STABILIZATION OF WIND ERODIBLE LOAMY SANDS BY AN OIL PRODUCTION WASTE SLUDGE

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ABSTRACT

A field experiment was conducted to determine the effectiveness of production oily waste sludges as stabilizers of wind erodible fraction, WEF (material < 0.84 mm), of sandy loams and to determine the persistence of stabilized fractions during cultivation. The waste sludge application resulted in 5 replicated soil oil contents, 0, 1.05, 1.45, 3.0, and 7.0% (by weight). Dry aggregate size distribution, DASD, determinations were carried out twice an year for five consecutive years. The soil oil content had significant influence on the temporal changes in both WEF and DASD. The amount of WEF that was stabilized by the sludge increased with soil oil content (R^2 = 0.88). Similar trends were observed for aggregates > 0.84 mm and < 34 mm. Depending on the soil oil content, the potential maximum amount of WEF stabilized into aggregates > 0.84 mm ranged from 41 to 63% (R^2 = 0.93). The half-life for destabilization of the stabilized WEF was 2 yr. The resieving data indicated that mechanical stress enhanced fragmentation of stabilized aggregates.

INTRODUCTION

About 304,000 ha of cultivated land located within 100 km radius of Lloydminster heavy oil drilling operation is susceptible to wind erosion. The extent of wind erosion in a soil depends primarily on source strength, i.e., the amount of wind erodible fraction, WEF,(material < 0.84 mm). Thus, crop and tillage management practices have been directed towards reducing source strength (Chepil, 1954; Biederbeck et al. 1984; Campbell et al, 1993). It may take as long as 5 to 9 yr to achieve significant improvement in aggregate stabilization to occur through crop-rotation and/or reduced till systems (Rasiah and Kay, 1994). Unpublished preliminary results indicate the benefits accrued through rotation or reduced till systems may not persist even for an year under conventional production system.

Synthetic organic polymers have been shown to be effective in aggregate stabilization in a short time (Marsh and Groenevelt, 1992; Armbrust and Dickerson, 1971). However, the persistence of the stabilized soil seem to be short lived, i.e., the effectiveness lasted for about 6 months (Marsh and Groenevelt, 1992). Dickson et al. (1990) have shown that some bio-organic industrial wastes were effecive in aggregate stabilization and their disposal on agricultural land could be permitted with intermittent monitoring of Na and Ba content in soil.

Oily waste sludges generated during field production of oil have been traditionally used by rural municipalities as material for dust control on rural roadways and for road bed stabilization during construction of municipal roads (Bernier, 199 1). However, the increasing volume of the sludge generated can not be accommodated in “road oiling” alone (Pescod, 1992; Lorenz, 199 1). From an agricultural standpoint the waste could be viewed as a source high in organic C which may transform in time to humus C, thereby increasing aggregation. In the short-term, on the other hand, the sticky oil may physically bind WEF, thereby reducing the susceptibility to wind erosion.

The objectives of this study were to (i) investigate the influence of an oily waste sludge on the stabilization of WEF and (ii) determine the persistence of the stabilized WEF and larger aggregates during cultivation.

MATERIALS AND METHODS

Soil and site Characterization

Two plot experiments were established on 2 ha of a Meota loamy sand (Black Chernozem) one in late spring (Experiment I) and the other in early fall (Experiment II) in 1986. The clay, silt, and sand content of the soil was 11, 9, and 80%, respectively. The WEF in the soil ranged from 75 to 90%. The organic C content in the soil was 2.2% and CEC was 5 meq/100g.

Experiment

The study employed a split-plot design with three replications. The sludge rate treatment was in the main plot, 14 x 18 m, and the fertilizer, N-rates, in the sub-plot, 14 x 4 m. The sludge was applied only once in 1986 and resulted in initial soil oil content of 0, 1.4, and 1.45% in experiment I and 0, 3.0 and 7.0% in experiment II. Prior to sludge incorporation fertilizer N, P, and S was applied at 0, 150 kg N + 15 kg P + 24 kg S/ha, and 300 kg N + 30 kg P + 48 kg S/ha in 1986.

On May 15, 1987, all plots in both experiments were seeded to spring wheat (Triticum aestivum L.) and harvested in mid-September. The cultivation of spring wheat was repeated in 1988, 1990, and 1991. In 1989 all plots in both experiments were summer fallowed.

Soil samples for stability measurements

Soil samples for WEF and DASD determination were collected in early spring (May) and in early fall (September) in each year beginning in the spring of 1987. The samples were air-dried and DASD was determined using a rotary sieve (Chepil, 1962). The sieved soil was separted into seven size fractions, i.e, < 0.42, 0.42-0.84, 0.84-2, 2-6.4, 6.4-12.7, 12.7-38, and > 38 mm. The last two fractions were collected as one sample. The mass of aggregates that passed through the 0.42 mm sieve and those retained on it is defined as WEF, i.e. material < 0.84 mm. The different size aggregates, for a given treatment, obtained after dry sieving of the whole soil collected in the spring of 1987 were recombined and resieved to determine the influence of mechanical force, such as tillage, on further fragmentation (Woodruff et al. 1965). The procedure was repeated for the samples collected in the spring of 1988. This data is referred to as resieved data in the text.

Computational Procedures

The changes in DASD subsequent to waste application over time was modeled using Rasiah and Kay's (1994) approach.

$$[W_{i\,a} - W_{i\,c}]_t = \Delta W_{i\,max}[\exp^{(-k_i t)}] \qquad [1]$$

where $W_{i\,a}$ is the mass of given size fraction in the treatment and Wi c is the mass traction in the control, AWi max is the potential maximum stabilized mass fraction and ki is the rate constant for destabilization, the subscripts a and c refer to treatment and control, respectively. In the case of WEF, the WEFa was always less than WEF_c, therefore WEF_c minus WEF_a at any point in time is the amount of WEF that remained as stabilized fractions greater than > 0.84 rnm and we define this as stabilized WEF and rewrite Eq.[1] as,

$$[WEF_c - WEF_a]_t = \Delta WEF_s \max [\exp^{(-kt)}] \qquad [2]$$

where S refers to stabilized WEF.The time required for AWi max or AWEFs max to reach a point midway between the maximum and minimum values is defined as half-life for destabilization and is calculated as follows:

$$t_{1/2} = - \ln(0.5)/k \qquad [3]$$

RESULTS AND DISCUSSION

Wind erodible fraction

The analysis of variance for WEF, for each sampling date, indicated the amount of WEF in DASD data was significantly influenced only by soil oil content ($P < 0.05$). Thus, the data on WEF across fertilizer application rates, for a given soil oil content, was pooled and used in further analysis. The WEF in the control ranged from 70 to 90% during the sampling period (Table 2 and Fig. 1). Compared to the control, the amount of WEF in the treatment was significantly less and it decreased with increasing soil oil content (Fig. 1, Table 2). This suggests the applied waste was effective in stabilizing the WEF into aggregates > 0.84 mm, which are resistant to wind erosion, and the extent of stabilization increased with increasing soil oil content.

The increases in WEF in the sludge treated soil with time (Fig. 1) suggest the stabilized WEF broken down into WEF over time. The analyses presented in Table 3 show that 88% of the variability in the stabilized WEF (AWEF), was accounted for by soil oil content and time.

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Figure 1. The influence of waste application rate on wind erodible fraction, WEF, over time in experiments I and II compared with the corresponding control.

Dry aggregate size distribution

The stepwise variable selection analysis indicated the net gain in stability of aggregates > 0.84 mm (AWi),i.e., the aggregates resistant to wind erosion, increased with soil oil content and decreased over time (Table 3, Eqs. 2 to 5). The gain in stability of aggregates > 0.84 mm due to sludge incorporation seems to be a morror image of the reduction in WEF. A comparison of the coefficients for soil oil content in Eqs. [2] to [5] (Table 3) suggests the largest net gain stability due to oil content occured in the 12.7-38 mm aggregates.

The impact of sludge application on further fragmentation of already fragmented material was investigated by resieving the recombined sieved material. The results indicate the material stabilized by the oily waste was potentially fragile under stress, eg. during tillage, thereby increasing the amount of WEF and the susceptibility to wind erosion.

Potential maximum stabilization

The data in stabilized portion of WEF (Fig. 2) was non-linearly regressed with sampling time using eq.[2]. The R^2 values for the best fits ranged from 0.59 to 0.96 and best fits were significant at $P < 0.05$ (Table 3). Depending on the soil oil content, the potential maximum amount of WEF, $AWEFs_{max}$' stabilized ranged from 41 to 63% (Table 3). At a given soil oil content, the sum of the potential maximum net gain in stability of aggregates >0.84 mm was approximately equal to $AWEFs_{max}$' except in one case. This suggests the potential maximum gain in the stability of aggregates > 0.84 mm occured at the expense of aggregates < 0.84 mm.

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Figure 2. The changes in the net stabilized portion of wind erodible fraction, WEF, over time in the two experiments.

The rate constant of $AWEFs_{max}$ or that of Wi max was not influenced by soil oil content. Thus, an average value, 0.030, was taken as the rate constant for destabilization of $AWEFs_{max}$. Using 0.030 as the rate constant, the half-life for $AWEFs_{max}$ was computed using Eq. [3] and it was 23 months. This suggests that more than 50% of the stabilized WEF remained as aggregates that are resistant to wind erosion for at least 3 yr subsequent to sludge application. For example, at 1.03% soil oil content the $AWEFs_{max}$ is about 4 **1 %,** implying that about 40% of WEF in the treated soil compared to 80% in the control. The WEF in the sludge treated soil increased to 60% three years after sludge application. Even though the applied sludge stabilized WEF into aggregates > 0.84 mm, the change was transient. This raises the question whether repeated waste application, once in 3 to 4 yr, is required to reduce the susceptibility of the soil to wind erosion. Further research is required to address this question.

CONCLUSIONS

One application of an oily waste sludge, resulting in 1.04 to 1.45% soil oil content (by weight) to a loamy sand with - 80% wind erodible fraction, WEF, was effective in stabilizing 41 to 63% of the WEF into aggregates that are resistant to wind erosion. On the other hand cultural practices, such as forages, may require as long as 7 to 8 yr to bring about comparable changes in aggregation. The aggregates stabilized by the oily waste had a half-life of about 3.0 yr during cultivation. This suggests that repeated application of the sludge, once in every 3 to 4 yr, may be required to protect these soils against wind erosion. The major portion of the WEF was stabilized into the largest aggregate size, i.e., 12.7-38 mm aggregates. The resieving analysis indicated that further fragmentation occured under stress, implying that tillage and cultivation parctices enhanced fragmentation.

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Table 3. Values of potential maximum change in stability AWi max) for each size aggre gates and the corresponding rate constant (k) obtained using Eq. [2] and [3].

Size (mm)	ΔW (g 100 g^{-1})		k ($month^{-1}$)		R^2	
Experiment I						
	L1	L2	L1	L2	L1	L2
< 0.84	41.4	53.2	0.042	0.042	0.88	0.96
0.84 - 2	5.5	7.8	0.050	0.044	0.82	0.59
2 - 6.4	8.3	15.2	0.025	0.035	0.88	0.57
6.4 - 12.7	9.5	12.6	0.029	0.053	0.82	0.71
12.7 - 38	10.4	13.7	0.015	0.039	0.24	0.80
Experiment II						
< 0.84	41.1	63.2	0.016	0.021	0.59	0.75
0.84 - 2	3.6	8.3	0.019	0.054	0.66	0.77
2 - 6.4	10.2	14.7	0.007	0.013	0.65	0.97
6.4 - 12.7	6.6	15.1	0.012	0.025	0.91	0.88
12.7 - 38	24.1	27.9	0.022	0.018	0.27	0.17

L1 and L2 refer to low and high soil oil content. The relations are significant at $P \leq 0.05$.

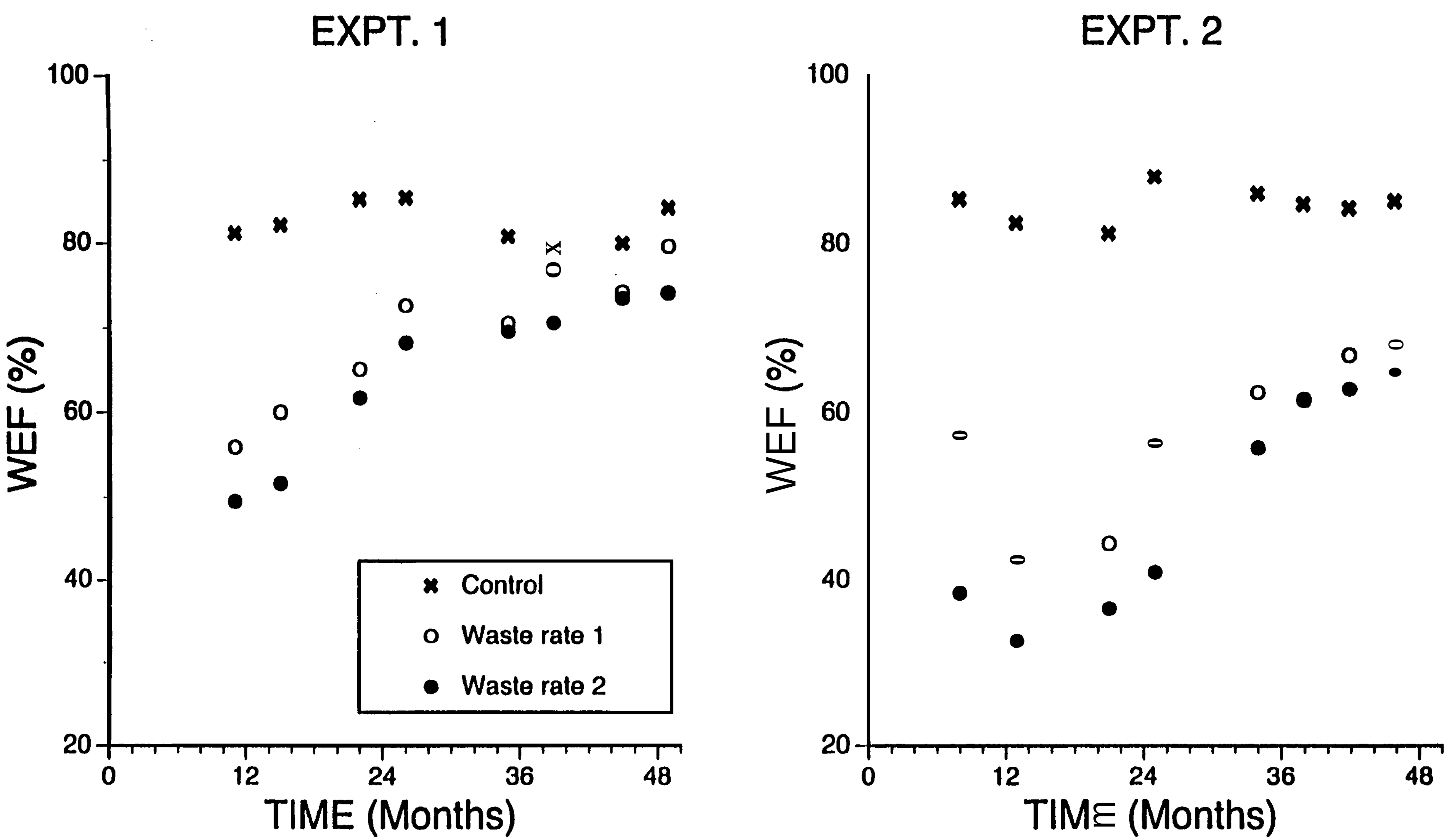
EXPT. 1
WEF (%)
TIME (Months)
Control
Waste rate 1
Waste rate 2
EXPT. 2
WEF (%)
TIME (Months)

Fig. 1

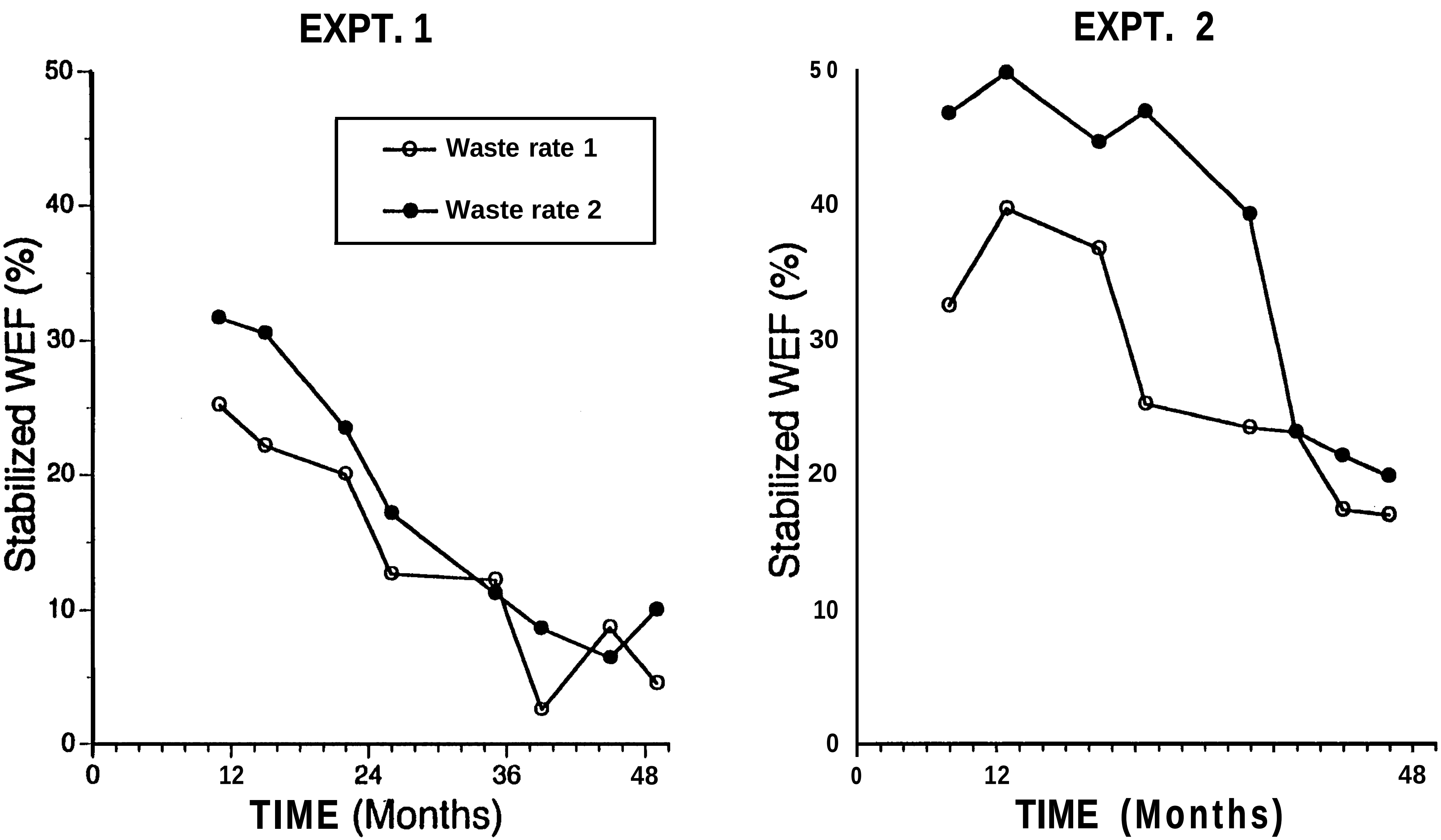
EXPT. 1
Waste rate 1
Waste rate 2
Stabilized WEF (%)
50
40
30
20
10
0
0
12
24
36
48
TIME (Months)
EXPT. 2
Stabilized WEF (%)
5 0
40
30
20
10
0
0
12
48
TIME (Months)

Fig. 2