**2007 STEEP PROGRESS (FINAL) REPORT**

**PROJECT TITLE:** Phosphorus and Sulfur Fertilization of Late-Seeded Winter Wheat in a Chemical Fallow System

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**PROJECT OBJECTIVES:** The general objective of this research was to develop phosphorus and sulfur fertilizer recommendations for the chemical fallow-winter wheat cropping system. Specific objectives are to:

(1) Characterize site conditions.
(2) Determine early-season tissue nutrient concentration and plant uptake.
(3) Evaluate nutrient bioavailability & effects of soil water content and temperature.
(4) Determine if P and/or S should be applied with N. Evaluate effects of P and S application on test weight, grain protein content, and yield of winter wheat.
(5) Quantify yield components and straw production.

**KEY WORDS:** Chemical fallow, fertilization, phosphorus, sulfur

**STATEMENT OF PROBLEM:** Winter wheat production on the Columbia Plateau occurs mostly on deep soils and in areas where average, annual precipitation ranges from 8 to 12 inches. Wheat is normally grown after a year of tillage fallow. An alternative to tillage fallow is chemical fallow. A renewed interest in chemical fallow can be attributed to: (1) limited success with annual cropping, (2) the ever-increasing cost of fuel, and (3) progress in control strategies for Russian thistle. Optimism about chemical fallow is tempered by an understanding that yield reductions are a consequence of delayed seeding. Delayed seeding in chemical fallow is necessary because seed-zone moisture during optimum planting dates is frequently less than that required for uniform germination and emergence. The effect of later seeding dates on stand establishment and grain yield may be offset by improved fertilizer management.

**ZONE OF INTEREST:** Low precipitation (8 to 12 inches) zone.

**ABSTRACT OF RESEARCH FINDINGS:** Phosphorus and S application had a small, but significant effect on early-season tissue nutrient concentration. Phosphorus application increased early-season dry matter and nutrient uptake. The most significant dry matter and nutrient uptake response occurred in Adams County, Washington when the bioavailability of P (in untreated control plots) was lower than that measured at any other site during the 3-year project. Phosphorus application increased grain yield by an average of 4.2 and 6.0% for application rates of 10 and 30 lb $P_2O_5$/ac, respectively. Response to P application in Adams County occurred two years out of three, and the greatest yield increase (13.9% for the 30 lb $P_2O_5$/ac treatment)

occurred at this location. Phosphorus and S application had no effect on grain test weight or protein content, but did increase heads per unit area (HPU) and straw production.

**RESULTS AND INTERPRETATION:** Field experiments were conducted in Adams County, Washington and Morrow and Umatilla County, Oregon during the 2003-2004, 2004-2005, and 2005-2006 crop years. In each experiment, winter wheat was planted in mid-to-late October at a depth of approximately 1 inch. Seeding rates ranged from 20 to 24 seeds/$ft^2$. Fertilizer treatments (placed below and beside the seed) are listed in Table 1. Site characterization data (Table 2) are being used to identify an appropriate recommendation domain. Additional results and interpretations are reported for P and S tissue concentration and uptake, dry matter accumulation, nutrient bioavailability, grain test weight, protein content, and yield, yield components, and straw production. Except where otherwise noted, data in this report are averages from all years and locations.

**Table 1.** Experimental treatments and corresponding application rates for nitrogen, phosphorus, and sulfur.

| Treatment | Application Rate (lb/ac) | | |
|---|---|---|---|
| | Nitrogen† | Phosphorus‡ | Sulfur‡ |
| N Only | 15 to 40 | 0 | 0 |
| N + P (10) | 15 to 40 | 10 | 0 |
| N + S (10) | 15 to 40 | 0 | 10 |
| N + P (10) + S (10) | 15 to 40 | 10 | 10 |
| N + P (30) | 15 to 40 | 30 | 0 |
| N + P (30) + S (10) | 15 to 40 | 30 | 10 |

† Dependent on results from a soil test. Nitrogen application rate held constant for all P and S treatments.
Application rate calculated using a 2.4 lb N/bu nitrogen requirement.
‡ Units for P and S rates are lb $P_2O_5$/ac and lb S/ac, respectively.

**Table 2.** Chemical characteristics of soil at experimental sites in Adams County, Washington and Morrow and Umatilla County, Oregon.†

| Location | Crop Year | P | $SO_4$-S | pH | CEC | OM | $CaCO_3$ |
|---|---|---|---|---|---|---|---|
| | | (ppm) | (ppm) | | (meq/100 g) | (%) | (%) |
| Adams County | 2003-2004 | 14 | 0.9 | 6.6 | 10.1 | 0.9 | 0.8 |
| Morrow County | 2003-2004 | 9 | 0.4 | 7.5 | 12.8 | 1.0 | 0.9 |
| Umatilla County | 2003-2004 | 6 | 4.0 | 8.3 | 13.2 | 0.9 | 2.0 |
| Adams County | 2004-2005 | 13 | 5.9 | 6.4 | 10.6 | 0.6 | 1.4 |
| Morrow County | 2004-2005 | 8 | 6.8 | 6.9 | 12.7 | 1.0 | 1.6 |
| Umatilla County | 2004-2005 | 16 | 6.2 | 6.2 | 13.5 | 1.1 | 1.4 |
| Adams County | 2005-2006 | 11 | 1.8 | 6.3 | 11.0 | 0.7 | 0.7 |
| Morrow County | 2005-2006 | 11 | 1.7 | 7.6 | 13.4 | 0.9 | 0.7 |
| Umatilla County | 2005-2006 | 13 | 1.9 | 6.3 | 13.5 | 0.9 | 0.7 |

† Samples collected from the surface-foot of the soil profile.

**Early-Season Tissue Nutrient Concentration and Uptake.** Phosphorus application had a small but significant effect on the concentration of P and S in above-ground plant tissue (Tables 3 and 4). Increases in P and S uptake are the result of improved dry matter production. Average, early-season dry matter responses to the 10 and 30 lb $P_2O_5$/ac application rates were 164 and 300 lb/ac, respectively. Orthogonal, linear contrast analysis revealed significant differences in P and S uptake between the control and 10 lb $P_2O_5$/ac application rate (Table 4). Differences between the 10 and 30 lb $P_2O_5$/ac treatments also were significant. There was a statistically insignificant trend for reduced nutrient uptake when 30 lb $P_2O_5$ was applied with 10 lb S/ac (Table 3). This trend may be a carry-over effect from the sulfentrazone (Spartan®) application made during

**Table 3**. Fertilizer application rate and corresponding averages for early-season P and S tissue concentration and uptake.†

| P Rate | S Rate | Plant P | P Uptake | Plant S | S Uptake |
|---|---|---|---|---|---|
| (lb $P_2O_5$/ac) | (lb S/ac) | (%) | (lb P/ac ) | (%) | (lb S/ac) |
| 0 | 0 | 0.23 | 3.1 | 0.19 | 2.7 |
| 0 | 10 | 0.24 | 3.3 | 0.19 | 2.8 |
| 10 | 0 | 0.24 | 3.5 | 0.18 | 3.0 |
| 10 | 10 | 0.24 | 3.6 | 0.20 | 3.2 |
| 30 | 0 | 0.25 | 4.2 | 0.20 | 3.5 |
| 30 | 10 | 0.25 | 3.9 | 0.20 | 3.3 |

† Plant samples collected at the 1st node stage of growth.

each fallow cycle. Sulfur is part of the sulfentrazone molecule. The addition of S with 30 lb $P_2O_5$/ac may have altered the S transport system in the developing wheat plant. An altered transport system might lead to increased sulfentrazone uptake and some level of crop injury. Increased crop injury, which was evident at two locations during the third year of the project, may have reduced early-season dry matter accumulation and nutrient uptake. **Spartan® is no longer labeled for use in fallow systems.**

**Table 4**. Statistical significance of responses for selected treatment comparisons.†

| Treatment Comparison | Plant P | P Uptake | Plant S | S Uptake |
|---|---|---|---|---|
| P(0) vs. P(10) | NS | *** | NS | *** |
| P(0) vs. P(30) | *** | *** | ** | *** |
| P(10) vs. P(30) | ** | *** | ** | *** |
| S(0) vs. S(10) | NS | NS | ** | NS |

† ***, ** Significant at the 0.001 and 0.01 levels, respectively.
NS indicates a non-significant difference for compared treatments.

Phosphorus application improved plant uptake of N. The average N uptake value for samples collected from untreated control plots was 37.3 lb N/ac. Nitrogen uptake in samples collected from plots that received 10 and 30 lb $P_2O_5$/ac increased to 40.6 and 44.4 lb N/ac, respectively. Nitrogen uptake responses, which were always statistically significant, are the result of increased dry matter accumulation and a more prolific root system—a common response to P fertilizer placed in close proximity to the seed.

**Bioavailability of P and S.** Bioavailability was measured in the spring when wheat plants were fully tillered. Small, rectangular sheets of resin were placed in contact with the 1-to-4 inch layer of soil (control plots only) for 48 hours. These sheets or strips of resin are often referred to as "root simulators" because they provide information about the quantity of nutrients that come in contact with a plant's root system. Information about nutrient bioavailability was used, in conjunction with soil and plant tissue data, to improve our understanding of early-season nutrient supply and its effect on the growth and development of late-seeded winter wheat.

The most significant dry matter and P uptake response to applied P fertilizer occurred in Adams County during the 2005-2006 crop year. The corresponding bioavailability of P (in untreated, control plots) was lower than that measured at any other location during the 3-year project (Table 5). Increased bioavailability of P at the Umatilla County location is consistent with soil test information (Table 2) and soil water content data.

Soil temperature at the Adams County location tended to be less than temperatures measured farther south in Morrow and Umatilla County. Differences among sites (for all three years of the project) ranged from 2 to 4 °F, and there is little or no evidence that these differences in temperature had an affect on the availability of P.

The bioavailability of S was significantly different among sites and across years. Differences among sites were most notable in the 2005-2006 crop year (Table 5), and this is interesting because soil test S values (Table 2) were similar. The S concentration of plant samples (2005-2006 crop year) was not affected by S application to any great extent, but effects were most pronounced in Adams County where bioavailability was equal to 2.12 ug $SO_4^{2-}/cm^2$.

**Table 5**. Bioavailability of P and S and corresponding soil water content and temperature values, by location. Data are from the 2005-2006 crop year.

| Location | Bio P | Bio S | Soil Water Content | Soil Temp |
|---|---|---|---|---|
| | (µg $PO_4^{2-}/cm^2$) | (ug $SO_4^{2-}/cm^2$) | (%, vol.) | (°F) |
| Adams County | 0.74 | 2.12 | 14.1 | 52.1 |
| Morrow County | 1.01 | 6.33 | 14.9 | 53.4 |
| Umatilla County | 2.27 | 9.32 | 18.3 | 53.4 |
| $LSD_{(0.05)}$ | 0.71 | 2.36 | 0.8 | 0.6 |

The bioavailability of S (across locations) was greatest in the third year of the project when soil test results (Table 2) were low (1.7 to 1.9 ppm $SO_4$-S). Increased bioavailability is most likely the result of mineralization that was favored by greater than average overwinter precipitation and warming of the soil early in the spring.

**Potential Effects of Calcium and $CaCO_3$ on the Availability of P.** The bioavailability of P in Adams and Morrow County was not statistically different during the 2005-2006 crop year (Table 5), but dry matter and P uptake responses to applied P only occurred in Adams County (data not shown). Phosphorus applied at the Morrow County site may have become unavailable when it reacted with calcium (Ca) to form dicalcium phosphate or some other unavailable form of P. It is important to understand that these reactions, which are favored by increasing soil pH, cannot be confirmed by data obtained from this experiment. It is interesting to note, however, that bioavailable Ca in Morrow County (862 ug $Ca^{2+}/cm^2$) was nearly two times that measured in Adams County (483 ug $Ca^{2+}/cm^2$). The presence of calcium carbonate ($CaCO_3$) or free lime in soil can also decrease P availability. This effect is illustrated in Figure 1. Plotted data were generated from a simple laboratory procedure that compared the quantity of P added to soil to the amount recovered in solution (an estimate of plant-available P).

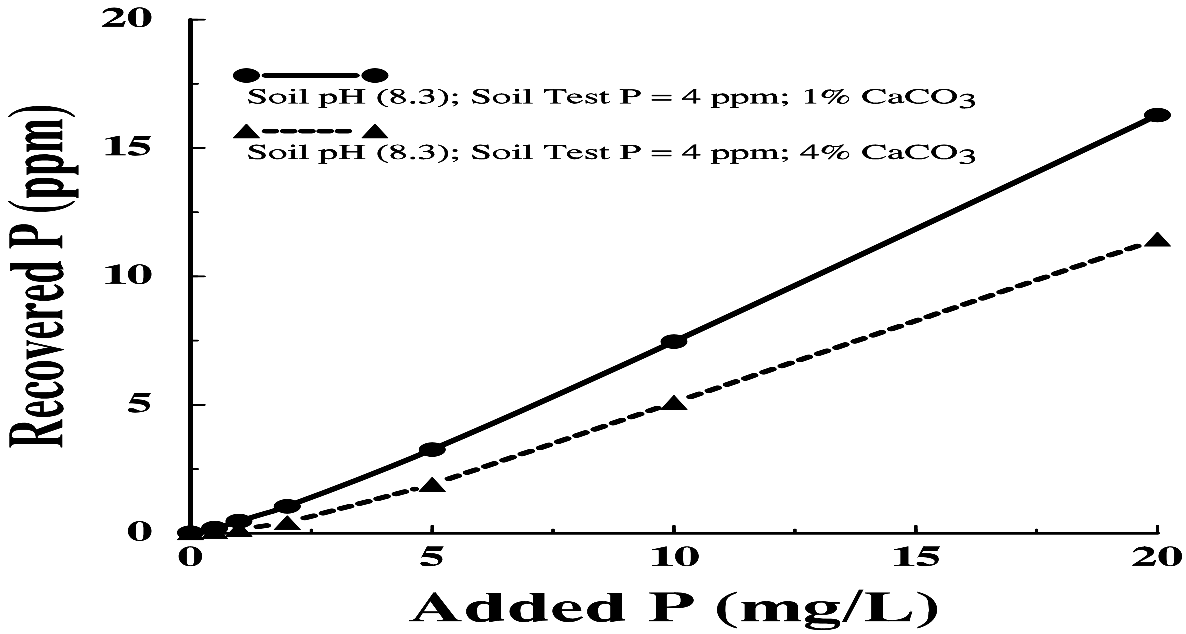


**Figure 1.** Phosphorus isotherm showing relationship between added (applied) P and the amount of P recovered in solution. Data are from 2003-2004 Umatilla County location.

Problems with P availability in calcareous soils and soils that contain appreciable amounts of $CaCO_3$ can only be overcome by applying heavy rates of fertilizer. Heavier application rates may be a justifiable part of a precision fertilizer program when small, localized areas of a field require treatment.

**Grain Test Weight, Protein Content, and Yield**. Phosphorus and S application rate had no effect on grain test weight or protein content (Table 6 and 7). Phosphorus application did increase grain yield. The overall response to P was 1.8 and 2.6 bu/ac for application rates of 10 and 30 lb $P_2O_5$/ac, respectively. The corresponding, average soil test P concentration, at sites where responses to P were observed, was 11 ppm. Individuals reading this report are cautioned about paying too much attention to absolute yield values associated with a given P application rate. Consideration of the percent yield increase (4.2 and 6.0% for rates of 10 and 30 lb $P_2O_5$/ac, respectively) may be a better approach since response to P is affected, in part, by yield potential. It is also important to note that yield increases from P fertilization can be much greater under some conditions. For example, yield at the 2005-2006 Adams County experiment was improved by 4.7 bu/ac in plots that received the 30 lb $P_2O_5$/ac treatment. The 13.9% yield gain at this location occurred during a year when crop year precipitation and yield potential were greater than average, The initial soil test P concentration at this highly-responsive site was 11 ppm, and the bioavailability of P was low (0.74 ug $PO_4^{2-}/cm^2$).

**Table 6.** Fertilizer P and S application rate and corresponding averages for grain test weight, protein content, and yield.

| P Rate | S Rate | Test Weight | Protein Content | Grain Yield |
|---|---|---|---|---|
| (lb $P_2O_5$/ac) | (lb S/ac) | (lb/bu) | (%) | (bu/ac) |
| 0 | 0 | 59.0 | 12.2 | 43.0 |
| 0 | 10 | 59.2 | 12.3 | 43.1 |
| 10 | 0 | 59.3 | 12.3 | 44.8 |
| 10 | 10 | 59.2 | 12.3 | 45.1 |
| 30 | 0 | 59.2 | 12.4 | 46.2 |
| 30 | 10 | 59.2 | 12.6 | 45.3 |

**Table 7**. Statistical significance of responses for selected treatment comparisons.†

| **Treatment Comparison** | Test Weight | Protein Content | Grain Yield |
|---|---|---|---|
| P(0) vs. P(10) | NS | NS | *** |
| P(0) vs. P(30) | NS | NS | *** |
| P(10) vs. P(30) | NS | NS | NS |
| S(0) vs. S(10) | NS | NS | NS |

† *** Significant at the 0.001 level.
NS indicates a non-significant difference for compared treatments.

**<u>Yield Components</u> <u>and</u> <u>Straw</u> <u>Production</u>.** Phosphorus and S treatments had no effect of 1000 kernel weight or the number of kernels per head (Tables 9 and 10). Phosphorus application did increase heads per unit area (HPU) and straw production (all above-ground biomass measured just prior to harvest). Maximum HPU (96.4 heads/m-row) was measured in plots treated with 30 lb $P_2O_5$/ac, but the reduction in HPU from the 10 lb $P_2O_5$/ac treatment (94.8 heads/m-row) was not significant. The overall correlation between HPU and grain yield data (Figure 2) is reasonably good and is consistent with research previously conducted by others in the Pacific Northwest. Increases in HPU were always associated with improvements in early-season dry matter accumulation (r = 0.83).

**Table 9**. Fertilizer P and S application rate and corresponding averages for 1000 kernel weight (KW), kernels per head (KPH), heads per unit area (HPU), and straw production.

| P Rate | S Rate | KW | KPH | HPU | Straw |
|---|---|---|---|---|---|
| (lb $P_2O_5$/ac) | (lb S/ac) | (grams) | | (heads/m-row) | (lb/ac) |
| 0 | 0 | 37.5 | 31.3 | 87.6 | 4148 |
| 0 | 10 | 37.5 | 30.6 | 90.4 | 4176 |
| 10 | 0 | 37.6 | 30.6 | 96.2 | 4422 |
| 10 | 10 | 37.6 | 30.3 | 93.4 | 4334 |
| 30 | 0 | 37.8 | 29.9 | 96.4 | 4469 |
| 30 | 10 | 37.9 | 29.9 | 96.3 | 4429 |

The 10 lb $P_2O_5$/ac application rate increased straw production, compared to the control, by an average of 215 lb/ac. Application of 30 lb $P_2O_5$/ac increased straw production by 287 lb/ac. Differences between the two P treatments are not significant. There is no evidence to suggest that greater straw production had any kind of a negative effect on grain yield—not for P application rates used in this study. Straw production is important, even in chemical fallow fields, because it reduces soil erosion to a point that is well below "T"—the maximum annual, tolerable loss of soil from a sustainable cropping system. A presumed reduction in weed populations (from plant competition) may be an added benefit of increased straw production.

**Table 10**. Statistical significance of responses for selected treatment comparisons.[†]

| **Treatment Comparison** | KW | KPH | HPU | Straw |
|---|---|---|---|---|
| P(0) vs. P(10) | NS | NS | *** | * |
| P(0) vs. P(30) | NS | NS | *** | *** |
| P(10) vs. P(30) | NS | NS | NS | NS |
| S(0) vs. S(10) | NS | NS | NS | NS |

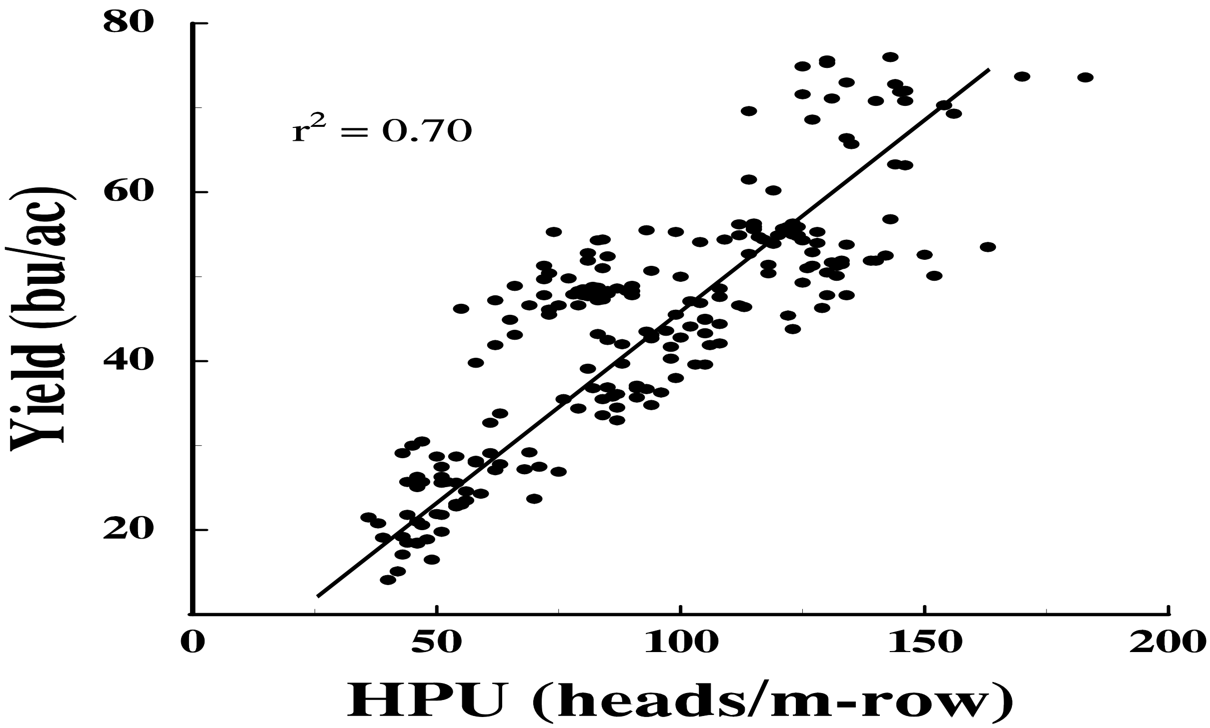


**Figure 2.** Relationship between winter wheat grain yield and heads per unit area (HPU).

**CONCLUSIONS AND IMPACTS OF RESEARCH:** Phosphorus application increased early-season dry matter accumulation. The net effect of improved dry matter accumulation and the number of heads per unit area (later in the season) was an increase in grain yield. Phosphorus rates of 10 and 30 lb $P_2O_5$/ac improved grain yield by 4.2 and 6.0%, respectively. The maximum yield response (13.9%) occurred in Adams County, Washington during a year when the soil test P concentration was equal to 11 ppm, bioavailable P was low (0.74 ug $PO_4^{2-}/cm^2$), and crop year precipitation and yield potential were greater than average.

There was little or no yield response to P fertilization on three higher pH ( $\geq$7.5) soils, and this is somewhat surprising because the initial soil test P concentration at two of these locations ranged from 6 to 9 ppm. Problems with P availability on these soils may be a consequence of reactions with Ca and/or $CaCO_3$, although specific mechanisms cannot be confirmed by data collected from this research.

Results from this project are being used to refine P and S fertilizer recommendations for winter wheat grown in the chemical fallow system (low precipitation zone). Improvements in nutrient use efficiency should increase economic returns for producers who choose to make use of this direct-seed farming method. Prudent use of P fertilizer will also increase straw production (above-ground biomass) and this should reduce soil erosion to a point that is well below “T”—the maximum annual, tolerable loss of soil from a sustainable cropping system.

**INTERACTION WITH OTHER SCIENTISTS CONDUCTING RELATED ACTIVITY:**
The PI is cooperating with Stewart Wuest, Bill Schillinger, Don Wysocki, and Dan Ball on chemical fallow and/or reduced tillage systems research.

**PUBLICATIONS:**
Lutcher, L.K., S.B. Wuest, W.F. Schillinger, D.J. Wysocki, and N.W. Christensen. 2006. Fertilization of late-seeded winter wheat in chemical fallow. *In:* STEEP 2006 Annual Report. Pp.97-103.

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**PRESENTATIONS:**
Lutcher, L.K., 2006. "Fertilization of late-seeded winter wheat in chemical fallow." STEEP Research Review, Pasco, WA. February 22.

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