POTASSIUM MANAGEMENT IN ALFALFA: A SUMMARY OF EIGHT YEARS OF RESEARCH IN AN ARID ENVIRONMENT

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ABSTRACT

Alfalfa is an important forage and cash crop in the Western U.S. In 1995, a long-term research program was initiated at Utah State University to evaluate phosphorus (P), potassium (K), and sulfur (S) fertilizer recommendations for irrigated alfalfa. The purpose of this paper is to summarize results from the K research. Experiments were conducted at three locations with low soil test K levels (49 to 105 mg/kg). Potassium was applied at rates ranging from 0 to 300 or 400 lb K_2O/acre primarily in single spring applications although some split spring/in-season applications were made. Hay yields and soil test and tissue K were measured. Yield responses to K were nil or linear. Linear responses suggested a return of 1 ton of hay per 350 to 960 lb K_2O applied, depending on location and year. Soil test K was not increased above 123 mg/kg at any location; therefore, additional studies with rates up to 600 lb K_2O/acre were conducted. Responses to the higher rates were linear for two site-years and quadratic for two site-years. Splitting applications of the 600 lb K_2O/acre rate resulted in higher yields than single applications at the sites with quadratic responses. The relationship between soil test K and relative alfalfa yield suggested a critical soil test K of 150 mg/kg for maximum yield. While not presented in this paper, tissue concentration did not relate well to relative alfalfa yield due to variations in tissue K concentration among harvests. Additional sampling showed that the time of year and depth at which soil samples were collected significantly affect the soil test value and resulting fertilizer recommendation. Once depleted, relatively high rates of K are necessary to rebuild low K-testing soils. Soil testing can be a reliable tool to diagnose a deficiency; however, to ensure accurate results, sampling and analytical methods must be the same as those used to develop the recommendation database.

Key Words: alfalfa, irrigation, potassium, management, soil, tissue, testing

INTRODUCTION

Alfalfa is an important forage and cash crop in the Western U.S. With relatively high yields achievable under irrigation, alfalfa hay removes large amounts of mineral nutrients such as potassium (K). In fact, more K is removed by alfalfa than any other mineral nutrient. Assuming a 2 % K concentration in the tissue, approximately 48 lb K_2O is removed with each ton of hay. In the mid-1950s, fertilizer guides in Utah stated that no known K deficiencies existed in the State due to the high levels of K in Utah soils and high K levels in many irrigation water sources

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(Nielson *et al.*, 1955). Average yields at that time, however, were less than 2 tons/acre. In the late 1900s, many growers were achieving irrigated alfalfa yields in excess of 8 tons/acre. The incidence of K deficiency has increased over time due in part to high yields and the long history of K removal under intensive alfalfa production (Lindstrom, 1983). During the period 1995 to 1999, 12% of the samples submitted to the Utah Sate University Soil Testing Lab had soil test K (0 to 12-inch sample depth; sodium bicarbonate extract method) levels below 100 mg/kg, the previous critical level established for soil test K in Utah (Topper *et al.*, 1993).

A long-term research effort was initiated in 1995 to evaluate K fertilizer recommendations and management for alfalfa in Utah. A series of experiments involving a range of K fertilizer rates and application timings at various locations was conducted during the period 1995 to 2002. Data collected included hay yield and soil test and tissue K concentrations. The purpose of this paper is to review results from this research and integrate them into a set of basic K management principles for alfalfa.

METHODS

Experiments were conducted at three main locations in northern (Cache and Weber) and central (Sevier) Utah. Baseline soil properties for these sites are summarized in Table 1. Soil test K was measured at the 0 to 12-inch depth in a 0.5 M sodium bicarbonate extract analyzed using atomic absorption spectrometry. Conventional randomized complete block designs with 3 to 4 replications of each treatment were used for each study. Plot dimensions were 5 to 10 feet wide by 20 to 50 feet long depending on the study location and year. The K source was potassium chloride (0-0-60) broadcast with a drop box spreader primarily in early spring on established stands of alfalfa irrigated by sprinkler (Cache and Weber) or corrugated furrow (Sevier). Yield was measured by harvesting the center of each plot, weighing forage fresh in the field, and adjusting to 100% dry matter content based on forage subsamples collected and weighed in the field and then returned to the lab for oven drying. Specific treatments and sampling details are described later in the review of the results.

Table 1. Selected soil properties for the surface 0 to 12-inch soil layer at each study site.

	Cache County	Weber County	Sevier County
Soil series	Millville	Crooked Creek	Redfield
Texture class	silt loam	silty clay loam	clay loam
%clay	22 to 26	24 to 31	26 to 29
Calcium carbonate Equivalent (%)	33 to 37	0	47 to 54
pH (1:1 soil:water)	7.8 to 8.1	6.7 to 7.2	8.1 to 8.3
Initial soil test K, mg/kg[1]	55 to 95	88 to 105	49 to 73

[1]Sodium bicarbonate or Olsen method.

RESULTS AND DISCUSSION

Yield responses to applied K. Potassium was applied in 1996 at rates ranging from 0 to 300

(Weber and Sevier) or 400 (Cache) lb K_2O/acre and hay yields were measured for two years following this single application. In 1996 and 1997, alfalfa responses to applied K were nil or linear (left side of Figure 1). For linear responses, the return was 1 ton of hay per 350 and 440 lb K_2O at Sevier and 1 ton of hay per 960 lb K_2O at Cache. Summing hay yields at Sevier over the two years, the return from the single application of K was 1 ton of hay per 190 lb K_2O applied. Assuming a price of $0.15/lb K_2O ($180/ton 0-0-60) and $100/ton of hay, the marginal cost of K fertilization would be lower than the marginal return at Sevier but not Cache. In essence, K fertilization would be a reasonable economic prospect at Sevier but not at Cache. Yield did not "plateau", and soil test values were not increased above the critical level of 100 mg/kg (see legend information in left panels of Figure 1), at the highest rate in half of the site-years. Therefore, additional studies with rates up to 600 lb K_2O/acre were conducted in 1999 at Cache and 2000 at all three locations. In these studies, yield responses to single spring applications were linear for two site-years and quadratic for two site-years (right side of Figure 1, solid lines). Quadratic responses suggest a negative impact on yield of the highest K rate. The application of 600 lb K_2O/acre equates to 1000 lb 0-0-60 fertilizer/acre and apparently caused a salt- or chloride-induced yield reduction at two of the three locations. When the 600 lb K_2O/acre rate was split into two applications (one in early spring and one following the first cutting), and this data point was substituted for the 600 lb K_2O/acre single application treatment, the response to K rate was linear for the two sites that were previously quadratic (right side of Figure 1, dashed lines). This suggests that the split application reduced the negative impacts of the high K rate. Interestingly, yield still did not plateau at the highest K rate with the split application.

Collectively, results suggest that, on low K-testing soils, the marginal (marginal meaning tons of hay yield increase per lb K_2O applied) response of alfalfa to K fertilizer is quite low. This is equivalent to saying that application of a large amount of K fertilizer results in a relatively small yield increase. In a single year the return from high rate K applications may not be economical. However, residual effects of single applications could be expected for several years and would significantly improve the economic returns from K fertilization. For example, K applications made in 1996 maintained their relative yield increases through the second season of production at Sevier (Figure 1). In order to spread the cost and return over time, annual maintenance applications of K should be considered before soils become depleted rather than attempting to rebuild soil test levels with single, high-rate applications. Also, rates of K exceeding 400 lb K_2O/acre may need to be applied in split treatments to prevent salt-induced yield reductions.

Soil test K responses to applied K. For the purpose of this discussion, soil test responses from the high rate studies in 1999 and 2000 will be emphasized. Soil test responses to K rate (change in soil test K with increasing fertilizer rate) were similar to the 1996 and 1997 studies. The amount of K fertilizer required to induce a unit change in soil test K was similar between the Weber and Sevier sites (12.5 lb K_2O to increase soil test K by 1 mg/kg) but was lower for the Cache site (5 lb K_2O to increase soil test K by 1 mg/kg) (Figure 2). The lower response of soil test K to K application at Weber and Sevier meant that, even at the 600 lb K_2O/acre application rate, soil test K was not increased much above the 1993 critical level of 100 mg/kg soil at these sites. Apparently, soils at the Weber and Sevier sites have similar K buffering capacities, and these are considerably different than for the Cache soil.

At the Weber site soil test K was measured over a one year period of time in unfertilized and fall-applied 200 lb K_2O/acre treatments (Figure 3). Soil test K increased slightly between November and December and then was maintained over the winter for the +K treatment but declined for the –K control. Soil test K declined for both treatments declined during the growing season (day 180 through 330) and then began to rebound as alfalfa entered dormancy in the fall of 1996. Clearly, complex interactions are occurring between K application and time. These data do highlight the importance of the time soil samples are collected as this can impact the soil test result and, consequently, the fertilizer recommendation. Results also suggest that sampling at non-standard times such as during the growing season may have limited utility in terms of diagnosing a K deficiency if results are compared to standard fertilizer recommendation databases. For accurate K fertilizer recommendations, the time of the year samples are collected should be standardized according to the database on which the original fertilizer recommendations were developed.

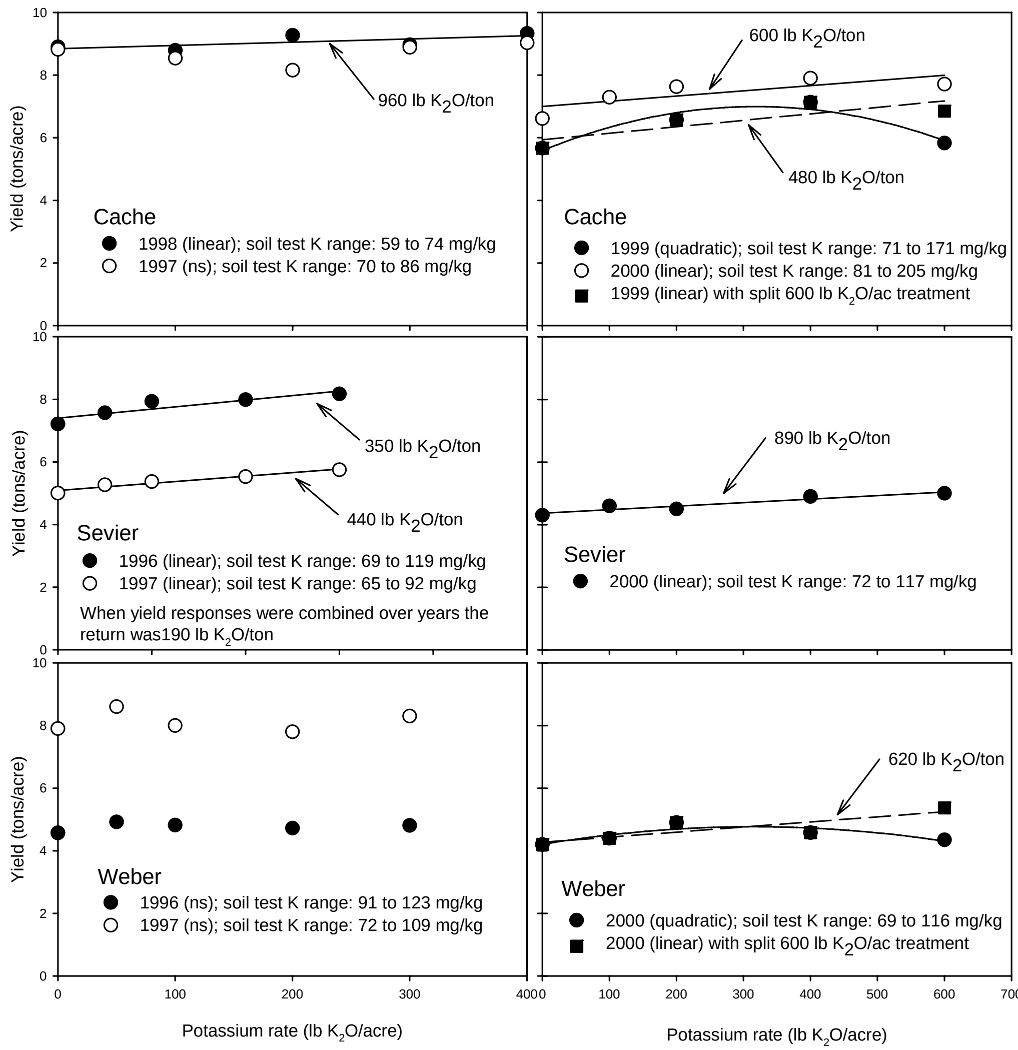

Figure 1. The effect of K rate on alfalfa yield at three locations in 1996 and 1997 (left panels) and 1999 and 2000 (right panels). Lines with linear and quadratic references in the legends are significant response trends ($p < 0.05$); ns = no significant trend.

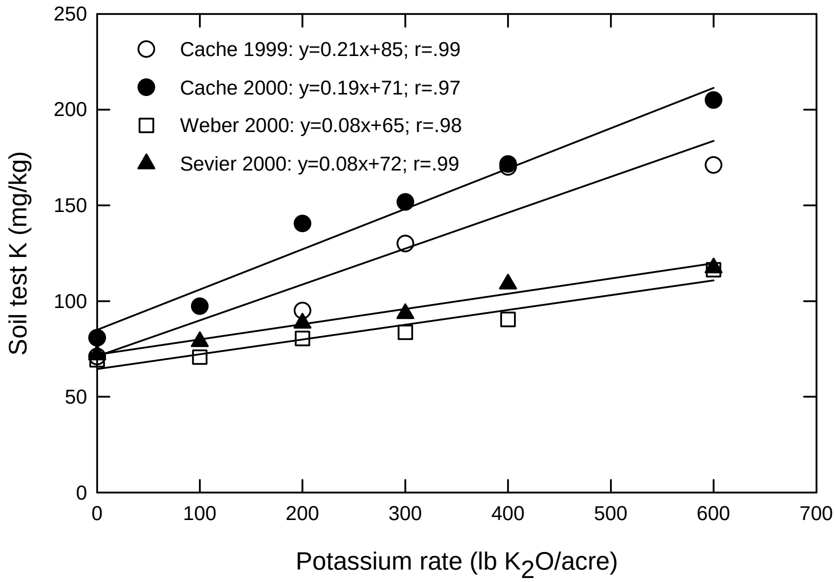

Figure 2. The effect of K rate on soil test K at the Cache, Weber and Sevier sites.

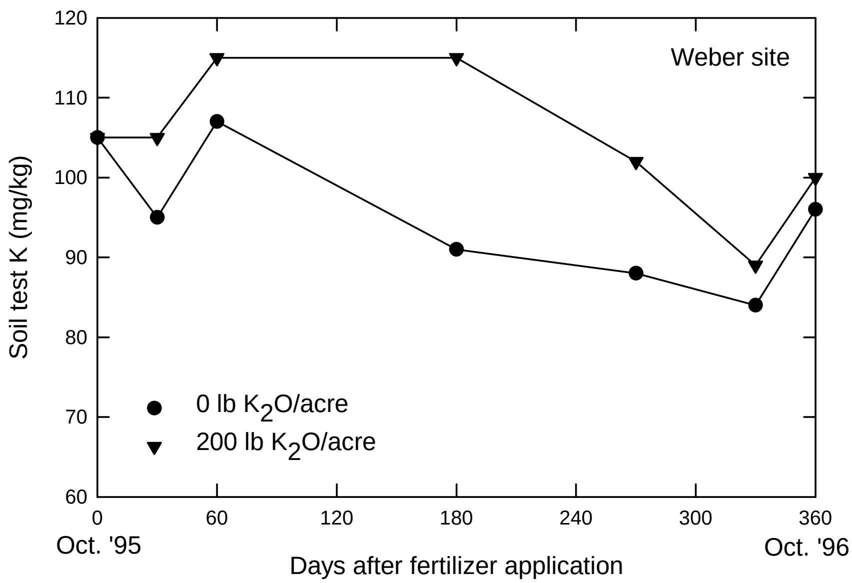

Figure 3. The effect of K rate and sampling time on soil test K at the Weber site. Fertilizer was applied on Day 0. The winter period was day 60 to 180 and summer growing season day 180 to 330.

Depth of sampling also influences soil test K and the resulting fertilizer recommendation (Koenig *et al.*, 2000). To illustrate this point, soil samples were collected in 1996 from the three sites described above. Samples were collected at depths of 0 to 4-inches, 0 to 6-inches and 0 to 12-inches. Data for the Sevier site are presented to demonstrate how soil test K varies with sampling depth and previous K treatment (Figure 4). The results are intuitive: in fields with a history of receiving broadcast K applications, sampling closer to the surface will result in a higher soil test K value. The differences in soil test K with sampling depth may be large enough to obtain a different K fertilizer recommendation depending on the depth sampled (Figure 4). These data indicate that depth of sampling is important and that the sampling depth should be the same as that used to develop the fertilizer recommendation database.

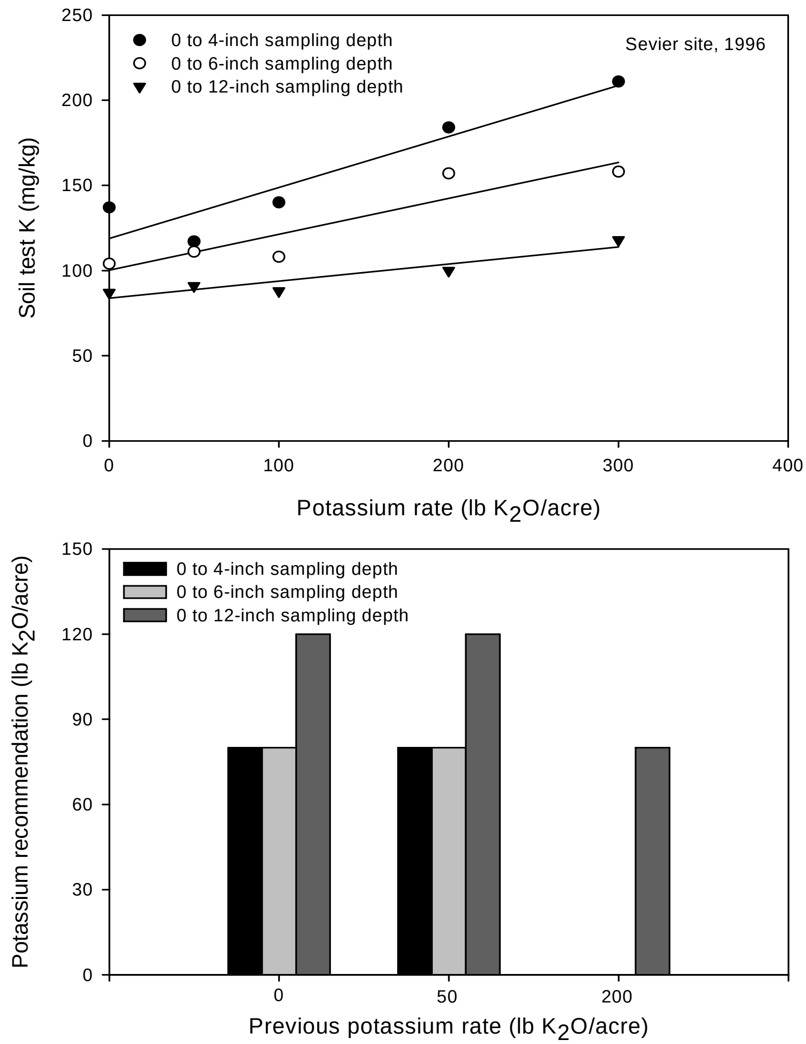

Figure 4. The effect of K rate and sampling depth on soil test K and fertilizer recommendations at the Sevier site. Data adapted from Koenig *et al*. (2000).

Soil test K – yield relationships. Soil test K data were used to develop a relationship between soil test level and yield. Data for the 600 lb K_2O/ac rate was omitted from the analysis for sites with a quadratic response (Figure 1) that indicated a negative response to the high rate. Yield was expressed as a percentage of the maximum for each location. Each data point represents an individual plot with the highest plot yield for a given location equaling 100% of maximum. Only datasets with soil test K levels in excess of 100 mg/kg were used. Data from these studies should be interpreted with care since yield responses were linear, suggesting no plateau or maximum yield point was attained, and soil test K values with the high K rate were still less than 120 mg/kg soil at the Sevier and Weber locations (see the legends of Figure 1 graph panels). There was a relationship between soil test K and relative alfalfa yield for these sites (Figure 5). Critical soil test K for near maximum yield was at or near 150 mg/kg soil, the value used in current alfalfa fertilizer recommendations from Utah (Koenig *et al.*, 1999). Maximum yield at the Cache site was achieved at higher soil test K levels than at either the Weber or Sevier sites, but this was due in part to the inability to reach soil test K values above 150 mg/kg soil with the range of fertilizer rates used at the Weber and Sevier sites (Figure 1).

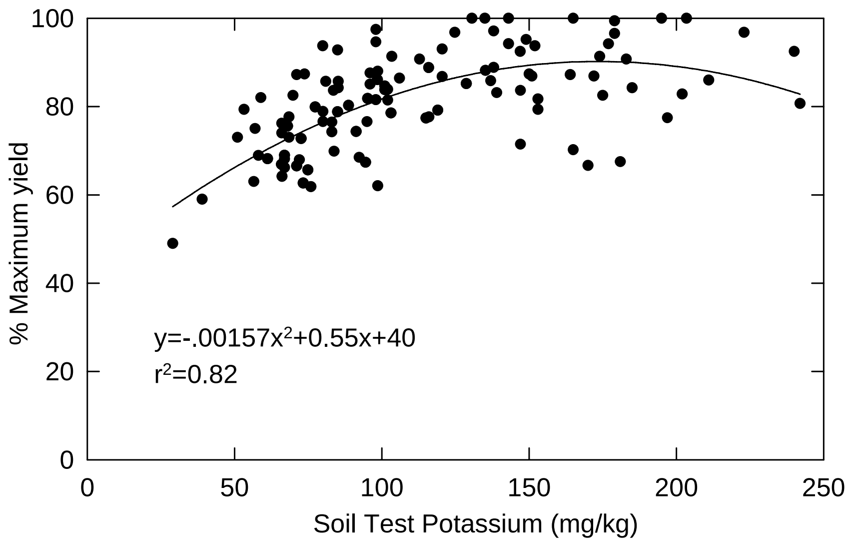

Figure 5. The relationship between soil test K and relative alfalfa yield. Data are for all sites and each point represents a single observation.

SUMMARY

Results from these studies suggest the following approaches to K management in alfalfa:

- When soil testing to monitor the K status of fields, adopt the same sampling (time, depth) and testing (extract method) methods as those used to develop the fertilizer recommendation database.
- Interpret the results of tissue tests with care. Though not presented in this paper, whole-plant tissue testing was less reliable than soil testing in terms of predicting the K status of alfalfa because tissue K concentrations varied with cutting during the season. Also, as with different soil testing methods, sampling different parts of the alfalfa plant at other than standard times may lead to widely different results.
- For long-term management on low K-testing soils, consider annual or maintenance applications of fertilizer to maintain soil test levels rather than making large, single applications to replenish depleted soils.
- If rates of K fertilizer above 600 lb K_2O/acre are applied split the application between early spring and mid-season times.
- A summary of basic K fertility and management considerations is presented in Table 2.

Table 2. A summary of basic K fertility data and recommendations for alfalfa.[1]

<table>
<tr><th>Data</th><th colspan="2">Value or recommendation</th></tr>
<tr><td>Critical tissue concentration</td><td colspan="2">2.0% (whole tops, 1/10 bloom)
2.0 to 2.5% (top 1/3 of plant, 1/10 bloom)
0.8 to 1.5% (middle 1/3 of plant stems, 1/10 bloom)</td></tr>
<tr><td>Visual deficiency symptoms</td><td colspan="2">Thin stands; leaf margin necrosis (dead spots on outer edges of leaves); low stress tolerance</td></tr>
<tr><td>Situations where deficiency may be observed</td><td colspan="2">Sandy soils, high elevations, sites with a long history of high-yielding alfalfa production</td></tr>
<tr><td>Critical soil test value (based on the “Olsen” or sodium bicarbonate extract method)</td><td colspan="2">150 mg K/kg soil</td></tr>
<tr><td rowspan="6">Fertilizer recommendations based on the sodium bicarbonate extract method</td><td>Soil test value (mg/kg)</td><td>lb K_2O/acre</td></tr>
<tr><td>0 to 40</td><td>300</td></tr>
<tr><td>40 to 70</td><td>250</td></tr>
<tr><td>70 to 100</td><td>150</td></tr>
<tr><td>100 to 150</td><td>100</td></tr>
<tr><td>>150</td><td>0</td></tr>
</table>

[1]Data adapted from the Western Fertilizer Handbook (Western Plant Health Association, 2002) and various state extension publications referenced at the end of this paper.

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