EFFECT OF POTASSIUM RATE, SOURCE AND APPLICATION TIMING ON POTATO YIELD AND QUALTY

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Potatoes use substantial amounts of potassium. In a survey of commercial potato fields, Dow et al. (1978) found potassium removal in the tubers ranged from 203 to 397 lb K/acre and was directly proportional to tuber yields. Hence, fertilizer recommendations for K on potatoes are commonly high. For example, current Wisconsin recommendations call for 260 lb K_2O/acre on sandy soils testing in the 100 to 130 ppm soil test K range (Kelling et al., 1998). Several calibration studies have shown yield responses up to soil tests of 250 ppm soil test K (James et al., 1970; Middleton et al., 1975; McDole, 1978; Roberts et al., 1984), although some Wisconsin work has shown a leveling of yields at soil levels ranging from 97 to 130 ppm K (Peterson et al., 1971; Liegel et al., 1981; Curwen, 1992).

The potassium fertilization program used by a grower can influence the crop in several ways. Insufficient K can result in reduced yields and smaller-sized tubers (McDole et al., 1978; Sharma and Arora, 1987; Tindall and Westermann, 1994), but there is no reported evidence of K shortages causing tuber malformation (offshape) or reduced tuber set (Roberts and McDole, 1985). There is considerable evidence, however, that K fertilization generally reduces specific gravity (Carpenter and Murphy, 1965; Schippers, 1968; McDole, 1978; Locascio et al., 1992) especially if applied in excess of rates needed for maximum yield (Berger et al.,1961). Furthermore, the reduction in gravity is more associated with the use of KCl rather than K_2SO_4 (Berger et al., 1961; Laughlin, 1962; McDole et al., 1978; Roberts and McDole, 1985). Potassium source differences have also been expressed through increases in bruising (Laughlin, 1962) and stem-end blackening (Harrap, 1960), a decrease in reducing sugars (Harrap, 1960) and delays in tuber development (Beringer et al., 1990) associated with the use of KCl; however, Silva et al. (1989) and Chapman et al. (1992) reported no significant effect of K fertilization on either bruising or hollow heart.

Potassium may also influence resistance to certain diseases. There is some evidence that the salinity associated with KCl applications may increase the incidence of *Rhizoctonia*. For example, Kassim et al. (1989) reported increased *Rhizoctonia solani* infection of tomato where NaCl was applied; however, Shen (1991) reported high susceptibility of sugar beet to infection by *R. solani* in absence of salinity stress.

According to Roberts and McDole (1985), there are fewer constraints on methods of applying K than other fertilizer nutrients. They suggest it can be successfully broadcast, banded or sidedressed. However, Berger et al. (1961) concluded that KCl banded in the row with phosphorus and nitrogen inhibited the uptake of P and reduced tuber yield and dry matter content compared to where K_2SO_4 was used. Separation of the chloride from the P (by broadcasting the KCl) restored the P uptake and yields.

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Although several studies have evaluated the effect of K sources and rates on tuber yield and quality, and several others have calibrated K soil tests with fertilizer response of potato, very few of these studies were conducted using a range of soil types and application rates that examined the interaction of rate and source on tuber quality. Therefore, our objectives were to study the effect of several K rates applied as KCl or K_2SO_4 on potato tuber yield, quality, and diseases of potato on three soil types representing major potato growing areas of Wisconsin, and to examine the relative usefulness of applying in-season potash.

METHODS AND MATERIALS

Rate/Source Experiment:

This research was designed to evaluate potato responsiveness to several rates of potassium (0, 100, 200, 300, or 400 lb K_2O/acre) when applied as either KCl or K_2SO_4 as a band application split on each side (about 2 inches to the side of the seed piece) at planting. The experiments were conducted at the Hancock, Antigo, and Spooner, WI, Agricultural Research facilities in 1992 through 1995, 1992 through 1995, and 1993 through 1995, respectively. 'Russet Burbank' was used as a part of the rate x source complete factorial at Hancock and Spooner, whereas 'Atlantic' was used at Antigo. Initial soil tests and the dates of various field and sampling operations are given in Table 1.

The plots were fertilized with about 300 lb/acre MAP (10-52-0) applied through the planter fertilizer equipment, and this was supplemented with the appropriate rate and source of potassium sprinkled through specially made supplemental fertilizer-tubes. Both materials were dropped through the fertilizer shoe ahead of the seed piece such that final placement was about 2 to 3 inches to each side of the seed piece. At all locations, application of N at emergence (100 lb N/acre) was as NH_4SO_4, whereas N application at hilling (100 lb N/acre) was as NH_4NO_3.

About 10 to 15 days after hilling, 10 plants from the border rows of each plot were hand-dug and evaluated for *Rhizoctonia*. The evaluations were conducted by University of Wisconsin-Madison Plant Pathology using a 0-11 Horsfall-Barrett visual rating system.

Petiole samples (40 stems/plot, or in some cases, per treatment) were analyzed for K using both a flame photometer and a Cardy potassium meter. The latter was used on the plant sap to determine if rapid in-field measurements were possible for K. The laboratory K measurements (flame photometer) were conducted on dried and ground tissue.

Statistical analyses were done using SAS ANOVA packages for factorial analyses and linear and nonlinear regressions.

In-Season Potassium Experiment:

This experiment examined the relative effectiveness of the various placement methods when the K is supplied at less than optimal or excessive rates. It is designed to determine if the use of any of the placement methods, including applications made in-season, result in more efficient use of the applied material. Only K_2SO_4 was used at either 100 or 400 lb K_2O/acre applied all broadcast preplant; all in the row as starter; all broadcast just prior to hilling; or one-half preplant, one-half row; one-half preplant, one-half hilling; or one-half row and one-half hilling. This experiment was conducted on a Plainfield loamy sand at Hancock or on Antigo silt loam at Antigo.

A second experiment examined the use of KNO_3 as a potash source when applied in-season as a supplement to more standard potassium applications. All treatments received 100 lb K_2O/acre as KCl in starter and a second 100 lb K_2O/acre applied as KCl or KNO_3 split between emergence and hilling or split four times later in the season (hilling and hilling + 10, 20, or 30 days). This experiment included a separate control where KCl was used as the potash source and the N as NH_4NO_3 is also split late in the season. It was also conducted at Hancock and Antigo.

For both experiments, insect, weed management and irrigation were dictated by need and followed standard farm practice at each location. Statistics were performed using the SAS statistical package for factorial or single factor ANOVA as is appropriate for each specific experiment;

RESULTS AND DISCUSSION

Rate/Source Experiment:

Tables 2 and 3 show the total yield, yield of prime tubers (U.S. No. 1, 6-13 oz.), specific gravity, and disease evaluations for each of the three sites. Potassium rate clearly influenced yield and quality in most years at all three locations. Responses were typically to 200 to 300 lb K_2O/acre applied and are consistent with the conclusions of others (Roberts et al., 1984; Chapman et al., 1992) when soil tests are in the ranges used in these experiments. The lack of response at some locations may be due to the relatively high soil tests at these locations. This is also consistent with others who observed that soil tests exceeding 150 to 200 ppm typically do not show responses to fertilizer K (McDole, 1978; Roberts et al., 1984; Chapman, 1992).

The influence of K source on potato yield and quality is somewhat less distinct than the rate influence on total yield and grade. At Hancock, few source differences were apparent except that the decrease in specific gravity with increasing rates of K_2O was less pronounced with K_2SO_4 than with KCl. This same trend for a smaller dry matter decrease with K_2SO_4 than with KCl at the same rate of K_2O applied was more obvious at the other locations where it was apparent in most years. At the 300 lb K_2O/acre rate, specific gravity averaged 0.006 higher at Antigo with K_2SO_4 versus KCl, and this average was 0.004 higher at Spooner. There also appeared to be a trend toward more U.S. No. 1 tubers with K_2SO_4 in 5 out of 11 site years (data not shown). Source also seemed to affect tuber size in some cases in that for some years more larger tubers were produced with KCl than where K_2SO_4 was applied at the same rate. The trend toward increased yield at Spooner with K_2SO_4 may be a sulfur response even though $(NH_4)_2SO_4$ was used as the N source for the first N application. This added about 114 lb S/acre. We expect this should have more than met the crop S need; however, Spooner has been a site where S responses are common.

In each of the years, 10 plants were dug from the plot non-harvest rows and visually rated for *Rhizoctonia* infection and average number of stems/seed piece. In four site years, there was a tendency (P levels = 0.12 to 0.15) for a somewhat higher *Rhizoctonia* rating where KCl was used instead of K_2SO_4. However, potassium rate apparently had no influence on these disease evaluations at any site or year.

A significant decrease in hollow heart with increasing K rate was evident in 5 of 10 site years in this study (Table 2). However, statistically significant yield responses to added K were obtained in only one of these site years; therefore, the effect of K on hollow heart may only be evident where excessive quantities of K are present. Similarly, Nelson (1970) reported a reduction in hollow heart in soils testing high in K when weather conditions were favorable for the development of this physiological disorder. Significant K source differences in hollow heart were found at Antigo in 1995, and Spooner in 1994 at the 0.05 probability level (Table 3). At both of these site years, tubers produced with K_2SO_4 resulted in a higher incidence of hollow heart than where KCl was used. This may be due to a greater percentage of tubers in the large categories produced when K_2SO_4 was the K source since larger tubers have a greater tendency to develop hollow heart.

Differences in internal brown spot due to K rate or source were not observed in any of the years and locations (data not shown).

Petiole Potassium Levels:

Potassium concentrations in dry petiole tissue as well as in petiole sap increased significantly ($P < 0.05$) as the K rate was increased, reflecting K availability to the plant from the soil and fertilizer applied. These increases were generally more pronounced in soils testing low in K (Hancock, 1993 to 1995; Spooner, 1994) compared to those soils testing high in K.

Furthermore, as available soil K increased, K concentration in dry petiole tissue also increased. In addition, as the growing season advanced, the K concentration in petioles decreased. Changes in nutrient concentration with plant age and initial soil tests have also been observed by others (James et al., 1970; Rhue et al., 1986; Westermann et al., 1994).

In six of the 11 site-years, there was a tendency for somewhat more K to be present in the dry petiole tissue where KCl was the K source. Where interactions were present, K_2SO_4 gave equal or slightly higher K concentrations in petiole tissue than KCl at the controls and lower rates, whereas at higher rates KCl showed higher petiole K levels. According to Marschner (1986), $SO_4^{=}$ depresses the uptake rates of K (relative to Cl^-) at high concentrations because the different uptake rate of anions and cations require electrical charge compensation within the cells and in the external solution.

The relationship between K concentration in petiole sap and K concentration in dry petiole tissue for 1995 is presented in Figure 1. Work from previous years showed that, at petiole sap K values above about 0.40%, the Cardy K^+ meter may underestimate the K concentration; therefore, for 1995, petiole K readings were taken on both undiluted and diluted sap [1:3 dilution with $(Al)_2(SO_4)_3$] at several of the locations and sampling times. On the undiluted sap, a poor relationship between K concentrations in dry petiole and petiole sap was obtained. However, when K concentrations in diluted petiole sap are used, the relationship between these two methods improved considerably ($r = 0.78$, $P < 0.01$, Fig. 1) suggesting that the diluted petiole K sap test could be used in place of the dry extraction procedure. This may be due to the dilution bringing the petiole sap K concentrations into the more linear portion of detection of the Cardy K^+ meter.

Critical concentrations of K in the petioles were determined for each sampling time and location at the K responsive sites, where significant ($P < 0.05$) tuber yield response to K fertilization was found. The calculated K critical values (Table 4) show some year-to-year variation at similar physiological ages; however, the observed values (5.4 to 7.2%) generally agree with critical K concentrations for sandy soils reported by others [McDole, 1978 (6.5 to 7.5%); Sharma and Arora, 1989 (7.1 to 7.6%)] at 45 to 75 days after planting.

In-Season Potassium Experiment:

Table 5 shows the influence of timing/placement method on tuber yield and quality where 100 or 400 lb/acre K_2O was applied by all methods. The no-potash control is not included in the statistical analysis of these data. It is clear that responses to potash were seen at Hancock in both years and at Antigo in 1993 and that few significant differences in placement/timing were detected. Furthermore, the interaction between rate and placement was only significant for size grade (somewhat fewer less than 6 and more 6-13 oz. tubers) at Hancock in 1993 for the treatments that included a hilling application at the low rate (data not shown). However, these data do show that potassium applied at hilling can be used by the crop, but there does not appear to be a yield or efficiency advantage for applying later K.

Results from the other in-season K experiment show the same trends. In both years at Hancock, and to a lesser extent at Antigo, responses to potash were seen, but there appears to be some actual disadvantage to applying the K as $KNO_3/Ca(NO_3)_2$ (data not shown). Furthermore, the Hancock results also show that splitting the K as KCl, although better than $KNO_2/Ca(NO_3)_2$, was not as effective as applying all of the potash in the row.

These experiments show that in-season applications of potash can be utilized by the plant, and where deficiencies are detected, potash applications are recommended to correct the problem. However, these data do not support the concept that in-season potash applications are yield or quality enhancing, nor do they appear to improve efficiency of fertilizer use. These data support the statement or Roberts and McDole (1985) that there are few constraints on how potash should be applied. Although we did not include fall preplant broadcast applications in these experiments, we continue to believe that this method results in some risk of K leaching losses on sandy and organic soils. These experiments also show no advantage to using potassium nitrate as a K source for in-season applications.

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Table 1. Potassium fertilization study, 1992 through 1995: Chronology of field plot operations and preplant soil tests.

	Antigo				Hancock				Spooner		
Activity	1992	1993	1994	1995	1992	1993	1994	1995	1993	1994	1995
Planting date	5/14	5/18	5/11	5/18	4/23	4/28	4/22	4/20	5/6	5/5	5/5
Emergence	6/4	6/15	6/7	6/10	5/21	5/20	5/18	5/21	6/2	5/27	5/29
Leaflet & petiole sampling	8/11	8/10	7/26	8/2	7/14	7/19	7/11	7/7	7/28	7/27	7/26
Harvest	10/1	9/22	9/19	9/18	9/15	9/15	9/21	9/11	9/20	9/26	9/26
Preplant soil test											
pH	5.3	5.8	5.3	5.6	6.5	6.3	6.8	6.1	6.7	6.8	6.8
Org. matter (%)	2.6	2.3	2.5	2.5	0.7	0.6	0.8	0.9	1.0	1.4	1.2
P (ppm)	140	125	175	135	85	110	90	72	95	145	110
K (ppm)	110	125	180	167	90	80	75	72	110	100	82

Table 2. Main effect of K rate on several potato tuber yield and quality parameters, 1992 to 1995.†

	Antigo				Hancock				Spooner		
K_2O rate (lbs/ac)	1992	1993	1994	1995	1992	1993	1994	1995	1993	1994	1995
					Total yield (cwt/acre)						
0	314	358	444	406	400	245	298	298	366	390	329
100	355	330	454	380	459	304	361	332	380	411	300
200	354	307	480	412	490	284	371	341	412	419	328
300	353	357	461	416	491	327	391	348	394	437	317
400	361	360	470	400	481	314	368	332	388	446	339
Significance ‡	+	NS	NS	NS	**	**	**	NS	I	+	NS
					Yield U.S. No. 1 6-13 oz. (cwt/acre)						
0	114	97	114	183	141	29	77	59	103	146	125
100	166	91	112	164	187	39	109	60	132	109	122
200	145	106	104	182	189	47	101	79	96	111	130
300	166	116	104	186	197	80	121	69	124	171	136
400	169	118	102	182	188	68	120	87	112	201	150
Significance ‡	**	NS	I	NS	**	**	*	NS	*	+	NS
					Specific gravity						
0	1.100	1.096	1.105	1.082	1.094	1.085	1.082	1.072	1.068	1.094	1.084
100	1.096	1.093	1.096	1.090	1.095	1.088	1.085	1.067	1.084	1.092	1.083
200	1.089	1.091	1.092	1.086	1.094	1.086	1.086	1.068	1.085	1.090	1.084
300	1.092	1.086	1.091	1.080	1.094	1.086	1.086	1.068	1.082	1.087	1.082
400	1.089	1.084	1.088	1.084	1.092	1.084	1.083	1.064	1.082	1.086	1.082
Significance ‡	**	I	**	I	*	*	*	**	**	**	NS

– continued –

Table 2. (continued).†

K_2O rate (lbs/ac)	Antigo 1992	Antigo 1993	Antigo 1994	Antigo 1995	Hancock 1992	Hancock 1993	Hancock 1994	Hancock 1995	Spooner 1993	Spooner 1994	Spooner 1995
Hollow heart incidence (%)											
0	--	7	5	15	5	11	2	2	16	58	71
100	--	2	3	14	3	15	2	1	5	36	61
200	--	3	1	14	2	31	1	0	6	30	45
300	--	1	2	16	7	21	2	1	4	33	53
400	--	5	2	14	6	17	2	1	2	26	45
Significance ‡	--	NS	**	NS	NS	NS	NS	*	**	**	**
Rhizoctonia severity (%) §											
0	6	9	10	8	13	17	17	1	--	9	10
100	5	10	20	8	14	17	15	6	--	8	14
200	3	11	8	6	15	11	15	9	--	8	13
300	2	6	8	5	12	16	14	11	--	7	8
400	5	6	11	6	15	18	16	7	--	10	11
Significance ‡	NS	NS	**	NS	NS	NS	NS	NS	--	NS	NS

† Varieties were Atlantic at Antigo and Russet Burbank at Hancock and Spooner.

‡ Significance denoted by +, *, or ** are at P values of < 0.10, 0.05, or 0.01, respectively; I where the interaction is significant at P < 0.05. NS, not significant.

§ Severity rated on a Horsfall-Barrett (1945) scale and ratings converted to percentages.

Table 3. Main effect of K source on several potato tuber yield and quality parameters, 1992 to 1995. †

K_2O source	Antigo 1992	Antigo 1993	Antigo 1994	Antigo 1995	Hancock 1992	Hancock 1993	Hancock 1994	Hancock 1995	Spooner 1993	Spooner 1994	Spooner 1995
Total yield (cwt/acre)											
KCl	353	361	461	402	462	300	344	324	396	407	314
K_2SO_4	341	350	462	404	467	289	372	337	380	430	322
Significance ‡	NS	NS	NS	NS	NS	NS	NS	NS	I	NS	NS
Yield U.S. No. 1 6-13 oz. (cwt/acre)											
KCl	158	113	106	171	181	62	97	56	116	152	129
K_2SO_4	146	98	111	187	180	54	113	83	111	179	137
Significance ‡	NS	NS	I	I	NS	NS	NS	*	NS	NS	NS
Specific gravity											
KCl	1.093	1.088	1.090	1.084	1.093	1.086	1.083	1.066	1.084	1.088	1.082
K_2SO_4	1.093	1.092	1.097	1.091	1.095	1.085	1.085	1.073	1.085	1.091	1.084
Significance ‡	NS	I	**	I	+	NS	+	*	NS	*	NS
Hollow heart incidence (%)											
KCl	--	4	3	11	4	21	2	1	6	30	54
K_2SO_4	--	4	3	18	5	21	2	1	7	43	57
Significance ‡	--	NS	NS	**	NS	NS	NS	NS	NS	**	NS
Rhizoctonia severity (%) §											
KCl	5	7	13	6	15	16	17	9	--	9	13
K_2SO_4	3	10	11	8	13	16	15	7	--	10	10
Significance ‡	**	NS	NS	+	NS	NS	NS	NS	--	NS	NS

† Varieties were Atlantic at Antigo and Russet Burbank at Hancock and Spooner.

‡ Significance denoted by +, *, or ** are at P values of < 0.10, 0.05, or 0.01, respectively; I where the interaction is significant at P < 0.05. NS, not significant.

§ Severity rated on a Horsfall-Barrett (1945) scale and ratings converted to percentages.

Table 4. Critical petiole K concentration in dry petiole tissue at several growth stages.

Location	Variety	Crop growth stage (days after emergence)	Critical petiole K (%)	Soil test K (ppm)
Antigo 1992	Atlantic	41	10.7	110
		52	9.8	
		67	8.3	
Hancock 1992	Russet Burbank	- -	- -	90
		54	7.5	
		69	4.5	
Hancock 1993	Russet Burbank	46	5.4	80
		59	3.5	
		73	2.3	
Hancock 1994	Russet Burbank	40	7.2	75
		54	6.1	
		68	4.1	
Spooner 1994	Russet Burbank	47	7.3	100
		61	6.1	
		73	4.9	

Table 5. Main effect of time of potassium application on potato tuber yield, grade, and value at two Wisconsin locations, 1992 to 1993. †

Treatment	Yield		U.S. No. 1		Yield U.S. No. 1 6-13 oz.		Specific Gravity	
	1992	1993	1992	1993	1992	1993	1992	1993
	---- cwt/acre —		------- % -------		------ cwt/acre -------			
				Hancock				
0 K check ‡	411	244	76	58	157	28	1.094	1.086
Preplant (PP)	477	298	77	60	190	57	1.096	1.082
Row (R)	460	299	76	61	181	55	1.095	1.083
Hilling (H)	465	294	78	60	204	60	1.097	1.085
PP + R	463	317	77	62	179	54	1.095	1.084
PP + H	478	317	79	64	205	54	1.095	1.086
R + H	449	285	76	65	175	54	1.095	1.083
Pr > F	0.30	0.45	0.50	0.30	0.17	0.99	0.52	0.47
				Antigo				
0 K check ‡	311	378	76	86	106	92	23.4 §	1.095
Preplant (PP)	323	388	77	87	110	90	23.4	1.091
Row (R)	320	398	75	85	137	88	23.2	1.091
Hilling (H)	309	402	77	85	116	91	23.8	1.095
PP + R	365	400	78	86	168	128	22.9	1.093
PP + H	341	395	74	87	138	98	23.2	1.094
R + H	295	409	77	86	106	108	23.5	1.094
Pr > F	0.27	0.95	0.73	0.82	0.15	0.12	0.47	0.06

† Potassium applied at 100 and 400 lb K_2O/acre as K_2SO_4 at both locations; Russet Burbank variety at Hancock, Atlantic at Antigo.

‡ Not included in statistical analysis.

§ Dry matter determined gravimetrically at Antigo in 1992.

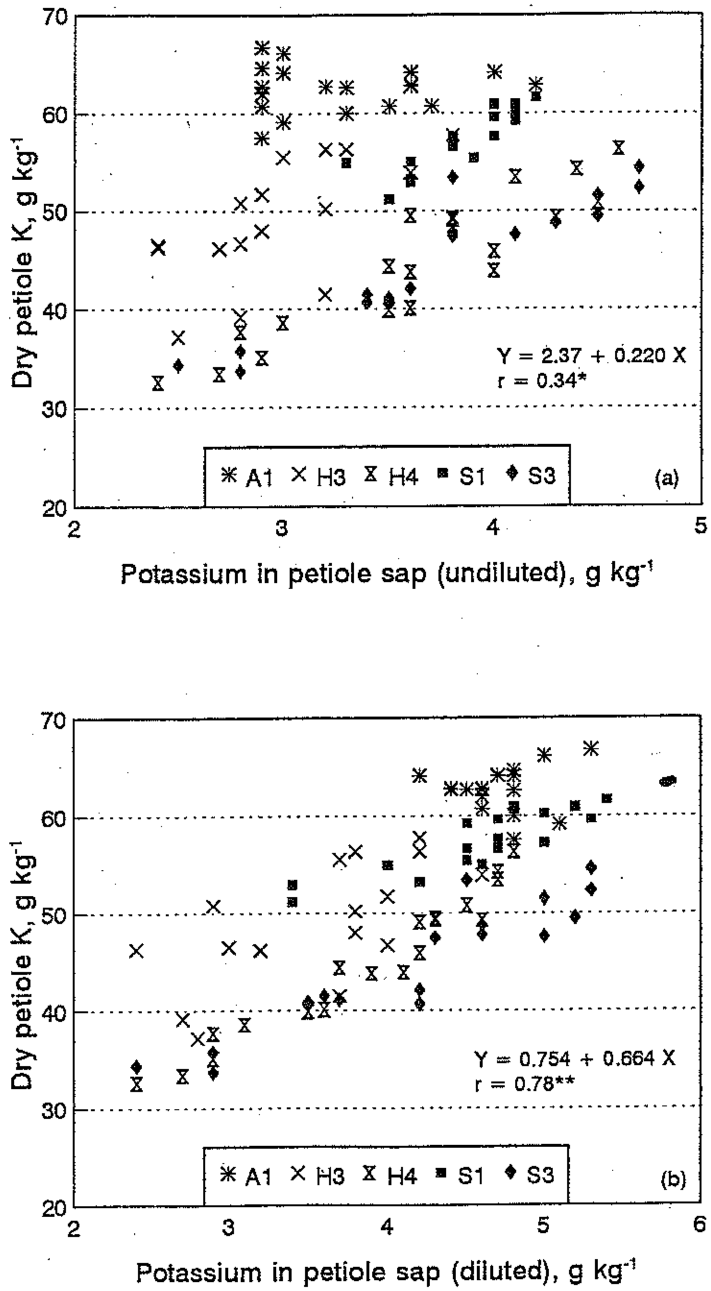

Figure 1. Relationship between K concentrations in dry potato petiole tissue and undiluted petiole sap (a) or dry potato petiole tissue and diluted petiole sap (b) at selected samplings times at Antigo (A), Hancock (H), and Spooner (S), 1995.