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Improving Exposed Subsoils with Fertilizers and Crop Rotations

C. W. Robbins,* B. E. Mackey, and L. L. Freeborn

ABSTRACT

Irrigation-induced erosion and land leveling have decreased crop yields on approximately 800 000 ha of south-central Idaho silt loam soils. Previous attempts to increase subsoil productivity to that of the topsoil have not been successful on these soils. This study was conducted to find a method(s) for increasing the productivity of freshly exposed subsoil to that of the topsoil and to determine the factor(s) limiting subsoil production. A 4-yr study was initiated by removing the surface 0.3 m of topsoil from strips between undisturbed topsoil strips of a Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthid). Different crop rotations were established within the strips and fertility treatments were applied across the strips. The fertilizer treatments were conventional fertilizer application according to soil test, dairy manure, and two cottage cheese (acid) whey rates. During the fourth year, dry edible bean (*Phaseolus vulgaris* L., cv. Viva) were grown on the entire plot area as a test crop. The application of 44 Mg manure ha^{-1} in the spring and 93 Mg manure ha^{-1} in the fall of 1991 (first year of study) was the only treatment that restored subsoil bean production to that of the topsoil plots. Plant Zn and soil organic C concentrations were the only measured factors that correlated with bean yield increases on the subsoil.

IRRIGATION-INDUCED EROSION from silt loam soils of south-central Idaho varies from 0.5 to 140 Mg ha^{-1} per season, depending on the field slope and crop grown (Berg and Carter, 1980). This, however, does not represent the total adverse topsoil displacement effect, since additional soil is moving from the upper ends of fields and being redeposited on the lower ends of the fields during irrigation. This exposes a greater subsoil area than indicated by the measured topsoil loss. Land leveling to increase field size and reduce irrigation labor has also exposed the subsoil on numerous acres. These combined processes affect crop yields on at least 800 000 ha locally (Carter et al., 1985).

When six field crops were compared for yield reduction response to topsoil removal on a Portneuf silt loam in south-central Idaho, Carter et al. (1985) found that sugarbeet (*Beta vulgaris* L.) yields were the least affected, bean, alfalfa (*Medicago sativa* L.), and barley (*Hordeum vulgare* L.) yields were intermediately reduced, and sweet corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) yields were the most severely reduced. Potato (*Solanum tuberosum* L. cv Norgold Russet) yields and quality were significantly reduced where the topsoil depth was decreased by erosion. Yield losses from erosion on the upper portions of fields are not offset by equal crop yield increases in the deposition areas (Carter, 1993).

Added N use efficiency by crops on eroded soils in rain-fed crop areas may be as low as one-third to one-fifth of N applied to noneroded topsoils (Wolman, 1985). Nutrient deficiencies in eroded soils can usually be corrected by fertilizer application, but generally, the soil productivity is not restorable (Burnett et al., 1985).

Phosphorus, K, N, or Zn applications to a Portneuf silt loam did not produce significant yield restoration to seven crops tested on artificially eroded soils (Carter et al., 1985). Carter (1993) suggested that, "Technology is not available to restore soil productivity potential to the level that would exist had there been no erosion except for returning topsoil to eroded areas" and that "the only effective treatment was to replace 30 to 40 cm of topsoil" (Carter, 1990).

The purpose of this long-term study was to first determine if methods can be developed to increase the productivity of eroded silt loam soils of south-central Idaho to that of noneroded topsoils, and secondarily to determine the specific factors that limit crop productivity on eroded soil sites where subsoil is exposed. We applied three very different nutrient sources to three different crop rotations grown on freshly exposed subsoil for 3 yr and then compared the production and composition of dry edible bean grown on the treated subsoil plots and the adjacent topsoil plots during the fourth growing season.

MATERIALS AND METHODS

The study was conducted on a Portneuf silt loam that has a 0.20- to 0.45-m-thick lime–silica cemented hard layer that starts at 0.30 to 0.45 m below the surface in native soils. The native topsoil is pale brown (10 YR 6/3) and the hard layer is white (10 YR 8/2). The material below the hard layer is a light gray (10 YR 7/2) silt loam. The average silt content increases from 62% in the surface to 67% at 1.3 m, the sand fraction is fairly constant at about 18% down to 1.3 m, and the clay fraction decreases from an average of about 20% in

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C.W. Robbins and L.L. Freeborn, USDA-ARS, Northwest Irrigation and Soils Research Lab., 3793 North 3600 East, Kimberly, ID 83341-5076; and B.E. Mackey, USDA-ARS, Pacific West Area Director's Office, 800 Buchanan Street, Albany, CA 94710. Received 25 July 1996. *Corresponding author (robbins@kimberly.ars.pn.usbr.gov).

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the surface to 15% at 1.3 m on noneroded sites (Robbins, 1977, p. 7). The plot area has a 1.1% slope and has been surface irrigated for >90 yr. There is a slight but definite indication of redistribution of topsoil from the top to the bottom of the field.

The plots were set out such that the top 0.3 m of topsoil could be removed to expose fresh subsoil in long narrow strips from the top to bottom of the field for the subsoil treatments. This arrangement was necessary because the plot area is furrow irrigated and the overall study is to last for at least 8 yr. Crop rotations were randomized across the field such that each of three crop rotations were grown on subsoil and two of the three rotations were grown on topsoil strips. The topsoil strips, the subsoil strips, and the crop rotation strips were all parallel to the irrigation furrows. The four fertilizer treatments were randomized strips, running perpendicular to the crop rotations and soil treatments. The design is shown in Fig. 1, with each subsoil crop–fertilizer combination treatment replicated four times and each topsoil–cropping treatment replicated 16 times. Fertilizer treatment was not a variable on the topsoil. The plots were 9 m wide and 21 m long.

On 16 Apr. 1991, 0.3 m of topsoil was removed from the strips that will be referred to as the subsoil plots and spread on an adjacent field. The subsoil plots were then ripped to 0.28 m on a 0.3-m spacing to shatter the hard layer so it could be plowed. The entire study area was plowed to 0.3 m to reduce surface compaction caused by the heavy earth-moving equipment and to allow treatment applications.

A composite of five, 75-mm-diam. soil samples were taken from each of 32 topsoil and 48 subsoil plots to a depth of 0.30 m, sieved through a 2-mm screen, and thoroughly mixed. The samples were analyzed for saturation paste pH (Robbins and Wiegand, 1990), $CaCO_3$ equivalent (Allison and Moodie, 1965), mineralizable N (N_m)(Keeney, 1982), organic carbon (OC) (Nelson and Sommers, 1982), bicarbonate-extractable P (Watanabe and Olsen, 1965) and K (Gavlak et al., 1994, p. 31–32), and diethylenetriaminepentaacetic acid (DTPA) extractable Zn (Baker and Amacher, 1982). These results are shown in Table 1.

The four fertilizer treatments were conventional (fertilized according to soil tests for calcareous soils, Painter and McDole, 1979), manure, high whey, and low whey. The conventional fertilizer subsoil plots received 135 kg P ha^{-1} as triple superphosphate and 245 kg N ha^{-1} as urea on 18 Apr. 1991. On 19 April, fresh dairy manure was applied at an air-dry rate of 44 Mg ha^{-1}. It contained 0.6 kg water kg^{-1} of wet manure, 22.2 g total N, 8.6 g total P, 19 g total K kg^{-1}, and 140 mg Zn kg^{-1} on the air-dry basis. This treatment applied 980 kg total N, 380 kg total P, 840 kg total K, and 6.2 kg Zn ha^{-1} to the manure plots. The subsoil plots were then furrowed with large shovels on 0.50-m centers and 0.25 m deep to make large ridges. This covered the manure and commercial fertilizer and provided the maximum surface possible for applying the whey treatments.

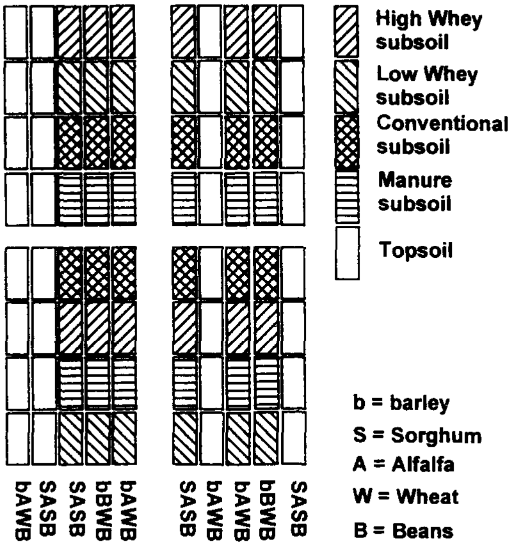

Fig. 1. Experimental design and treatment plot layout. Topsoil plots and crop rotations were positioned the length of the field and the fertilizer treatments were across the field on the subsoil plots only. (Wide spaces represent replication boundaries for illustration purposes only.)

Berms were made at both ends of the whey plots for whey application. Cottage cheese whey (acid) was surface applied to the whey plots through gated irrigation pipe. The whey was the byproduct of cottage cheese produced by adding an equivalent of 3 kg of H_3PO_4 to each 1000 kg of milk and contained 1346 mg N kg^{-1}, 1050 mg P kg^{-1}, 1650 mg K kg^{-1}, and 1.1 mg Zn kg^{-1} of whey. The low whey treatment applied 230 m^3 whey ha^{-1} (equivalent to 23-mm depth of whey) and the high whey treatment added 920 m^3 whey ha^{-1} (92-mm depth). The low whey treatment added 310 kg N ha^{-1}, 242 kg P ha^{-1}, 380 kg K ha^{-1}, and 0.25 kg Zn ha^{-1}. The high whey treatment added 1230 kg N ha^{-1}, 970 kg P ha^{-1}, 1520 kg K ha^{-1}, and 1.0 kg Zn ha^{-1}.

All topsoil plots received 100 kg N ha^{-1} as urea. Because of the low subsoil DTPA-extractable Zn values and previous data (Leggett and Westerman, 1986) showing Zn-deficient bean when grown following a fallow year, Zn was added to all plots (1 May 1991), with the idea of removing Zn nutrition as a variable. Zinc in the EDTA [(ethylenedinitrilo)tetraacetic acid] form was applied at 1.5 kg Zn ha^{-1} since this is the form and rate currently used by most growers in the area. The subsoil plots were harrowed to remove the ridges from the whey applications and the entire plot area was plowed to 0.30 m to mix the treatments with the subsoil and to prepare the entire plot area for planting.

The three crop rotations grown on the subsoil were: sorghum [*Sorghum bicolor* (L.) Moench]-sudangrass [*Sorghum sudanense* (Piper) Stapf] hybrid, alfalfa, sorghum–sudan hybrid, bean (SASB); barley, alfalfa, winter wheat, bean (bAWB); and barley, bean, winter wheat, bean (bBWB). The SASB and bAWB rotations were grown on the topsoil plots. Barley and the sorghum–sudangrass hybrid were grown in 1991. Alfalfa and Viva pink bean were grown in 1992. Winter wheat and sorghum–sudangrass were grown in 1993 and only Viva pink bean was grown in 1994.

The SASB rotation was selected because of the beneficial soil productivity building characteristics that the sorghum–sudangrass hybrid and alfalfa have shown on high-pH soils (Robbins, 1986) and the beneficial effects that grain sorghum often exhibits when grown before Zn-sensitive crops (Boawn, 1965). The bAWB rotation is typical of, or similar to, the first four of 5- or 6-yr dry bean production rotations commonly used on these soils. The bBWB rotation is a worst-case bean production scenario that is occasionally used but is a particu-

Table 1. Topsoil and freshly exposed subsoil surface (0–0.3 m) pH, electrical conductivity (EC), calcium carbonate equivalent (CCE), organic carbon (OC), mineralizable N (N_m), bicarbonate-extractable PO_4-P and K, and DTPA-extractable Zn means prior to treatment applications (16 Apr. 1991).

	pH	EC	CCE	OC	N_m	PO_4-P	K	Zn
		dS m^{-1}	— g kg^{-1} —		——— mg kg^{-1} ———			
Topsoil	7.9	1.4	83	9.4	31.0	23.5	416	3.8
Subsoil	8.0	1.4	250	4.5	11.9	9.0	259	0.6

larly poor choice on eroded southern Idaho silt loam soils in terms of increasing soil organic matter and developing desirable soil structure.

At the end of the 1991 growing season, all plots were sampled and tested for bicarbonate-extractable P. On the basis of the soil tests, 130 kg P ha^{-1} as triple superphosphate was added to the conventional fertilizer subsoil plots (17 Oct. 1991). Dairy manure was applied to the manure treatment plots at 93 Mg ha^{-1} on an air-dry basis (18 Oct. 1991). This added 2060 kg total N, 800 kg total P, 1770 kg total K, and 13 kg Zn ha^{-1}. The low whey plots received 200 m^3 ha^{-1} (20-mm depth) of acid whey and the high whey plots received 400 m^3 ha^{-1} (40-mm depth) of acid whey (4–6 Nov. 1991). These treatments added 540 kg total N, 420 kg total P, 660 kg total K, and 0.44 kg Zn ha^{-1} to the high whey plots and half that amount to the low whey plots. The entire plot area was then plowed to mix the added materials with the soil on 7 Nov. 1991.

Alfalfa and bean were planted in the spring of 1992. The alfalfa was harvested on 8 July and 13 August. The bean was harvested 3 September. The 5-wk-old alfalfa third crop regrowth was killed with 2,4-D (2,4-dichlorophenoxyacetic acid) on 21 September, and the entire field was plowed 1 Oct. 1992 and planted to winter wheat on 5 Oct. 1992.

On 14 Apr. 1993, 110 kg N ha^{-1} as NH_4NO_3 was applied to the 1992 bean strips. The winter wheat on the 1993 sorghum–sudangrass plots was killed with glyphosate [isopropylamine salt of N-(phsphonomethyl) glycine] on 13 May 1993, and the sorghum–sudangrass was planted on 25 May. The winter wheat was harvested on 20 August. Because of an unusually cool summer, the tallest sorghum–sudangrass was only 1.5 m high and was not harvested.

The grain straw and shredded sorghum–sudangrass (from the 1993 cropping season) was plowed under in May 1994. The entire plot area was planted to bean on 6 June 1994 without additional fertilization. Ten whole plants were taken from each plot on 18 July and 5 August, and five whole plants were taken on 31 August from rows with representative plant populations. Total dry matter per plant was determined on all three sample sets. The nodes per plant were counted on the first two samplings. The pods per plant that had started to swell from seed growth were counted on the second sampling. The fresh whole plants were washed in distilled water, dried at 55°C and ground to pass a 1-mm-mesh stainless steel screen. The plant samples were then dry ashed at 500°C, and the ash was dissolved in 0.5 *M* HNO_3 and analyzed for Zn, Cu, Mn, Fe, Ca, Mg, P, and K. The bean was harvested on 27 and 28 Sept. 1994 and yields were determined from four 18-m-long rows in each plot.

Each spring and fall (1991–1994), five soil samples of 75-mm diam. by 300 mm deep were taken from each plot, combined, and thoroughly mixed. A 5-kg subsample was saved for chemical analysis. Soil pH was measured on saturation pastes. Electrical conductivity (EC_{sp}), Ca, Mg, Na, K, Cl, NO_3, SO_4, ortho and organic P, and Na adsorption ratio were determined on the saturation paste extracts. Mineralizable N, bicarbonate-extractable K, ortho-P, and organic P concentrations were also determined.

It was initially assumed that applying 1.5 kg Zn ha^{-1} to all plots would remove Zn as a variable from the study (Leggett and Westerman, 1986; Carter et al., 1985), but after evaluating bean seed yield and plant composition of the 1994 crop and finding low Zn concentrations, we decided to measure the DTPA-extractable Zn on all soils from previous samplings. Lindstrom et al. (1986) also found Zn availability to be low in calcareous Beadle clay loam (fine, montmorillonitic, mesic Typic Argiustoll) that had the surface 0.30 and 0.45 m of topsoil removed 20 yr previously.

Statistical analyses were run separately for the topsoil and subsoil plots since each topsoil treatment appeared four times in each replication for a total of 16 per treatment. Each subsoil treatment occurred once per replication (Fig. 1). This difference resulted in an unbalanced design. In the topsoil analysis, the rotation treatment × column block interaction was used as an error term for rotation treatment. In the subsoil plot analysis, a split-block or strip-plot design was used (Milliken and Johnson, 1984, p. 316–321). The analyses were carried out using the SAS GLM procedure (SAS Institute, 1989, p. 891–996). All 1994 soil ortho-P and subsoil K data were transformed by reciprocal square roots, plant P by logarithms, and plant K by square roots to stabilize the variances among treatments prior to analyses of variance. Differences are based on nonoverlap of 95% confidence intervals of the means, a conservative approach relative to most multiple comparison procedures.

RESULTS AND DISCUSSION

The focus of this discussion will be limited to the fertilizer source treatment and crop rotation effects on the 1994 bean seed yield, soil chemical composition changes, and whole bean plant composition.

The 95% confidence interval range method to evaluate fertilizer source effects on bean seed yield suggested that manure was the only treatment that increased the subsoil yield to that of the topsoil (Table 2). The whey-treated plot yields were not significantly better than the conventional fertilizer plot yields.

The spring 1994 mineralizable N (N_m) was greater in the manure plots than in the topsoil and other subsoil plots. The high whey plot N_m concentrations were also greater than in the conventional fertilizer plots. Only the conventional fertilizer plot N_m values were not signif-

Table 2. Total Zn applied, 1994 ‘Viva’ bean yield, and soil chemical composition of the initial topsoil, freshly exposed subsoil, and surface and subsoil at the end of the 1994 cropping season.

Treatments	Zn applied	Bean yield	Mineralizable N	NO_3–N	Bicarbonate-extractable Ortho-P	Bicarbonate-extractable K	DPTA Zn	Organic C
	kg ha^{-1}	kg ha^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}
Initial topsoil (1991)		–	31.0 d†	16.9 c	23.5 d	416 b	4.0 c	9.4 b
Initial subsoil (1991)		–	11.9 a	16.2 c	9.0 a	249 a	0.6 a	4.5 a
1994 topsoil	1.5	3150 b	34.0 d	11.5 b	18.2 bc	392 b	3.8 bc	9.4 b
Manure	20.7	3360 b	42.6 e	26.8 d	87.9 f	594 c	2.4 b	10.4 b
Low whey	2.0	2300 a	16.6 bc	5.4 a	24.9 d	257 a	0.6 a	5.3 a
High whey	3.0	2110 a	19.3 c	7.2 a	34.9 e	277 a	0.7 a	5.8 a
Conventional	1.5	1960 a	13.5 ab	6.0 a	21.0 cd	249 a	0.6 a	5.1 a

† Numbers in a column followed by the same letter are not significantly different as judged by overlap of 95% confidence intervals.

Table 3. 1994 'Viva' bean yield and whole-plant N, P, and Zn concentrations.

Treatment	Bean yield	Total N			P			Zn		
		18 July	5 Aug.	31 Aug.	18 July	5 Aug.	31 Aug.	18 July	5 Aug.	31 Aug.
	kg ha^{-1}	g kg^{-1}						mg kg^{-1}		
Topsoil	3150 b†	36.1 b	28.8 b	18.5 a	3.9 a	3.5 a	2.8 a	36.6 c	31.2 c	18.6 e
Manure	3360 b	29.7 a	26.5 a	19.3 a	4.0 ab	3.6 ab	2.8 a	26.2 b	23.1 b	16.7 d
Low whey	2300 a	31.8 a	27.1 a	18.9 a	5.5 bc	4.7 c	3.5 b	15.9 a	16.0 a	10.3 b
High whey	2110 a	33.9 ab	27.4 ab	18.7 a	6.2 c	4.9 c	4.1 c	13.5 a	15.1 a	9.1 a
Conventional	1960 a	30.1 a	26.7 a	18.9 a	4.7 b	4.2 bc	3.3 a	16.7 a	18.3 ab	11.5 c

† Numbers in a column followed by the same letter are not significantly different as judged by overlap of 95% confidence intervals.

icantly greater than the 1991 subsoil values. The spring 1994 manure plot NO_3–N concentrations were considerably greater than in the topsoil plots, while the other three subsoil treatments were less than the 1991 subsoil NO_3–N concentrations. Topsoil NO_3–N concentrations decreased from spring 1991 to fall 1994.

Bicarbonate-extractable ortho-P concentrations in the manure plots were excessive, while the two whey and the conventional fertilizer treatment plot ortho-P concentrations were increased to greater than the 1994 topsoil value, which was adequate (>10 mg P kg^{-1} soil, Lamborn, 1975).

Soil test K concentrations in all treatments were at least twice as high as needed (100–120 mg K kg^{-1} soil) for bean production (Lamborn, 1975), and whole-plant K concentrations were not affected by fertilizer treatment or crop rotation (data not shown).

The 20.7 kg Zn ha^{-1} applied with the manure increased the soil DTPA-extractable Zn to four times that of the other three subsoil treatments. The Zn added by the whey treatments and the initial 1.5 kg Zn ha^{-1} application did not significantly increase the DTPA soil Zn over that measured in the 1991 subsoil plot samples.

Table 4. Bean seed yield, spring 1994 soil mineralizable N and NO_3–N concentrations, and 31 Aug. 1994 whole-plant Zn concentration, as affected by soil, fertilizer treatment, and crop rotation.

Treatment†	Seed yield	Mineralizable N	NO_3–N	Whole-plant Zn
	kg ha^{-1}	mg kg^{-1}		
		Topsoil		
SASB	3410 b‡	32.8 a	10.8 a	19.7 b
bAWB	2890 a	35.1 b	12.1 a	18.0 a
		Subsoil		
Manure				
SASB	3410 a	41.2 ab	33.2 b	17.9 b
bAWB	3350 a	48.2 b	26.1 a	17.6 b
bBWB	3320 a	37.5 a	22.6 a	16.2 a
Low whey				
SASB	2630 b	18.3 b	10.1 c	12.3 b
bAWB	2370 ab	16.9 b	6.0 b	10.7 a
bBWB	1910 a	12.8 a	3.1 a	10.6 a
High whey				
SASB	2300 a	21.2 b	17.1 c	12.1 b
bAWB	2240 a	18.7 ab	6.1 b	9.6 a
bBWB	1790 a	15.3 a	4.5 a	9.6 a
Conventional				
SASB	2270 b	11.9 a	13.1 c	12.9 b
bAWB	2040 ab	13.1 a	6.0 b	11.5 a
bBWB	1550 a	11.0 a	3.3 a	11.5 a

† SASB = sorghum, alfalfa, sorghum, bean; bAWB = barley, alfalfa, wheat, bean; bBWB = barley, bean, wheat, bean.

‡ Numbers in a column, for the same soil and fertilizer treatment, followed by the same letter are not significantly different as judged by overlap of 95% confidence intervals.

The manure treatment increased the OC in 1994 to that of the topsoil but the other treatments did not significantly increase the OC above the 1991 subsoil concentration.

Even though there were treatment effects on soil N_m and NO_3–N concentrations, the whole-plant total N concentrations did not appear to be influenced by the soil N_m or NO_3–N concentrations (Table 3). The highest yielding treatment (manure) had the lowest (although nonsignificant in most cases) total plant N concentration. This suggests that soil N was not a limiting factor in this study.

Whole-plant P concentrations did not appear to be related to bicarbonate-extractable ortho-P levels. Bean yields were not positively related to whole-plant P concentrations or soil test P values. There was adequate available soil P and P did not limit bean production.

Zinc concentrations were adequate in the topsoil and manure treatment plants for the 18 July and 5 August sampling. The rest of the samples had marginal Zn concentrations except that the 18 July and 31 August high whey and the 31 August low whey and conventional treatment plants were low in Zn (Leggett et al., 1975). For all three samples dates, plant Zn concentrations were topsoil > manure > conventional ≥ low whey ≥ high whey treatments.

Crop rotation effects within soil treatments on bean seed yield, soil N_m and NO_3–N, and whole-plant Zn for the 13 Aug. 1994 plant sampling are given in Table 4. The crop rotation effect on yield was SASB > bAWB > bBWB across soil and fertilizer treatments. In some cases, manure as an example, the differences were not significant but the trend was followed. There was not a crop rotation × fertilizer yield interaction. The crop rotation effect on soil N_m and NO_3–N concentrations were SASB > bAWB > bBWB for both whey and the conventional treatment plots, mixed in the manure plots, and bBWB ≥ SASB in the topsoil plots. Whole-plant Zn concentrations for the 31 Aug. 1994 sample date were SASB ≥ bAWB ≥ bBWB. Whole-plant Zn, in the 31 Aug. 1994 plants, was the only plant factor measured that followed bean seed yield trends across crop rotations within each soil and fertilizer treatment.

Crop rotations did not significantly affect the whole-plant Zn concentrations on the two earlier sampling dates (data not shown). Crop rotations did not affect soil bicarbonate-extractable ortho-P or K, DTP- extractable Zn, or soil OC (data not shown).

Whole-plant Ca, Mg, Cu, Mn, and Fe concentrations on all three plant sampling dates were not affected by the fertilizer treatments or crop rotation treatments (data not shown).

CONCLUSIONS

Dry bean seed yields were increased to slightly greater than topsoil bean yields the fourth year after applying 137 Mg dairy manure ha^{-1} (air-dry basis) to freshly exposed subsoil. Fertilizing the subsoil according to standard soil test recommendations or applying cottage cheese (acid) whey produced bean yields of 63 to 68% of the topsoil and manure-treated plot yields, even though available soil N, P, and K were adequate. Crop rotations alone made only minor differences in bean seed yields compared with the manure treatments.

The large manure application with its accompanying Zn and OC was the only treatment applied that increased the subsoil bean yields to that of the topsoil. Interactions among the Zn, organic matter, and the recently exposed subsoil minerals, particularly lime, are probably the factors controlling the restoration effects of the various treatments. A treatment that will restore these subsoils to full production is significant, since the yields on >800 000 ha are known to be affected by topsoil loss.

Zinc uptake by bean and other crops has been shown to be affected by previous crops, even though DTPA-extractable Zn concentrations did not differ (Boawn, 1965; Leggett and Westerman, 1986). The challenge now is to determine if the yield increase was due to the high Zn application, the OC increase, or a combination of the two. The design of this study does not allow for separating these two, or other possible effects on bean seed yield increases on the subsoils. Ongoing research on these plots includes studying the interactions among the original and recently applied manure, mycorrhizal activity, and Zn uptake by Zn-sensitive crops.

REFERENCES

Allison, L.E., and C.D. Moodie. 1965. Carbonates. p. 1379–1396. *In* C.A. Black et al. (ed.) Methods of soil analysis. Part 2. Agron. Monogr. 9. ASA, Madison, WI.

Baker, D.E., and M.C. Amacher. 1982. Nickel, copper, zinc and cadmium. p. 331–333. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Berg, R.D., and D.L. Carter. 1980. Furrow erosion and sediment losses on irrigated cropland. J. Soil Water Conserv. 35:267–270.

Boawn, L.C. 1965. Sugarbeet induced zinc deficiency. Agron J. 57:509.

Burnett, E., B.A. Stewart, and A.L. Black. 1985. Regional effect of soil erosion on crop productivity — Great Plains. p. 335–356. *In* R.F. Follett and B.A. Stewart (ed.) Soil erosion and crop productivity. ASA, CSSA, and SSSA, Madison, WI.

Carter, D.L. 1990. Soil erosion on irrigated lands. p. 1143–1171. *In* B.A. Stewart and D.R. Nielsen (ed.) Irrigation of agricultural crops. Agron. Monogr. 30. ASA, CSSA, and SSSA, Madison, WI.

Carter, D.L. 1993. Furrow irrigation erosion lowers soil productivity. J. Irrig. Drain. Eng. 119:964–974.

Carter, D.L., R.D. Berg, and B.J. Sanders. 1985. The effect of furrow irrigation erosion on crop productivity. Soil Sci. Soc. Am. J. 49:207–211.

Gavlak, R.G., D.A. Horneck, and R.O. Miller. 1994. Plant, soil, and water reference methods for the Western Region. Western Regional Ext. Publ. 125. Washington State Univ., Pullman.

Keeney, D.R. 1982. Nitrogen — Availability indices. p. 711–733. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Lamborn, R.E. 1975. Tentative soil test adequacy levels for phosphorus and potassium. p. 195–196. *In* Proc. Annu. Pac. Northw. Fert. Conf. 26th, Salt Lake City, UT. 15–17 July 1975. Northwest Plant Food Assoc., Portland, OR.

Leggett, G.E., and D.T. Westerman. 1986. Effect of corn, sugarbeets, and fallow on zinc availability to subsequent crops. Soil Sci. Soc. Am. J. 50:963–968.

Leggett, G.E., D.T. Westerman, and M.J. LeBaron. 1975. A survey of the status of beans grown in southern Idaho. p. 131–138. *In* Proc. Annu. Pac. Northw. Fert. Conf. 26th, Salt Lake City, UT. 15–17 July 1975. Northwest Plant Food Assoc., Portland, OR.

Lindstrom, M.J., T.E. Schumacher, G.D. Lemme, and H.M. Gollany. 1986. Soil characteristics of a Mollisol and corn (*Zea mays* L.) growth 20 years after topsoil removal. Soil Tillage Res. 7:51–62.

Milliken, G.A., and D.E. Johnson. 1984. Analysis of messy data.Vol. 1: Designed experiments. Lifetime Learning Publ., Belmont, CA.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p. 539–579. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Painter, C.G., and R.E. McDole. 1979. Soils handbook. Univ. of Idaho, Coop. Ext. Serv., Moscow, ID.

Robbins, C.W. 1977. Hydraulic conductivity and moisture retention characteristics of southern Idaho's silt loam soils. Res. Bull. no. 99. Idaho Agric. Exp. Stn., Moscow.

Robbins, C.W. 1986. Sodic calcareous soil reclamation as affected by different amendments and crops. Agron. J. 78:916–920.

Robbins, C.W., and C.L. Wiegand. 1990. Field and laboratory measurements. p. 201–219. *In* K.K. Tanji (ed.) Agricultural salinity assessment and management. Am. Soc. Civ. Eng., New York.

SAS Institute. 1989. SAS/STAT user's guide. Version 6, 4th ed. Vol. 2. SAS Inst., Cary, NC.

Watanabe, F.S., and S.R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soils. Soil Sci. Soc. Am. Proc. 29:677–678.

Wolman, M.G. 1985. Soil erosion and crop productivity: A worldwide perspective. p. 9–21. *In* R.R. Follett and B.A. Stewart (ed.) Soil erosion and crop productivity. ASA, CSSA, and SSSA, Madison, WI.