed, lead to the formation of genetic horizons of a restrictive nature. Thus, miniature claypan horizons seem to be forming on top of "tillage pans".

Yield Response to Subsoiling in General

Background. Over the years, much attention has been given to subsoiling. Yield response, water infiltration as it affects plant growth, bulk density of the soil (16), and other phenomenon influenced by subsoiling, have been inconsistant and ranged from very high to very low.

Between 1912 and 1918, twelve Dry Land Stations in the Great Plains conducted studies, averaging 5 1/2 years in duration, on subsoiling, deep tilling and soil dynamiting. Chilcott and Cole (7) summarized this work and concluded in part:

> As a general practice for the Great Plains as a whole, no increase of yields or amelioration of conditions can be expected from the practice.

During the same period and through the year 1925, other workers in five mid-western states (20,39,43,50,59) independently concluded that no material increase in crop yields could be expected from deep soil breaking.

Agriculture at this time had not been exposed to the compaction of heavy rubber-tired machinery, the various plowing and cultivating operations, or other practices contributing to "induced hardpan" development. Compaction problems then were mostly confined to genetic pans. There is no mention that the deep application of fertilizer was being considered.

The availability of powerful, convenient tractors coupled with the managerial necessity to produce high crop yields per acre unit of allotted crops has helped to revitalize intensive interest in deep tillage practices during the last fifteen years.

More recent investigators have reported inconsistent response. From Louisiana, Saveson (54) reports that:

> Deep tillage has resulted in pronounced increases in yields of cotton where soil compaction problems limit water intake, storage and root development.

At Mississippi State College (48), subsoiling results varied according to soil type. On those soils having layers that restricted the movement of water and roots, significant yield increases were reported for cotton and corn. Other benefits to the soil include an increased water intake, increased root development, less drouth injury, reduced grass and weed population and an improved stand. It was indicated that breaking through a restricting soil layer may be an adequate tillage depth and will vary with soil conditions. On clay loam where the entire profile was compacted, deep breaking had no effect on cotton or on soil properties. It is thought that response to deep tillage may be less in years having more rainfall and more response in years of insufficient rainfall, providing the subsoil has had prior moisture storage opportunity. These trials recommend deep breaking when soil is relatively dry to satisfactorily shatter the hardpan.

In Kansas, Hobbs, et. al., (21) report that deep tillage gave no important response and the extra power costs could not be justified. Rice (49) had a similar result in Georgia.

Alabama (25) reported no significant effect on crop yields, but did have an increased depth of rooting.

Schmantes (56) of Minnesota did not find significant yield differences on three stations during a six year study.

In their review of "Current status of research in soil compaction", Raney and Edminster (46) summarized deep tillage work by saying "increased crop yields are possible in certain years where tillage treatments shatter induced pans, where deep tillage may be limited to one season, and that treatment of clay pan soils has not been very successful". The review points out that in those soils where deep tillage was not effective, the placement of lime and fertilizer may be beneficial and suggest more research in this area. It concludes (46) that:

> Existing research data do not justify any general statement concerning the effects of deep tillage on soils with fragipan, indurated hardpan, or compact C or D soil horizons.

The Concept of Deep Fertilization is Three Dimensional

Out of the effort "to do something about" (46) soil physical conditions, investigation and conceptions have gradually broadened from thinking of a six-inch seedbed to a desire to understand and control those factors in - fluencing plant growth throughout an entire soil profile penetrated by the root development of a particular crop.

It has been recognized that in many soils, the presence of "induced pans", (46,48,51,29,44,45) acid subsoil, (70,13,29,27) high water table of poorly aerated rootzones, (4,54) "genetic pan" formations (46) and subsoils naturally low in plant nutrients (29,13) all severely depress crop production. There is now a growing understanding of root penetration in relation to soil bulk densities, (4,60,16) of water infiltration, soil moisture, plant water requirements, (29,6,26) soil microbilogy, aeration and nitrogen fixation as related to plant root growth (29,60). Mechanical deep breaking alone has given significant yield response in only some selective soil conditions (29,59,36).

The concept of "third dimensional" agriculture (17) has been introduced, with the controlled placement of lime and complete fertilizers below normal tillage depth. This mibht mark a turning point from the present extensive type of production practices brought about by an effort to spread machinery cost over many acres, thus lowering the per unit capital investment. There now seems to be a trend toward more intensive systems where year by year the normal top soils will be vertically extended from 8 to 10, 10 to 12, 12 to 14 inches and deeper, where crop yields under irrigation will increase and where higher capital expenditures per acre for machinery and other costs of production might be justified.

During the last ten years, much attention has been given to subsoiling. Gradually, this information indicated that mechanical tillage was not adequate in most cases to increase or to sustain crop yields profitably. Gradually, it was found that lime and complete analysis fertilizers placed in the 6-to 2?-inch root zone could help correct soil acidity, and stimulate the growth of nitrogen fixing bacteria.

Purdue University (4?) like many other research institutions started subsoil fertilization investigations because it was recognized that while the general climate permitted large crop yields, the weather was not consistent. In some years crop yields were reduced by drought that caused water deficiency in the shallow root zone, while there was generally adequate available moisture deeper in the profile. It was found that the subsoil environment did not encourage deep rooting. Most Indiana subsoils are acid and low in available plant nutrients.

General Comments on Yield and Root Growth Response in Relation to Fertilizer Placement

Where subsoils are very dense (4), plant roots will not penetrate below the plow depth. Kohnke and Bertrand (66) found a direct relation between root penetration and the depth to which fertilizer was incorporated by tillage practices. Where plowing was seven inches deep the concentration of crop roots was in the top 7 inches of soil. Since soils below plow depth were compact and high in acidity, it was reasoned that soil nutrients were not annually being replenished in the lower root zone, thus discouraging deeper root development. Plate I illustrates this root response (29).

The benefits to the soil and plant from both subsoil tillage and from deep fertilizer application compliment each other. Lime can be added to correct acidity, and proper amounts of phosphate, potassium and nitrogen can be added to restore plant food shortages. For maximum yields, these additions must be coupled with good surface drainage, good seed, weed control and other sound agronomic practices.

After four years of investigation, Kohnke and Bertrand (29) believe that "Subsoil fertilization can serve well in the corn belt" by helping to increase infiltration capacity, to increase the soil moisture content, and to cause crop roots to penetrate deeper and make use of the subsoil moisture. They emphasize that roots can be baited deeper by fertilizer placement and that deep rooting contributes to the organic matter content of the subsoil. Plate I, Fig. 1 illustrates the root response to placement of fertilizer, while Plate I, Fig. 2 illustrates the distribution pattern.

Many Indiana soils are extremely low in plant nutrients and are acid with a low Ph factor. It was reported (29) that:

> Yield increases from subsoil fertilization have been substantial in many cases, but not consistent. In 10 out of 16 cases, the subsoil fertilization showed a significant increase in yield over the check plots.

It is believed that benefits from the practice will increase if repeated each year.

Hansen, et. al., at Michigan State University (19) tested fertilizer placement with subsoiling at depths of 14 to 20 inches spaced 40 inches apart in soils with genetic or traffic pan structures. In many locations, corn showed significant increases one year, but not the next. For the period 1954-55-56:

> In many instances oats and corn yields were increased by the addition of supplemental fertilizer to the subsoil. These yield increases were equal to those where equivalent amounts of supplemental fertilizer had been applied to the surface of the soil.

There was no significant difference in yield between the subsoiled and non-subsoiled plots in tests through 1958.

Deep Plowing. Hansen, et. al., (19) reported that in 1957 tests on sugar beets did not respond to mixing of supplemental fertilizer by deep plowing (depth of 18 to 20 inches with a 38-inch diameter disc plow), but fertilizer placed in the bottom of the furrow increased beet yields 3.6 tons per acre. The furrow bottom placement of fertilizer did not significantly affect corn yields. Deep plowing alone increased corn yields by 12 percent.

Fertilizer applied with the moldboard plow did not affect corn yields. However, corn from the deep plowed plots yielded an average of 7.5 bushels per acre more than from those plots which were conventionally tilled. The deep plow-applied fertilizer practice increased yields about five bushels per acre. Most important, there was a significant interaction between plowing depth and fertilizer application rate. In 1958, medium plowing depths of 14 inches with high manure amendments gave high corn yields, averaging 107.2 bushels per acre.

The above Michigan studies showed:

> A highly significant interaction between variety and plowing depth which suggest that in the future more emphasis will have to be placed on the selection of crop varieties in deep tillage experiments.

This is important because it could influence the desired placement of fertilizer and the design of applicators to serve the needed placement patterns.

<u>A Random Review of Various Tillage and Fertilizer Placement</u>. In Florida, Robertson (52,51) found that "On acid flatwood soils, corn yields were increased significantly by deep application of lime and fertilizer."

In working with Havana Seed Tobacco, De Roo (9) washed roots to show profuse development of secondary roots (Plate II, Fig. 3) in those areas where fertilizer was banded behind a chisel shank set to follow the tractor furrow wheel to penetrate below the plow sole level (Plate II, Fig. 1 and 2). Root response was also pronounced on a fine sand where organic hardpan existed. However, on another fine sand soil with an open profile, fertilizer placed on the surface was as effective as placing it 5-6 inches below the plowsole.

EXPLANATION OF PLATE I

Fig. 1. This plate illustrates washed corn roots as an example of growth response to the baiting of roots with deep fertilizer banding.

UNIFORM FERTILIZATION OF PLOW LAYER - No treatment.

Previous to corn, all treatments had 900 lb/acre of 10-10-10 and 400 lb/acre of 33% Ammonium Nitrate plowed under.

DEEP TILLED OR SUBSOILED

This plot had the plow layer fertilized the same amount as did the plot with no treatment.

DEEP TILLED AND FERTILIZED

These plots had 1000 lbs. of 4-16-16 and one ton of limestone put in the subsoil in bands beginning at 8 inches deep and going down to 20 inches deep. The bands were 28 inches apart.

All subsoiling operations were performed in the Fall when the soil was dry.

(Courtesy Purdue University Agr. Exp. Station.)

Fig. 2. This figure illustrates how, from a toolbar mounted hopper, a dry-type fertilizer is gravity fed through a spout behind a subsoil tool, falling out through baffled openings so that it is distributed in a vertical band from 8 to 20 inches deep in the disturbed soil slot.

Left picture - Schematic diagram showing soil loosening and fertilizer placement with a subsoiler.

Right picture- Schematic cross section of the action of subsoil fertilization.

(Courtesy Purdue University Agr. Exp. Station.)

PLATE I

Figure 1.

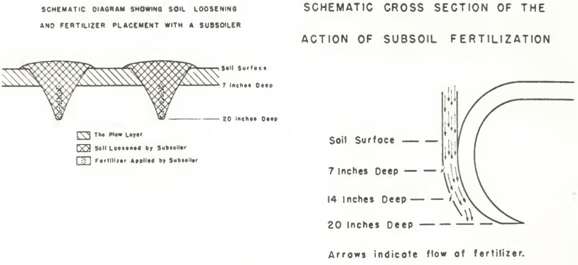

Figure 2.

EXPLANATION OF PLATE II

Fig. 1. View of the subsoiling apparatus loosening and fertilizing the plow sole and subsoil to a depth of 16 inches in conjunction with plowing to a 8-to 9-inche depth.

De Roo has given a fairly detailed description of assembly procedures in his report (9).

Fig. 2. The subsoiler apparatus exposed, showing subsoiling beam with attached fertilizer chutes and chisel reaching 7 inches below furrow bottom.

Fig. 3. View of a 6-inch thick cross section through a Havana Seed tobacco root system taken with a needleboard. Roots have developed profusely in the three fractured and fertilized zones in the plow sole and deeper subsoil.

(Courtesy H. C. De Roo, Connecticut Agr. Exp. Station.)

PLATE II

Figure 1.

Figure 2.

Figure 3.

Jamison (27) of Missouri working with Mexico silt loam found that lime and fertilizer applied in subsoil bands or by deep plowing gave significant increases on corn and alfalfa in some trials. Surface secondary treatments for both the deep-treated and check plots consisted of plowing 10 inches deep. The yield increase from deep treatments, although significant, was discounted as being impractical because of the additional tillage cost. However, it should be noted that the 10-inch plow depth might decrease the spread of results between the check and the deeper treatment. The conception of substituting chisels with fertilizer applicators followed by disking or till-planting as a normal preparation was not included. Equipment costs could be reduced by methods other than moldboard plowing on the clay soil.

Extensive work in Louisiana (44) on four soil types concluded that deep fertilizer placement and deep tillage show an increased root development in the subsoil. Crop yield increases can be expected from this practice on soils that possess traffic pans. Yield responses were particularly evident in years of below average rainfall. The practice promoted a much deeper root system. Surface vs. deep fertilizer placement coupled with subsoiling was not consistent in yield response. Conventional tillage accompanied by heavy fertilizer surface applications resulted with a moisture stress and gave a low yield.

In 1956, Engelbert (12) found that subsoil liming and fertilizing promoted alfalfa roots to penetrate deeper and helped establish alfalfa stands. Hay fields increased up to one-half ton per acre and were sustained over a four-year period. Plowing 12 inches deep gave better results than did shallower plowing. Corn and oats did not respond to these treatments.

Of the famous Morrow Plots established on the University of Illinois campus in 1876, some were continuously cropped in corn with no fertilizer added. Russell (53)[1], in 1955, restored plots to full corn production by adding the required limestone, phosphorus, potassium and nitrogen to the surface six inches on a portion of each of the depleted areas. Russell summarized his work by saying:

> Yield differences associated with previous management practices largely were removed by the application of liberal amounts of plant food. The extra nutrients did not, however, result in added yields on plots that had received good management in previous years.

High yields continued on all newly treated plots for four years, with each year being favorable to high crop production.

Lang (31)[2] reported, that in 1959 the same Morrow plots gave striking yield differences due to moisture stress. Since 1955, plots had received equal amounts of N, P, and K. The plots yielding 96 bushels per acre had been manured and fertilized since 1904; the one yielding 56 bushels per acre had a record of continuous corn with no fertilizer amendments before 1955. The 1950 rainfall was less than half of normal with a large portion occurring during the critical growth period July 15 to August 15. Moisture stress resulted in a large yield difference although equal amounts of heavy fertilizer were used.

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[1]M. R. Russell is Head of the Department of Agronomy, College of Agriculture, University of Illinois.

[2]A. L. Lang is Professor of Soil Fertility, Department of Agronomy, University of Illinois.

In the North Central corn belt, Larson, et. al., (33) obtained a higher corn response from fertilizer plowed under than by placement behind subsoil shanks. Placement and distribution patterns of the fertilizer might have affected the results, in that fertilizer was applied to the bottom of 16-inch and 24-inch slots on respective trails and not banded from the surface down in stages to bait roots deeper from early development to maturity.

In Louisiana (8) results of a three year study showed that:

> Cotton may respond to either deep placement of fertilizer or to subsoiling on certain soils. The yield response from deep placement has been considerably greater in dry seasons than in wet seasons.

Swanson and Jacobson (60)[1] report that corn yields varied inversely as the compactness or hardness of the soil. It was found that greatest returns from nitrogen side dressing on corn were obtained from soils in optimum physical condition. The application of N side dressing on corn growing in soils with poor structure may be wasted.

The trend toward preparation of a deeper root bed seemed to be present but the way was not clear. It has been suggested that yield alone might not be a good measure of results. Certainly the relationship of many variables concerning the plant, soil and moisture complex is not fully understood.

In September, 1955, while employed by the Fabick Bros. Equipment Company, a Caterpillar track-type tractor distributor located in Sikeston,

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[1]C. L. W. Swanson and H. G. M. Jacobson are Chief Soil Scientist and Soil Scientist, respectively, Department of Soils, Connecticut Agr. Exp. Station, New Haven, Connecticut.

Missouri, the writer cooperated with State and Federal agencies[1] to initiate 18 observation plots on deep placement of fertilizer on 12 identified soil types in the 11 county boot-heel delta area of Southeast Missouri. The writer was responsible for installing, picking and weighing cotton and corn on these plots, each with 4 combinations replicated 3 times.

A 10-10-10 complete analysis liquid type fertilizer (new to the area at that time) was used. Each soil fertility level was analyzed in each 6-inch vertical layer to 24 inches deep. The fertility tests established that in many of the major soils wide variation could exist in a given soil between the 6-inch soil layers, in the amounts of available phosphate, potassium, magnesium, and calcium. To apply the fertilizer, the writer invented a new principle of fertilizer placement. A tool was designed to accomplish predetermined patters of fertilizer application in a 24-inch vertical soil profile. This tool is shown in Appendix and Plate V, and will be discussed later in more detail on Page 19.

Analysis of the first year's results from this applicator were documented by Jamison (24), but not published as it was the forerunner of more detailed studies. However, Jamison stated, in part, that deep tillage of the:

> Medium and coarse textured soils more generally resulted in significant yield increases both from corn and cotton. In the evaluation, it was suggested that the destruction of traffic pans so prevalent in these soils should be beneficial to subsoil moisture storage, to root penetration and ramification, and to crop plant growth. It was further suggested that deep fertilization of the coarser soils with less fertile subsoils

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[1]Agriculture Research Service, University of Missouri, Agricultural Experiment Station, Soil Conservation Service in Southeast Missouri, County Agents and Vocational Agriculture Instructors in Southeast Missouri.

> should also be expected to give yield increases, though extra fertilizer on the surface may be about as effective. However, in some coarse textured infertile soils, a deeper distribution of fertilizer salts or electrolytes should reduce the hazard of an osmotic increase in moisture stress in droughty periods, especially where the soil is heavily fertilized.

It was pointed out that cultivation may not be necessary in seasons of low intensity rainfalls, but in seasons having rains of high intensity which result in puddling and packing of soil, cultivation would be essential for maximum crop production especially in soils containing high silt and clay content.

On the other hand, excessive cultivation packed the soil, retarding nitrification and root growth, thus decreasing yields.

TRENDS IN COMMERCIAL FERTILIZER PLACEMENT

Some 40 years ago, fertilizer placement studies were started in America. Starter fertilizers in small amounts of low analysis application were used to help the young plants along. Organic manures were widely used, but rapidly became less important as tractors replaced horses.

The land has become older agriculturally, making increasingly higher amounts of soil amendments necessary to sustain and increase crop yields.

As larger amounts of fertilizers were used, it became increasingly apparent that a major part of the heavy dosages should be incorporated deeper in the soil.

Bear (2)[1] has suggested two different schools of thought concerning the use of complete analysis fertilizers regardless of whether all or only a part of the required nitrogen for the crop season is applied

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[1]Firman E. Bear is Editor-in-chief, Soil Science, Rutgers University, New Brunswick, New Jersey.

initially. One school thinks in terms of fertilizing the crop and the other of fertilizing the soil.

In the "fertilizing-the-crop" concept, the use of fertilizer side-dressing equipment and "once-over" type planting equipment is involved. With this method, the planter prepares the soil, applies the fertilizer, plants the seed and applies an herbicide to control weeds, all in one operation. More conventional planting equipment will band a "starter" portion of fertilizer 1 1/2 to 2 inches to the side and 1 1/2 to 2 inches below the level of the seed on one or on both sides. This may be followed after plants emerge by another side dressing, basically of nitrogen. With "once-over" planters, heavy applications of fertilizers might be made at planting time, part as side dressing, but mostly deeper in the soil to one side of the row.

With the concept of "fertilizing-the-soil", emphasis is on building up the fertility level in the entire soil profile, thus increasing the volume of soil in which plant roots can feed. Ideally, the concept is to build a deeper top-soil by farming progressively deeper from 6 to 8, 8 to 10, 10 to 14, 14 to 16 inches and thereby progressively improving the soil aeration, soil structure, soil bulk density, the plant food availability and reserve, plus other desirable effects associated with a top soil in good tilth. Once the level of fertility has been built up, phosphates and potassium can be applied on a maintenance basis at any convenient time and manner. The concept of "fertilizing-the-soil" has been used for 50 years in many of the intensively cropped market-gardening and truck-farming areas of the eastern United States (2), of California, and elsewhere. To maintain maximum yields, many more pounds of plant nutrients have been applied to the soil in these areas than the harvested portion of the crops has removed.

The development of more concentrated forms of both complete fertilizers and single analysis fertilizers has enabled the advancement and change in fertilizer metering and distribution equipment. At first, concentrated dry type fertilizer in the raw crystal forms was very hygroscopic. This ability to attract moisture would cause fertilizers to cake, become hard, and clog distributors. Metering the correct amounts of plant food was allied to these same problems. Today, improved techniques provide for a wide choice of mixtures and analyses in concentrated forms that do not readily attract moisture.

Standards for a "Modulus of Uniformity or Finess" (67) for dry forms have not been defined. At present, these forms may be fine, granulated or roughly pelleted.

Walker (67)[1] pointed out great need from the engineering view for spherical pellets of uniform size regardless of the combinations of nitrogen, phosphorus, and potassium. It is predicted that pellet uniformity would make possible more accurate placement and uniformity of distribution resulting in better efficiencies from fertilizers.

Merrill (35)[2] in his review of new fertilizer application equipment expressed concern over the differences of opinion among agronomists and farmers as to the proper placement on various crops. This is now the case as well with deep placement of plant food. Therefore, the only consideration should be the degree of fertilization for the greatest long range economic return.

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[1]Harry B. Walker, deceased, Professor Emeritus of Agricultural Engineering, University of California, Davis, California.

[2]R. N. Merrill, Chairman, Subcommittee on Machinery for Placement, National Joint Committee on Fertilizer-Application. He is engaged in product research for Deere & Co., Moline, Illinois.

It is the response of a crop that dictates the success of fertilization methods. For this reason, the specific needs of plants have a great influence on specifications for fertilizer placement.

FERTILIZER PROPERTIES THAT INFLUENCE APPLICATOR DESIGN

A Statement of Scope in Dealing with Applicators

In 1953, the "National Joint Committee on Fertilizer Application published a directory of the "Manufacturers of Fertilizer Distribution Machinery"[1] (61, pp. 135-150). It included a directory of experimental fertilizer machines with brief listings of specifications, uses, origin, and references on equipment concerned with test plot work. In 1956, (11) the joint committee also set up a "Subcommittee On Machinery For Fertilizer Placement and For Research." This special subcommittee produced a 101-page directory and in 1959 an appendix to it (62), classifying, describing and documenting all known fertilizer application machines and devices used in research work. The information was very general, relying on pictures for design description details. A review of literature has revealed very little design detail concerning the construction of deep applicator units.

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[1]Directories are made up of special fertilizer application machines and devices used in research, prepared by a subcommittee of the National Joint Committee on Fertilizer Application. Organizations represented are the American Society of Agricultural Engineers, American Society of Agronomy, American Society For Horticultural Science, Farm Equipment Institute, National Canners Association, and the National Plant Food Institute.

Fertilizer Materials

Fertilizer materials are available in dusts, granules, pellets, gaseous or liquid forms. They have been applied in many ways including the use of dry, liquid, high pressure, low pressure, gravity flow, surface and sub-surface applicators.

It is with the fertilizer placement by sub-surface applicators and methods that this report is primarily concerned, and not with a review of the multitude of chemical formulations. However, the two broad physical categories of fertilizer that directly dictate equipment design, are liquid types including anhydrous ammonia and other nitrogen forms, and dry types.

Liquid Types

These include anhydrous ammonia which is compressed and stored as a liquid, but which is a gas under normal atmospheric conditions. Included also would be aqua ammonia which is anhydrous ammonia diluted with water to decrease its vapor pressure and permit handling in low pressure types of equipment. In addition, liquid fertilizers include nitrogen salts dissolved either in water or aqua ammonia (65). Dissolved in water, these nitrogen salt solutions would contain no free or volatile ammonia.

Phosphoric acid is a liquid used to limited extent in the western states.

Liquid fertilizers are commonly accepted as meaning, complete fertilizers containing nitrogen, phosphorus, and potassium in one complete solution. These are now in general use on farms.

<u>Liquid Nitrogen Forms</u>. Nitrogen liquid forms have their own properties

and commonly fall into three groups: (1) High pressure materials; (2) low pressure materials; (3) non-pressure materials.

High Pressure Materials. Pressure is determined by the volatile ammonia in the liquid. Anhydrous ammonia is the main high pressure material used.

Low Pressure Materials. Low pressure liquids are aqua ammonia and nitrogen salts in ammonia and water solution.

Non-Pressure Materials. Non-pressure solution is commonly a water solution of urea and ammonium nitrate containing 32 percent nitrogen.

A volatile high pressure material like anhydrous ammonia must be applied deeper in the soil than the low pressure materials. A low pressure solution can be placed as shallow as two inches if well covered with soil. It is reported (2) that anhydrous ammonia, when applied four inches or deeper during late fall, winter, or early spring well in advance of planting corn or cotton, is so strongly adsorbed by the soil that leaching losses are not serious. When the soil warms up later to about 45° F., the nitrifying bacteria transform the ammonia to nitrate, thus releasing available nitrogen from the soil adsorption complex for immediate plant use.

Sub-surface placement of anhydrous ammonia should be accompanied with some method to firm or agitate the surface to close the open crack left by the tool, usually by large size tractors (67).

In the far West, in the Mississippi River Valley, and in some other areas, contract or custom service is proving popular for the application of low cost anhydrous ammonia, particularly on small and average size farms.

A Stoneville, Mississippi, test (8) on anhydrous ammonia in connection with chiseling 10 and 14 inches deep gave good response to chiseling, but did not show significant benefit from applying nitrogen deeper than 10 inches. There was considerable variation in the test.

The most recent work on applying anhydrous ammonia was reported by Hopkins, Wells and Butler (22)[1] at the A. S. A. E. Winter Meeting, 1962. Their comprehensive paper concerns the high pressure injection of the gas, directly into the soil from a nozzle, as a substitute for conventional knife type applicators which have rather high power requirements. Injection pressures up to 4000 psi were used and could penetrate clay soil about 6.5 inches and requiring about one horsepower per nozzle as opposed to 5 to 7 horsepower required per knife applicator. The efficiency of the method was 80 percent.

It might be practical to mount such nozzles at intervals down the back of chisels and inject the nitrogen horizontally to the side at desired levels, provided the tillage was beneficial as it well might be in the corn belt.

Non-pressure solutions of nitrogen contain no free ammonia and can be deep placed or surface broadcast with loss of nutrients to the air (65).

Minimum Temperature Range For Nitrogen Solutions. When temperatures are lowered, nitrogen solutions become super saturated and may crystalize or solidify as indicated in Table 1. This action is called salting out. In general, the salting out temperature increases as the salts in solution increase.

In the use and design of application equipment, salting out characteristics should be considered for accurate distribution patterns through small

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[1]D. F. Hopkins, G. L. Wells and B. J. Butler, Engineer, Missiles and Space Division, Douglas Aircraft Company, Santa Monica, California; Test Engineer, International Harvester Company, East Moline Works, East Moline, Illinois; and Assistant Professor, Agricultural Engineering Department, University of Illinois, Urbana, Illinois, respectively.

Table 1. Representative nitrogen solutions and their properties.

Liquid	Nitrogen Content %	Volatile Ammonia %	Ammonium Nitrate %	Urea %	Water %	Vapor Press. #psig @104° F.	Salting Out Temp. °F.
			High Pressure				
Anhydrous Ammonia	82.0	99.5	-	-	-	211	-108
			Low Pressure				
Aqua Ammonia	24.3	29.4	-	-	70.6	10	-110
Solution 1	41.0	22.2	65.0	-	12.8	10	+21
Solution 3	37.0	16.6	66.8	-	16.6	1	+48
			Non-Pressure				
Solution 32	32.0	-	44.3	35.4	20.3	-	+32
Solution 31	28.0	-	38.8	31.0	30.2	-	0
Solution 40	18.6	-	-	40.0	60.0	-	+33
Solution X	21.0	-	60.0	-	40.0	-	+47

(Courtesy Sohio Chemical Company.)

spray orifices. At the present time most fertilizer is applied well above the critical temperatures. But if the trend continues for applying quantities of soil amendments during cool late fall and early spring in connection with primary tillage operations, then salting out problems will be a needed consideration (65).

Complete Liquid Fertilizers. Bear (2) recognized that placement of a complete liquid fertilizer will differ little from that of solid granular forms. He states in part:

> The evidence indicates that, when used at heavy rates of application, plow-under or similar deep placement procedures may come to be standard practice with the liquid as well as with the solid forms of complete fertilizer.

[illegible]-pressure complete liquid fertilizers derive their phosphate from phosphoric acid, which commonly contains 75 percent H_3PO_4 or 54.3 percent of P_2O_5 equivalent (65).

Nitrogen salts can be supplied in dry or liquid forms as sources of ammonia or from high solubility nitrogen salts such as urea and/or ammonium nitrate.

The potash is usually derived from highly refined potassium chloride salts containing 62 percent K^2O.

As shown in Table 1, there is a limit to the concentrations possible. When liquid fertilizers become super-saturated, salts will crystallize out. Again this could cause distributor clogging and poor application.

Table 2. Complete liquid fertilizer.

Analysis	8-24-0	6-18-6	9-9-9	8-8-8	14-7-7
			Formulations %		
29.4% Aqua Amm.	33.21	24.90	12.30	10.91	9.56
75% Phos. Acid	44.48	33.36	16.68	14.83	12.97
Urea	-	-	13.33	11.85	25.74
KCl (62%)	-	9.70	14.54	12.93	11.31
Water	22.31	32.04	43.15	49.48	40.42
			Crystallization Data		
Crystallization Temp. °F.	23	7	13	0	14
Crystallization Material °F.	DAP	DAP	KCl	KCl	Urea

(Courtesy Sohio Chemical Company.)

Table 2 illustrates how complete liquid fertilizers may be formed to prevent crystallization. However, most producers try to make grades where salting out occurs at 32° F. temperatures or below.

Tucker (65) states (as shown in Table 2) that the least soluble of the salts in a solution will crystallize out first and this in turn will reduce and alter the analysis of the remaining liquid.

In the high potassium grades which do not contain a nitrate, the KCL usually salts out first. KNO_3 usually salts out first in the high potassium grades when nitrates are present. Other salts might be diammonium phosphate in the high phosphate grades and urea in the very high nitrogen grades such as a 14-7-7 made using urea.

Methods of Liquid Fertilizer Application. Because the complete liquid fertilizers contain no volatile ammonia, they can be applied by almost any method. They can be applied deep, on the surface, or plowed under. Being liquid, they can be pumped, metered, gravity fed, or transferred by air pressure. They can be transferred easily from bulk storage by pumping and therefore are convenient and labor saving in handling.

Application equipment is designed to handle low pressure and non-pressure liquids (64,65,37). Equipment for handling liquid fertilizer is of three general types, gravity, compressed air, and pump.

In 1956, Miller and Gantt (37)[1] made a review of liquid application equipment. They pointed out that liquids are becoming increasingly popular because of low initial cost and simple operation.

Rates of application are determined by the size and number of outlet orifices and the speed at which the tractor travels. Flat terrain and narrow swaths are well suited to the use of gravity systems.

Gravity Systems. Various methods are employed to help compensate for fluctuation in the rate of flow due to variation in heights of liquid level in tanks. Non-pressure liquids are the only ones readily adaptable to the gravity methods. A disadvantage is that close attention to equipment during application is generally necessary to insure proper operation and uniform distribution.

Compressed Air Systems. In compressed air systems, the rate of application is governed by the pressure in the tank, the tractor speed, and the

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[1]H. F. Miller, Jr. and C. W. Gantt, Jr. are, respectively, Head, Farm Machinery Section and Agricultural Engineer, Agricultural Engineer, Agricultural Engineer, Agricultural Engineering Research Branch, ARS, USDA, Beltsville, Maryland.

number and size of orifices or nozzles. This system is adaptable to solutions with some pressure, for spray type equipment, for any width swath, and for any number of orifice outlets. An air compressor equipped with air regulator and relief valves and an air-tight tank are necessary.

Pump Systems. Pump equipment used in liquid fertilizer systems is the most varied and generally used of all the methods, and is similar to that used to spray pesticides and herbicides. Rotary pumps have long been classified by the petroleum industry into approximately 12 types (37):

Vane	Gear	Oscillating shuttle
Lobe	Squeeze or hose	Centrifugal
Screw	Diaphragm	Rotary
Piston	Universal	Nylon roller

A further subdivision of pump types can be made into, (1) power pumps, (2) ground driven metering pumps. Power driven pumps may be divided further into (1) power-take-off, driven, and (2) auxilliary, engine driven pumps. Each of these pumps has individual operating characteristics of volume, pressure and speed that vary in their advantages and disadvantages so far as their usefulness in designing applicators for deep placement work is concerned.

Georgia Experiment Station Liquid Distributor System. For precision metering of liquids on research test plot work, Futral (14) of Georgia designed a unit unlike any other. Plans and a complete description of this unit have not been published and are not yet available. However, a good picture and basic information are documented (14,62). The metering device as described by Futral (22) is shown and described in Plate III.

EXPLANATION OF PLATE III

This plate shows a reproduce diagram of the Georgia Experiment Station precision liquid fertilizer distributor, showing the working principle.

Basically a cylinder, the volume of which is large enough to contain the largest amount of liquid material to be used for a plot row. A piston is driven upward by the action of an inclined plane which in turn is moved by a rack and pinion driven from the tractor planter gears. The drive is geared to move the rack its full stroke in one test plot length. A simple clutch and crank is attached to the pinion for returning the rack to its original position after completion of each row. The length of the piston arm is adjusted so that the top of the piston coincides with the top of the cylinder at the highest point of the incline plane. In use, the rack is cranked back until the piston is at its lowest position; then the correct volume of liquid is poured into the cylinder. Next the inclined plane slide is raised, which also raises the piston, until the liquid level coincides with the top of the cylinder. It is then locked at this angle. Since the rack always moves its full stroke in a plot length, the piston has to end up even with the cylinder top regardless of its starting point or of the original volume used.

There are three essentials to consider in the construction of this unit:

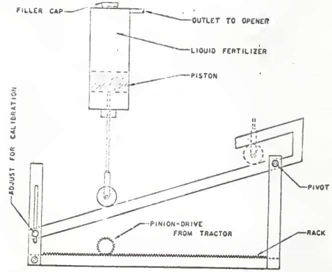
1. The rack must run off of the pinion or be declutched accurately at the end of each plot to prevent damage.

2. The highest part of the inclined plane must be rounded to prevent the piston from striking the cylinder top after angular adjustment, and very strong guides must be provided for the piston arm to resist lateral forces produced by the action of the inclined plane.

3. The output may be divided accurately between two rows only if siphon breakers are used on the tubing to compensate for differences in length or height.

(Courtesy of J. G. Futral, Georgia Experiment Station.)

PLATE III


FILLER CAP
OUTLET TO OPENER
LIQUID FERTILIZER
PISTON
ADJUST FOR CALIBRATION
PIVOT
PINION-DRIVE
FROM TRACTOR
RACK

Johnston (28)[1] who classifies the systems as follows:

1. The variable volume, positive displacement metering pump powered by ground driven wheel. These systems are recommended either for a pressure injection type of applicator or for nozzle spray applications.
2. The constant speed orifice system utilizes a rather large volume pump running at constant speed. By means of a pressure regulator, a constant pressure is maintained on the applicator spray nozzle orifices. The excess or overflow from the pressure regulator is returned to the tank by means of an adjustable bypass valve on the regulator.

Dry Type Fertilizers

There is a continuing trend toward ever higher analysis of mixed and complete fertilizers and materials. The use of nitrogen is going more and more to concentrated forms. With these forms of concentrates, precision metering equipment becomes increasingly important (63). The trend is toward more handling of fertilizers in bulk, and probably more important is the trend of applying only a nominal amount of side dressing at planting time with the major portion applied in conjunction with primary tillage operations. Acceptance of late fall and early spring fertilizer application permits the practice of broadcasting ahead of deep plowing or impregnation behind subsoil tools.

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[1]Douglas Johnston is Chief Engineer, John Blue Company, Inc.

The lack of uniformity in pellet size is of concern to the industry (67). If uniform sizes could be produced, the problem of dry fertilizer metering accuracy would be greatly simplified.

The Subcommittee (62, 61, 11) has published most of the available information concerning applicator methods and devices for metering dry fertilizers into vertical tubes behind soil engaging tools. Satisfactory innovations have been developed that can be adapted to meter quantities of both lime and complete fertilizers normally used with deep tillage. The devices are selected according to the needs of a specific application and custom designed to become a part of the applicator machine.

Corrosion of Equipment by Fertilizer

The most direct means of preventing corrosion when designing an applicator is to use corrosion-resistant construction materials. Shaffer (58) mentions that each situation requires its own solution because different metals will often react differently in different environments.

Liquid Fertilizers. Aluminum tanks may not withstand corrosive effects of complete liquid fertilizers, but carbon steel tanks usually will. Stainless steels can be used for all liquid fertilizers and are especially recommended for filters, screens and nozzles (64, 35). The most promising in the stainless steels are several chromium and chromium-nickel grades such as types 302, 304, and 316 that offer complete resistance to corrosion (37,58).

Tucker (65) states that in mixing complete fertilizers, the amount of free ammonia which will be used is that amount needed to neutralize the phosphoric acid required to supply the phosphate. To reduce corrosion to the minimum, the final fertilizer liquid should have a pH of at least 6.2. As the pH is increased above 6.2, the solubility of the ammonium phosphates is decreased, and above 7.8 (the reaction of diammonium phosphate) ammonia volatilizes and is lost.

Anhydrous ammonia is considered non-corrosive to carbon steel. Aqua ammonia is slightly corrosive to carbon steel, but nitrogen solutions containing ammonium nitrate are very corrosive and are usually handled in aluminum.

Materials that should be avoided because they are very subject to corrosion, when used to handle liquid fertilizers, are copper, brass, bronze, monel, zinc, galvanized metals, mild steel, and the usual die castings (64,37,58).

Because there is wide variation in corrosive action between the many different liquid-mix solutions, Miller (37) mentions that corrosive inhibitors or neutral solutions may in many instances make possible the use of mild steel or aluminum.

Reinforced plastics, such as fiber glass reinforced polyester resins, have shown good resistance to both nitrogen and to liquid-mix fertilizers and are becoming increasingly more popular.

BASIC POWER REQUIREMENTS AS RELATED TO TOOL DESIGN

The design of any deep applicator of fertilizer must be concerned with both the pattern of distribution and the tool-soil relationship. Soil physical characteristics and tool design are of prime importance in deciding if a practice is economically justified from both the standpoint of power requirements and the rate of production.

Draft of Subsoiler and Chisel Tools

Investigators (41) have found that a major factor concerning draft requirement is the horizontal pressure of the tool standard against the soil which greatly increases the force required for shear or fragmentation. Previous work (42) has shown the shear value of the soil to be directly proportional to the upward and horizontal pressures applied by the subsoiler point and standard to the soil. Tool pressures on soil directly affect draft.

At the National Tillage Machinery Laboratory, Nichols and Reaves (40) found that the resistance to forward movement of the subsoiler was largely due to the buckling pressure of soil against the front shin of the tool standard, and that the soil formed a cone shaped build-up on the top of the point which materially reduced the buckling pressure effect. The action formed a new flow line with less resistance. This discovery led to design changes of subsoilers. The principle change gave a curvature to the subsoiler's leading edge. The curved shank is important in reducing the draft of applicator tools. For example (40), at a depth of 11.5 inches in heavy Sharky clay soil, the curved standard required 1820 pounds of draft while the straight shank required 2000 pounds of draft. In another test at 1.5 MPH in heavy Hurricane soil the straight standard, operating 14 inches deep, required 2790 pounds of pull, the slightly curved standard 2340 pounds, and the fully curved standard 2315 pounds of pull. Many tests have been made including the design of points and large sweeps. Studies were made of draft, fracture patterns, soil bulk densities, swell factors and height of lift. Studies were also made on fracture in relation to soil moisture content and speed of ground travel in relation to tool draft increases (41, 40, 42, 32).

The Soil Laboratory (40) reported that fragmentation and rupture resulted in soil with a tillable moisture content if the resistance to compression is greater than the shear value of the soil. The strength or resistance values governing draft for any particular soil depend on several interrelated variables such as moisture, density, degree of confinement or depth, adhesion and coefficient of friction on the soil, cohesion of the soil, coefficient of internal friction, and the moment of inertia.

Soil plastic flow characteristics may be expected from a high moisture content that results in a low coefficient of internal friction, or where a soil is sufficiently compactible to compress enough to permit the subsoiler passage without resulting rupture planes that are transmitted to the surface.

The critical limits of soil moisture evaluation are important because the effectiveness of subsoiling seems to depend upon the shattering of the soil. Moisture has a direct effect on soil draft, and on those physical factors associated with good seed bed preparation. The National Tillage Laboratory (40) , has extensively studied moisture effects on soil draft.

Larson and Fairbanks (32)[1], used a dynamometer to measure the draft of a Killifer Chisel in soil comprising a silty clay loam surface overlaying

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[1]G. H. Larson and G. E. Fairbanks, Head of Department and Professor, respectively, of the Agricultural Engineering Department, Kansas State University, Manhattan, Kansas

silty clay. A graph showing the relationship of these specific tests are reproduced in Plate IV.

Michigan State University (19) chose to measure power requirements for subsoiling under different soil conditions, by using strain gage equipment mounted on a D-2 Caterpillar Track Type Tractor equipped with standard type tool bar and mounted subsoiler tool. Strain gages were installed on each of the four sides of the tool bar draft arms. The test procedure is fully described in the above mentioned paper.

The Michigan paper further reported that power requirements to subsoil depths of 20 inches varied between 3460 and 4425 pounds draft per tool. A continuous load of 4425 pounds at the rate of 1.59 MPH is equivalent to 18.75 HP. (19, p.3). This high draft load may indicate (19, p. 3) that subsoiling is not a matter of HP alone but of draft under a sustaining load. This thought brings to mind the well know issues regarding advantages and disadvantages of wheel tractors vs. track-type tractors. These issues include soil compaction, ground pressure and floatation, speed of travel, rate of wear, dust factors, traction characteristics, and a few others.

Deep Plowing Draft

In the Michigan tests, Hansen, et. al. (19), reported a power requirement of 230 and 410 pounds per inch width using a 38-inch diameter disk plow, cutting to a depth of 20 inches. It was said, that much of the draft variation could be attributed to differences in plow settings rather than a difference in soil structure.

EXPLANATION OF PLATE IV

Draft in pounds and HP per chisel point vs. depth in inches at relatively constant speed (average 1.69 MPH) for a Killifer Chisel. Average soil moisture taken to a depth of 15 inches was 24.8 percent (dry weight basis).

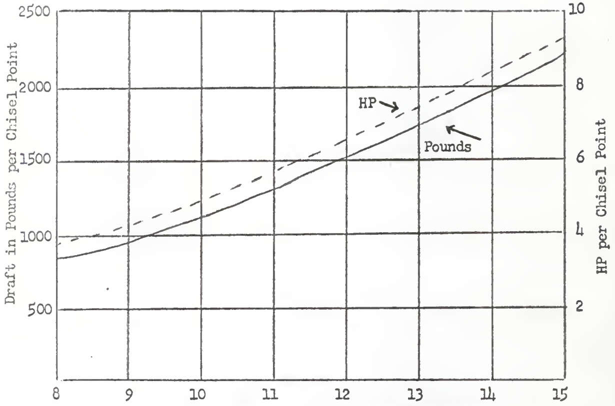
The graph shows that as the tool depth is increased, the draft per chisel point is increased, resulting in a greater horsepower requirement.

Other workers (41) have shown that as the speed of ground travel increased, there was a corresponding increase in draft.

These relations will have a direct influence in the design and the production rate of deep fertilization equipment.

(Graph, courtesy, G. H. Larson and G. E. Fairbanks, Kansas State University.)

PLATE IV



Depth In Inches

The requirements for power increased when disks were set for greater mixing action in the soil. Of significance also was a marked reduction in the necessary power when the soil was plowed for the second and third times.

EQUIPMENT CONCEPTS AND DISTRIBUTION PATTERNS USED TO DEEP PLACE SOIL AMENDMENTS

There is evidence that patterns of fertilizer distribution in the soil may be important or even critical in relation to crop root development and corresponding yields.

On page 2 of the 1956 Directory (11), the Subcommittee point out in part, concerning placement in general that:

> Many examples have been noted by various research workers which indicate that results of some fertilizer placement experiments have contained serious error due to inaccurate and irregular performance of placement equipment. Such occurrences definitely point up the importance of effective and reliable placement equipment. Some research stations have concentrated heavily on development of special equipment for the application of fertilizers; others have done little, or possibly only a minimum of work to justify some department responsibilities.

At present there there is not a clear approach to the problem of fertilizer distribution patterns in the soil. Nearly every worker has attempted to incorporate a new angle, device, or method to till and incorporate fertilizer into the soil profile. This is shown by the many innovations documented by the Subcommittee on Machinery for Research (11,61,62).

Various concepts of desirable soil fracture and fertilizer distribution patterns have guided the creation of tool and distributor combinations which basically treat the soil by stirring the rootbed, but leaving the topsoil in place or by stirring or inverting the topsoil into the rootbed.

If the subsoil below normal plow depth is of soil bacteria (29); if it is acid as indicated by a low Ph factor (27,12,13); if there is low natural levels of available phosphorus and potassium (13), or if the soil has an undesirable structure, it might not be advisable to mix the top soil with the subsoil. In preference to total mixing, a tillage system to leave the top soil in place may sustain higher yields (44,12,13). Primarily, such a system would be consistent with those tillage practices associated with minimum tillage and stubble mulch tillage practices.

Applicators That Stir the Rootbed, but Leave the Topsoil in Place.

Controlled Placement of Complete Analysis Liquid Fertilizer Applied Behind Subsoil and Chisel Type Tools. The writer's letter file documents the date of June 20, 1955, for first projecting the idea of designing a tool system or apparatus for distributing chemical liquids, particularly liquid fertilizer, in a predetermined pattern distribution at levels below the surface of the soil.

The apparatus was built and mounted on a Caterpillar D-4 track-type tractor. The first public demonstration was held July 26, 1955, on the Pat Burlison farm near Hornersville, Missouri. The writer, then employed by the Fabick Bros. Equipment Co., a Caterpillar tractor distributor, worked in the Company's interest to establish eighteen test plots with the new applicator in cooperation with Missouri University, State, and Federal Research, as well as Conservation Agencies (24). Merits of this unit are revealed in the copy of United States Patent 2,874,656, Appendix (3).

This applicator is designed so a forward motion of the spray pattern protector provides a mobile umbrella of soil under which the spray pattern

EXPLANATION OF PLATE V

Fig. 1. Set for deep application fo complete analysis liquid fertilizer, this tool bar is equipped with protector shields mounted on a subsoil tool (center) and chisel shanks on either side. Liquid fertilizer is pumped under pressure to a common stainless steel manifold, to individual pressure hoses, to a 3/8-inch I.D. stainless steel downtubes on the back edge of each tool, to nozzle openings set 8-,12-and 18-inch levels below the soil surface in the case of the center tool, and at 6-and 12-inch levels on the chisel shanks.

Fan shaped Tee-Jet nozzles spray 80-degree horizontal bands into the voids created by the forward movement of the protector shields. The shields are vertically flexible on a single pivot to facilitate a faster, smoother penetration and lead out of the soil engaging tools. The tractor swath shown is 6 1/2 feet operating at normal travel speeds of 1.7 to 2 miles per hour.

Fig. 2. The labeling in this plate emphasizes the major component functions of the tractor mounted spray unit.

A 35 gallon steel tank was fabricated to mount over the tractor front hood with supports on the tractor main frame. Stainless steel strainers were located in the tank inlet and outlet and in the manifold inlet line.

An adjustable pressure and bypass valve was located convenient to the operator's control. The pressure regulator was cast from aluminum with a coating of baked-on enamel that lasted only one season due to corrosion.

A "Hypro", nylon roller, power-take-off mounted pump was successfully used to discharge the liquid.

PLATE V

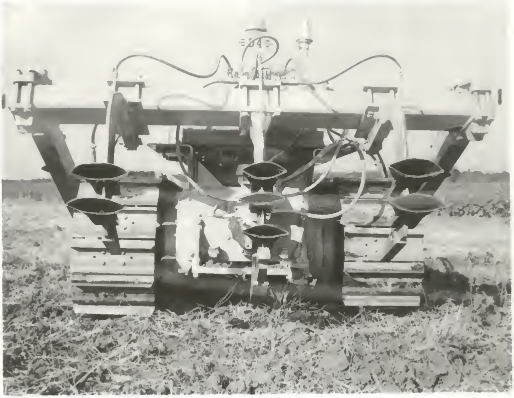


Figure 1.

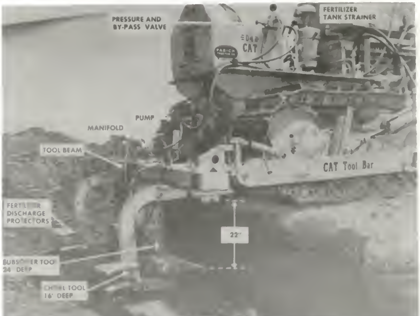


Figure 2

EXPLANATION OF PLATE VI

Fig. 1. The Caterpillar D-4 track-type tractor is equipped with hydraulic tool-bar and five chisel tools spaced on 20 inch centers. Soil in good plowing condition or drier can be completely shattered and aerated to a depth of 16 inches or less, thus eliminating the need for other primary tillage operations. With the fertilizer dispenser principle illustrated in Plate V, initial tillage and precision fertilization are done in one operation. With power, it is now easy to add lister or surface type planters to further speed field operations. Rolling coulters are available as chisel attachments.

Fig. 2. Chisel tools help build a deeper top soil. The surface inches are left in place and sterile, infertile or poorly aerated lower soil layers are left in place to be corrected by injections of chemical additives.

PLATE VI

Figure 1.

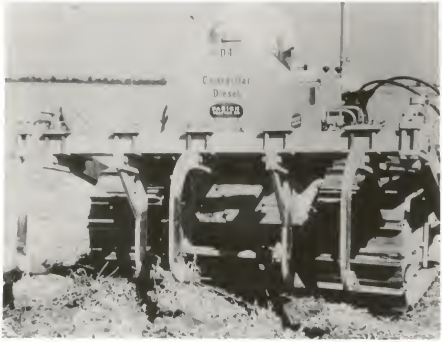


Figure 2.

can pass undisturbed into the soil. A horizontally positioned fan type Tee-Jet orifice that produced a spray pattern angle of 80 degrees with a pressure range of 10 to 60 pounds per square inch (psi) was used on initial tests. The patterns produced only slight vertical spread as they were collapsed into a thin horizontal line by the flow of settling soil. Plate V, Figures 1 and 2 further explain this application. The principle is extremely flexible in that there are so many assembly variables for distribution which include (1) pressure, (2) change of nozzle orifice size, (3) design of wider protector shields and use a wider spray pattern, (4) mounting protectors at any desired vertical interval on the tool, (5) adjusting the tool spacing along the tool bar, (6) use of various tool combinations including subsoilers, chisels and assorted sweeps, (7) varying the ground travel speed of the tractor, (8) and easy hydraulic adjustment of tool depth.

In summary, the rate of application varies with pressure, size of nozzles, spacing, depth, and speed of travel.

Lister Bedding Over Vertical Bands of Fertilizer. Chisels equipped with liquid fertilizer applicators were assembled by the writer in conjunction with lister bedding tools preparing land for cotton planted on top of the beds. A picture is not available, but Plate VII is substituted to illustrate how this tool combination would work.

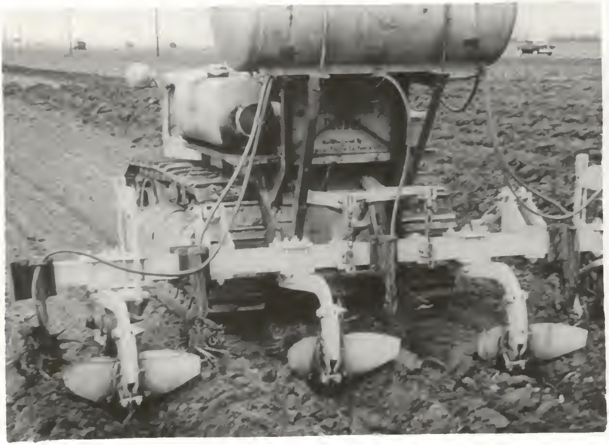
Vertically Adjustable Sweeps Mounted on the Back of a Subsoiling Tool. In the cotton areas of the Mississippi River Valley, there are compacted soils where the formation is not over 3 to 5 inches thick and is located just below a depth penetrated by plows and particularly listers. For those soils ranging from clay loam to lighter textures,

EXPLANATION OF PLATE VII

Shows a combination of seedbed preparation tools mounted on the tool bar of a track type tractor. Anhydrous ammonia is being distributed through knife-type applicators under beds being constructed by the listers.

An illustration of a more current but less accepted application, which is the use of chisel tools penetrating 14 to 15 inches deep and equipped with liquid fertilizer applicators. The chisels are centered between the lister bedders. The application is for cotton or other deep-rooted crops.

PLATE VII



the writer constructed and mounted a sweep on the back of a subsoil tool. Another consideration for designing the adjustable sweep was an effort to obtain a wide fracture pattern without the coarse, blocky soil fracture and the excessively high draft requirements commonly associated with the conventional sweeps attached to the subsoiler base.

The sweep was vertically adjustable by pinning at two-inch intervals and was designed to have similar vertical flexibility as illustrated in Fig. 3 of Appendix. This flexibility permitted the sweep to float with slight tool depth variations and also aided in putting the tool into and taking it out of the soil. Without this feature, a much longer distance was necessary to plane the sweep to the desired depth, and the same was true for taking it out. An abrupt lifting of a ridged sweep would pick up a volume of soil leaving a deep depression. This sweep was 30 inches wide with a 2-inch vertical lift.

In field trials, this application appeared practical. The subsoil shank was placed between the 36-inch cotton rows to loosen field travel compaction. Soil shattering was excellent in each of five trials in different cotton fields and with varied soils, where water was known to stand for long periods in the furrows. Pulling a disc harrow and a spike tooth harrow diagonally to the row direction satisfactorily leveled ridges and made a good seedbed for drilling small winter grain. Some plots were left fallow after fall treatment to re-bed in the spring by breaking beds out, putting the new bed on top of the subsoil mark. The old practice of breaking beds out and then back in was not necessary, therefore, one field bedding operation was eliminated. The practice of flat planting also appeared practical because of the improved drainage.

These studies were more in the form of demonstrations and were not documented at the time. However, it was observed that water did not stand over winter in the field as it did in adjacent areas. The soil surface dried earlier in the spring.

Plans to adapt and distribute liquid fertilizer from behind this sweep and subsoil tool for further tests did not materialize.

Fertilizer Distributor Designed to Renovate Old Grass Stands. The need has long been recognized for some way to fertilize, till, and to aerate existing stands of grass without destroying the present growth. This need is found in such places as pastures, golf courses, and public parks.

During February, 1956, the writer, while employed by the John Fabick Tractor Company, St. Louis, Missouri, assembled the machine shown in Plate IX, Fig. 1. This unit included the track type tractor shown in Plate V, Fig. 2. It pulled a hydraulically operated Rome tool carrier, equipped with heavy duty subsoilers, 30-inch sweeps with a minimum 1 1/4-inch lift and 30-inch diameter notched coulters. A sweep and subsoiler similar to that used is shown in Plate IX, Fig. 2, mounted on a Rome tool bar. The same fertilizer distribution assembly shown in Plate V, Fig. 2, was used except for the extension of hoses to the rear of the tool carrier and for alterations on the back of each sweep. From the common manifold, a fertilizer hose supplied the stainless steel tube attached to the rear of each subsoiler. The tube was encased in a semi-flattened 1 1/4-inch water pipe for protection against the soil. Wide angle Tee-Jet spray nozzles were inset in the back of the sweep.

Ten acres of thick, sod-bound, brome grass pasture were treated with

EXPLANATION OF PLATE VIII

Fig. 1. Shown is the side view of a vertically adjusted sweep fabricated to attach on the back of a standard Rome subsoil shank. The sweep is vertically flexible about a pinned pivot, to facilitate lead in and lead out of the soil. The front sweep edge is adjustable from 6 to 18 inches above the tool base in 2-inch pinned incliments.

Fig. 2. A rear view of the sweep shown in Plate IX, Fig. 1. This particular sweep was 30 inches wide with a 100-degree angle and a 2-inch lift. It was fabricated from a motor grader moldboard cutting edge. Liquid fertilizers could easily be discharge behind this unit.

PLATE VIII

Figure 1.

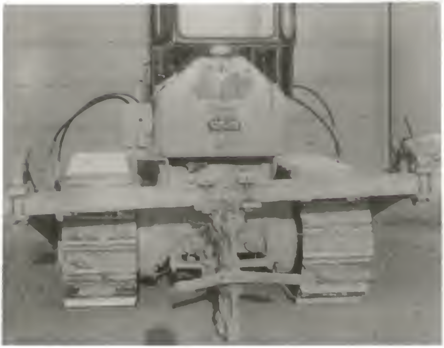


Figure 2.

EXPLANATION OF PLATE IX

Fig. 1. A Caterpillar D-4 track type tractor with liquid fertilizer equipment, pulling a Rome tool carrier. The carrier is equipped with rolling coulters and commercially made sweeps. Wide angle, Tee-Jet spray nozzles are set in the back of the sweeps in such a way that when the brome-grass sod is lifted a continuous horizontal band of fertilizer is applied. A large diameter roller is then used to press the moist sod back into place.

Fig. 2. A rome coulter and sweep, similar to the combination shown was used on the tool carrier in Plate IX, Figure 1 to treat brome-grass sod pasture.

PLATE IX

Figure 1.

Figure 2.

a complete analysis liquid fertilizer leaving untreated strips for check areas. This work was done early in February. When the grass was dormant and the soil very moist. The sweep penetrated a depth of 5 to 6 inches, to just below the bulk of the grass root sod. A coulter split the wet sod, the low lift sweep raised the sod to create a void space into which fertilizer was sprayed. A home-made type concrete roller, not shown, immediately followed to press the sod back into place. In late May, the treated areas had a much more luxuriant growth and were preferred by the pasturing dairy cattle. It was not possible at the time to make further studies.

Anhydrous Ammonia Application Behind Deep Tillage Tools. Anhydrous Ammonia metering and applicator systems have long been documented (28,1).

For many years, large cotton producers in both irrigated and non--irrigated lands have improvised ways of pushing yields ever higher. Plate X, Figures 1 and 2 show one of many track-type tractor attachments constructed by the Stribling Bros. Corporation, A Caterpillar Tractor distributor, located in Greenwood, Mississippi. Many distributors have constructed similar units for customers.

Vertical Banding of Liquid Fertilizer in Conjunction With Lime and Other Dry Soil Amendments. Investigators have attempted to combine deep applications of liquid fertilizers, lime, and other dry soil amendments. In 1957, Myers[1] designed a subsoil attachment with spray nozzles

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[1] Earl A . Myers is Associate Professor, Department of Agricultural Engineering, at Pennsylvania State University.

EXPLANATION OF PLATE X

Fig. 1. This plate is illustrative of many arrangements, built by both tractor customer-owners and dealers, mounted on large tractors to place anhydrous ammonia deep in the rootbed for both cotton and sugar cane. The unit shown has a standard pressure tank supported by specially fabricated brackets. The pressure regulator is located on the tractor seat convenient to the operator.

Fig. 2. Reinforced Caterpillar chisel shanks support stainless steel down tubes. The ammonia gas is discharged below angled baffle plates designed to agitate the slot walls and seal the gas from escape to the surface, up the slot.

PLATE X

Figure 1.

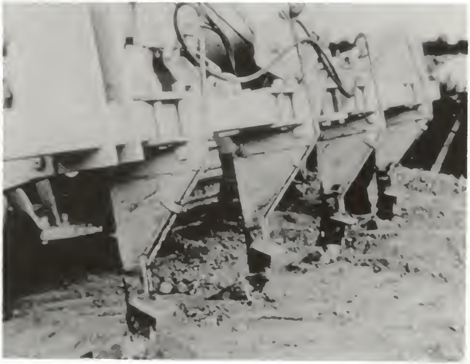


Figure 2.

and lime distribution box for test plot work (62, p. 123). Results of the tests have been published (68,71).

In a letter dated February 11, 1963 to the writer, Myers revealed that no papers had been written on the design of his applicator. The letter gave additional information which is found with the explanation of Plate XI.

The Myers applicator appears tohave the capability of continuous distribution of fertilizer from the surface down, to encourage deep root feeding by baiting or leading. A disadvantage may be the very thin band of fertilizer in contact with the soil.

Hulburt and associates (11, p. 43), developed equipment shown in Plates XII, XV, and XIV while working on a joint Fertilizer Distributing Machinery Project. This project was jointly sponsored between the U.S.D.A. Agricultural Research Service (ARS) and a unit of the Soil and Water Research Service. Pictures from the Beltsville file show an early development date of October 27, 1955. The most current date was November 15, 1957. The project has been discontinued. Documented material on this project is limited. Available information is included with the explanation of plates listed above.

Banding Dry Fertilizer Behind Deep Tillage Tools. More than a dozen different machines have been assembled from a combination of standard equipment and fabricated parts, all designed to distribute a vertical band of lime and mixed dry fertilizer in the soil to maximum depths of 18 to 24 inches (11,62,61).

During the last fifteen years, most land grant institutions and many private companies have in some way been involved with the practice of deep banding dry fertilizer. Without exception, these attachments have been

EXPLANATION OF PLATE XI

"The three point hitch is supporting a Pittsburgh forgings' subsoiler. The apparatus used a crankshaft-driven Oberdorfer No. 4ZX gear pump equipped with a pressure regulated bypass. The calculated amounts for various applications (500 lb. and 1000 lb. per acre of 5-10-10) of fertilizer were applied through calibrated stainless steel Delevan No. 4.5 FS and No. 6.5 FS nozzles under constant pressure of 20 psi observed on a pressure gage. A quarter turn valve provided the desired quickness in starting and stopping of the flow of fertilizer.

The lime distributing device on a Pittsburgh Forgings' 'Deep Feeder' subsoiler was redesigned to cause the lime to fall into the path of the fertilizer spray. This spray then carried the lime with it giving the required uniformity of distribution of both lime and fertilizer. The fan-shaped spray pattern was rotated sufficiently from the vertical plane to carry the lime and yet give a uniform distribution of fertilizer.

The Pittsburgh Forgings' subsoiler was connected to the three point linkage of the Ferguson TO 35 tractor. The fertilizer pump, tank and other required parts were then attached and thecomplete unit was field tested on the University Farms. After sufficient field testing, this unit was used to install the Hess-Palmer Subsoil Project in Fulton County.

There were no problems of clogging, corrosion, or metering while actually using the apparatus. One must be certain, however, to clean thoroughly before storing over winter, or the fertilizer will cause much pitting of the steel. The 5-10-10 liquid fertilizer isthe only material used through the nozzles."[1]

[1]The above quotation is from a letter written February 11, 1963 by Earl A. Myers, Associate Professor, Department of Agricultural Engineering, Pennsylvania State University, to the writer.

(Picture, courtesy of Earl A. Myers, Pennsylvania State University)

PLATE XI

EXPLANATION OF PLATE XII

Fig. 1. Illustrated is a hose metering pump and separate down tubes mounted on a tool bar and subsoiler, ready for applying liquid fertilizer to the subsoil. Small white spots found on the soil profile show points of fertilizer discharge at locations of 3, 9, and 20 inches below the surface, with lateral placement on beet wing edges about 10 inches each side of the subsoil slot.

(Picture courtesy W. C. Hulburt, ARS, Beltsville, Maryland)

Fig. 2. Subsoiler with beet wings attached support tubes for distributing liquid fertilizer at five locations indicated by the white dots on the soil cross-section. Fertilizer is metered by the tool bar mounted hose pump, ground driven through sprockets from the cleated wheel on the right.

(Picture courtesy W. C. Hulburt, ARS, Beltsville, Maryland.)

PLATE III

Figure 1.

Figure 2.

EXPLANATION OF PLATE XIII

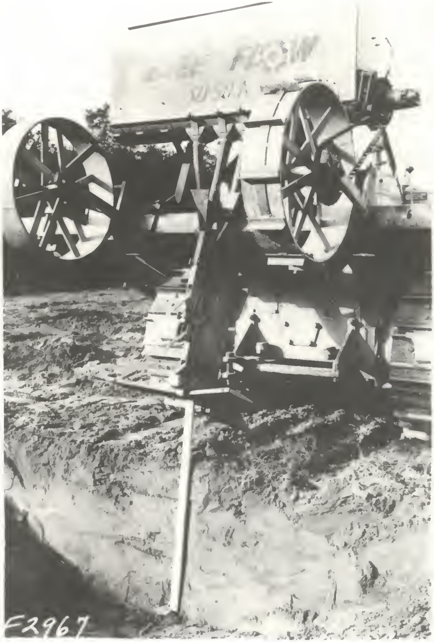
Individual down tubes discharge dry type fertilizers in the soil profile at levels of 12, 18, and 24 inches below the soil surface. The three angled chutes located at the back of the tool are points of fertilizer discharge, one being above the other distributing a narrow vertical band of fertilizer as the subsoiler moves through the soil.

A standard fertilizer hopper meters the material and is powered by a ground wheel.

Depth gage wheels insure a constant operating depth of the tool.

(Picture courtesy W. C. Hulburt, ARS, Beltsville, Maryland.)

PLATE XIII



EXPLANATION OF PLATE XIV

A combination of lime and dry or liquid fertilizer can be vertically banded in the soil with this apparatus. Liquid solutions are supplied from gravity tank and metered through a hose pump to an outlet in the subsoil slot.

Dry materials are metered from a standard Ezee Flow hopper into three separate down tubes arranged to leave a vertical band in the subsoil slot left by the subsoiler tool.

A rubber-tired ground-wheel furnishes power to the hopper and pump through chain and sprocket drives.

The equipment is mounted on a Caterpiller D-4 track type tractor, equipped with hydraulic tool bar, subsoiler and depth-gage wheels.

(Picture courtesy W. C. Hulburt, ARS, Beltsville, Maryland.)

PLATE XIV

mounted in the wake of chisels or larger subsoiler tools necessary to break an opening in the soil so the fertilizer can enter.

Fertilizer amounts have been metered by a choice of commercially available distributors mounted above variations of down-tubes, all designed to carry the fertilizer by gravity into the soil slot. A design feature, common to all units, is the use of a ground wheel driving a sprocket and chain to furnish power. This method gives a direct relation between speed ground travel and the quantity of metered fertilizer.

Hanson et al. (19) used the hopper-belt conveyor device, shown in Plate XV, Fig. 1, in an effort to obtain fertilizer metering accuracy.

When designing applicators for deep fertilizer distribution, adjustment flexibility with percision placement must be incorporated. The final location pattern of the fertilizer in the soil profile is of basic importance to plant growth, and has not been dealt with in some cases. Distributors that drop all the fertilizer to the bottom of an 18 inch subsoiler opening give little opportunity for a plant to assimilate nutrients during the growing season on many soil types. The literature indicates plant roots have developed more when fertilizer is progressively available from early stages of growth to maturity. This phenomenon is illustrated in Plate I and Plate II, Fig. 3. Vertical banding or fertilizer distribution in successive vertical stages has caused stimulation of root development and has encouraged deeper root growth, making moisture and plant food available from a large soil volume.

Purdue, Plate I, and Michigan State, Plate XV, Fig. 2, have been progressively working with fertilizer distribution patterns. Some

EXPLANATION OF PLATE XV

Fig. 1. A two-belt type fertilizer was used at Michigan State in an effort to get the desire fertilizer metering accuracy for research purposes. The device was powered by a ground wheel and mounted on the tool bar of a Caterpillar D-2 track type tractor.

(Picture courtesy C. M. Hansen, Michigan State University.)

Fig. 2. Shown is an arrangement of down tubes that deposit fertilizer onto fins which rotate as they move forward through the soil and impart a mixing action to insure that materials remain at the desired levels and in intimate contact with the soil complex.

(Picture courtesy C. M. Hansen, Michigan State University.)

PLATE XV

Figure 1.

Figure 2.

distributors are designed in such a way that all the fertilizer material is placed near the bottom of the slot opening 18 to 20 inches below the soil surface. In most cases where fertilizer was placed in the bottom of the slot, there was little or no yield response reported, and the tests were discontinued as being of little value. It appears that the importance of fertilizer distribution in the soil profile has not been fully recognized and incorporated into the planning of all deep placement investigations.

Distribution of Dry Fertilizer Behind a Chisel Tool in the Furrow Bottom During Plowing Operation. A continuing investigation first reported in 1956, by De Roo (9), may show the most practical, short term, approach to field traffic compaction and in addition will stimulate gradual deepening of the soil rootbed. This project applied fertilizer behind a chisel shank penetrating an open plow furrow functioning as part of the plow unit as show in Plate II, Figures 1 and 2. The conversion of moldboard plows to carry chisel and fertilizer distribution equipment should be practical because of the ridged support frame for mounting and because plows are widely accepted and available. This permits placement of lime and fertilizer in an untreated subsoil to build gradually a deeper top soil with regular plowing equipment. The chisel type tool operating in an open furrow, would not be hampered by the weight of an overlying furrow slice of soil.

Applicators That Stir or Invert the Rootbed

Field Broadcast and Plow-down Dry or Liquid Type Fertilizers. The practice of spreading lime and mixed fertilizers over a field surface, followed by plowing to incorporate the material into the soil, has long been an accepted practice by farmers. However, without extending the depth of tillage, there is a maximum limit beyond which increasing amounts of fertilizers to increase crop yields could have a reverse effect and decrease yields. In Illinois, Fehrenbacher et. al. (13), working with corn, found that in fertilizing a top 9-inch plow depth there were no significant yield increases for rates over the minimum requirement. In general, the higher rates of fertilizer tended to depress yields when restricted to the top 9-inch soil profile.

Applicators Mounted on Disk or Moldboard Plows Distribution Dry or Liquid Concentrates. It is not a new practice to mount a fertilizer applicator on the frame of a plow to distribute nutrient material in the furrow during field work. Many individual farmers have custom built their own machines. Few of these units have been documented. At Michigan State, a deep plowing study is in progress and results have been encouraging (19). A 38-inch diameter disc plow pulled with a track type tractor was used for these tests. Areas in different soil types were plowed in September when soil was relatively dry at a depth of 18 and 20 inches. The plow was adjusted to give maximum mixing of the surface soil with the disturbed subsoil. A close view of the mixing action is shown in Plate XVI, Fig. 1. This tillage was compared with moldboard plowing tests. Fertilizer treatments, carried out by the use of fertilizer hoppers shown in Plate XVI, Fig. 2, were uniform throughout both areas except for the no-treatment check plots to which no fertilizer was added. Fertilizer rates of 500 and 1000 pounds per acre were plowed down with 500 pounds being placed in bands 2 inches to the side and 2 inches below the corn seed at planting time.

EXPLANATION OF PLATE XVI

Fig. 1. As this 38-inch diameter disk plow moves through the soil it rotates. The revolving action imparts mixing that blends the surface soil volume with the subsoil. A scraper is provided to improve the blending action. Near the disk's upper edge, a fertilizer down-tube can be seen. Distribution at this point gave a uniform mixing of fertilizer and soil.

(Picture courtesy C. M. Hansen, Michigan State University.)

Fig. 2. A Caterpillar D-4 track type tractor is pulling a Towner disk plow equip ed with two-belt type fertilizer hoppers turned through a power train from the left rear plow wheel.

(Picture courtesy C. M. Hansen, Michigan State University.)

PLATE XVI

Figure 1.

Figure 2.

EXPLANATION OF PLATE XVII

Fig. 1. A 14-inch moldboard plow bottom replaced the first and third disk bottom to place a layer of top soil in the furrow bottom at subsoil level.

(Picture courtesy C. M. Hansen, Michigan State University.)

Fig. 2. A full view of the plow showing the moldboard and the disk plow combination.

(Picture courtesy C. M. Hansen, Michigan State University.)

PLATE XVII

Figure 1.

Figure 2.

The Michigan studies on deep plowing were not all conducted with a standard disk plow. A variation is shown in Plate XVIII. Hansen (19) explained that, provisions were made to use either two or four disks depending upon soil conditions or the kind of tillage desired. When it was necessary to place a layer of top soil on the bottom of the furrow, the first and third disks were removed and replaced by conventional 14-inch moldboard plow bottoms. This work is still in progress, no results are available.

Moldboard T-N-T Plow With Mounted Applicator. The T-N-T plow consists of a standard moldboard with a stinger or smaller moldboard attached on the rear and lower down. The purpose of this smaller share is to turn the furrow bottom without mixing this less fertile layer with the top soil. In theory, there is only slight application difference between a T-N-T unit and a moldboard carrying a chisel tool. The chisel tool may require less draft to pull because there is less metal area in contact with the soil. Nichols and Reaves (41), found that a major factor in power requirement is the horizontal pressure of the standard against the soil which materially increased the force required for shear or fragmentation. Data from experimental subsoilers designed to relieve this pressure are included in their report.

In Louisiana, Patrick (44) included an Oliver T-N-T plow with other methods of deep fertilizer treatments. Corn and cotton responded with greater root development in the subsoil and increased yields with plowing, but response was more with deep placement by subsoil tools. The method of fertilizer distribution was not reported.

Jamison of Missouri (27) used a version of T-N-T plow which he called "plow sole tillage". This method consisted of plowing to a depth of 9 inches with a 16-inch single bottom moldboard plow, spreading lime on each furrow bottom at 4 tons per acre, and shattering to an additional depth of 7 to 8 inches with a 12-inch road plow before turning the next furrow. Jamison states that practice gave significant corn or alfalfa yield increases in some cases. However, if the soil surface was adequately fertilized, the increases over surface treatment alone were small and of questionable value on Missouri clay-pan soils.

A comprehensive study was conducted in Wisconsin by Engelbert and Troug (12), that included the use of an Oliver T-N-T plow. Results of the practice were encouraging, but specific design of the applicator was not mentioned.

SUMMARY

1. Nearly all the attachments to facilitate deep placement of fertilizer in a soil profile deeper than 7 to 8-inches have been custom built.
2. Very little has been written or published concerning the engineering and design of the custom built equipment in regard to fertilizer metering, placement, and distribution.
3. Information is not sufficient to attempt a deep placement specification for fertilizer distribution patterns in relation to optimum root growth, plant growth or yield response.
4. Soil management technology has broadened from the conception of a six-inch seedbed with the desire to understand and control all

factors influencing plant growth throughout an entire soil profile.

5. It has been suggested that yield alone might not be a good measure of deep placement results.

6. When initiating a deep fertilizer test, each six-inch level of the soil profile down to 30 inches should be analyzed for soil acidity and available plant nutrients. These tests should be a guide in planning for the addition of soil amendments, and for designing the apparatus to do the job.

7. There are two schools of thought concerning amounts of fertilizer to use and when to apply it. One school thinks in terms of "fertilizing the crop" and the other of "fertilizing the soil".

8. The many physical forms of fertilizer on the market add to the difficulty of designing efficient distribution and metering equipment. The fertilizer industry is trying to meet these problems.

9. There is not yet available in the equipment and fertilizer industry, equipment which can accurately meter quantities of liquid fertilizer.

10. Patterns of fertilizer distribution in the case of deep placement may be important or even critical in relation to crop root development and corresponding yields.

11. The design of deep fertilizer applicators must include wide flexibility in adjustment for accuracy, quantity of fertilizer applied and for the desired pattern of distribution in the soil profile. Unless the applicator has these capabilities research investigations will be impaired.

12. The liquid fertilizer subsoil injector, Patent 2,874,656, announced in this paper has wide flexibility in designing equipment to meet requirements for patterns of fertilizer distribution.

ACKNOWLEDGMENT

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2,874,656

LIQUID FERTILIZER SUBSOIL INJECTOR

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Application January 17, 1956, Serial No. 559,581

2 Claims. (Cl. 111—7)

This invention relates to means for dispensing fluid materials in subsoil and in particular is concerned with apparatus for distributing liquid fertilizer in a predetermined pattern at spaced levels below the surface of the soil.

In the past, it has been conventional practice to spray liquid fertilizer over the surface of the ground. This method is unsatisfactory due to evaporation and the fact that subsequent precipitation may wash away much of the remaining fertilizer. Surface spraying also results in a high concentration of fertilizer near the surface of the soil with relatively little deep penetration. Agronomists have found that deep placement of fertilizer is extremely beneficial to plant growth, but prior to this invention no practical tool has been devised for distributing liquid fertilizer in a desired impregnation pattern at various predetermined levels below the surface of the soil. Likewise, in apparatus previously used in liquid fertilizer distribution, there is no controlled soil fracture to aid in defusing the fertilizer and the spray nozzles employed are also subject to clogging and damage.

It is an object of the present invention therefore to provide an attachment for tillage tools for distributing liquid fertilizer at spaced levels below the surface of the ground.

It is a further object of this invention to provide an attachment for distributing liquid fertilizer in which the fertilizer is sprayed into the soil in a desired impregnation pattern.

It is a still further object to provide a means of preventing damage and clogging of the spray nozzle as well as creating a horizontal fracture or void in the soil as an aid in dispersing the fertilizer.

In the drawings:

Fig. 1 is a perspective view of the liquid fertilizer distributor of the subject invention attached to a conventional deep tillage tool;

Fig. 2 is an enlarged perspective view with parts broken away showing the liquid dispersing structure in more detail;

Fig. 3 is a view in side elevation with parts broken away showing the preferred method of attaching the subject invention to a tillage tool; and

Fig. 4 is a view in plan with parts broken away.

In Fig. 1 a conventional deep tillage tool, commonly known as a subsoiler, is shown at 10 as comprising a shank 11, the upper end of which is attached as by bolts 12 to a tool bar 13 or other means such as the draw bar of a tractor for advancing the subsoiler through the ground. As the subsoiler is advanced through the ground a tooth portion 14 supported at the lower end of the shank 11 penetrates the ground at a preselected depth so that the subsoil is shattered.

A conduit 15 is attached to the rearward side of the tillage tool 10 and is in communication with a suitable regulated pressurized source of supply (not shown) of the liquid fertilizer. One or more spray nozzles 16 for dispensing the liquid fertilizer are attached to that portion of the conduit 15 extending downwardly of the tillage tool. When more than one nozzle is employed, the vertical spacing between them may be as desired.

As shown in Figs. 2, 3, and 4, a laterally flared protective shield indicated generally at 20 is provided at the location of each spray nozzle. The shield 20 is shown as being pivotally attached to the tillage tool by means of pin 21 in order that the shield may be free to yield or float over small stones or other obstacles and to ride more freely through the ground. To prevent pinching and restriction of the conduit 15 by the shield 20 as it yields to irregularities in the soil, a recess 22 slightly larger than the conduit 15 is provided in the shield. In this manner, sufficient clearance exists between the conduit and the shield to allow the shield to pivot without damaging the conduit. Shoulders 23 are provided to restrict the pivotal movement of the shield 20 to prevent pinching or damage to the conduit. The forwardly extended portions of the shield 20 are wedge-shaped to aid in shearing the soil and thus reduce the amount of power necessary to advance the tillage tool through the soil. The trailing portion of the shield is flared laterally to enable distribution of the fertilizer in a wide band. Assuming constant fluid pressure and soil conditions as the fertilizer is discharged from the nozzle, the width of the fertilizer pattern deposited in the soil may be varied by using shields of varying widths. The depth of the pattern may also be varied in a similar manner.

As the tillage tool is advanced through the soil, a fracture or fissure is created at the trailing edge of each shield and the forming of this fissure greatly assists in the thorough dispersal of the fertilizer. The fertilizer is discharged a sufficient distance behind the tillage tool so that the fracture created by the advancement of the tillage tool through the ground is partially closed by the flow of shattered soil around it. In this manner, fertilizer discharged from the shield can flow freely into fractures formed by the shield but will not flow to the bottom of the fracture created by the tillage tool previously described.

As the tillage tool 10 is raised out of the ground, it assumes an upward direction of travel. In order to prevent the shield 20 from being fouled with dirt during this arcuate movement of the tillage tool, its top 24 extends in overhanging relationship to the bottom 25. The overhanging top edge also insures time for dispersal of the fertilizer before the fissure closes behind the shield.

I claim:

1. A fertilizer attachment for the draft beam of an agricultural vehicle comprising a tillage tool to be advanced through the soil, a conduit secured to the tillage tool for conveying liquid fertilizer under pressure, vertically spaced spray nozzles attached to said conduit, and a protective shield with a rearwardly flaring portion of greater width than the tillage tool attached to said tillage tool in surrounding relationship to each of said spray nozzles for distributing liquid fertilizer at different levels in the fissures created by said shield below the surface of the soil.

2. In combination with a spray nozzle for liquid fertilizer distributors attached to the trailing edge of a tillage implement which is drawn through the soil, a shield mounted in surrounding relationship to said spray nozzle, the shield having a flared trailing portion of greater width than the width of the tillage tool for creating a lateral fracture beneath the surface of the soil and the top of the shield extending in overhanging relationship to the bottom of the shield.

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Feb. 24, 1959 F. W. BENNETT 2,874,656

LIQUID FERTILIZER SUBSOIL INJECTOR

Filed Jan. 17, 1956

FIG. 1

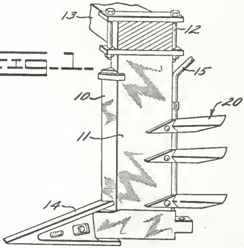


FIG. 2

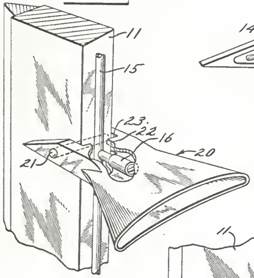


FIG. 3

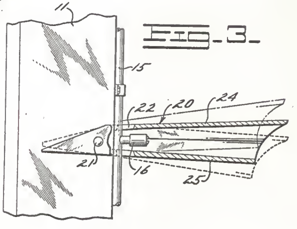
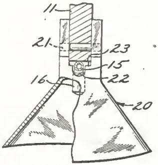


FIG. 4



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MERITS AND EQUIPMENT FOR DEEP
PLACEMENT OF FERTILIZER

by

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of

Agriculture and Applied Science

1952

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

in

FARM MECHANICS

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1963

The last fifty years of progress in crop production in the United States is largely indebted to research workers keenly interested in finding new combinations of the many inter-related variables of plants, soils, machines and combinations which continue to reveal secrets that push yields per acre ever higher. Reports are limited with regard to appraising the cost and design of deep placement of fertilizer equipment in its total economic relationship. Presently most experiments have been accomplished with custom-built equipment.

The purpose of this report was to review the concepts of deep tillage and deep fertilization methods, also the availability of equipment to accomplish various applications. The report deals with the various principles of deep application and the distribution patterns of fertilizer that might be desirable. In addition it elaborates on timely applicator information previously unpublished.

Workers in basic research should not be concerned with justifying the tool design to fit into commercial operations initially. After basic desirable agronomic principles have been established, it is the agricultural engineers responsibility to redesign the tool for economical operation if possible for customer acceptance.

Currently, fertilizer and lime are incorporated into a soil profile only as a companion operation with deep tillage tools. Those factors of soil physical make-up which directly affect design of deep tillage equipment to place chemical plant food into a soil profile below the surface 7-to 8-inch seedbed have been identified and defined.

The availability of powerful, convenient tractors coupled with the managerial necessity to produce high crop yields per acre unit of allotted crops has helped to revitalize interest in deep tillage practices. Concepts of tillage have broadened from thinking of a six-inch seedbed to a desire to understand and control those factors influencing plant growth throughout an entire soil profile penetrated by the root development of a particular crop.

Where subsoils are very dense acid or less fertile, plant roots will not penetrate below the plow depth. The benefits to the soil and plant from both subsoil tillage and from deep fertilizer application compliment each other. Lime can be added to correct acidity, and plant nutrients can be added to restore plant food shortages.

Two schools of thought exist concerning the use of plant nutrients. One school thinks in terms of fertilizing the crop and the other of fertilizing the soil. With the "fertilizing-the-soil", concept emphasis is on building up the fertility level in the entire soil profile, thus increasing the volume of soil in which plant roots can feed.

The two broad physical categories of fertilizer that directly dictate equipment design are, liquid types including anhydrous ammonia, and dry types. This report was concerned with methods of fertilizer placement by sub-surface applicators for applying both types.

There is concern for draft requirements with deeper tillage. It is thought that the shear value of the soil is directly proportional to the upward and horizontal pressures applied by the subsoiler point and standard to the soil. Tool pressures on soil directly affect draft. With deep plowing the power requirements increased when disks were set for greater mixing action in the soil. In addition there was a marked reduction in the necessary power when the soil was plowed for the second and third times according to Michigan study.

Patterns of fertilizer distribution in the soil may be important or even critical in relation to crop root development and corresponding yields. There presently is not a clear approach to the problem of fertilizer distribution patterns in the soil.

The report documents, United States Patent No. 2,874,656, issued to the Caterpillar Tractor Company of Peoria, Illinois and credited to the writer for a Liquid Fertilizer Subsoil Injector which is a tool system or apparatus for distributing chemical liquids, particularly liquid fertilizer, in a predetermined pattern of distribution at levels below the soil surface. This applicator is designed so a forward motion of the spray pattern protector provides a mobile umbrella of soil under which the spray pattern can pass undisturbed into the soil.

Apparatus for deep fertilizer placement have been discussed in two main catagories; those that stir the rootbed, but leave the topsoil in place and those that stir or invert the rootbed while incorporating the plant nutrients.

There is not yet available in the equipment and fertilizer industry, equipment which can accurately meter quantities of liquid fertilizer.

The design of deep fertilizer applicators must include wide flexibility in adjustment for accuracy, quantity of fertilizer applied and for the desired pattern of distribution in the soil profile. Unless the applicator has these capabilities research investigations will be impaired.