ROWCROP YIELD RESPONSE TO SOIL HORIZON REPLACEMENT

I. J. Jansen, R. E. Dunker, C. W. Boast, and C. L. Hooks[1]

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ABSTRACT

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Two research sites, one in western Illinois and the other in southern Illinois, were designed to determine the relationships between thickness of replaced soil material, and yields of corn (Zea mays) and soybeans (Glycine max). The western site is in a region having highly productive natural soils with excellent quality topsoil (A horizon) material. A wedge of topsoil material grading from 0 cm to 60 cm in thickness was replaced over graded mine spoil that is chemically and texturally suitable for plant growth. Subsequent rowcrop yields were regressed against thickness of replaced topsoil. The southern site is in a region which has natural prime farmland soils that are less productive and have lower quality A and B soil horizon materials than those of the western site. A wedge of subsoil material (mostly B horizon) ranging in thickness from 0 cm to 120 cm was placed by scrapers over rocky shovel spoil, then topsoil was replaced over half

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[1] I. J. Jansen and C. W. Boast are Associate Professors, and R. E. Dunker and C. L. Hooks are Agronomists in the Department of Agronomy, University of Illinois, 1102 S. Goodwin, Urbana, IL 61801.

of the experimental area so that subsequent rowcrop yields could be regressed against thickness of replaced subsoil material both with and without replaced topsoil.

A significant, but small, increase in corn yield was associated with increasing thickness of replaced, excellent quality, A horizon material over good quality wheel spoil at the western site. Replacement of lower quality topsoil material over hauled rooting medium material in southern Illinois increased yields of both corn and soybeans in the first year after reclamation, but actually decreased yields in some subsequent years. Yields of both crops at the southern site increased with thickness of hauled rooting medium material over rocky spoil until maximum yields were reached at about 60 cm to 80 cm thickness.

More of the total variation was associated with weather effects than with soil horizon replacement. Weather effects were greater on these soils than on undisturbed land, because the mine soils at both sites were droughty due to severe compaction during construction. Less compacted mine soils at both sites have proven to be less droughty.

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INTRODUCTION

Soil horizon replacement has been widely advocated as a reclamation practice, particularly where prime farmland is mined. Conceptually one would expect the response to soil horizon replacement to vary with the characteristics of the natural soils before mining and with the characteristics of the alternative material. The alternative material is commonly mine spoil consisting of a mixture of the overburden materials. The degree to which the most favorable overburden materials can be concentrated near the surface varies with mine site and the type of mining equipment used. Climatic region, vegetative species, and cultural practices might also affect response to soil horizon replacement.

Power et al.(1) observed a favorable response to both topsoil and subsoil replacement in North Dakota. Plots that had topsoil replaced separately over subsoil produced higher yields than where a mixture of topsoil and subsoil was used. Alfalfa, crested wheatgrass, native grasses and spring wheat were the test crops; the mine spoil was sodic.

Barth(2) placed a mixture of A, B, and C horizon materials in a wedge design over mine spoil at fifteen sites in the Northern Great Plains. Perennial grass yield response to replaced soil material varied with the characteristics of the underlying spoil. Soil material thickness required for maximum perennial grass yields was about 100 cm where the underlying spoil was acidic and about 70 cm where the underlying spoil was sodic. Fifty cm of soil material was adequate for maximum yields where the underlying spoil was neither acidic nor sodic, and one site which had unusually favorable spoil produced higher yields on the spoil than on replaced soil material. A minimum of 30 cm of loess material was needed over acid spoil materials in Iowa for successful maintenance of a grass cover.(3)

Sites in Illinois with replaced topsoil had better tilth, which led to easier seedbed preparation and stand establishment than those without topsoil.(4) Topsoil materials have also generally produced somewhat better plant growth in green house studies than materials from soil B or C horizons, but mixtures of B and C horizon materials were commonly equal to or better than B horizon materials alone.(4,6)

This study was designed to evaluate corn (Zea mays) and soybean (Glycine max) yield responses under field conditions to topsoil (A horizon) replacement where western Illinois Mollisols (Norris site) and southern Illinois Alfisols (Captain site) are being mined. The design at the Captain site also provides for evaluating subsoil replacement.

METHODS

Two sites were selected to include a range in soil quality in the study. Natural soils in the Norris mine area are of excellent quality; topsoils and subsoils are nearly ideal for rowcrop production. The graded cast overburden (spoil) at the Norris site consists of a mixture of loess and glacial till materials which were blended together while being dug, transported, and placed by a mining wheel. The wheel spoil was graded with bulldozers to form the desired surface. It is generally good quality material both texturally and chemically for use in constructing a soil. The Udolls and Aquolls of the Norris mine area commonly have 45 cm or more of topsoil. A topsoil wedge (Figure 1) was constructed over graded wheel spoil at this site so that yields could be related to thickness of replaced topsoil. The experimental tract included a nine-meter-wide strip along one side that had wheel spoil exposed to the surface (no topsoil). This strip will be referred to as the spoil bench. Adjacent to the spoil bench on a strip 36 m wide was the topsoil wedge. The wedge had 0 thickness of replaced topsoil along the spoil bench side and graded continuously to the maximum 60 cm thickness of replaced topsoil along the other side. Beyond the wedge was another nine-meter-wide strip designed to have a uniform 45 cm of replaced topsoil (the topsoil bench). The experimental tract was then divided into two length segments, each 30 m long and separated by a turn strip. Each year, one of the segments was planted to corn and the other to soybeans, the pattern being switched in each succeeding year to provide for a corn-soybean rotation.

For corn, twelve harvest samples were collected each year from each of the bench strips and four harvest samples were collected from each of twelve different topsoil thicknesses, regularly spaced on the topsoil wedge. Each corn harvest sample was from a 6.3 m^2 tract. For soybeans, six harvest samples were taken from each of the bench strips and two samples were collected at each of twelve different topsoil thicknesses on the topsoil wedge. Each soybean harvest sample was from a 12.6 m^2 tract. Regression analysis was used to relate corn and soybean yields to topsoil thickness. The spoil bench data were included in the regression analysis, but the topsoil bench data were excluded, because of observed variation from design topsoil thickness. Excluding the topsoil bench data reduced extraneous variability, but did not change the trends. Straight line models were used because they were conceptually appropriate for the experiment, and because, for most years, little improvement in fit could be achieved by using more complex models.

Many natural soils at the Captain mine site qualify as prime farmland, but have topsoils and subsoils that are less desirable than those at the Norris site. The graded cast overburden at the Captain wedge site is shovel spoil and includes fragments of sedimentary rock. It is generally coarser in texture than the Norris spoil and somewhat less suited for rowcrop agriculture. The Captain shovel spoil had to be covered with topsoil from the premine soils and enough suitable rooting medium material to achieve a total cover depth of 1.2 m in order to meet the requirements of state law for reclamation of cropland.

The Aqualfs and Udalfs of the Captain mine vicinity commonly have less than 30 cm of topsoil, so the topsoil experiment at this site was an all-or-none comparison with no attempt to evaluate the effect of varying thickness. A hauled rooting medium (subsoil) wedge 0 to 120 cm thick was constructed at this site to relate corn and soybean yields to thickness of hauled rooting medium material. The hauled rooting medium at the Captain wedge site is selected material, mostly from soil B horizons but also including some C horizon material, that was used to build a soil on top of the graded shovel spoil. It was hauled and placed by rubber-tired scrapers, which tended to compact the material excessively as it was being placed. Hauled material is commonly used where the spoil does not meet state or federal requirements for use as a final soil.

Figure 2 provides the plot design for the Captain wedge site. Twenty two cm of topsoil was replaced on each of eight strips randomly located in relation to the eight strips without topsoil. Each strip was divided in the middle to provide for two crops. Corn and soybeans were rotated as at Norris. Each year, eight harvest samples, uniformly spaced along the rooting medium thickness wedge, were taken from each plot, each year. Harvest samples were from 6.3 m^2 tracts for corn and 9.5 m^2 tracts for soybeans. Yields from the topsoil and the non-topsoil treatments for each crop were regressed separately against hauled rooting medium thickness. Quadratic models were used for this experiment, because shallow rooting of the test crops made it unlikely that response would be constant across the total depth range, and because a better fit was achieved in most years with quadratic models than with straight line models.

Conventional farming equipment was used for tillage and planting. Row spacing was 76 cm for both crops. The plots were chiseled (fall or spring), disced, and harrowed before planting. Williams soybeans were planted at both sites and the corn hybrid used was FRMO17 x FRB73. Final stands were determined by planting rate and survival, with no hand thinning to achieve a uniform stand. Corn was hand harvested for yield measurement, but all soybean sample tracts were direct cut with a combine.

RESULTS AND DISCUSSION

A wedge of excellent quality topsoil material was replaced at the Norris site over graded wheel spoil that is favorable both texturally and chemically for plant growth. Both corn and soybean yields increased with increasing thickness of replaced topsoil (Figure 3). Averaged over years the yield response to topsoil thickness was statistically significant for corn, but not for soybeans, and was small for both crops. Both average yield and response to topsoil thickness varied greatly from year to year. The strongest positive corn yield response to topsoil thickness was in 1979, the first crop year after reclamation (Figure 4). That was followed by a significant negative response in the 1980 season and modest positive responses in 1981 and 1982.

The negative yield response to topsoil thickness in 1980 appears to be caused in part by the corn on spoil having pollinated under somewhat more favorable weather conditions than that on the replaced topsoil. Corn at this site as well as at other sites has quite consistently tasseled and pollinated a few days later on spoil than it does where topsoil has been replaced. The 1980 season was one of severe moisture stress, particularly during mid-July. Significant rainfall and somewhat cooler temperatures were received at Norris during the last week of July. By then the corn on topsoil had failed to pollinate and was too far along to benefit. The corn on spoil had also been damaged by stress, but was far enough behind in maturity that it was able to pollinate under the more favorable weather conditions. The 1981 and 1982 seasons had favorable weather with little or no moisture stress. There was such severe stress in the 1983 season, that no grain was produced on the Norris wedge corn plots.

Soybean yield levels also varied greatly from year to year (Figure 5). The response to topsoil thickness was significantly positive only in the years 1980 and 1982.

Crop failures were experienced at the Captain wedge site in both 1980 and 1983, hence data from only three of the five years over which the experiments have run were entered in the analyses. Natural topsoils of the Captain mine vicinity are inferior to those of the Norris area.

As was true for corn at Norris, both corn and soybeans responded more positively to topsoil replacement in the first year after reclamation than in succeeding years. There was a positive corn response to topsoil on the Captain wedge in 1979, but that was off-set by significant negative responses in both 1981 and 1982. When the data were combined over years, corn yields were significantly higher where no topsoil was replaced than on replaced topsoil (Figure 6). Soybean yields in 1979 were only half as high on plots without topsoil as on plots where topsoil was replaced, but the soybean yields were significantly higher with no topsoil than on topsoil in 1981, and there was no significant yield difference in 1982. The combined three years's data still shows a positive soybean yield response to replaced topsoil (Figure 7).

Yields of both corn and soybeans increased with increasing thickness of hauled rooting medium material over shovel spoil. About 60 cm to 80 cm of hauled rooting medium was enough to achieve maximum yields. The lack of response to increasing thickness beyond about 80 cm might be caused by high soil strength in the hauled material due to compaction when it was placed. Few roots penetrate beyond 60 cm at this site, so the crops can not effectively exploit soil materials below that depth. These crops commonly root to 150 cm or more in depth under favorable soil conditions, hence the shallow rooting is believed to be caused by poor physical condition or high soil strength in the hauled material. One can not exclude the possibility that favorable yield response would have continued to a greater thickness if compaction had been avoided so that plant roots could exploit deeper materials.

Compaction induced high soil strength appears to be a major factor in the high susceptibility to moisture stress observed at both sites. The mine soils at both the Norris wedge and the Captain wedge sites have bulk densities ranging from 1.7 to 1.9 gm/cc in that portion of rooting zone which lies below the topsoil or tillage zone. Undisturbed natural soils have subsoil bulk densities of about 1.4 to 1.5 gm/cc near the Norris site and about 1.4 to 1.7 gm/cc near the Captain site.

In the mine soils, deep soil moisture is not available for growing plants because of the restricted rooting depth. Even within the top 60 cm, roots tend to be confined to desiccation cracks, so that some of the soil volume between cracks is not effectively exploited.

The effect of physical improvement in increasing the productivity of these newly constructed soils was explored by digging and back-filling in 1979 a trench about 150 cm deep and 60 cm wide across the Norris top-soil wedge (from the thin topsoil side to the thick topsoil side) with a wheel ditching machine. Nothing was placed in the trench before backfilling, but all topsoil was blended with other materials in the top 150 cm by this deep tillage operation. Corn was planted across the filled trench in 1980, a season of severe moisture stress. Corn on or near the filled trench was visibly less stressed during the season and grew about 50 cm taller than corn on adjacent areas un-affected by the trench. Grain yield from a 150 cm wide strip centered above the trench was 6500 kg/ha, whereas grain yield from adjacent areas on the topsoil wedge and not affected by the trench was less than 100 kg/ha. There was no visible effect of the trench on soybeans in 1981 nor on corn in 1982, both being low stress seasons. Soybeans were planted across the trench in 1983 which was another severe stress season. Beans above the trench grew taller than on adjacent areas and produced 570 kg/ha (2 m wide strip centered over the 60 cm wide trench) as compared to 240 kg/ha beside the filled trench.

Compaction has been avoided and an artificial soil structure created during more recent mining and reclamation operations at the Captain mine by using a bucket wheel excavator-conveyor-spreader system to dig, move, and place the soil material. Bulk densities in these soils range from about 1.4 to 1.7 gm/cc, and the high end of that range typically is approached only in the top 30 cm or so of graded spoil below any replaced topsoil. Corn root systems explore these noncompacted, low strength, spoils effectively to 150 cm depth or more.(7) During the severe stress season of 1983, soils built by the Captain wheel-conveyor-spreader system produced 2500-4500 kg/ha of corn and 750-1200 kg/ha of soybeans as compared to total crop failure on soils of the Captain wedge plots, which had been severely compacted during construction by rubber tired scrapers. Yields on natural soils one kilometer away and having the same management produced about 3600 kg/ha corn and 980 kg/ha soybeans in 1983.

CONCLUSIONS

Some, but a relatively small portion of the total, rowcrop yield variation at the two sites studied was associated with the thickness of soil horizons replaced. A much greater portion of the total variation was associated with year-to-year weather effects, which were enhanced by the droughty nature of the mine soils at both sites. The droughty character of these soils appears to be due to poor physical condition, resulting in part from compaction during soil construction, and consequent inhibited root system development. It is probable that response to soil horizon replacement might have been greater had crop yield not been so severely limited by physical soil problems, but it is clear that soil physical condition is a much more significant issue in reclamation for rowcrop production at many sites than is soil horizon replacement.

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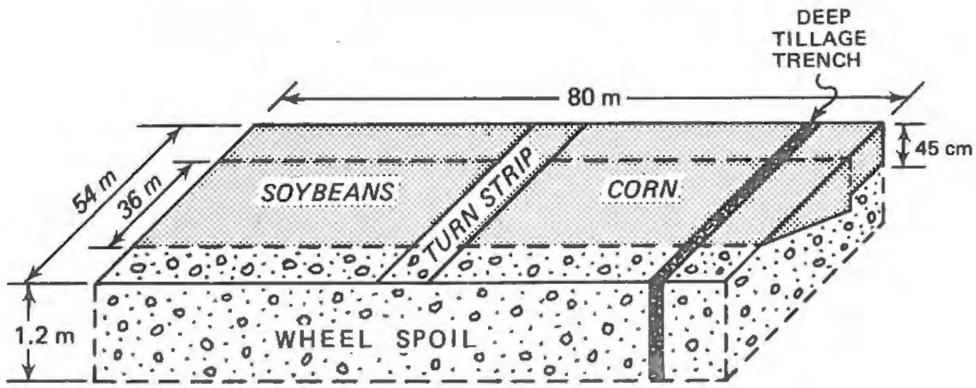

Figure 1. Schematic of the Norris topsoil wedge site. The shaded area represents replaced A horizon material.

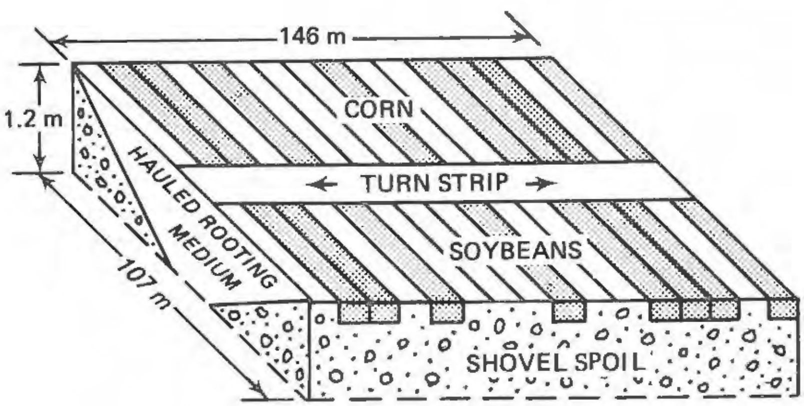

Figure 2. Schematic of the Captain wedge plots. The shaded plots have A horizon material replaced.

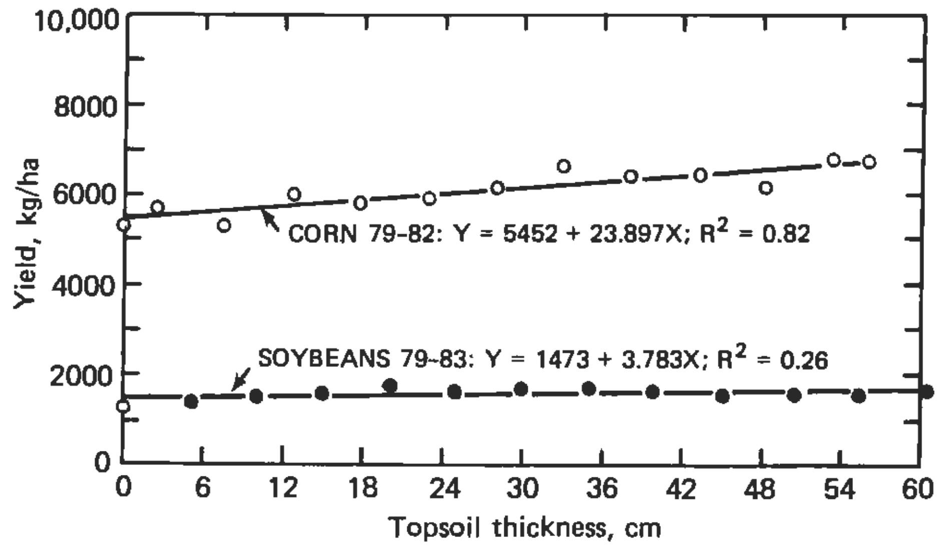

Figure 3. Yield response to topsoil thickness at Norris averaged over years. The 1983 season was excluded for corn because of crop failure induced by moisture stress.

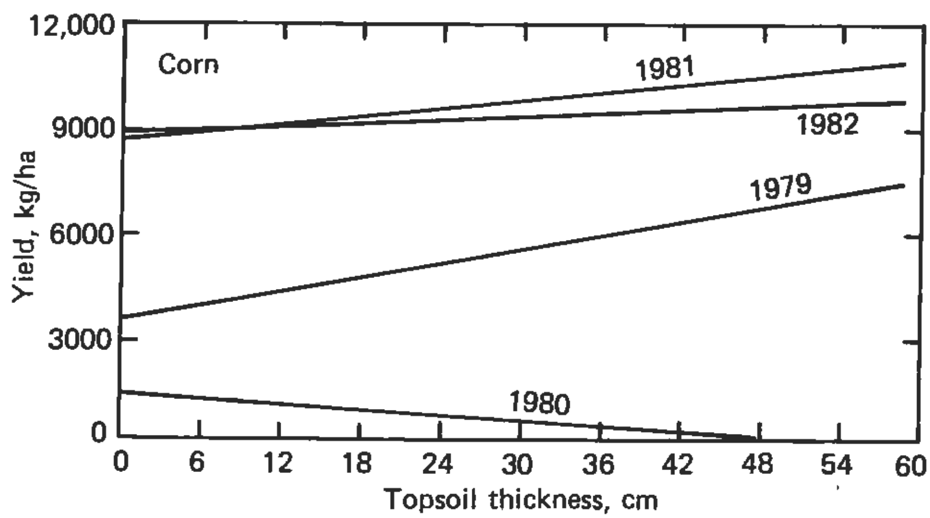

Figure 4. Corn yield response to topsoil thickness at Norris.

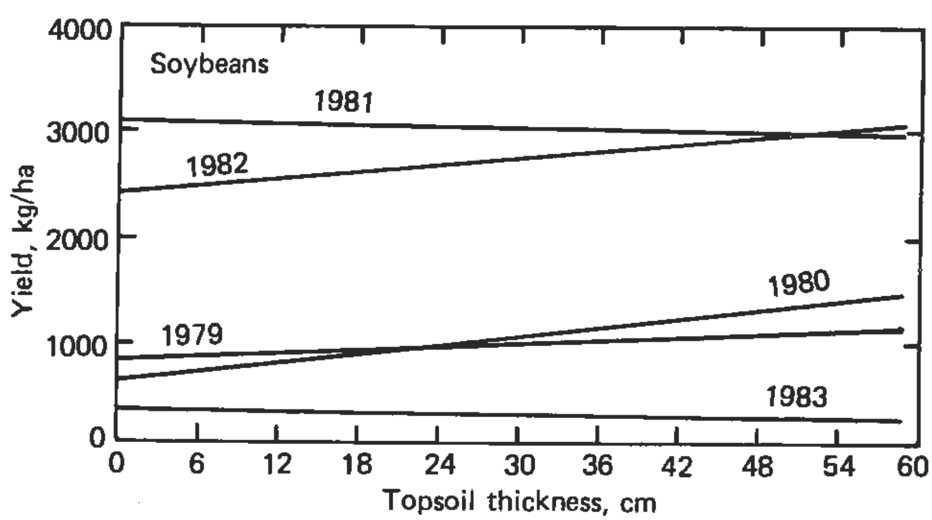

Figure 5. Soybean yield response to topsoil thickness at Norris.

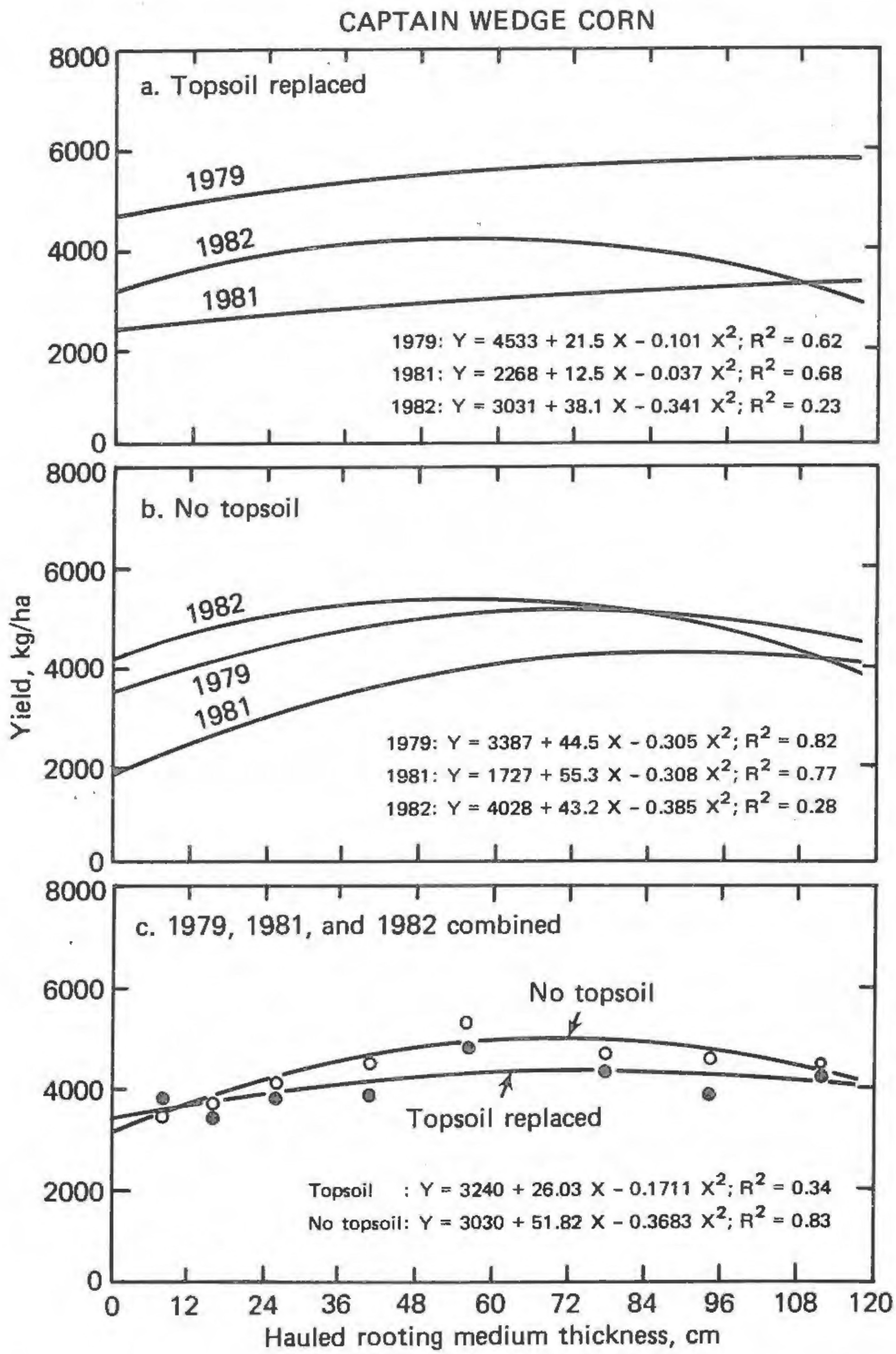

Figure 6. Corn yield response to topsoil replacement and hauled rooting medium thickness.

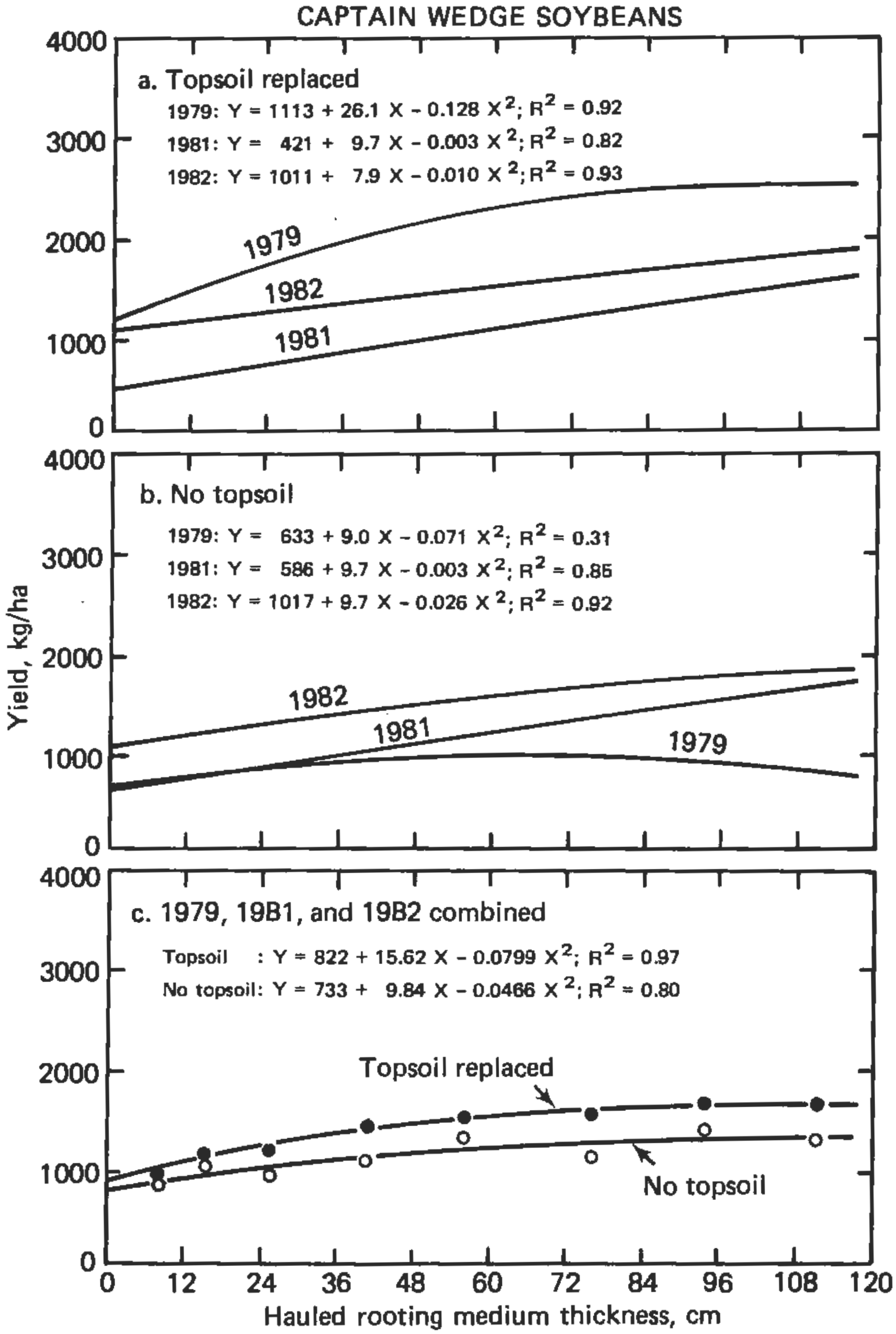

Figure 7. Soybean yield response to topsoil replacement and hauled rooting medium thickness.