ASSESSING ORGANIC AMENDMENTS USED BY SUGARCANE GROWERS FOR IMPROVING SOIL CHEMICAL AND BIOLOGICAL PROPERTIES

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Abstract

Sugarcane has been produced as a sole crop for at least 30 years in the Midlands area of KwaZulu-Natal and for more than 75 years on the coast. On poor soils a yield decline or plateau has been observed, despite the release of new sugarcane varieties with increased yield potential. Soil surveys conducted in the sugar industry have shown a steady deterioration of soil chemical, physical and biological properties as the period under sugarcane cultivation has increased. Proactive growers have used a range of organic amendments to improve and sustain soil quality, including filtercake, flyash, pine bark, cane trash, poultry and cattle manures, and the incorporation of a fallow crop (green manuring,). A survey conducted in 2001 to determine the efficacy of these amendments, in particular on the biological properties of soils, found that filtercake and green manuring had the greatest effect on improved soil biological properties, as indicated by microbial biomass carbon and metabolic quotient.

Keywords: sugarcane, soil amendments, biological properties, chemical properties, trash, filtercake, manure

Introduction

Sugarcane growers in South Africa have become aware of the importance of maintaining soil quality through the use of organic amendments. Soil quality is defined largely by soil function or use, and represents a composite impact of physical, chemical and biological properties on an ecosystem (Doran *et al*., 1996). These authors defined soil health as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity. Two microbial indices that are important in monitoring soil health are microbial biomass (Jenkinson and Ladd, 1981) and soil microbial respiration (Anderson, 1982). However, microbial quotient (microbial-C/total-C) has been regarded as a more useful indicator of soil health than either microbial-C or total-C considered individually (Anderson and Domsch, 1989). In general, soils under monocropping have lower microbial quotients than those under multicropping due to a more rapid rate of decline in microbial C pools relative to total organic matter. More recently, Anderson and Domsch (1990) suggested that the respiratory or metabolic quotient (soil respiration/microbial biomass C) could be used to investigate soil development, substrate quality, ecosystem development and response to stress. In general higher metabolic quotients suggest stress response and poor health.

Soil amendments used by growers include sugarcane by-products such as trash, filtercake, bagasse and flyash, all by-products of the sugarcane industry. Other sources of organic soil amendments include poultry and cattle manure, pine bark chips and green manuring.

Numerous workers have reported on the beneficial effects of trash (Thompson, 1966; Thorburn *et al*., 2001; van Antwerpen *et al*. 2001), filtercake (Henry and Rhebergen, 1994; Meyer *et al*., 1992; Paul, 1974), bagasse (Georges *et al*., 1985), flyash (Maclean, 1976), poultry manure (Judge, 2001; Moberley and Stevenson, 1971), cattle manure (Ekwue and Stone, 1995), pine bark chips (Smith, 1985) and green manures (Garside and Bell, 1999; Nixon, 1992; Schumann *et al*., 2000) on the chemical and physical properties of soils. Information on the effect of these soil improvers on the biological properties of soils in the South African sugar industry is limited to that on cane trash (Graham *et al*., 1999, 2001, 2002), filtercake (Dee *et al*., 2002; Roth, 1971) and flyash (Dee *et al*., 2002).

This paper reports the findings of a recent survey undertaken to assess the efficacy of a range of soil amendments on the chemical and biological properties of South African sugar industry soils.

Materials and Methods

The two main criteria used for the Survey procedure

selection of suitable sampling sites were (i) that fields had to have been under the same management system for at least five consecutive years and (ii) that soils from paired sites had to be comparable in terms of belonging to the same management unit (Table 1). In soil surveys where systems are compared, an assumption must be made that the control group soils (conventional practice) would have provided similar results had the soils been treated in a similar manner to the soil amendment group.

Soil samples were collected from eight paired sites located between latitude $28^{o}23'$ and $30^{o}45'$ south and longitude $31^{o}20'$ and $32^{o}03'$ east, representing the north and south coasts, and the Midlands north and south, within the South African sugar industry. A paired site consisted of an area where the conventional practices of burning before harvest and fertilising with inorganic fertilisers only had been in use, and an adjoining area where the grower had applied a soil amendment which, over time, would improve the health of the soil. Organic manures were applied in all cases except two, where the cane was grown (i) in pure flyash 2 m deep and with all particles less than 2 mm in diameter, and (ii) in pine bark chips, originally 1 m deep, decreasing to 0.2-0.5 m in depth over a period of seven years. One of the paired sites sampled (field number 106, Table 1) had a history of green manuring coupled with trash management, and was grazed by cattle between ratoons (trash + cattle).

Soil sampling procedure

Soil samples were taken in triplicate from each of three fields treated with a soil amendment, and triplicate samples were taken from three untreated (control) fields on an adjacent farm. The samples were taken next to the cane row to depths of 50 and 100 mm; however, data from the 50 mm depth only are reported in this paper. Each soil sample was analysed in triplicate in the laboratory, bringing the total number of replicates per treatment to 27. For purposes of comparison, data were divided into eight groups, based on the number of sampling events. Each of these groups were divided into two sub-groups, with one sub-group representing the soil amendment used and the other sub-group representing conventional practice. Groups 3, 4 and 7 were divided into three sub-groups because more than one soil amendment treatment was sampled (Table 1). The mean and standard deviations were calculated for each sub-group.

Chemical analyses included pH (water), P (Truog), K, Ca and Mg (Meyer *et al*., 1989), organic C and potentially mineralisable N (Sahrawat, 1982).

Physical analyses included clay percentage, determined by the hydrometer method, and soil aggregate stability using the wet sieve technique (Sumner, 1958). Microbial biomass C was determined by the fumigation-extraction method based on the difference between C extracted with 0.5 M K_2SO_4 from chloroform fumigated and unfumigated soil samples, using a K_c factor of 0.38 (Vance *et al*., 1987). Basal respiration was determined by placing 30 g oven-dried equivalent of field moist soil in a 50 ml beaker and incubating the sample in the dark for 10 days at 25°C in a one litre airtight sealed jar containing 10 ml of 1 M NaOH. The CO_2-C that evolved was determined by titration (Anderson, 1982). Microbial quotient was calculated by expressing microbial biomass C as a percentage of total organic C. Metabolic quotient was calculated as the ratio between basal respiration and microbial biomass C.

Results and Discussion

The mean results obtained from each sub-group (27 replicates) are summarised in Table 2. All the amendments used by growers participating in this survey were organically based, and enhanced the organic C content of soils by 1% on average relative to conventional practice (Table 2). In general, soil nitrogen content doubled from an average of 0.08% under conventional practice to 0.14% after the use of organic amendments, and the mean soil C:N ratio was reduced by 16% in the organic amendment treatment compared with conventional practice. The exceptions were flyash and pine bark chips, which had higher C:N ratios than soils under conventional practice. Although soil data for conventional practice compared with pine bark chips was not available, it may be assumed that the soil C:N ratio under the conventional practice was similar to that in the other areas, and that pine bark chips therefore increased rather than reduced the C:N ratio (Table 2).

Soils on which organic amendments had been used for at least five years contained, on average, more than double the amount of plant available P, K, Ca and Mg found in conventionally treated soils with no organic matter returns (Table 2). Filtercake, flyash and the manures were effective Ca carriers, and filtercake and the manures were effective also as P carriers. Sodium was on average only marginally higher in the ameliorated sites, with the largest increase from flyash (95 mg/kg) compared with a mean of 44 mg/kg for the other soil amendments. The increased Ca, Mg, K and Na contents of the soils receiving organic amendments was also reflected by the soil pH values, which were on average 0.64 units higher than the average pH of 5.30 obtained under conventional practice. Filtercake, cattle and poultry manure, and cane trash + cattle all helped to reduce acidity. Cane trash without cattle had a slight acidifying effect, as reported previously by van Antwerpen *et al*. (2001), due to denitrification of ammonium released during mineralisation of the decomposing trash blanket (Wood, 1966). The low pH of pine bark chips should not be confused with soil pH, as it merely indicates that the chips will have an acidifying effect should they be mixed with soil.

All microbial biomass C values were higher where organic amendments had been used than with conventional practice (Table 2). However, flyash and pine bark chips caused marked reductions in microbial quotient when compared with conventional practice (Figure 1). Surprisingly, filtercake had a slightly lower quotient relative to conventional practice, which was exceptionally high when compared with the conventional practice from other areas. The lower filtercake value is therefore not regarded as showing a negative effect. Figure 1 also shows that the proportion of C that came from microbes was 7-10% for filtercake, compared with 2-7% for most other soil amendments and for conventional practice. An exception to this was pine bark chips, where microbial biomass C was less than 1% of total C. The large standard deviations obtained (see Figure 1) were the result of data from the three sampling points per field and three fields per farm being combined to form a single comparative value per sampling event.

Although all basal respiration effects were in favour of the applied soil amendments, the levels at which they differed from conventional practice varied between amendments. The most marked difference (33.3 *u*g CO_2/g/day) was found between flyash and conventional practice (Table 2). The reason for this is unclear, as flyash supported the second lowest (after pine bark chips) amount of microbial biomass C. The marked difference might indicate that the microbes were under stress or that they were in a young system, and were thus very active but not efficient. Brooks (1995) commented that basal respiration is difficult to interpret with regard to soil health because of the variability caused by substrate differences, temperature and soil water content, even under laboratory conditions.

Metabolic (or respiratory) quotient is the ratio between basal respiration C and microbial biomass C, and is regarded as an indicator of soil health (Anderson and Domsch, 1990). From Figure 2 it is clear that the metabolic quotients calculated for flyash and pine bark chips were the highest (>10 *u*g CO_2-C/hr/mg C_{mic}), not only in absolute terms, but also relative to conventional practice. These large metabolic quotients indicated that the flyash and pine bark chips supported microflora, which probably experienced stress due to insufficient amounts of N (see C:N ratios in Table 2). The lowest metabolic quotient values (2 *u*g CO_2-C/hr/mg C_{mic}) were obtained where filtercake and green manure (cowpeas) had been used as soil amendments. Both are known to contain relatively high amounts of N (Roth, 1971, Schumann *et al*., 2000), which supports a large microbial biomass (Table 2). The relatively large microbial biomass numbers and low basal respiration rates thus indicated that the microbial population was not under stress, and that the health of these soils was relatively good compared with soils at other sites. Similar metabolic quotients were obtained for trash, and poultry and cattle manures, and ranged from 2 to 6 *u*g CO_2-C/hr/mg C_{mic}.

Probably the most sensitive soil physical indicator of soil quality, is aggregate stability. All the organic amendments used in this survey increased the stability of aggregates in the 5 to 2 mm fraction by an average of 17% (Figure 3). The effects on the smaller 2 to 1 and 1 to 0.5 mm fractions varied, and the overall improvement of aggregate stability in the 5 to 0.5 mm fraction remained at 17% relative to conventional practice (Table 2). Aggregate stability tests were not done for flyash and pine bark chips, as they were not mixed with the soil.

Conclusions

All the organic amendments were shown to be effective in increasing the quality of soils through improved organic C content, increased pH, sum of cations and mineralisable N, reduced C:N ratio and improved aggregate stability. Organic amendments were also effective in improving soil health through increased microbial biomass C, despite the fact that cattle and poultry manures were applied in relatively small quantities (30 and 10 tons/ha respectively) spread on the soil surface after harvest. The practices of applying thick layers of flyash or pine bark chips were shown to be less effective in supporting a higher microbial biomass C. Also shown was that the microflora present in these treatments were probably under stress due to insufficient amounts of N in relation to total organic C.

Although growers are often tempted to use whatever organic matter is available to them, especially where their farms are close to the source and it can be delivered in large quantities at no cost, such material should be evaluated carefully. The C:N ratio must be taken into account to ensure that the appropriate amounts are applied to individual fields, and sound agronomic practices should be followed, e.g. incorporation and, where required, supplementary fertilisation.

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Table 1. Geographic and soils information for fields sampled, and soil amendment practices applied.

Area	District	Farm	Parent material	Soil form(s)	Practice	Field no(s)
Zululand Central	Entumeni	Ntumeni	Natal Sandstone	Fernwood, Kroonstad, Oakleaf	Filtercake	57
Zululand Central	Entumeni	Ntumeni	Natal Sandstone	Kroonstad, Oakleaf, Fernwood	Conventional	56
Midlands North	Claridte/Otto's Bluff	Glenann	Middle Ecca Shale, Dolerite	Mispah,Glenrosa, Hutton	Cattle manure	106, 107, 59
Midlands North	Claridte/Otto's Bluff	Illovo (Mattisons)	Middle Ecca Shale, Dolerite	Glenrosa, Hutton	Conventional	MT30, MT29, MT02
Zululand South	Mandini	Cranburn	Dwyka, Alluvium, Lower Ecca Shale	Glenrosa, Oafleaf, Swartland	Trash + cattle	46, 121, 119
Zululand South	Mandini	Cranburn	Lower Ecca Shale	Swartland	Green manure	106
Zululand South	Mandini	Michelan	Dolorite, Lower Ecca Shale	Swartland,, Milkwood	Conventional	31, 19, 18
South Coast Highflats	Umzimkulu	Poleni		Cartref, Westleigh, Avalon	Poultry manure	6, Nyosi, 5A
South Coast Highflats	Umzimkulu	Poleni		Cartref	Poultry manure dump	
South Coast Highflats	Umzimkulu	Poleni		Cartref, Westleigh, Avalon	Conventional	5, Opposite Nyosi
South Coast	Umtentweni	Kurnalpi	Granite, Alluvium, Recent sand	Mayo, Dundee, Fernwood	Trash	021B, 110B, 016B
South Coast Highflats	Umzimkulu	Raptor	Middel Ecca Shale, Granite	Glenrosa	Conventional	220, 1250
Zululand South	Amatikulu	Ntabeni	Recent sand	Not soil*	Flyash	16, 11, 11A
Zululand South	Amatikulu	Ntabeni	Recent sand	Hutton	Conventional	11B
North Coast	Darnall	Scmidt	Dwyka	Glenrosa, Strekspruit	Trash	235, 217, 224
North Coast	Darnall	Entelberg	Dwyka	Cartref	Poultry manure	12
North Coast	Darnall	Entelberg	TMS order, Dwyka	Swartland	Conventional	239, 376, 4
North Coast	Mandini	Khanyakude	Dwyka	Not soil*	Pine bark	15, 21, 31
North Coast	Darnall	Entelberg	Dwyka	Glenrosa	Conventional	4

*Samples were collected in a 2 m layer of flyash and a 0.5 m layer of pine bark chips.

Table 2. Mean values of soil chemical, physical and biological properties at each sampling site.

Property	Filter cake	Conv[1]	Cattle Manure	Conv	Green manure	Trash + Cattle	Conv	Poultry manure	Poultry manure dump	Conv	Trash	Conv	Flyash	Conv	Trash	Poultry manure	Conv	Pine bark	Conv	Amend[2]	Conv
Sample order	1	1	2	2	3	3	3	4	4	4	5	5	6	6	7	7	7	8	8	Mean	Mean
pH (water)	5.77	5.51	6.47	4.79	5.57	5.55	5.04	6.97	7.62	5.26	5.06	5.26	6.76	6.70	4.98	6.64	4.86	3.98	4.99	5.94	5.30
P mg/kg	273	227	325	32	305	48	190	2124*	4815*	50	39	42	80	66	35	47	24	87	17	138	81
K mg/kg	146	110	667	220	305	167	192	553	587	254	110	209	752	125	93	129	95	186	117	336	165
Ca mg/kg	1118	148	2351	726	3213	1887	952	2400	1930	560	716	410	1775	400	534	855	201	680	280	1587	460
Mg mg/kg	157	25	821	278	987	602	481	863	1263	236	271	196	579	154	288	194	99	320	146	577	202
Na mg/kg	23.22	25.78	52.33	32.44	64.00	67.11	44.78	26.56	22.00	28.00	40.67	41.89	95.22	50.00	36.11	20.00	35.44	39.44	52.00	44	39
C %	1.86	0.89	2.68	3.57	5.31	3.24	3.14	3.24	3.68	2.29	1.72	1.57	3.51	1.22	1.80	1.57	1.12	17.11*	1.30	2.86	1.97
N %	0.09	0.04	0.15	0.11	0.16	0.15	0.11	0.20	0.22	0.10	0.09	0.09	0.08	0.05	-	-	-	0.23*	-	0.14	0.08
C:N ratio	21.1	30.0	20.4	37.7	33.5	23.7	39.6	16.8	16.1	23.9	17.3	20.6	47.0	22.6	-	-	-	73.4*	-	24.5	29.1
Basal respiration ug CO_2-C/g/day	31.3	19.3	33.5	31.2	34.9	26.3	24.8	39.5	42.6	31.9	21.2	15.2	44.8	11.5	30.7	28.1	12.4	26.1	12.1	32.6	19.8
Microbial biomass C mg C/kg	1579	770	1149	919	1655	792	776	1156	1513	753	644	367	469	149	844	644	346	223	205	970	536
Microbial quotient %	8.68	9.03	5.14	2.68	3.21	2.30	3.06	3.62	4.45	3.17	4.90	3.18	1.64	3.57	4.60	4.15	2.97	0.17	1.74	3.90	3.68
Metabolic quotient ug CO_2-C/hr/mg C_{mic}	2.08	2.49	3.21	4.14	2.11	5.95	4.10	3.83	2.85	5.15	3.86	4.34	10.18	6.57	3.93	4.39	4.12	12.34	9.32	4.98	5.03
SAS % (5-2mm)	34.5	9.5	55.9	45.2	50.4	69.9	49.2	54.8	42.9	25.9	59.3	50.7	-	8.1	53.5	14.7	24.5	-	36.5	48.4	31.2
SAS % (2-1mm)	10.5	10.3	6.7	4.8	7.4	6.8	8.3	11.7	17.3	15.5	9.8	9.4	-	5.0	9.0	3.8	9.7	-	14.3	9.2	9.7
SAS % (1-0.5mm)	3.1	3.4	2.5	2.9	5.8	1.6	2.7	4.9	9.9	8.1	4.0	3.5	-	4.5	4.5	3.6	2.6	-	4.0	4.4	4.0
SAS % (%-0.5mm)	48.1	23.2	65.1	52.9	63.7	78.3	60.2	71.5	70.1	49.6	73.0	63.6	-	17.6	67.0	22.1	36.8	-	54.9	62.1	44.8
Clay %	13.2	9.0	27.8	32.9	25.4	26.4	44.1	24.3	14.3	33.9	24.1	20.8	-	8.1	21.2	9.3	15.0	-	8.7	20.7	21.6

[1] Conv = Conventional practice   [2] Amend = Amendments used   * Data not used in calculations of the mean

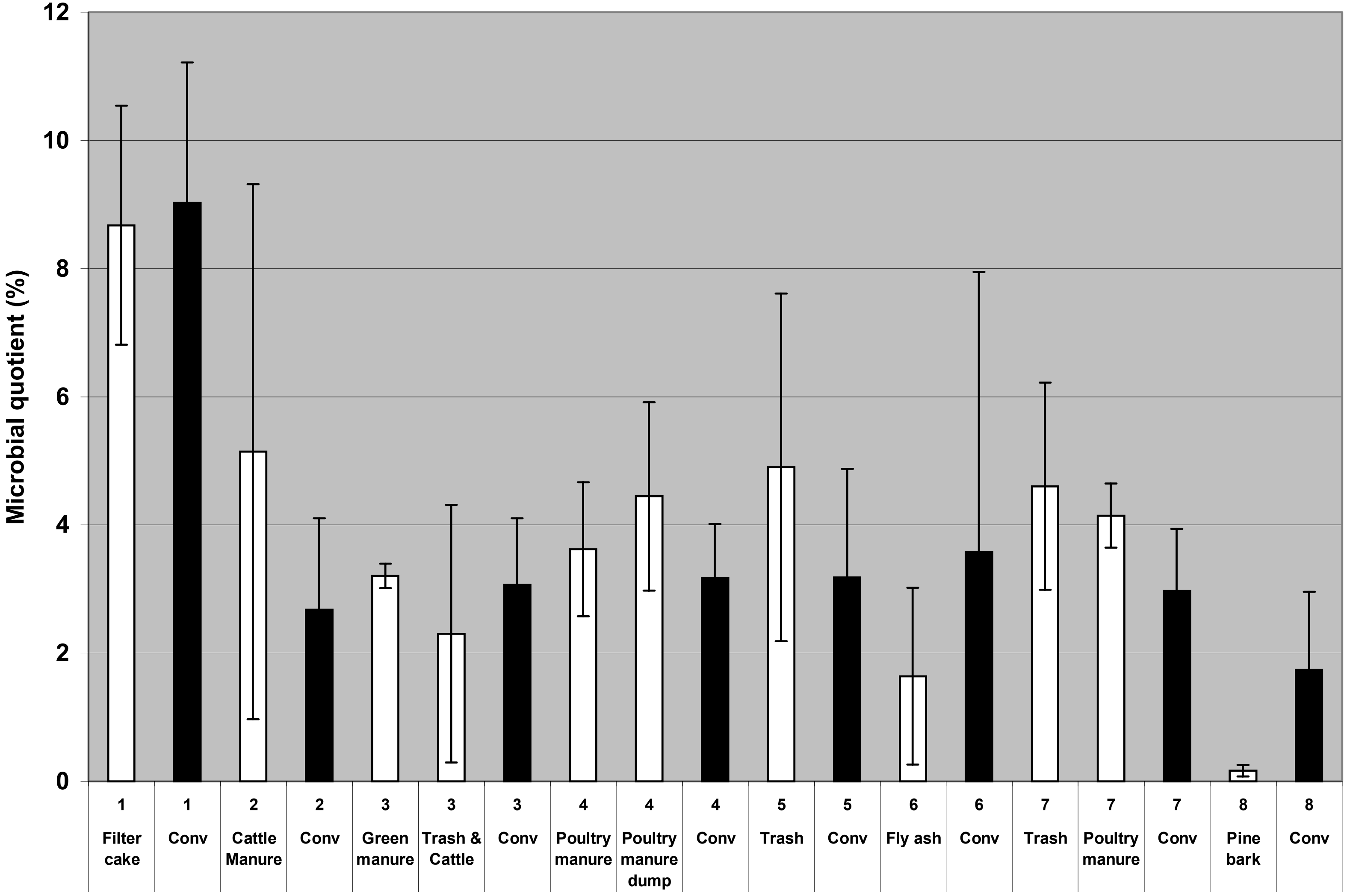

Figure 1. The effect of various organic amendments on microbial quotient compared with conventional practice (conv). Standard deviations are indicated by vertical bars.

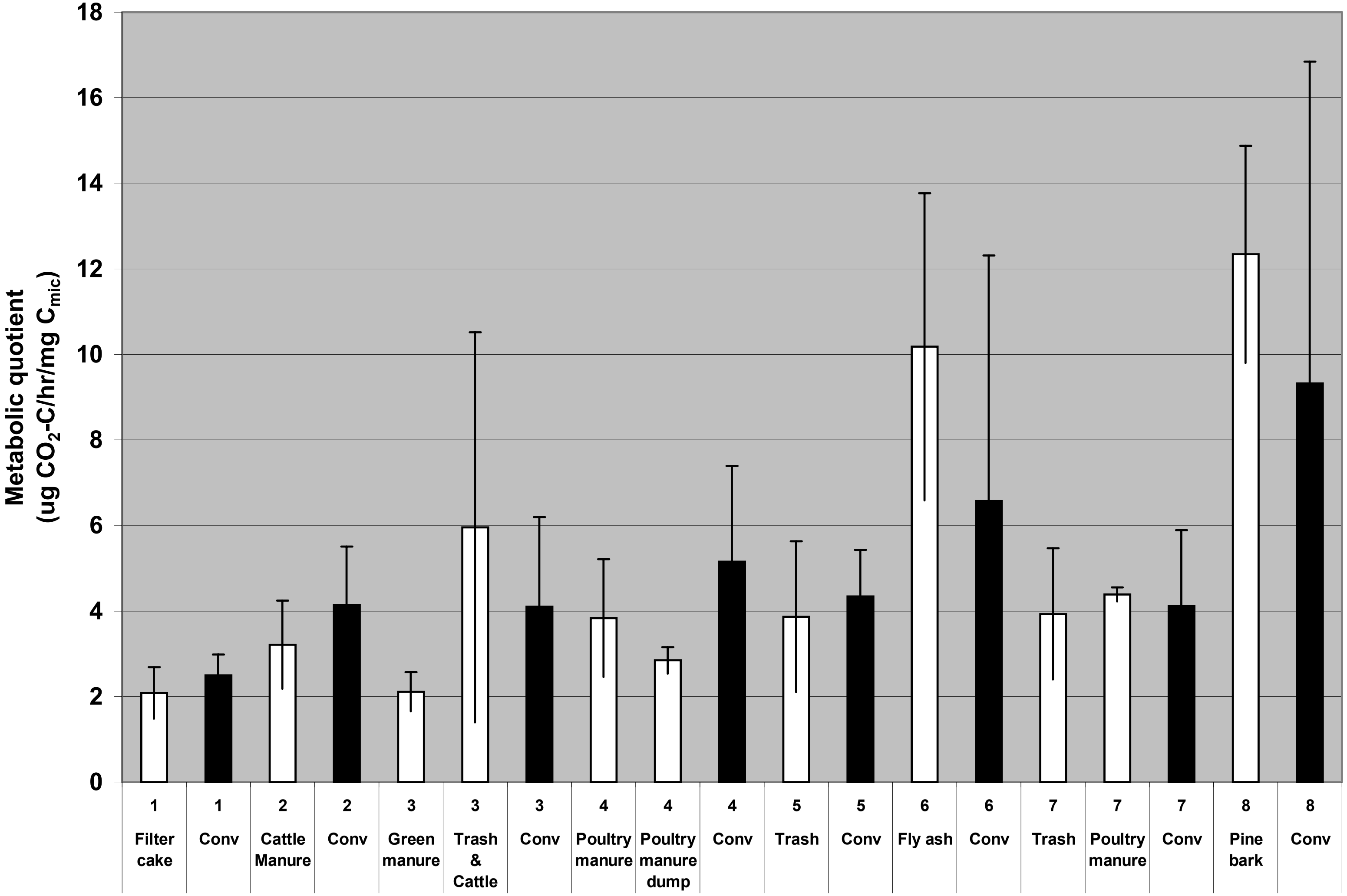

Figure 2. The effect of various organic amendments on metabolic quotient compared with conventional practice (conv). Standard deviations are indicated by vertical bars.

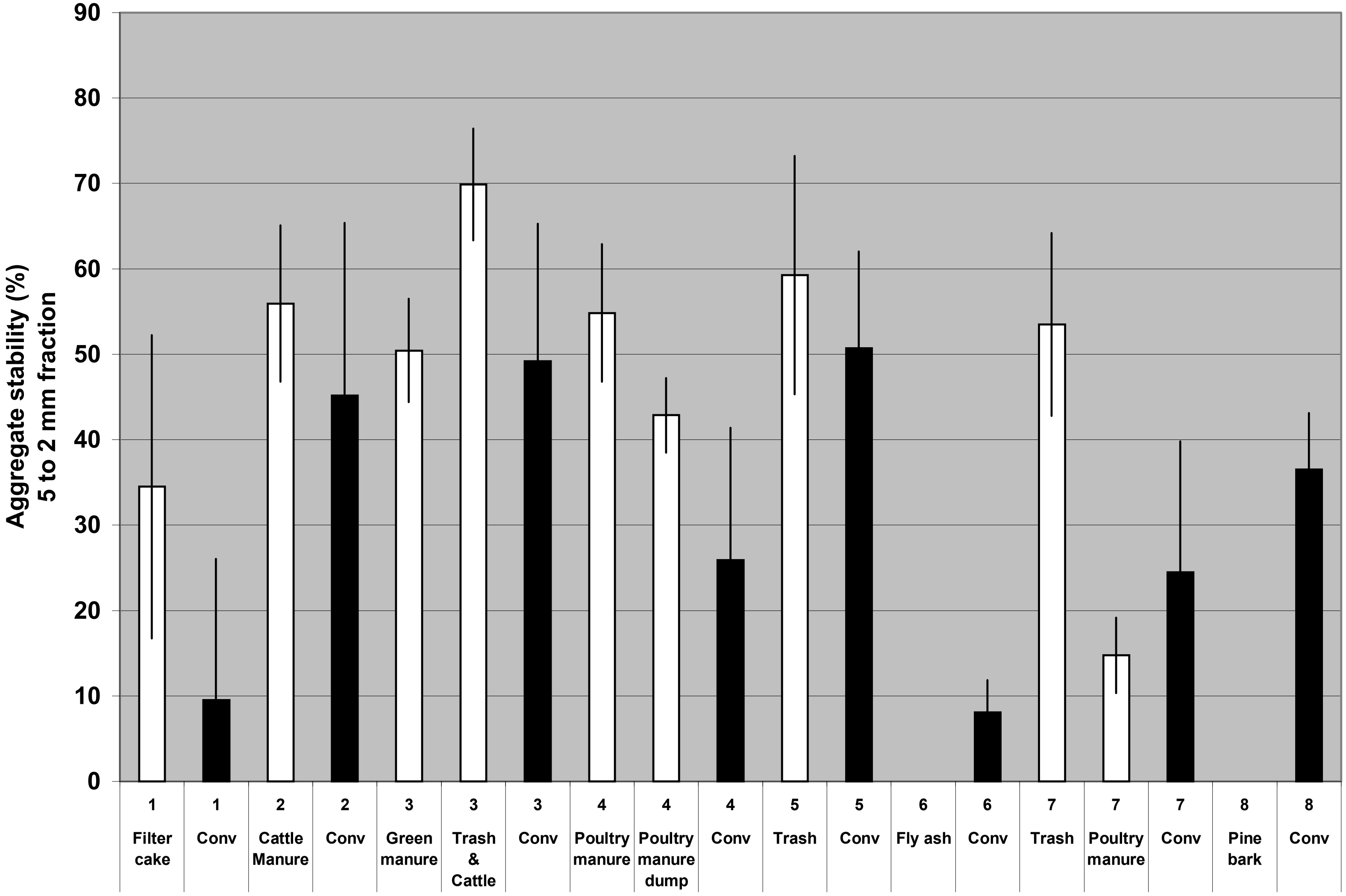

Figure 3. The effect of various organic amendments on aggregate stability (5 to 2 mm fraction) compared with conventional practice (conv). Standard deviations are indicated by vertical bars.