SOIL APPLICATION OF PAPERMILL AND MUNICIPALBIOSOLIDS FOR COTTON PRODUCTION

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Abstract

Field Experiments were initiated at the Macon Ridge Research Station to assess the effects of various organic wastes on the growth and yield of dryland cotton (*Gossypium hirsutum* L.). The soil used for these experiments (Gigger-Gilbert complex) contains a shallow hard pan (16 to 21" deep) and is characteristic of the Macon Ridge region. Greenhouse and laboratory studies showed that the compacted, acidic hardpan and underlying subsoil contained high amounts of Al and Mn and will not support cotton development. Field experiments were performed to assess the ability of organic amendments to enhance dryland cotton production on this droughty soil. Four of the most abundant organic wastes in the Macon Ridge area (papermill sludge, papermill fly ash, municipal sewage sludge, composted sewage sludge and selected combinations of these materials) were applied alone or as mixtures as vertical mulches or as broadcast treatments. Responses to these wastes applied as vertical mulches (6" trenches cut to a depth of 21") were compared to those of similar rates applied by broadcast and incorporation. These experiments showed that broadcast applied sewage sludge and sewage sludge plus fly ash significantly increased yields over conventional production practices. In contrast, papermill sludge or a combination of papermill sludge and fly ash significantly reduced yields. Overall, broadcast applications were as effective as vertical mulching. Yield responses were due to combinations of factors. For sewage sludge alone and with fly ash, sustained nutrient supplying ability, net mineralization of nutrients, pH buffering properties, and increased aeration and water holding capacity may have contributed to the increased yields. In the case of papermill sludge, with and without fly ash, decreased yields may be attributed to an net immobilization of nutrients.

Introduction

Enactment of the 1972 Federal Water Pollution Control Act amendments, the Clean Water Act, the Ocean Dumping Act, and various other regulations have stimulated research to develop alternative disposal methods for organic wastes generated by municipalities, industry and agriculture. The beneficial use of suitable organic wastes as soil amendments is an attractive disposal alternative in that it conserves essential plant nutrients contained in organic wastes and possibly can preserve or enhance the long-term productivity of lands used for intensive modern agriculture.

Transportation and application costs, however, limits the practical value of organic wastes in production agriculture because these materials typically contain low amounts of N and other essential plant nutrients when compared to commercial fertilizers. The value of organic wastes is greater when they can be used to overcome specific production problems that are not easily resolved by conventional practices.

Much of the cotton acreage of the Macon Ridge region of Louisiana is subject to drought stress because the soils in that region typically contain a shallow hardpan that inhibits root development. The availability of low-cost irrigation water is limited because of the high salinity of near surface aquifers. In recent years, the productivity of dryland cotton in this region has been increased by use of reduced tillage, cover crops and other practices that increase soil organic matter.

The principal goal of this research was to determine if similar increases could be achieved by amending soils with organic wastes. The principal sources of organic wastes in this region are municipal sewage sludge, papermill sludge and papermill fly ash.

Specific objectives were :
(1) Confirm the toxicity of the hardpan (E horizon) and assess the underlying subsoil (B horizons) as a medium for plant growth and potential source of soil water in greenhouse trials. If the underlying subsoil was a suitable medium, application of vertical mulches that penetrated the hardpan may significantly improve water-availability and cotton yields.

(2) Assess the potential of sewage sludge, sewage sludge compost, papermill sludge and fly ash to enhance the productivity of dryland cotton grown in field trials on Gigger-Gilbert soil typical of the Macon Ridge. The merits of vertical mulching and broadcast applications were also compared.

Greenhouse Experiments

Greenhouse experiments were conducted to determine whether the limited ability of hardpan soil (E horizon) or underlying subsoil (B horizons) to support cotton growth and development was due primarily to toxicity or compaction.

Cotton was planted in planters consisting of an upper and lower section each 8" x 3" in diameter. Each section was filled with top soil (Ap horizon), hardpan soil (E horizon) or subsoil soil (Btg and upper Bx horizons). PVC planters were used. The top section contained 7" of soil, while the bottom contained 8" of soil. Treatments included topsoil on topsoil, topsoil on top of crushed B soil, topsoil on top of

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:652-655 (1997)
National Cotton Council, Memphis TN

undisturbed B soil, crushed B soil on top of crushed B soil, topsoil on top of crushed E soil, and crushed E soil on top of crushed E soil. All of the soil, except the undisturbed B core, was air dried and ground prior to use.

Six seeds (Delta Pine 50) were planted in each planter. After germination, planters were culled to two seedlings. All treatments received the equivalent of 80 lbs N/Acre as a complete fertilizer (15-30-15) containing micronutrients. Moisture was maintained near field capacity. Treatments were replicated three times. All planters were placed randomly in the greenhouse. After fourteen days, the planters were randomized again. After 35 d, the aboveground portion was harvested, dried and weighed. Root densities in upper and lower sections were determined as described by Newman (1966).

Field Study

Field experiments were conducted on a field at the Macon Ridge Branch of the Northeast Research Station located south of Winnsboro, LA. Papermill sludge, papermill fly ash, sewage sludge, and composted sewage sludge and selected combinations of these materials (Table 1) were applied by broadcast and incorporation or as a vertical mulches. Supplemental N was applied as a sidedressing when leaf tissue analyzes indicated acute N deficiency. Lime was applied to those plots not receiving fly ash. Each treatment was applied to four replicate plots (4 rows x 50 ft.) arranged in a strip plot design.

Broadcast applications were applied to the soil surface as a 2" layer, except for the papermill fly ash, which was applied as a 1" layer. Application rates ranged between 45 and 100 dry tons/acre (Table 1). After spreading the material, a Triple K™ implement was used to incorporate the amendments into the soil. Rows were rehipped, ridges dragged smooth, and the rows planted.

Vertical mulches were applied by filling ~24" deep x 6" wide trenches with the waste materials. Application rates ranged between 60 and 115 dry tons/acre (Table 1). Prior to planting, 16" hipped rows were constructed of top soil directly over the trenches.

The uppermost fully expanded leaves of twenty cotton plants were collected at weekly intervals for seven weeks commencing with first bloom. The leaf blades were analyzed for total N and the petioles for petiole nitrate. Immediately prior to defoliation, leaves were collected from 20 plants from each plot and their total elemental composition determined. At harvest, the center two rows of each plot were hand harvested, the cotton ginned and the lint yield determined.

Discussion

Greenhouse Experiments

Results from the greenhouse experiments clearly demonstrated that soil collected from hardpan (E horizon) greatly restricted plant growth. Even when soil from this compacted zone was crushed prior to filling planters, plant growth was markedly reduced and root densities in sections filled with this soil were substantially less than in corresponding sections filled with top soil (Fig. 1). Toxicity caused by elevated levels of Mn in this acidic (pH 4.7) soil may have been principally responsible for the observed reduction in plant growth. Compaction may have also contributed to reduced growth because even though the soil was crushed prior to use, sections rapidly compacted upon re-wetting of the soil.

The underlying subsoil (B horizons) appeared to be more inhibitory to plant development than the hardpan. This finding was somewhat surprising since soil analyzes indicated that the pH and concentrations of Mn and Al of the subsoil were similar to those of the top soil (Ap horizon). Elemental analyzes of harvested tissue showed that plants grown exclusively on subsoil contained highly elevated concentrations of Al and Na and significantly reduced concentrations of K. Growth in planters containing crushed B soil was similar to that in planters containing undisturbed cores, and therefore the inhibitory effects of this layer were not likely due solely to compaction (field bulk density 1.89 g/cm^3). Additional research is needed to identify the factor or combination of factors that greatly restrict the underlying subsoil of the Gigger-Gilbert complex as a medium for cotton growth.

Field Study

Application of sewage sludge and combinations of sewage sludge and fly ash or papermill sludge led to lint yields 1.9% to 35.6% greater than those obtained by conventional management (Fig. 2). Composted sewage sludge was generally less effective than raw sludge. The highest lint yield (820.5 lbs lint/acre) was obtained by broadcast application of a combination of sewage sludge and papermill fly ash. Broadcast applications led to consistently higher yields than did application of the corresponding amendment as a vertical mulch. Apparently, mixing of subsurface soil with top soil that occurred as a result of trenching tended to reduce overall crop performance.

Application of papermill sludge or a combination of papermill sludge and fly ash inhibited crop development and significantly reduced cotton yields, especially when these materials were applied as a broadcast treatment. Analyzes of leaf tissue indicated that application of papermill sludge or a combination of this sludge and fly ash led to pervasive and prolonged immobilization of N and other crop nutrients (Table 2). Sidedress applications of fertilizer N (50-75 lbs N/acre) were not sufficient to offset immobilization of plant nutrients by soil microorganisms decomposing the added papermill sludge. However, amending papermill sludge with nutrient-rich sewage sludge sewage sludge (3:1 mix) offset immobilization and led to yields that exceeded conventional management.

These findings are consistent with those of Zibilske et al.(1987) who found that discovered that extractable soil N decreased as the rate of papermill sludge increased. In corn production, yields increased as the rate of supplemental N increased, but even when N was applied at the high rate of 210 lbs/acre, plants were still found to be nitrogen deficient (Logan and Esmaeilzadeh, 1985). Prior to application, the C:N ratio of papermill sludge was 317:1. Similar extremely high C:N ratios for papermill sludge were reported by Watson and Hoitink (1985) who suggested that the largely undecomposed cellulose fibers is this material induced prolonged immobilization of crop nutrients when added to soil.

The increased yield obtained by adding sewage sludge alone or in combination with other wastes was likely due to a combination of factors. This nutrient-rich material no doubt contributed N and other nutrients to the cotton crop, but tissue analyzes indicated that the N status of cotton receiving sewage sludge did not exceed that of cotton receiving a conventional application of fertilizer N. While supplying nutrients in organic form may have resulted in more consistent availability throughout the growing season, it is more likely that the stimulatory effects of sewage sludge on dryland cotton production on this shallow, droughty soil were caused by the beneficial effects of sewage sludge on soil physical properties, including improved water infiltration and water-holding capacity (Wei et al., 1985)

Summary

Application of sewage sludge and combinations of sewage sludge and papermill sludge or fly ash resulted in lint yields of dryland cotton that were 2-26% greater than those obtained by conventional management practices. Raw sewage sludge was more effective than sewage sludge composted with pine bark. Papermill sludge applied alone or in combination with fly ash caused acute immobilization of plant nutrients and significantly reduced yields. Broadcast applications were more effective than vertical mulches, presumably because trenching introduced toxic subsoils into topsoils. Greenhouse studies showed that both the hardpan and underlying subsoil of the Gigger-Gilbert complex were toxic to cotton. Mn in the hardpan (E horizon) appears to account for the toxicity of that horizon, but the cause of toxicity in the underlying subsoil is less evident.

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Table 1. Treatments used in field experiments.

Waste Applied†	Mix Ratio	Placement	Quantity Used	Inorg. N Applied	Lime Applied
			Dry kg ha^{-1}	------kg ha^{-1}-------	
PS	---	Vert. Mulching	67	89.6	2240
CSS	---	Vert. Mulching	108	---	2240
SS	---	Vert. Mulching	76	---	2240
FA	---	Vert. Mulching	123	---	---
PS & FA	7:3	Vert. Mulching	92	44.8	---
CSS & FA	7:3	Vert. Mulching	120	---	---
SS & FA	3:2	Vert. Mulching	129	---	---
PMS & SS	3:1	Vert. Mulching	69	---	2240
PS & SS & FA	8:5:7	Vert. Mulching	73	---	---
None (Trench)	---	Vert. Mulching	---	---	2240
None (Trench)	---	Vert. Mulching	---	---	---
None (No trench)	---	Vert. Mulching	---	---	---
PS	---	Broadcast	53	89.6	2240
CSS	---	Broadcast	81	---	2240
SS	---	Broadcast	55	---	2240
FA	---	Broadcast	55	---	---
PS & FA	7:3	Broadcast	73	44.8	---
CSS & FA	7:3	Broadcast	96	---	---
SS & FA	3:2	Broadcast	112	---	---
PMS & SS	3:1	Broadcast	50	---	2240
PS & SS & FA	8:5:7	Broadcast	56	---	---
None (No trench)	---	Broadcast	---	---	2240
None (No trench)	---	Broadcast	---	89.6	---
None (No trench)	---	Broadcast	---	---	---

† PS, Papermill sludge; CSS, Composted municipal sewage sludge; SS, Municipal sewage sludge; FA, Papermill fly ash.

Table 2. Height and weight of the above ground plant tissue in the greenhouse experiments.

Upper Soil	Lower Soil	Height	Weight
		cm	g
Topsoil	Topsoil	19.92	1.59
Topsoil	Crushed B	16.50	1.02
Topsoil	Undisturbed B	14.88	0.96
Crushed B	Crushed B	2.17	0.07
Topsoil	Crushed E	19.63	1.13
Crushed E	Crushed E	12.46	0.65
lsd (p=0.05)		5.04	0.40

Table 3. Root density in upper and lower sections of planters in the greenhouse experiments.

Upper soil	Lower soil	Upper soil density	Lower soil density
		cm roots/ cm^3 soil	cm roots/ cm^3 soil
Topsoil	Topsoil	2.41	1.51
Topsoil	Crushed B	2.12	0.19
Topsoil	Undisturbed B	3.24	0.12
Crushed B	Crushed B	0.05	0.03
Topsoil	Crushed E	2.40	1.29
Crushed E	Crushed E	0.85	0.53
lsd (p=0.05)		0.89	0.55

Table 4. Cotton lint yields after two pickings.

Amendment	Placement	1st picking	2nd picking	Total yield
		-------------------kg ha^{-1}	----------------	
PS†	Vert. Mulching	321.08	48.52	369.60
CSS‡	Vert. Mulching	613.62	114.16	727.78
SS§	Vert. Mulching	555.11	135.57	690.68
FA¶	Vert. Mulching	586.51	99.89	686.40
PS & FA	Vert. Mulching	371.03	37.10	408.13
CSS & FA	Vert. Mulching	583.65	108.45	692.11
SS & FA	Vert. Mulching	667.85	99.89	767.74
PMS & SS	Vert. Mulching	575.09	68.50	643.59
PS & SS & FA	Vert. Mulching	625.04	115.59	740.63
Lime only	Vert. Mulching	509.45	77.06	586.51
None	Vert. Mulching	495.18	85.62	580.80
PS	Broadcast	161.25	37.10	198.36
CSS	Broadcast	592.22	112.74	704.95
SS	Broadcast	714.94	108.45	823.39
FA	Broadcast	606.49	99.89	706.38
PS & FA	Broadcast	181.23	41.38	222.62
CSS & FA	Broadcast	655.00	119.87	774.87
SS & FA	Broadcast	826.25	92.76	919.00
PMS & SS	Broadcast	664.99	136.99	801.99
PS & SS & FA	Broadcast	739.20	102.75	841.95
Lime only	Broadcast	552.26	71.35	623.61
Conventional	Broadcast	593.64	84.19	677.84
None	Broadcast	525.57	91.33	616.90
lsd (p=0.05)		120.2	48.4	127.57

† PS, Papermill sludge; CSS, Composted municipal sewage sludge; SS, Municipal sewage sludge; FA, Papermill fly ash.

Table 5. Average leaf blade N and petiole nitrate concentrations of leaves collected at weekly intervals for seven weeks commencing at first bloom.

Treatment†	Placement	Blade N	Petiole NO_3
		%N	μg N/g
PS	Vert. Mulching	4.5	2217.4
CSS	Vert. Mulching	4.7	6461.4
SS	Vert. Mulching	5.1	6804.2
FA	Vert. Mulching	4.5	3500.4
PS & FA	Vert. Mulching	4.2	2958.1
CSS & FA	Vert. Mulching	4.6	4716.0
SS & FA	Vert. Mulching	5.0	7356.6
PMS & SS	Vert. Mulching	5.0	6777.6
PS & SS & FA	Vert. Mulching	5.1	6637.6
Lime only)	Vert. Mulching	4.6	4728.0
None (trenched)	Vert. Mulching	4.5	4982.1
None(No trench)	Vert. Mulching	4.8	5791.0
PS	Broadcast	4.1	1535.9
CSS	Broadcast	4.7	6058.2
SS	Broadcast	5.0	7266.1
FA	Broadcast	4.7	6090.1
PS & FA	Broadcast	4.2	1933.4
CSS & FA	Broadcast	4.7	5256.9
SS & FA	Broadcast	5.2	5786.5
PMS & SS	Broadcast	4.9	6390.9
PS & SS & FA	Broadcast	4.9	5148.8
Lime only	Broadcast	4.8	4599.6
Conventional	Broadcast	5.0	5216.3
None	Broadcast	4.9	6805.7

† PS, Papermill sludge; CSS, Composted municipal sewage sludge; SS, Municipal sewage sludge; FA, Papermill fly ash.

Table 6. Elemental composition of organic amendments.

Element	Units	Papermill Sludge	Fly Ash	Municipal Sludge	Composted M. Sludge
C	%	42.0	18.3	25.7	19.6
N	%	0.13	0.18	4.5	0.77
C/N		317	102	5.7	25.7
Al	mg/kg	912.8	6471.2	13679.5	8229.9
As	mg/kg	0.0	2.6	2.9	3.0
B	mg/kg	8.4	37.4	73.2	48.6
Ba	mg/kg	49.3	307.9	295.2	256.9
Ca	mg/kg	3200	39527	13993	12170
Cd	mg/kg	0.6	1.9	6.8	5.1
Cr	mg/kg	2.8	7.7	38.3	25.1
Cu	mg/kg	14.8	28.0	316.8	110.4
Fe	mg/kg	844	2681	15918	11884
Hg	mg/kg	0.0	0.0	0.4	0.4
K	mg/kg	276.3	4692.8	3224.8	1757.5
Mg	mg/kg	417.2	2061.6	4917.2	2550.6
Mn	mg/kg	90.8	977.4	618.9	316.0
Na	mg/kg	2371.3	4227.4	1882.9	220.0
Ni	mg/kg	4.9	11.7	21.8	13.4
P	mg/kg	143.8	546.0	12680.0	3212.7
Pb	mg/kg	1.1	8.4	39.7	42.5
Se	mg/kg	1.1	0.0	0.0	0.0
Si	mg/kg	25.9	63.6	106.8	2023.7
Sr	mg/kg	19.6	281.8	111.8	73.2
Ti	mg/kg	13.2	115.4	29.1	8.4
Zn	mg/kg	29.4	75.4	323.4	190.6