Vertical Topsoiling, A Practicable Technique to Manage Soils with Markedly Compact Subsoils[1]

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INTRODUCTION

Subsoiling, the well-known practice of breaking or shattering the subsoil' has been used quite extensively in attempts to reduce the adverse effects of a plow pan. The practice has had variable results. The shattered subsoil tends to seal again under wet conditions thus losing effectiveness.

In 1956, Spain and McCune (6) developed the idea of filling the opening left by a subsoiler with an organic material to prevent the slot from sealing. They called this practice vertical mulching. It is essentially a subsoiling operation during which organic residues, particularly those having wide carbon-nitrogen ratios, are incorporated into the channel directly behind a subsoiling machine. The vertical mulching operation uses a subsoiler to loosen the soil and open a slot in the ground. The subsoiler is modified by adding wings to the standard to open the soil more widely than normal subsoiling and to hold the slot open. A forage harvester is used to cut and chop the crop residues and then blow these residues into the slot held open by the subsoiler wings.

Parr (2) found favorable changes in bulk density and soil aggregation as a result of using the vertical mulching technique in a Crosby silt loam with an impermeable A_2 horizon.

Watson and Phillips (7) found in non-irrigated field experiments that statistically significant differences occurred in corn yields due to vertical mulching. The increased yields were due to increased soil water in the vertically mulched soil as compared with soil that had not been vertically mulched.

Approximately 90,000 acres of land occur in Puerto Rico with markedly compact subsoils (5). In 1952 Martínez and Lugo-López (1) found an increase in water infiltration due to subsoiling in a Caguas clay, most likely an Alfisol, from east-central Puerto Rico. This improvement was not reflected in sugar yields, however.

The paucity of investigational effort in Puerto Rico along this line led to the initiation of the research reported herein.

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MATERIALS AND METHODS

The experiments were conducted in a Mabí clay soil, a Vertisol in east-central Puerto Rico. This soil[3] is characterized by a rather high, uniform clay content to at least 8 feet. Its structure varies from fine granular in the surface horizon to weak, fine, medium angular blocky and massive arrangements below the surface, resulting in poor air-water relations with the subsequent presence of abundant gray mottles. The soil reaction ranges from slightly acid in the top 24 inches to neutral and alkaline in the lower layers. Disturbed soil samples show a moisture content of 40 percent held at 1/3 atm. and 26 percent at 15 atm. Under actual field conditions, water availability drops markedly since that held at 15 atm. is sometimes 40 percent. The clay fraction contains abundant to dominant montmorillonite and a moderate amount of kaolinite and small amounts of mica, feldspar, quartz and amphibole. The coarse silt and very fine sand are high in mafic minerals. The epidote group and pyroxene are major constituents. The soil, with a cation exchange capacity of approximately 35 meq. per 100 g. of soil, is considered productive if properly managed.

The experiments were conducted on sites previously under pasture. The initial pH values were 5.0 and 4.7. The site of the first experiment had a pH of 5.0. It was disc-plowed to a depth of 8 inches and harrowed. Lime was applied at a rate of 2 tons to the acre to bring the soil pH to 6.0. After liming, three treatment differentials were established in plots 100 feet long and 30 feet wide with 10-foot borders on all four sides. A randomized block design with 4 replications was employed, which included the following:

Treatment No.	*Treatment*
1	Check
2	Vertical mulching with bagasse (16 tons/acre)
3	Vertically opened slots without bagasse

The vertically opened slots, with or without bagasse, were made by an M & W Vertical Mulcher pulled by a D-7 Caterpillar tractor. The slots were 30 inches deep with an average width of 7 inches and were 10 feet apart. All drained into a collector ditch 36 inches deep. Sugarcane variety P.R. 980 was the test crop. The cane rows, following the Louisiana system, ran parallel to and were planted 2.5 feet from the slots so that the regular 5-foot distance was kept between rows.

Fertilizer mixture 14-4-10 was applied at a rate of 12 hundredweights to the acre 1 month after the cane was planted. The cane was adequately cultivated and hand harvested when 13 months old. After harvest, infiltration rates were run on all plots. In this determination, a galvanized zinc cylinder 20 inches long and 10 inches in diameter was driven into the

[3] From Soil Survey Investigation Report No. 12, August 1967.

soil in the area between the vertically opened slot, with or without bagasse, and an adjacent cane row. A standard burette having a volume to deliver 2 inches of water was used in a 4-hour run.

The ratoon crop was adequately conditioned for a second crop, receiving a 14-4-10 fertilizer mixture at the rate of 12 hundredweights to the acre.

An interesting observation was noted during the time the collector drain was being dug. The sides of the main ditch, which were of a dense, massive and highly mottled nature, developed an excellent soil structure when exposed to sun and wind. These newly exposed sides developed a color as red as a typical Oxisol. Free iron oxide content determined on subsoil aggregate samples showed a content of 14 percent, a common value of typical Oxisols (4). This observation, and the further finding that undisturbed soil cores of the subsoil held approximately 40 percent of moisture at 15 atm. pressure, led the authors to consider the possibility of deep plowing as a means of improving soil structure and water intake by the soil to render better air-water relationships for plant growth.

Another interesting observation noted was that the slots made by the vertical mulcher which did not receive bagasse filled with topsoil sloughed off on account of wind and runoff. This well-aggregated topsoil appeared to form a bed which seemed to insure adequate root penetration. These two observations led the authors to consider conducting a second set of experiments in the same soil type adjacent to the first. The second site, with a pH of 4.7, was disc-plowed to a depth of 8 inches and then harrowed. Lime was applied at a rate of 4 tons to the acre to bring the soil to pH 6.0. After liming, 5 soil modification technique differentials were established in plots 90 feet long and 20 feet wide with 10-foot borders on all four sides. A randomized block design with 4 replications was employed which included:

1. Check.
2. Vertical topsoiling.
3. Deep-plowing.
4. Vertical mulching with bagasse (16 tons to the acre).
5. Vertical mulching and deep-plowing.

The deep-plowing technique was established first. It was applied 18 inches deep with a moldboard plow pulled by a D-7 Caterpillar tractor. A week after, the whole field was disc-plowed twice and harrowed. Then, the bagasse and vertical topsoiling techniques were established.

The vertical topsoiling modification consisted of filling with topsoil the 30-inch-deep and 7-inch-wide slots made by the vertical mulcher. This was carried out by means of hand hoes which scraped the topsoil from the upper 3 inches adjacent to the slots. Because these topsoil-filled slots constituted the place where the crop was to be planted in this technique, and to conform with a common 6-foot sugarcane planting distance between rows, the vertically topsoiled slots were made that far apart.

The slots in which bagasse was to be applied, whether deep-plowed or not, were 10 feet apart. This required that the cane be planted in rows in vertically mulched plots 1 and 3 feet from any two adjacent vertically mulched slots to keep them 6 feet apart.

After the plot differentials were established, two collector drains were dug across the field. One divided the experimental area in halves and helped drain the slightly higher half in which sugarcane variety P.R. 980 was planted. The other collector drain was localized at the lower half where field corn variety Mayorbela was planted.

The sugarcane crop received an application of 12 hundredweights of a 14-4-10 fertilizer mixture per acre and was harvested 13 months thereafter. The ratoon crop was adequately conditioned for a second and third crop, and each received the same treatment. Immediately after the first harvest, infiltration rates were run on all plots to evaluate the effect of the several soil modification techniques. The infiltration rate was measured in the cane row. After the second harvest, infiltration rates were run only on the check and vertical topsoiling plots. After the last harvest, undisturbed soil cores were taken at 0-inch to 3-inch-, 10-inch to 13-inch-, and 20-inch to 23-inch depths below the rows where cane was planted. Water held at 60 cm. tension and percent drainable pores were determined on the saturated cores at that negative pressure.

Two successive corn crops were planted, each receiving 10 hundredweights of a 9-10-5 fertilizer mixture when the crop was 3 weeks old. The corn planting distance was 2 feet between any two rows and 1 foot within the row. After the first crop, the field was disc-plowed and harrowed for the second. The vertically opened slots where topsoil was added were 6 feet apart as in the case of sugarcane. The harvested corn was spatially consistent with these filled slots. The corresponding rows were harvested in the other plots to minimize differences other than those that could have been brought about by the several techniques. After the first corn crop, infiltration rates were run on all plots using the same procedure as for the sugarcane planted in the second experiment.

RESULTS AND DISCUSSION

The results of the experiments on a Mabí clay soil are shown in tables 1 through 7. Vertical mulching resulted in significant differences in cane and sugar yields of 5 and 0.51 tons, respectively, with respect to the check. The vertically opened slot technique yielded intermediately between the check and vertical mulching, although the differences were not statistically significant. The same trend occurred when infiltration rates were run on the three techniques. The differences in yields can be ascribed to vertical mulching which must have served as a water storage and as a drainage outlet at the same time. When the slots were made it was noticed that big cracks were formed on the sides of the walls. These occurred at approximately 1-foot separation and some penetrated 8 inches into the walls of the slot. The vertical mulching slots also served as drains because the bagasse rendered the slots open and porous.

The results of the first ratoon crop are shown in table 2. The yields were relatively low on all plots and the differences were not statistically significant. It should be noted that the plant cane was harvested during a period

TABLE 1.—*Sugarcane yields of plant cane P.R. 980 and infiltration rates after harvest in first experimental site*

Treatment	Cane per acre	Sucrose	Sugar per acre	Infiltration rate
	Tons	*Percent*	*Tons*	*Inches/hour*
Check	45.8	13.4	6.06	0.30
Vertically opened slot	47.4	13.1	6.20	0.62
Vertical mulching	50.6*	13.2	6.57*	0.87

* Significantly higher than check.

TABLE 2.—*Sugarcane yields of first ratoon P.R. 980 and infiltration rates after harvest in first experimental site*

Treatment	Cane per acre	Sucrose	Sugar per acre	Infiltration rate
	Tons	*Percent*	*Tons*	*Inches/hour*
Check	32.2	12.26	3.95	0.19
Vertically opened slot	32.6	12.66	4.13	0.37
Vertical mulching	32.9	12.70	4.18	0.82

of about 3 inches of rainfall when the tractor and cane wagons severely damaged the plantation by creating low spots in the area which held water. When infiltration rates were run after the harvest, the values were somewhat similar to those obtained after the plant cane.

The results of the plant cane of the second experiment in which vertical topsoiling and deep plowing techniques were included, are shown in table 3. These two techniques significantly outyielded the control by 5.1 and 4.7 tons of cane and 0.5 and 0.33 tons of sugar, respectively. Combining the vertical mulching and deep plowing techniques, and the vertical mulching technique alone, do not differ statistically from the control, although any technique causing subsoil disturbance produced a higher yield.

The infiltration rates are shown in the last column of table 3. The differences are not statistically significant because of extreme variations among replicates.

As noted previously, response to any soil modification resulting in subsoil disturbance could be predicted because of the extremely small pores observed in the soil below the top 8 or 10 inches. Before establishing this experiment, the authors examined a cane stool showing water stress symptoms in an adjacent field. The stool was taken out and soil moisture deter-

TABLE 3.—*Sugarcane yields of plant cane P.R. 980 and infiltration rates after harvest in second experimental site*

Treatment	Cane per acre	Sucrose	Sugar per acre	Infiltration rate
	Tons	*Percent*	*Tons*	*Inches/hour*
Check	44.0	11.34	4.99	0.22
Vertical topsoiling	49.1*	11.18	5.49*	.59
Deep plowing	48.7*	10.93	5.32*	.33
Vertical mulching	46.8	11.35	5.31	.35
Deep plowing plus vertical mulching	48.0	10.91	5.24	.31

* Significantly higher than check.

TABLE 4.—*Sugarcane yields of first ratoon P.R. 980 and infiltration rates after harvest in second experimental site*

Treatment	Cane per acre	Sucrose	Sugar per acre	Infiltration rate
	Tons	*Percent*	*Tons*	*Inches/hour*
Check	31.6	11.79	3.71	0.29
Vertical topsoiling	36.2**	11.96	4.35**	.49
Deep plowing	32.9	12.72	4.18	
Vertical mulching	33.6	13.11	4.40	
Vertical mulching plus deep plowing	31.7	12.35	3.92	

* Significant at the 5-percent level.
** Significant at the 1-percent level.

mined beneath it. It contained close to 40-percent moisture but held so tightly that the cane was unable to absorb it. Pérez Escolar and Lugo-López (3) found water availability to increase as aggregate size decreased from 7 mm. to 1 mm. The larger aggregates held more water at the wilting point and less at ⅓ atm.

After rainfall, one could observe water moving in the vertically topsoiled slot and draining without difficulty into the collector ditch.

The results of the first and second ratoon crops are shown in tables 4 and 5. The first ratoon crop underwent the stress of half the normal rainfall, 34.7 inches. The vertical-topsoiling plots outyielded the check in a highly significant way in both cane and sugar. The other plots produced higher yields than the check but the differences were not statistically significant. The vertically topsoiled slots appeared able to absorb and retain moisture in a manner rendering it more available to the crop. After the second ratoon at the conclusion of the experiment, the vertically topsoiled slots were examined to a depth of 30 inches and abundant roots were

TABLE 5.—*Sugarcane yields of second ratoon P.R. 980 in second experimental site*

Treatment	Cane per acre	Sucrose	Sugar per acre
	Tons	*Percent*	*Tons*
Check	42.8	11.99	5.14
Vertical topsoiling	48.4	11.95	5.71
Deep plowing	43.9	12.46	5.53
Vertical mulching	45.7	12.02	5.50
Vertical mulching plus deep plowing	46.7	11.65	5.41

TABLE 6.—*Corn yields of two successive crops and infiltration rates after first corn crop harvest*

Treatment	Shelled corn		Infiltration rate
	First crop	Second crop	
	Hundred-weights/acre	*Hundred-weights/acre*	*Inches/hour*
Check	22.7	31.5	0.28
Vertical topsoiling	35.5*	39.8	0.62
Deep plowing	24.2	34.0	0.57
Vertical mulching	32.2	36.2	0.87
Vertical mulching plus deep plowing	38.2*	36.0	0.78

* Significantly higher than check.

found at that depth. Roots were not found commonly at that depth in other plots. Roots in check plots were not found below 10 inches.

Water infiltration rates were run only in the check and vertical-topsoiling plots and again, because of rather large variations, statistical significant differences were not attained.

The differences in cane and sugar content between the vertical-topsoiling plots and the check in the second ratoon were 5.6 and 0.57 tons, respectively. The differences, however, were not statistically significant.

The results of the experiments in which Mayorbela corn was employed as the test crop are shown in table 6. The plots treated by vertical topsoiling and the combination of vertical mulching and deep plowing outyielded the check plots in the first crop. Both vertical mulching and deep plowing techniques produced higher yields than the check but the results were not statistically significant.

Infiltration tests again showed better water movement in all plots where the subsoil was disturbed by deep plowing, vertical mulching or topsoiling techniques.

Prior to planting the second crop, the entire experimental field was disc-plowed, breaking the continuity of the vertically opened slots in which the bagasse had been applied. The corn was planted in the same rows used previously during the first test. Despite the higher yields of all plots with respect to the check, the differences were not statistically significant due to rather large variations among replicates.

Table 7 shows the values obtained upon examining the water held by

TABLE 7.—*Water held at 60-cm. tension and percent drainable pores of undisturbed soil cores taken at the end of the sugarcane experiment*

Treatment	0-inch to 3-inch depth		10-inch to 13-inch depth		20-inch to 23-inch depth	
	Percent water held by volume	Percent porosity	Percent water held by volume	Percent porosity	Percent water held by volume	Percent drainable pores
Check	52.5	12.6	57.5	8.8	64.0	1.6
Vertical topsoiling	51.3	14.5	52.0	17.5	54.0	17.2
Deep plowing	55.0	8.3	61.0	3.2	58.9	9.4
Vertical mulching	53.9	10.2	59.3	5.9	59.9	8.0
Vertical mulching plus deep plowing	55.6	7.4	59.0	6.4	59.2	8.9

undisturbed soil cores in equilibrium with a 60-cm. tension column immediately after the last cane crop. Although the differences in porosity were not statistically significant, vertical topsoiling appeared to result in greater porosity, particularly at 10-inch to 13-inch- and 20-inch to 23-inch depths. This greater porosity can be associated with the presence of abundant root penetration at those depths.

The data resulting from these experiments indicate that any mechanical disturbance of the subsoil of Mabí clay and similar soils tends to increase sugarcane and corn yields. In Mabí clay soil, vertical mulching and deep plowing resulted in a significant increase of 0.5 tons of sugar over the control in the first cane crop whereas vertical topsoiling resulted in significant sugarcane increases of 0.5 and 0.64 tons in the first and second crop, respectively.

Vertical topsoiling induced abundant root penetration to a depth of 30 inches. Roots in control plots were confined to a depth of 10 inches. The vertical topsoiling technique is a money saving one, being confined to the row area in which the crop is to be planted. This technique, if conducted between the opened slots upon sugarcane renovation, could convert clay soils, such as that upon which these investigations were conducted, into well drained ones. According to field estimates, this soil modification technique should cost approximately $12.00 per acre. The increase in sugar from the plant crop over the control was 10 hundredweights. At an approximate price of $8 per hundredweight, this would mean an additional $80 per acre. The additional net income after deducting $15 for manual harvesting and hauling operations would be $68. The second crop outyielded the control by 13 hundredweights. The additional net income per acre would be $89 or 13 × $8 − $15. No extra cost is charged to vertical topsoiling in these computations; this was a ratoon crop and the operation was not repeated.

It might be convenient to widen the vertical mulcher wings to create a more ample slot thus enabling more topsoil to fill it, as the 7-inch width may not be sufficient. However, this requires more power.

The vertically opened slots in the experimental plots were filled with hand hoes. Disks can be attached easily to the upper part of the opening wings to scrape topsoil into open slots.

The results of the investigations reported here show the importance of recognizing and determining the physical and mineralogical properties of the soil and using them in predicting its behavior. Field observations indicate that Mabí clay and similar montmorillonitic soils have extremely fine pores with weakly developed aggregates in the subsoil. Such soils decrease available water by holding large amounts at tensions under which plant wilting occurs. Mechanically created aggregation and further stabilization of such soils is desirable. Free iron oxide occurs freely in Mabí clay; this is a natural soil conditioner.

SUMMARY

The effects of vertical topsoiling, vertical mulching, deep plowing and a combination of vertical mulching and deep plowing were studied in field experiments conducted on a Mabí clay soil, a Vertisol in east-central Puerto Rico. The results obtained in these experiments indicate that any mechanical soil modification technique that disturbs the subsoil of Mabí clay and similar soils, which comprise around 90,000 acres in Puerto Rico, tends to increase sugarcane and corn yields. Vertical mulching and deep plowing resulted in significant increases of 0.5 tons of sugar over the control in the first cane crop, whereas vertical topsoiling resulted in significant and highly significant increases of 0.5 and 0.64 tons in the first and second crop, respectively. Water infiltration rates were generally 2 to 3 times higher in the vertical mulching and vertical topsoiling plots than in the

control although the differences were not statistically significant due to extreme variations. A combination of deep plowing and vertical mulching resulted in a 70-percent increase of shelled Mayorbela corn over the control, while vertical topsoiling alone produced a 57-percent increase. Vertical topsoiling induced abundant root penetration to a depth of 30 inches whereas roots in the control were confined mostly to a depth rarely exceeding 10 inches.

RESUMEN

Se estudiaron los efectos del rellenado vertical del subsuelo con tierra de su misma capa superficial o con bagazo de caña, de la aradura a profundidad y de una combinación de las dos últimas prácticas agrícolas sobre la producción de caña de azúcar y maíz en Mabí arcilloso, un suelo Vertisol de la sección este-central de Puerto Rico. Los resultados obtenidos en estos experimentos indican que cualquier modificación que altere la condición masiva del subsuelo del Mabí arcilloso y otros suelos similares, de los cuales hay 90,000 acres en Puerto Rico, tiende a aumentar la producción de azúcar y de maíz. El rellenado vertical con bagazo y la aradura a profundidad aumentaron la producción de azúcar en media tonelada por cuerda en siembras de plantilla, mientras que el rellenado vertical por sí solo produjo aumentos significativos y altamente significativos en una siembra de plantilla y una de retoño, respectivamente. La tasa de infiltración de agua fue generalmente dos a tres veces mayor en el rellenado vertical con bagazo y rellenado vertical con tierra superficial que en el caso de los controles, aunque debido a la extremada variación entre las repeticiones las diferencias no fueron estadísticamente significativas. La combinación del rellenado vertical con bagazo y la aradura a profundidad propició un aumento de un 70 por ciento en la producción de maíz Mayorbela con relación al control. Al rellenado vertical se le puede atribuir un 57 por ciento de aumento en la misma cosecha. Este último tratamiento dió lugar a que la penetración de las raíces de la caña alcanzara una profundidad de 30 pulgadas, mientras que el sistema radical de las plantas en el control solo se extendió a 10 pulgadas superficiales del suelo.

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