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Title: Phosphorus Response and Critical Phosphorus Levels of Winter Wheat Varieties in Western Oregon

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Winter wheat (Triticum aestivum) varieties display a range of tolerance to low levels of plant available P in western Oregon soils. The objectives of this study were to: 1) evaluate variety differences in tolerance to low soil P and response to fertilizer P, 2) identify the most appropriate stage of growth for assessing P nutrition by plant analysis, and 3) compare the critical level and nutrient balance approaches for interpreting plant analysis data.

Field plots were established at six locations with varieties and P fertilizer treatments as experimental variables. The varieties 'Yamhill', 'Stephens', 'McDermid', 'Hyslop', 'Hyslop Al Tolerant', 'Nugaines', and 'Daws', and the selections Ymh/Hys 2M6 and Hyslop R9401 were chosen to give a range of P responses. Monocalcium phosphate, $Ca(H_2PO_4)_2$, was banded with the seed at planting at rates of 0 and 29 kg P/ha. Lime treatments (0 and 4480 kg $CaCO_3$/ha) were included at one location. Chemical analyses of leaf samples taken during tillering were used to assess the relationship between yield response, plant P, and P uptake.

A number of effects of lime and P fertilization were observed. Phosphorus fertilization increased grain yield, plant P concentration during tillering, plant survival during the extreme winter of 1978-79, and P uptake measured just prior to ear emergence. Liming and P fertilization resulted in comparable yield increases, but P fertilization produced a much larger increase in plant P at early tillering (Feekes 2-3). It was not possible to clearly separate P deficiency and Al or Mn toxicity responses under field conditions.

The time of sampling was very important in relating yield response

to leaf P. Phosphorus deficient plants maintained approximately the same P concentration throughout tillering, while leaf P decreased markedly in P fertilized plants between early tillering (Feekes 2-3) and jointing (Feekes 6). The best growth stages for relating leaf P to yield response were early and mid-tillering (Feekes 2-4). The P critical level (90% of maximum yield) ranged from .30 to .40% in all varieties. By jointing, leaf P was not related to yield response because of dilution effects.

'Stephens' and 'Yamhill' represented the extremes in variety P response on low P soils in western Oregon. These varieties had comparable yields with optimum fertilization. However, 'Yamhill' outyielded 'Stephens' on plots where P and/or lime was not applied. These varieties had approximately the same P critical level, but below the critical level the yield of 'Stephens' decreased more rapidly than 'Yamhill.'

The effect of growth stage and P fertilization on nutrient balance (leaf K/P ratios) was evaluated. The K/P ratio was only an indirect measurement of leaf P, since P fertilization did not affect leaf K. Leaf K/P ratios on P fertilized plots increased during tillering as a consequence of the rapid dilution of leaf P, with leaf K remaining nearly constant. The diagnosis of plant P and K nutrition via a nutrient balance system (DRIS) changed as leaf K/P ratios increased during tillering. Phosphorus fertilized plots were diagnosed as K deficient at early tillering, while K/P ratios at mid-tillering were in the range of optimum P and K balance.

Phosphorus Response and Critical Phosphorus Levels of Winter Wheat Varieties in Western Oregon

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PHOSPHORUS RESPONSE AND CRITICAL PHOSPHORUS LEVELS OF WINTER WHEAT VARIETIES IN WESTERN OREGON

INTRODUCTION

Winter wheat (Triticum aestivum) is a crop of major importance in western Oregon, with about 125,000 hectares planted in 1979-80. Adapted varieties under good management have a yield potential exceeding six metric tons/ha on deep, well drained soils.

Low soil P limits crop yield on many western Oregon soils. Traditionally, the need for P fertilization has been determined by soil testing prior to planting. However, other factors besides soil P availability govern P response. Response to P fertilization is increased by low soil temperatures at planting, by soil acidity, and by severe infestations of Take-All root rot (Gaeumannomyces graminis var. tritici). There are also variety differences in tolerance to low soil P.

Soil acidity (pH less than 5.5) frequently limits yield on western Oregon soils that have never been limed, or which have been acidified by N fertilization. Soil acidity can have a number of effects on nutrient availability and plant growth. As soil pH decreases, the solubility of Al and Mn increases. Soluble Al and Mn may inhibit plant growth directly, or act indirectly by precipitating P, thereby reducing P availability to the plant. Soil acidity also decreases microbial activity, reducing the supply of N, P, and S to the plant from breakdown of organic matter.

Plant analysis can be used to assess the nutritional status of crops. Plant nutrient content can be correlated with yield increases from fertilization, provided that the nutrient under study is the only factor limiting yield. The minimum concentration of a nutrient required for maximum yield is known as the critical level.

Critical levels are established for a specific stage of growth, plant part, and variety. The tillering growth stage has been identified as the best time for relating plant P to yield in western Oregon (Roberts et al., 1972), but the change in the P critical level between early tillering (Feekes growth stage 2) and late tillering (Feekes 5) has not been studied. Also, P critical levels for different varieties have not been identified.

Nutrient ratios have been used as a measure of the nutritional status of plant tissue, instead of the critical level approach. Sumner (1977) has proposed a method (Diagnosis and Recommendation Integrated System -- DRIS) using K/P, N/P, and N/K ratios for identifying N, P, and K deficiencies in wheat plants at any stage of growth. Widespread trials with DRIS have not been conducted, so the validity of the system is still in question.

The purposes of this study were to characterize variety yield responses on acid low P soils, and to improve the diagnostic value of plant analysis in assessing P nutrition during tillering growth stages. More specifically, the objectives were:

1. To evaluate variety differences in tolerance to low soil P and response to fertilizer P.
2. To identify the most appropriate stage of growth for assessing P nutrition by plant analysis.
3. To compare the critical level and nutrient balance (DRIS) approaches for interpreting plant analysis data.

LITERATURE REVIEW

Variety Responses to Phosphorus Supply

Introduction

It is well known that the variety giving the highest yield under one set of field conditions may not give the highest yield under all conditions. Variety differences in root growth, winter hardiness, straw strength, and disease resistance are some of the factors contributing to variability in yield response. A variety x P interaction occurs when differences in P supply are responsible for differential yield responses by varieties.

Variety x P interactions can be studied by growing different varieties on media (soils or solutions) having a wide range of P levels, with all other nutrients present in adequate amounts. The results of such studies can be presented diagramatically by plotting media P levels (ppm available P in soils, P concentration in solution) vs. yield for each variety. Normally, the yield response curve illustrates Mitscherlich's law of diminishing returns. At low media P, the plant yields poorly. As media P is increased, yield increases, until a media P value is reached where P deficiency is no longer limiting yield.

Phosphorus response curves for different varieties may vary in the following ways:

1. The magnitude of the yield at optimum media P (variety yield potential).
2. The minimum media P required for optimum yield (critical level).
3. The slope (yield increase/unit media P) of the response curve below optimum media P.

A given variety may differ from another in one or all of these ways.

Root Characteristics

Variety differences in P response are related to differences in root growth and development. In general, greater rates of root growth and development and larger root surface areas increase P uptake. A rapid rate of root growth is advantageous because young root tissues have root hairs which are particularly active in taking up P. A large root surface area increases the opportunity for soil P to reach the roots via diffusion (Mengel and Kirkby, 1978).

Variety P responses have been related to differences in root quantity, morphology, and activity. In a wheat variety study, 'Israel M68' responded to P fertilization with increased grain yield, root number, root area, and lateral root volume per unit root fresh wt. In comparison, 'Olympic' did not increase its root growth or grain yield with P fertilization (Palmer and Jessop, 1977). A reciprocal grafting experiment with soybean (*Glycine max*) varieties 'Lincoln' and 'Chief' showed that variety root differences were related to P uptake (Foote and Howell, 1964). 'Lincoln' tops on 'Lincoln' roots and 'Chief' tops on 'Lincoln' roots accumulated large amounts of P from nutrient solutions. Either of the varieties grafted on 'Chief' roots took up considerably less P. Experiments with corn (*Zea mays*) hybrids have also shown a strong relationship between root surface area and P response (Nielsen and Barber, 1978; Lyness, 1936).

Phosphorus Utilization

Some of the differences in variety P response have been attributed to differences in P utilization in the plant. Phosphorus is readily mobile in plants with reserve P stored in cell vacuoles, and redistribution taking place via the phloem. The efficiency with which P is transferred from older leaves to developing leaves and the inflorescence could be important when external P supply is limited (Mengel and Kirkby, 1978).

Phosphorus utilization differences have been reported in several crops. Bean (*Phaseolus vulgaris*) lines grown at stress levels of P had efficiency ratios (mg dry weight yield/mg P in tissue) ranging from 380 to 671 (Whiteaker et al., 1976). Efficient bean lines at low P were not always the highest yielding when larger amounts of P were present in the nutrient solution. Wheat varieties, 'Bencubbin' and 'Charter', differed in P utilization efficiency on a low P soil (Lipsett, 1964). Total P uptake (straw + grain) of both varieties was comparable, but 'Bencubbin' had a greater grain yield and therefore a larger yield/unit P uptake. The grain P concentration was much lower in 'Bencubbin' than 'Charter'. The author suggested that the lower grain P content of 'Bencubbin' was the result of selection for high grain yield on low P soils where this variety was developed.

Phosphorus Nutrition of Wheat

Pattern of Uptake

Phosphorus uptake by wheat over a growing season is best described by a sigmoid curve. Only 25 to 35% of total P uptake occurs during tillering. The most rapid P uptake takes place between jointing (Feekes 6) and heading (Feekes 10.1). At heading, P uptake is 80 to 100% complete (Miller, 1939; Lewis and Quirk, 1967; Karlen and Whitney, 1980).

Critical Growth Stages

The importance of adequate P nutrition at various growth stages has been studied by growing wheat plants in solution cultures. Phosphorus is removed at different growth stages and the effects on dry matter production, grain yield, and yield components are measured.

The major yield component affected by a P deficiency at early growth stages is tiller number. Chapman and Keay (1971) withheld P from spring wheat plants for two weeks starting at the 1-2 leaf stage. Grain yield and tiller number were reduced, while other yield components were unaffected. Boatwright and Viets (1966) found that P uptake during seedling growth stages was small, but had a large effect on grain yield. Removing P from spring wheat plants for the first two weeks of growth reduced grain yield to 42% of the maximum, associated with decreases in tiller production and secondary root growth. In winter wheat, fertile tiller numbers were maximized when P was supplied through noding

(Feekes 7-9) (Sutton, 1980).

The development of the inflorescence and the filling of the grain are also dependent on an adequate P supply. Rahman and Wilson (1977) found that P fertilization increased the rate of spikelet initiation and the spikelet number per ear in seven spring wheat varieties. After head emergence, adequate P is important for the production and translocation of carbohydrates to the grain, since both processes require the expenditure of energy in the form of ATP (Mengel and Kirkby, 1978). A large portion of the P supplied to the head is derived from senescing leaf and stem tissue (Williams, 1948), so continued P uptake after heading is not required for maximum dry matter production or grain yield in many cases (Boatwright and Viets, 1966; Chapman and Keay, 1971). However, in one study, winter wheat was shown to require P in the nutrient solution up to ripening (Feekes 11.2) for maximum grain yield (Sutton, 1980).

Plant Part

The plant part sampled must be specified in establishing a critical level. The two plant parts most commonly sampled in assessing the P nutrition of wheat are green leaves and whole tops. Both plant parts have comparable P levels during tillering, because of the large percentage of leaf tissue present. However, as the plant matures, whole plants contain an increasing proportion of stem tissue and older leaves which have a lower P concentration. Therefore, at noding and heading growth stages, the P concentration in whole tops is generally less than in green leaf tissue (Ward et al., 1973).

Comparisons between leaf and whole plant samples show little difference in P concentration. Whitney and Petersen (unpublished data, Kansas State Univ., 1970) found P concentrations of whole plants and flag leaves sampled at heading were essentially the same. Karlen and Whitney (1980) reported a linear decrease in P concentration for both whole tops and living leaves of winter wheat sampled at weekly intervals between jointing and heading; whole plant P decreased from .30 to .20%, while leaf P decreased from .35 to .30%.

Leaf Age

The P content of a wheat leaf is controlled by the soil P supply, the movement of carbohydrates, and the age and metabolic activity of the leaf tissue. Young, expanding leaves import carbohydrates, and therefore have high P levels regardless of the soil P supply (Greenway and Gunn, 1966). But once leaves stop importing and start exporting carbohydrates, they also export P. A leaf may export P in the phloem and import P in the xylem simultaneously. Leaf P concentration depends on how much P is imported in the xylem and exported via the phloem (Bielski, 1973; Greenway and Gunn, 1966).

A number of studies illustrate the relationship between leaf age, soil P supply and leaf P content. Field experiments with spring wheat plants showed that net export of P by a leaf generally began when the leaf attained its maximum dry weight (Mohamed and Marshall, 1979). Williams (1948) showed that mobilization of P from a leaf to the meristem began at a much earlier leaf age in P starved oat plants, compared to plants receiving a sufficient P supply. Greenway and Gunn (1966) found the best relationship between leaf P content and P fertilizer treatments when mature, fully expanded leaves were sampled. These studies confirm the suggestion of Ulrich (1952) that young, fully expanded leaves of the same physiological age be sampled in establishing critical levels.

Plant Age

Leaf P content decreases as the wheat plant matures, even if leaves of the same physiological age are sampled throughout the growing season. Mohamed and Marshall (1979) found that the maximum P concentration of main shoot leaves in spring wheat varied with the level of leaf insertion. The lowest leaves reached a P concentration of .48% at the leaf dry weight maximum, while the flag leaf attained a P concentration of .24% at the same physiological age.

A possible explanation for the production of leaves with lower P contents as a wheat plant matures is found in Australian research on the P content and leaf anatomy of green panic grass (*Panicum maximum* var.

trichoglume 'Petrie'). Smith (1975) found almost identical P concentrations in whole tops and the youngest expanded leaf of Panicum at different vegetative growth stages. Wilson (1976) studied the variation in leaf anatomical characteristics with level of insertion in Panicum plants grown in a controlled environment. Leaf blades of higher insertion level had a higher proportion of sclerenchyma and vascular tissue, thicker lignified cell walls and cuticle, and a smaller average size of mesophyll, bundle sheath and epidermal cells. The increase in vascular and cell wall materials decreased the overall P concentration of the upper leaves.

Critical Levels

Fertilizer trials with winter wheat under a variety of soil and climatic conditions have shown that plant P concentration is best related to P fertilizer response at early tillering (Feekes 2-3). Because of dilution effects, plants responding to fertilizer P usually do not exhibit increased P concentrations after tillering. For example, yield responses to P fertilization in northwest Montana were related to P concentration at Feekes 2, but not at any growth stage thereafter (Wilson, 1970). At later growth stages, P fertilization stimulated increased dry matter production, but did not affect the P concentration of whole tops.

Other researchers have emphasized the need for plant sampling at early growth stages in assessing P fertilizer effects on yield. Baker et al. (1973) reported large differences in plant P at Feekes 2-3 in Oklahoma field plots; plant P increased from .21% without P fertilization to .32% with application of 15 kg P/ha. Grain yield was nearly doubled by P fertilization. However, at jointing (Feekes 6), control and P fertilized plots had comparable plant P concentrations. Roberts et al. (1972) also identified the tillering stage of growth as the most appropriate time for evaluating the P status of winter wheat in western Oregon.

The minimum P concentration needed for maximum yield is known as the critical level (Ulrich, 1952; Melsted et al., 1969). Stage of growth must be specified when identifying a critical level. Reported P critical levels for winter wheat sampled at tillering are .45% (Baker et al., 1973), and .37% (Roberts et al., 1972). Phosphorus fertilizer experiments with other small grains and grasses show that critical P concentrations generally range from .30 to .40% during tillering (Racz et al., 1965; Negi, 1979; Lunt et al., 1965).

Phosphorus critical levels in wheat at later growth stages have been reported. Melsted (1969) proposed a critical level of .30% P based on whole tops sampled at the boot stage (Feekes 10). Ward et al. (1973) interprets P concentrations in whole tops at heading less than .15% as deficient, while plant P greater than .20% is considered sufficient. It must be recognized, however, that the range between deficient and optimum P concentrations at boot or heading growth stages is often very small (Negi, 1979; Racz et al., 1965; Wilson, 1970).

Varieties

Wheat varieties have been shown to vary widely in P content. Spring wheat varieties sampled at the four leaf stage varied from .25 to .31% P (Kleese et al., 1968). Winter wheat varieties sampled at heading varied from .10 to .30% P in the flag leaf (Rassmusson et al., 1971). Ward et al. (1973) reported a large difference in P concentrations of two winter wheat varieties. 'Lancer' had .43% P, while 'Wichita' had only .19% P in leaves plus straw at heading. It is apparent from these studies that P uptake is genetically controlled. However, variety yields are controlled by many genetic factors in addition to P uptake efficiency.

Varieties having high leaf P concentrations are not necessarily high yielding under P stress (Baker et al., 1967; Vose, 1963). In many cases, P accumulation is most evident in varieties having limited yields due to environmental or genetic factors (Terman et al., 1975; Rasmusson et al., 1971). In work with corn hybrids, it has been demonstrated that varieties which accumulate high levels of P in ear leaves have a large percentage of total P in the inorganic form (Phillips, 1971). Large reserves of inorganic P are commonly found in plants having a P supply greater than the requirement for growth (Williams, 1948; Bielski, 1973).

Soil Temperature Effects

Low soil temperatures reduce P solubility and diffusion rate in soil solution, and limit the ability of the plant to absorb and utilize P (Sutton, 1969). Phosphorus fertilization can overcome some of the reduction in plant growth caused by low soil temperatures. Power et al. (1963) grew barley (*Hordeum vulgare*) at soil temperatures of 7, 11, and 15^{o}C with different rates of P fertilization. Barley yield was maximized at 15^{o}C without P fertilization. The minimum temperature required for maximum dry matter production was decreased with each increment of P fertilizer applied. Follett and Reichman (1972) also reported that P fertilization overcame the adverse growth effects of the lowest soil temperature (9^{o}C) in their study on barley.

In the field, P uptake under low temperature conditions is increased by placing (banding) water soluble P fertilizer near the seed at planting. Responses to banded P are more common at low soil temperatures. Fixen and Carson (1978) reported larger small grain yield responses to banded P fertilizer on Borolls compared to Ustolls in South Dakota. Hipp and Hooks (1978) banded P fertilizer on winter wheat planted Sept. 15, Nov. 15, and Dec. 15 in north Texas. Banded P increased grain yield only on the Nov. and Dec. planting dates when soil temperatures were lower.

At very low soil temperatures, the ability of the plant to produce dry matter is restricted to an even greater extent than is P uptake. Continued P uptake with restricted growth results in high P concentrations in the plant. For example, Power et al. (1970) found that P concentrations in whole barley tops were highest at the lowest soil temperature studied (9^{o}C) from tillering to maturity; plant P on the 9^{o}C treatment at the four leaf stage was .66%. The accumulation of high P concentration during winter periods of low soil temperature may be of benefit to plants growing in the field as stored P can be utilized for growth in the spring.

Soluble Aluminum Effects

Excess soluble Al is a growth-limiting factor in many acid soils. As soil pH decreases below 5.5, the solubility of Al increases dramatically. In western Oregon, Jory and Nekia soils having a pH less than 4.6 in 1N KCl have large quantities of soluble Al (Petersen, 1972; Janghorbani, 1969).

Soluble Al interacts with P in soil solution and also decreases P uptake indirectly through effects on root growth. The presence of soluble Al in soil solution decreases P solubility by formation of Al-phosphates (Mengel and Kirkby, 1978; Moore et al., 1976). Aluminum inhibits cell division in root apical meristems, causing the development of roots which are thickened and stunted (Foy, 1974). The reduced root system produced by plants suffering from Al toxicity has less surface area for P uptake. As a result, plants suffering from Al toxicity commonly show P deficiency symptoms in plant tops.

DRIS Nutrient Ratios

Description of the DRIS System

Sumner (1977) has proposed the Diagnosis and Recommendation Integrated System (DRIS) for interpreting plant analysis data. DRIS is based on a statistical relationship between nutrient ratios and crop yield.

Plant analyses and corresponding yield data are used in setting up the DRIS system for a particular crop. The DRIS data base for wheat includes 1500 sets of yield and plant analysis data, chosen to reflect the variability of the crop in the field. The total population of observations is divided into two subpopulations on the basis of yield. The high yielding subpopulation exceeds 2600 kg grain/ha; the low yielding subpopulation has yields lower than this level.

Nutrient ratios (N/K, N/P, K/P) which differ in low and high yielding subpopulations are selected as measures of desired nutrient balance. These ratios are then interrelated in a three coordinate DRIS chart

(Fig. 1). The means of the ratios in the population of high yielding plants are at the center of the two concentric circles; the value of the ratio at the center is the desired nutrient balance. The mean K/P ratio is 8.80.

The desired balance between two nutrients is not considered to be a single point, but a range of values bounded by the inner circle in Figure 1. The diameter of this circle is 4/3 of the standard deviation of the population of high yielding plants. The range of optimum balance for K/P is 7.91 to 9.79.

The degree of nutrient imbalance increases moving along any axis away from the inner circle. Nutrient ratios which fall outside the outer circle show marked imbalance (greater than 10.79 or less than 7.18 for K/P). The diameter of the outer circle is 8/3 of the standard deviation of the population of high yielding plants.

Different Growth Stages

One of the proposed advantages of DRIS is that the system can be used to diagnose the P and K status of wheat plants at any stage of growth. DRIS operates on the assumption that P and K concentrations in wheat plants decline at the same rate during the growing season, resulting in the same ratios between these nutrients at all growth stages (Sumner, 1977).

The hypothesis of a constant K/P ratio at different growth stages is not supported by plant analysis data from other research workers (Baker et al., 1973; Miller, 1939). For example, Karlen and Whitney (1980) found leaf K concentration in 'Centurk' winter wheat remained constant at 3% between early tillering and flowering, while leaf P declined linearly from .45 to .30%. The K/P ratio was 6.7 at early tillering and 10.0 at flowering.

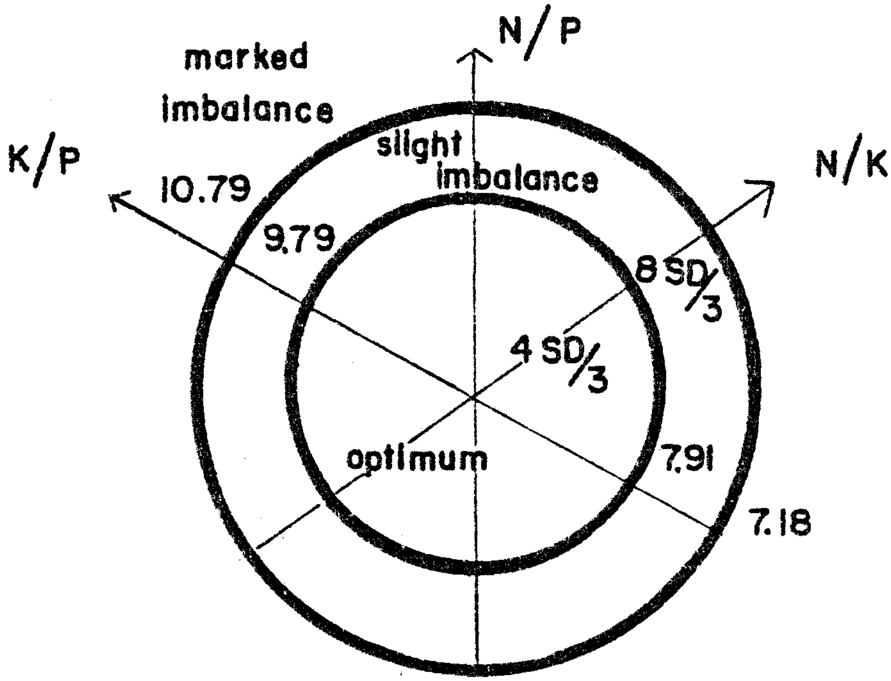

Figure 1. DRIS chart for obtaining the qualitative order of requirement for nitrogen, phosphorus, and potassium in wheat (Sumner, 1977).

MATERIALS AND METHODS

Six field experiments were conducted in western Oregon during 1979 and 1980[1/] to evaluate wheat variety responses to lime and P fertilization. The soil classification and legal description of each location is found in Table 1. Initial soil test values are given in Table 2.

Varieties

The varieties and selections in this study were developed by Oregon State University and Washington State University breeding programs. 'Stephens', 'McDermid', 'Hyslop', 'Hyslop Al Tolerant', and Hyslop selection R9401 (from Oregon State) are crosses of 'Pullman Selection 101' and 'Nord Desprez' (Fig. 2). 'Yamhill' was developed from a cross between 'Redmond' and 'Heines VII'. Ymh/Hys 2M6 is a selection from a cross between 'Yamhil' and 'Hyslop'. 'Daws' and 'Nugaines' were produced at Washington State University. 'Nugaines' is a sister selection to 'Pullman Selection 101'. Cereal Investigation/Plant Introduction numbers for each of the varieties are given by McCuistion (1978).

Field Experiments

Field plots were seeded with a 1.5 meter drill equipped with six sets of double disc openers spaced 23 cm apart. Each double disc opener had two flexible spouts so that fertilizer and seed were placed together in the soil at planting. The seeding rate was 112 kg/ha on all plots.

Fertilizer treatments were: Phosphorus as monocalcium phosphate at rates of 0 and 29 kg P/ha; lime at rates of 0 and 4480 kg/ha (Douglas Co. location only). The lime was applied and disced into the soil 12 months before the start of the experiment. Two additional rates of monocalcium phosphate, 15 and 44 kg P/ha, were applied to 'Stephens' and 'Yamhill' plots at the 1980 Benton Co. location, and KCl at 93 kg K/ha, was broadcast over all plots in the fall after seeding. Ammonium

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1/ Refers to year of grain harvest.

TABLE 1. Soil Classification and Legal Description of Field Plot Locations.

Location, Yr.	Legal Description	Soil Classification Series, Family, and Subgroup
Douglas Co. 1979	NW 1/4 Section 20 T24S, R5W	Nonpareil Loamy, mixed, mesic shallow Dystric Xerochrept
Linn Co. 1979	NW 1/4 Section 1 T10S, R1W	Nekia Clayey, mixed, mesic Xeric Haplohumult
Benton Co. 1980	SE 1/4 Section 28 T10S, R4W	Hazelair Fine, mixed, mesic Ultic Haploxeroll
Hyslop Farm (Benton Co.) 1980	NW 1/4 Section 8 T11S, R4W	Woodburn Fine-silty, mixed, mesic Aquultic Argixeroll
Jackson Farm (Linn Co.) 1980	NW 1/4 Section 7 T12S, R2W	Amity Fine-silty, mixed, mesic Argiaquic Xeric Argialboll
Polk Co. 1980	NE 1/4 Section 23 T6S, R5W	Willamette Fine-silty, mixed, mesic Pachic Ultic Argixeroll

TABLE 2. Initial Soil Test Values on Experimental Field Plots.

Location	Year	Soil Tests*				
		pH	P	K	Ca	Mg
			--- ppm ---		- meq/100 g -	
Douglas Co. (unlimed)	79	5.2	12	467	7.5	4.2
Douglas Co. (limed)	79	6.4	10	459	13.6	3.6
Linn Co.	79	5.3	24	207	8.8	1.3
Benton Co.	80	5.9	8	96	8.2	1.8
Hyslop Farm (Benton Co.)	80	5.6	112	371	6.7	0.9
Jackson Farm (Linn Co.)	80	6.1	37	94	8.9	1.6
Polk Co.	80	6.4	110	289	5.8	0.7

* Soil test procedures are described in Berg and Gardner (1978).

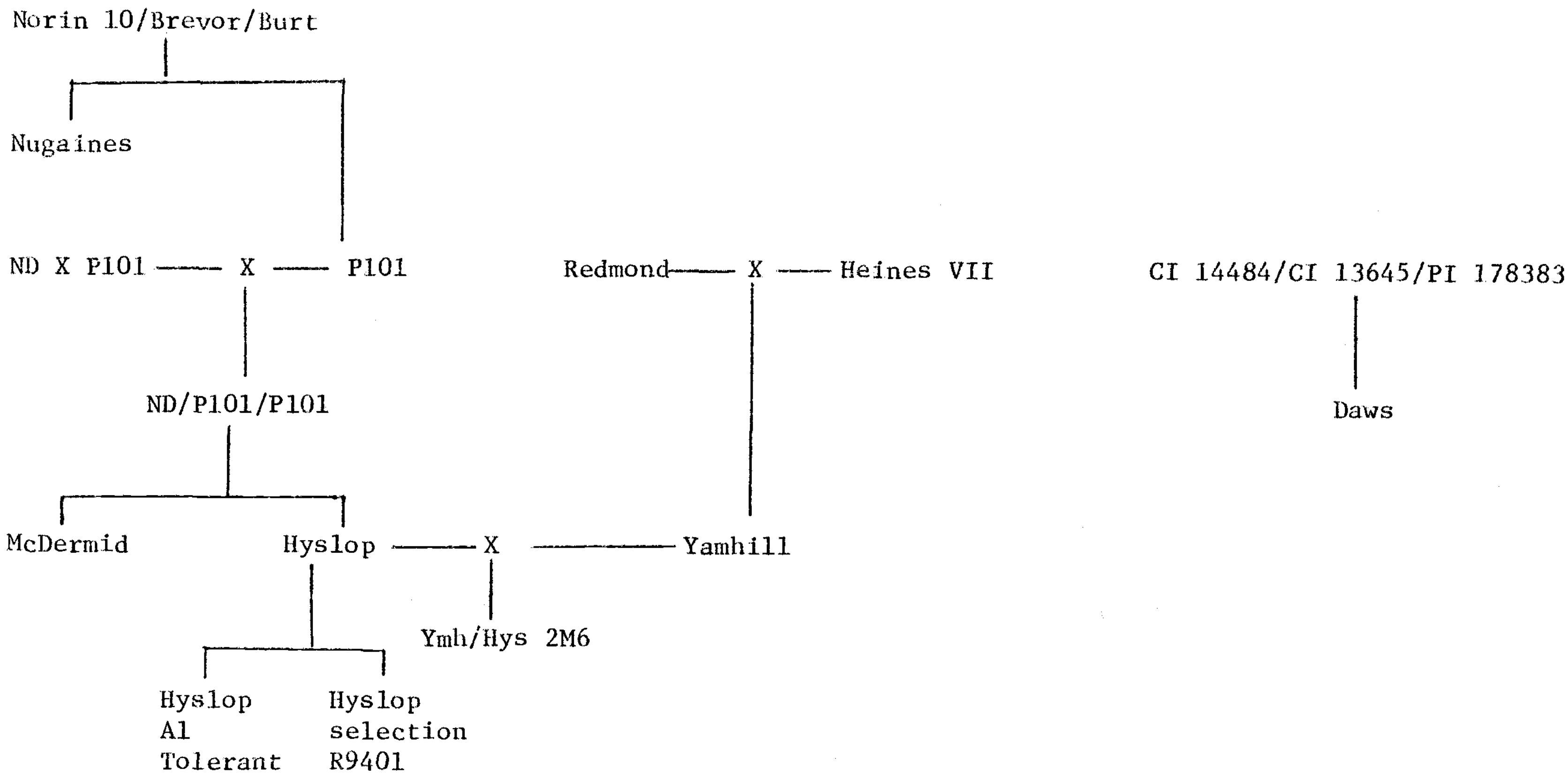

Figure 2. The parentage of the varieties and selections from the Oregon State University and Washington State University breeding programs. ND = 'Nord Desprez', P101 = 'Pullman Selection 101'.

sulfate was applied in the fall and spring at rates given in Table 3 to supply N and S.

The experimental design at each location is shown in Table 3. Phosphorus fertilizer treatments were randomized within a larger fertilizer experiment at locations where the randomized block design was used. Poor drainage eliminated two of four replications at the 1980 Benton Co. location, so analysis of treatments effects using the split-plot design was not possible.

Two herbicide applications were made each year. Diuron (Karmex) was applied at 1.8 kg of active ingredient per hectare in the fall after wheat emergence. In the spring, 2.4-D, MCPA, or dicamba were applied at recommended rates to control broadleaf weeds.

Plant survival (stand) was visually estimated on a scale of 1 to 10. The visual estimate was related to actual plant numbers in each of 20 plots having a range of stand densities.

Border rows were removed from each plot with a Jari mower. Grain was harvested with a small plot combine. The plot area harvested at each location is shown in Table 3. Winter-kill at the 1979 Linn Co. location reduced the stand, so a combine was not used for harvest. Instead, 3.7 meters of row in each plot having maximum stand were selected for harvest, cut manually, and thrashed in a Vogel thrasher.

Plant Sampling and Analysis

Leaf samples were taken at different growth stages as identified by the Feekes scale (Large, 1954). At early tillering (Feekes 2-3), the whole plant top was sampled. At growth stages ranging from mid-tillering (Feekes 3-4) to noding (Feekes 7), the two uppermost fully expanded leaves were sampled. At heading (Feekes 10.1) and flowering (Feekes 10.5) only the flag leaf was collected.

The plant material was oven dried at 70^{o}C, ground and digested in HNO_3:$HClO_4$. Manganese, Ca, Mg, and K were analyzed by atomic absorption, using procedures specified by the manufacturer (1976 Perkin Elmer manual, Analytical Methods for Atomic Absorption Spectrophotometry). Phosphorus was measured by the vanadomolybdo-phosphoric acid colorimetric method

TABLE 3. Summary of Experimental Design, Planting Date, Nitrogen Fertilization, and Plot Area Harvested at Six Western Oregon Locations.

Location, Yr.	Experimental Design*	Replications	Planting Date	N Fert. fall	N Fert. spr.	Area Harvested
				- kg/ha -		-- m^2 --
Douglas Co. 1979	Split/split plot Varieties (MP) Lime (SP) P (SSP)	4	10-12	28	100	4.1
Linn Co. 1979	Split plot Varieties (MP) P (SP)	4	10-20	28	112	0.8
Benton Co. 1980	Split plot Varieties (MP) P (SP)	2**	11-9	28	140	4.7
Hyslop Farm (Benton Co.) 1980	Randomized complete block	4	10-10	28	140	4.5
Jackson Farm (Linn Co.) 1980	Randomized complete block	3	10-11	22	134	6.7
Polk Co. 1980	Randomized complete block	4	10-31	28	140	6.3

* MP = main plots, SP = subplots, SSP = sub/subplots

** Only two replications were harvested due to poor drainage

(Jackson, 1958) for samples taken at 1979 Linn and Douglas Co. locations. Samples in 1980 were analyzed for P by formation of the phosphomolybdenum complex (Technicon industrial method 334-74A/A), using a Scientific Products CFA 200 auto-analyzer. Both P analysis methods had comparable accuracy.

Whole plant samples were collected from 1.8 meters of row within each plot at Feekes 8-9 at the 1979 Linn Co. location. The samples were dried, weighed, and a subsample analyzed for P. The sample weight and P analysis were used to compute P uptake.

Statistical Analysis

Statistical analysis of data was performed by the Statistical Interactive Programming System (SIPS) at the OSU Computer Center. Treatment interactions and main effects were tested using the F statistic. Treatment means were compared using an appropriate LSD at the 1, 5, or 10% level (Little and Hills, 1978). Lines were fit to data points with linear or quadratic equations. A quadratic model was used only when the residual sum of squares was significantly reduced by addition of X^2 to the linear model. Coefficients of simple and multiple correlation were computed to assess relationships of biological importance. Emphasis in results and discussion will be given to treatment differences that are statistically significant.

RESULTS AND DISCUSSION

Variety Yield Responses

Douglas Co., 1979

The effects of lime and P fertilization on variety grain yields are shown in Table 4. A marked lime x P interaction was evident (Appendix Table 1), with comparable yields on L_0P_+, L_+P_0, and L_+P_+ treatments. Average yield increases over the L_0P_0 plot were 2.60, 2.05, and 2.85 metric tons/ha for P, lime, and lime + P treatments, respectively. All varieties responded to P fertilization except Ymh/Hys 2M6. All varieties except 'Yamhill' and Ymh/Hys 2M6 responded to lime.

Phosphorus deficiency was probably a more limiting factor at this location than Al and Mn toxicities associated with acid soils. Phosphorus fertilization resulted in greater yields than did liming for all varieties except 'Stephens'. Phosphorus fertilization can reduce the severity of an Al toxicity (Foy and Brown, 1964), but yield increases ranging from 1.25 to 3.60 metric tons/ha on the L_0P_+ treatment are much larger than expected for an Al x P interaction.

The smaller fertilizer responses of 'Yamhill' and Ymh/Hys 2M6 can be attributed to their superior yields on L_0P_0 plots: 5.00 and 4.80 metric tons/ha, respectively. Other varieties ranged from 1.40 to 2.55 metric tons/ha on L_0P_0 plots. The variety differences in yield on L_0P_0 plots were associated with differences in root growth. Bolger (1980) took root samples from the upper 20 cm of soil in 'Yamhill' and 'McDermid' plots at this location. She reported that 'Yamhill' had 125% greater live root length than 'McDermid' on L_0P_0 plots in samples taken April 7.

'Stephens' was the only variety which responded more to lime than P. 'Stephens' had a similar response pattern in a 1978 experiment at the same location (Fig. 3). Take-All root rot (*Gaeumannomyces graminis* var. *tritici*) was a major factor limiting yield in 1978, but was not important in 1979. 'Yamhill' and Ymh/Hys 2M6 outyielded 'Stephens' on

TABLE 4. Lime and Phosphorus Fertilization Effects on Variety Grain Yields. Douglas Co., 1979.

Variety	Fertilizer Treatments*			
	L_0P_0	L_0P_+	L_+P_0	L_+P_+
	-------- metric tons/ha ----------			
Yamhill	5.00	6.80	5.05	6.50
Ymh/Hys 2M6	4.80	6.05	5.50	5.90
Stephens	2.55	4.65	6.15	5.90
McDermid	2.05	5.15	4.65	6.05
Hyslop	2.40	5.50	4.20	4.60
Hyslop Al. Tol.	2.35	5.60	4.90	5.85
Hyslop sel. R9401	1.40	5.00	4.60	5.80
Ave.	2.95	5.55	5.00	5.80

*L_0, L_+ = 0 and 4480 kg $CaCO_3$/ha, respectively

P_0, P_+ = 0 and 29 kg P/ha, respectively

LSD (.05) between varieties within a fertilizer treatment = 1.76

LSD (.05) between L_0P_0 and L_0P_+ within a variety = 1.32

LSD (.05) between L_0P_0 and L_+P_0 within a variety = 1.56

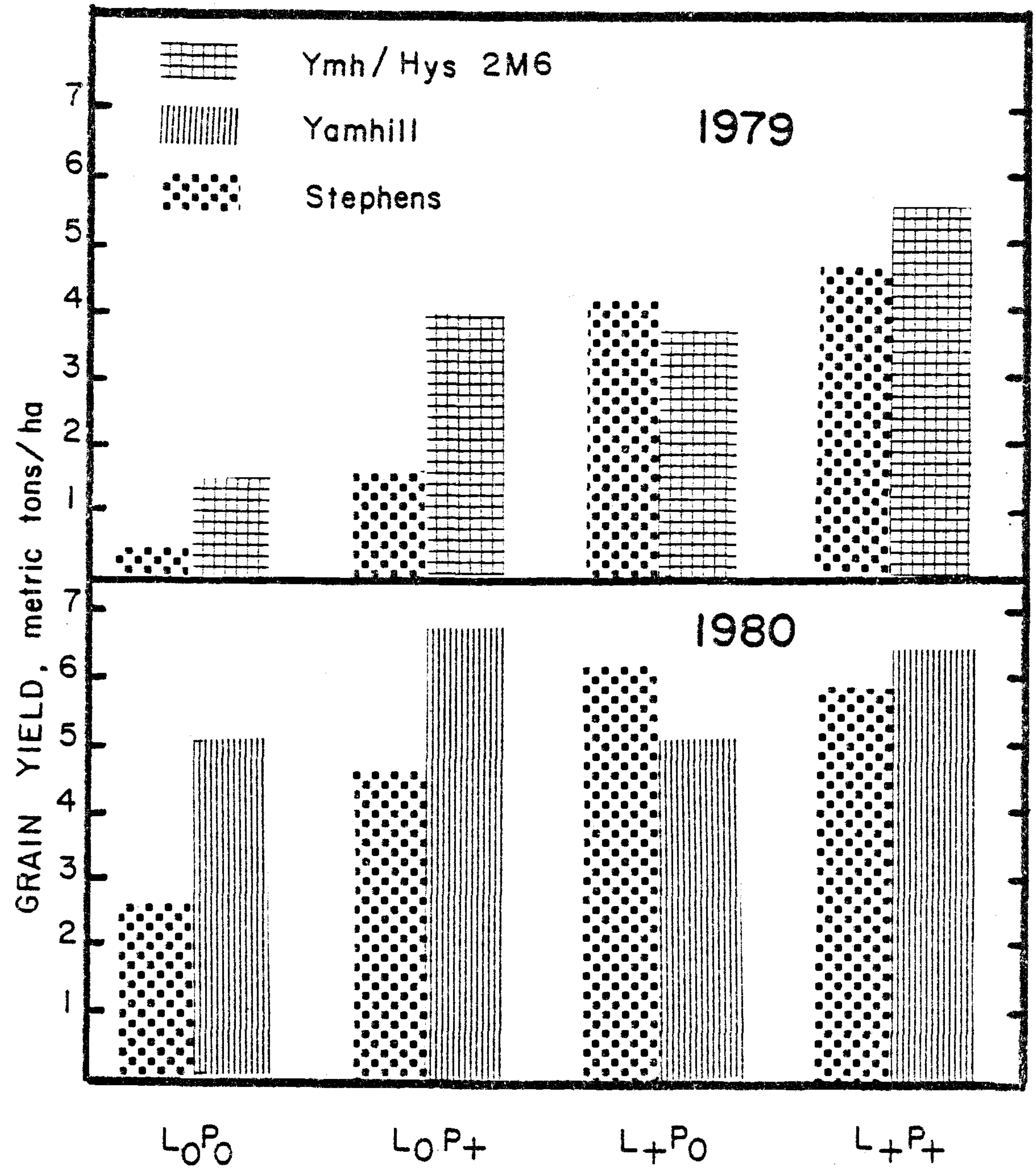

Figure 3. Lime and phosphorus fertilization effects on grain yield of 'Stephens', 'Yamhill' and Ymh/Hys 2M6 winter wheat. 1979, 1980 Douglas Co. location.

L_0P_0 and L_+P_0 plots in both years,[2/] while variety yields were comparable on L_+P_0 and L_+P_+ treatments.

The lime response of 'Stephens' suggests that this variety is especially sensitive to soil acidity. Aluminum toxicity could be responsible for the low yield of 'Stephens' on L_0 plots. 'Stephens' has been shown to be very sensitive to soluble Al in solution cultures (Konzak et al., 1976). However, the following observations suggest that Al toxicity was of limited importance at this location:

1. 'McDermid' and 'Hyslop' are as sensitive to Al as 'Stephens' (Moore et al., 1976), but these varieties responded more to P fertilization than liming.

2. 'Hyslop Al Tolerant' did not outyield 'Hyslop'.

3. Total bases on the unlimed soil averaged 11.7 meq/100 g, which should reduce the potential for Al toxicity (Ali, 1973).

The lime response of 'Stephens' could also be associated with greater susceptibility to Mn toxicity than the other varieties. Wheat varieties have shown striking differences in tolerance to high levels of Mn (Foy et al., 1973; Neenan, 1960). Yield reduction from Mn toxicity has been reported at leaf Mn concentrations of 200 mg/kg in barley (White, 1970) and 400 mg/kg in 'Atlas 66' wheat (Foy et al., 1973). Leaf Mn averaged across varieties at mid-tillering was reduced from 196 mg/kg on L_0P_0 plots to 115 mg/kg on L_+P_0 plots as soil pH increased from 5.2 to 6.4 (Table 5). 'Stephens' had the highest leaf Mn concentrations, while 'Yamhill' and Ymh/Hys 2M6 had the lowest Mn levels. The other varieties had intermediate Mn concentrations.

A number of factors must be considered in evaluating the leaf Mn concentrations for 'Stephens' and 'Yamhill'. The plant part sampled (two uppermost fully expanded leaves) probably does not show the highest Mn levels in the plant. In a toxicity situation, leaf Mn increases with leaf age (Reid, 1965). The different leaf Mn values for the two varieties could be a product of the more rapid growth of 'Yamhill', resulting in a dilution effect. 'Stephens' may also be more sensitive than 'Yamhill' to comparable leaf Mn levels. Further research is needed to determine

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[2/] Yamhill and Ymh/Hys 2M6 had similar yield responses in 1980 at the Douglas Co. location. In 1979, 'Yamhill' was not harvested due to bird damage.

TABLE 5. Lime and Phosphorus Fertilization Effects on Leaf[1/] Manganese Concentration. Douglas Co., 1979.

Variety	Fertilizer Treatments[2/]				
	L_0P_0	L_0P_+	L_+P_0	L_+P_+	Ave.
	-----------------	mg Mn/kg	-----------------		
Yamhill	193	155	102	111	134
Ymh/Hys 2M6	147	155	98	108	126
Stephens	224	209	123	126	171
McDermid	196	207	122	122	161
Hyslop	207	187	121	107	156
Hyslop Al Tol.	190	189	115	122	154
Hyslop sel. R9401	186	163	118	113	145
Nugaines	227	198	122	141	169
Ave.	196	179	115	118	

1/ Two youngest fully expanded leaves sampled at mid-tillering (Mar. 6)

2/ L_0, L_+ = 0 and 4480 kg $CaCO_3$/ha; P_0, P_+ = 0 and 29 kg P/ha

LSD (.05) for fertilizer treatment averages = 10

LSD (.05) for variety averages = 33

the susceptibility of 'Yamhill' and 'Stephens' to Mn toxicity.

Linn Co., 1979

Soil acidity was not a major factor limiting yield at this location. Two lime applications in the five years previous to the experiment had raised soil pH to 5.3 and left pockets of unreacted lime. The potential for Mn reduction under waterlogged soil conditions was minimized by tile drainage.

Plant survival was reduced by a combination of late planting (Oct. 20) and low temperatures during Nov., Dec., and Jan. The effects of P fertilization on plant survival were evident in stand counts taken in March; P_0 and P_+ plots averaged 31 and 37 plants/m of row, respectively (Table 6). Stand counts for whole plots in March were not related to grain yield of the harvest rows (r = 0.11). Stand differences were minimized by the harvest method or by higher yields per plant on plots with poor stand.

The effects of P fertilization on variety yields are shown in Table 7. Average P response was significant at the 1% level; P_0 and P_+ plots averaged 452 and 522 g/plot, respectively. The spotty stand and the small area harvested increased the variability of the yield data, obscuring variety differences in P response. However, the relative performance of the varieties suggested three distinct groups: 1) low yielding, not responsive to P: 'Daws', 'Nugaines', and 'McDermid', 2) high yielding, not responsive to P: Ymh/Hys 2M6, 'Yamhill', 'Hyslop', 'Hyslop Al Tolerant', and Hyslop sel. R9401, and 3) low yielding on P_0 plots, highly responsive to P: 'Stephens'.

Phosphorus Uptake, P Concentration, Yield Relationships

Phosphorus uptake (whole tops at Feekes 8-9) and P concentration (whole tops at Feekes 2-3) increased as a result of P fertilization at the Linn Co. location (Table 6). Phosphorus fertilization increased P concentration from .28 to .44% and P uptake from 122 to 172 mg P/m of row.

Relationships between P uptake, P concentration and grain yield were

TABLE 6. Summary of Phosphorus Fertilization Effects. Linn Co., 1979.

Fert. Trt.	Variety[+] Ave.	LSD[§]	Correlation[¶] With Grain Yield	Varieties: Ymh/Hys 2M6	Varieties: Stephens	Varieties: Nugaines	LSD[†]
kg P/ha	---- SURVIVAL, plants/m of row (Mar. 2, Feekes 3-4) ----						
0	31	4	.11	30	16	34	11
29	37			39	27	41	
	---- LEAF P, % (Jan. 25, Feekes 2-3) ----						
0	.28	.01	.24	.27	.28	.27	.03
29	.44			.39	.44	.40	
	---- WHOLE PLANT P, % (May 7, Feekes 8-9) ----						
0	.29	NS	NS	.27	.30	.27	NS
29	.27			.27	.29	.28	
	---- P UPTAKE, mg P/m of row (May 7, Feekes 8-9) ----						
0	122	18	.61	140	100	97	48
29	172			183	200	121	
	---- GRAIN YIELD, g/plot ----						
0	452	39		600	290	310	116
29	522			635	560	420	

[+] Averaged across varieties in Table 7.

[§] LSD (.05) for average P response across varieties.

[¶] Each simple correlation coefficient has 71 degrees of freedom
p (.05) = .23
p (.01) = .30

[†] LSD (.05) for P response within varieties.

TABLE 7. Phosphorus Fertilization Effects on Variety Grain Yields. Linn Co., 1979.

Variety	Fert. Trt.* P_0	Fert. Trt.* P_+	Variety Ave.
Yamhill	490	520	505
Ymh/Hys 2M6	600	635	618
Stephens	290	560	425
McDermid	380	430	403
Hyslop	490	540	515
Hyslop Al Tol.	590	580	585
Hyslop R9401	560	580	570
Nugaines	310	420	365
Daws	370	440	405
Ave.	452	522	

* P_0, P_+ = 0 and 29 kg P/ha, respectively

LSD (.05) Between variety means = 170

LSD (.05) Response to P within a variety = 116

LSD (.05) Average response to P = 39

investigated using simple correlation (Table 6). The correlation between P concentration at early tillering and yield was very low (r = 0.24), showing that varieties had widely different yield responses with comparable P concentrations. A better relationship (r = 0.61) was found between P uptake at Feekes 8-9 and yield (Fig. 4).

The relationships between yield and P uptake for 'Stephens' and Ymh/Hys 2M6 are shown in Table 6. Phosphorus fertilization increased P uptake and yield 100 and 93%, respectively for 'Stephens'. Ymh/Hys 2M6 was less responsive to P fertilization. Grain yield of Ymh/Hys 2M6 increased 6% and P uptake 30% with P fertilization.

Increases in P uptake can be due to increases in P concentration or dry matter produced, or a combination of the two factors. Phosphorus concentrations in whole plants on May 7 (Feekes 8-9) were the same for all varieties and both P treatments (Table 6). Therefore, variation in P uptake was primarily due to differences in dry matter production.

In relating P uptake to yield, it is important to remember that P deficiency affects many yield components. Reductions in spikelet number/ear (Rahman and Wilson, 1977), tillers/plant (Boatwright and Viets, 1966), and kernel weight (Sutton, 1980) have been attributed to P deficiency. The varieties used in this experiment have genetic differences in these yield components. Varieties from the WSU breeding program have the most tillers, but produce the smallest heads. OSU varieties produce fewer tillers, but have larger heads; 'Stephens' has the largest heads, while 'Hyslop' and 'Yamhill' have about equal head size (personal communication, Dr. Fred Cholick, Crop Science Dept., OSU).

The Linn Co. experiment shows that variation in P uptake is related to variety yield responses on soils where P supply is the primary limiting factor. The interaction between P nutrition, tiller production, and head size in these varieties needs further study.

Leaf Phosphorus Critical Levels

The previous section showed that 'Stephens' and 'Yamhill' responded differently to low soil P. The second objective of this study was to

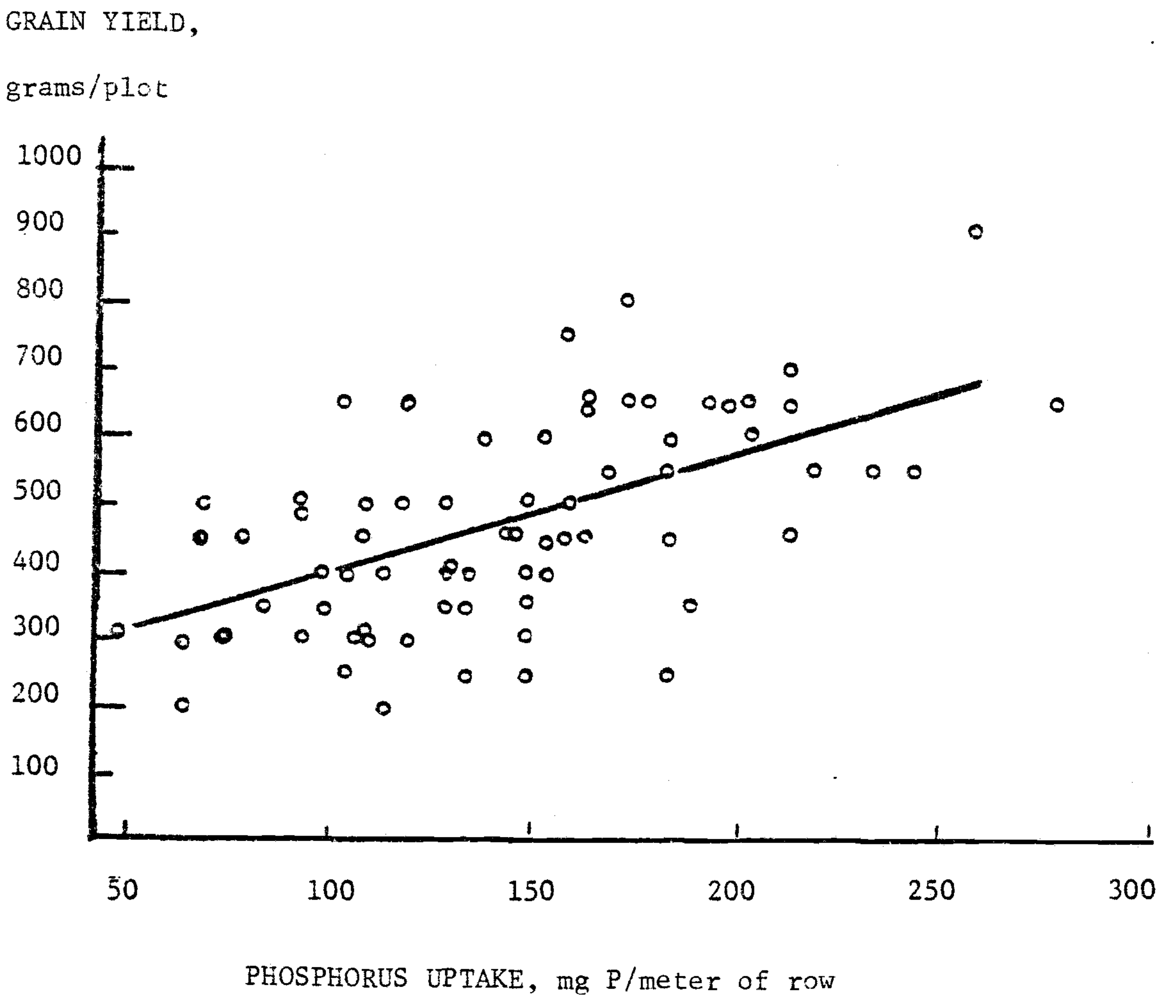

Figure 4. The relationship between phosphorus uptake of nine winter wheat varieties at the Feekes 8-9 growth stage and grain yield. 1979 Linn Co. location.

determine leaf P critical levels for these varieties at different growth stages during tillering.

Changes in Leaf Phosphorus During Tillering

Variation in planting date, location, and winter temperatures produced large differences in growth stage at the same calendar date. For example, on March 18, 1980, wheat seeded Oct. 11 at Hyslop farm was at Feekes 6; while the Nov. 9 planting at the Benton Co. location was at Feekes 3-4.

The effects of lime and P fertilization on leaf P concentration during tillering at the 1979 Douglas Co. location are shown in Table 8. Both 'Yamhill' and 'Stephens' maintained a nearly constant leaf P concentration on L_0P_0 plots; 'Yamhill' ranged from .33 to .34% P, 'Stephens' from .36 to .38% P across sample dates. Liming did not affect leaf P concentration at early tillering, while P fertilization increased leaf P dramatically. Lime, P, and lime + P treated plots had similar leaf P at mid-tillering, ranging from .38 to .43% for 'Yamhill', and .41 to .42% for 'Stephens'. Between early and mid-tillering, P concentrations increased slightly on limed plots, and fell dramatically on P fertilized plots. At late tillering (Feekes 4-5), leaf P was not positively related to grain yield, with P fertilized plots having lower leaf P concentrations than L_0P_0 plots.

Lime and P fertilizer treatments resulted in similar yield responses at the 1979 Douglas Co. location, but had different effects on leaf P at early tillering. The failure of liming to increase leaf P at early tillering is probably due to low soil temperatures and the low P supply at this location (12 ppm P -- Bray #1 soil test). Low soil temperatures slow the rate of P release from the solid phase and the rate of diffusion to the plant root (Sutton, 1969). Banded monocalcium phosphate supplies P even under cold soil conditions by maintaining zones of high P concentration near seedling roots. Power et al. (1964) demonstrated that barley is capable of continued P uptake at temperatures which restrict top growth, resulting in high P concentrations in the tops. The very high leaf P (.60 to .67%) on the banded P treatment at early tillering

TABLE 8. Lime and Phosphorus Fertilization Effects on Leaf Phosphorus Concentration of Yamhill and Stephens Winter Wheat. Douglas Co., 1979.

Variety	Fertilizer Treatment Lime	P	Feekes Growth Stage 2-3 early tillering Dec. 15	3-4 mid tillering March 6	4-5 late tillering March 21
	- kg/ha -		---------------- P, % ----------------		
Yamhill	0	0	.34	.33	.34
	0	29	.60	.41	.31
	4480	0	.34	.38	.36
	4480	29	.62	.43	.30
Stephens	0	0	.36	.36	.38
	0	29	.69	.41	.32
	4480	0	.37	.41	.38
	4480	29	.67	.42	.36

is probably the result of continued P uptake from the fertilizer band accompanied by limited top growth.

A rapid change in leaf P concentration during tillering was found on P fertilized plots at sites having initial P soil test values ranging from 8 to 112 ppm P (Bray #1 method) (Fig. 5). Leaf P decreased from .63 to .36% across locations between Feekes 2-3 and Feekes 5-6. Leaf P at early tillering was comparable at high and low initial P soil test values, indicating that a large portion of leaf P was derived from the fertilizer band. Leaf P was related to P availability in the bulk soil at Feekes 5-6. The correlation between leaf P and P soil test ($r = 0.89$) was significant at the 5% level.

Critical P Levels for 'Yamhill' and 'Stephens'

The relationship between leaf P concentration and relative grain yield[3/] across locations at two growth stages is shown in Figure 6 for 'Stephens' and Figure 7 for 'Yamhill'. Relative yield (%) was used instead of absolute yield to minimize the variation in yield potential between locations, growing seasons, and varieties. Leaf P concentration at 90% relative yield was defined as the critical level. Critical levels were .42 and .39% P for 'Stephens', .39 and .31% P for 'Yamhill' at early and mid-tillering, respectively. The relationship between leaf P and yield at early tillering was significant at the 1% level for 'Stephens' ($R = 0.95$), and at the 10% level for 'Yamhill' ($r = 0.69$). At mid-tillering, the amount of variation in yield explained by leaf P was lower, but still significant for 'Stephens' ($R = 0.78$); the yield of 'Yamhill' ($r = 0.43$) was not significantly related to leaf P. A quadratic equation best fit the relationship between yield and leaf P for 'Stephens'. The yield response of 'Yamhill' was best described by a straight line because of the high yields of this variety on P_0 plots having low leaf P.

[3/] Relative yield at each location =

$$\frac{\text{Yield without P fertilization } (P_0)}{\text{Yield with P fertilization } (P_+)} \times 100$$

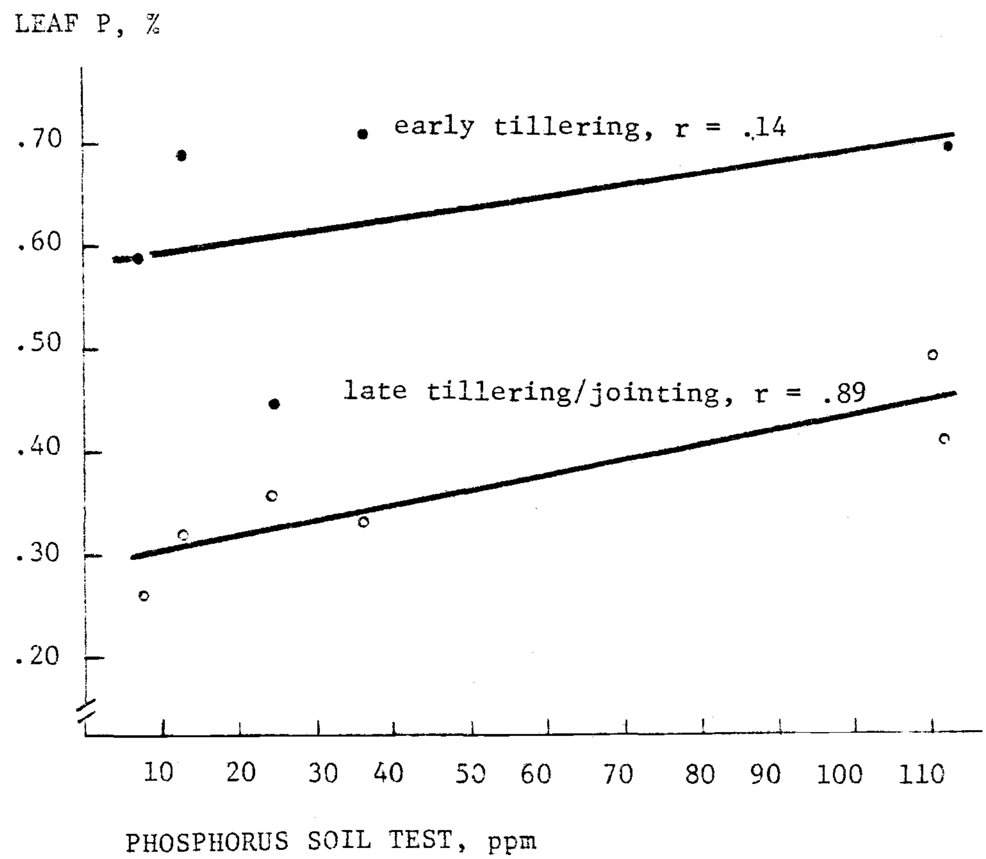

Figure 5. The relationship between the initial Bray #1 soil test and leaf phosphorus concentrations at early tillering (Feekes 2-3) and late tillering/jointing (Feekes 5-6) on phosphorus fertilized plots. 1979, 1980 Western Oregon locations.

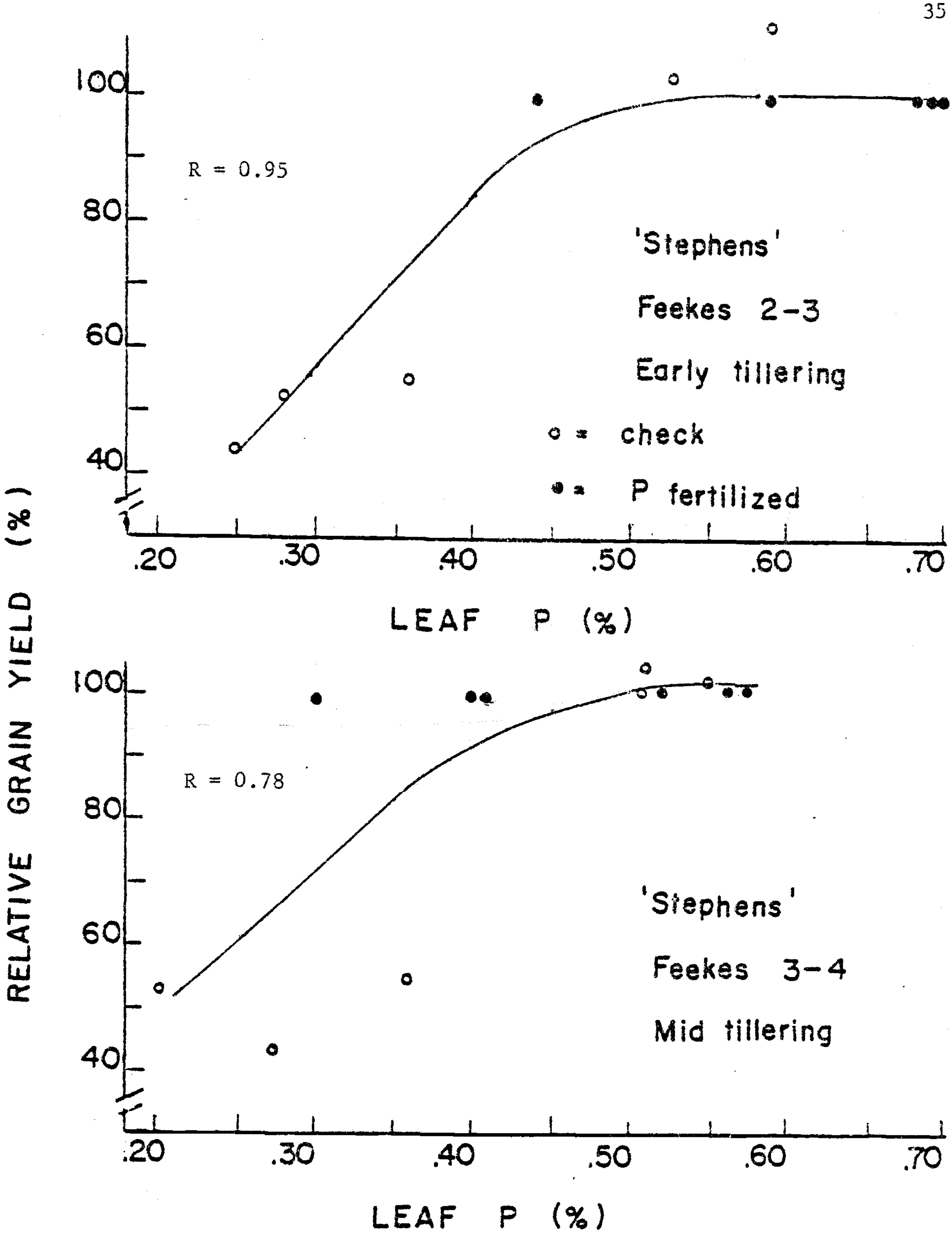

Figure 6. The relationship between leaf phosphorus concentration and relative grain yield of 'Stephens' winter wheat at two growth stages. 1979, 1980 Western Oregon locations.

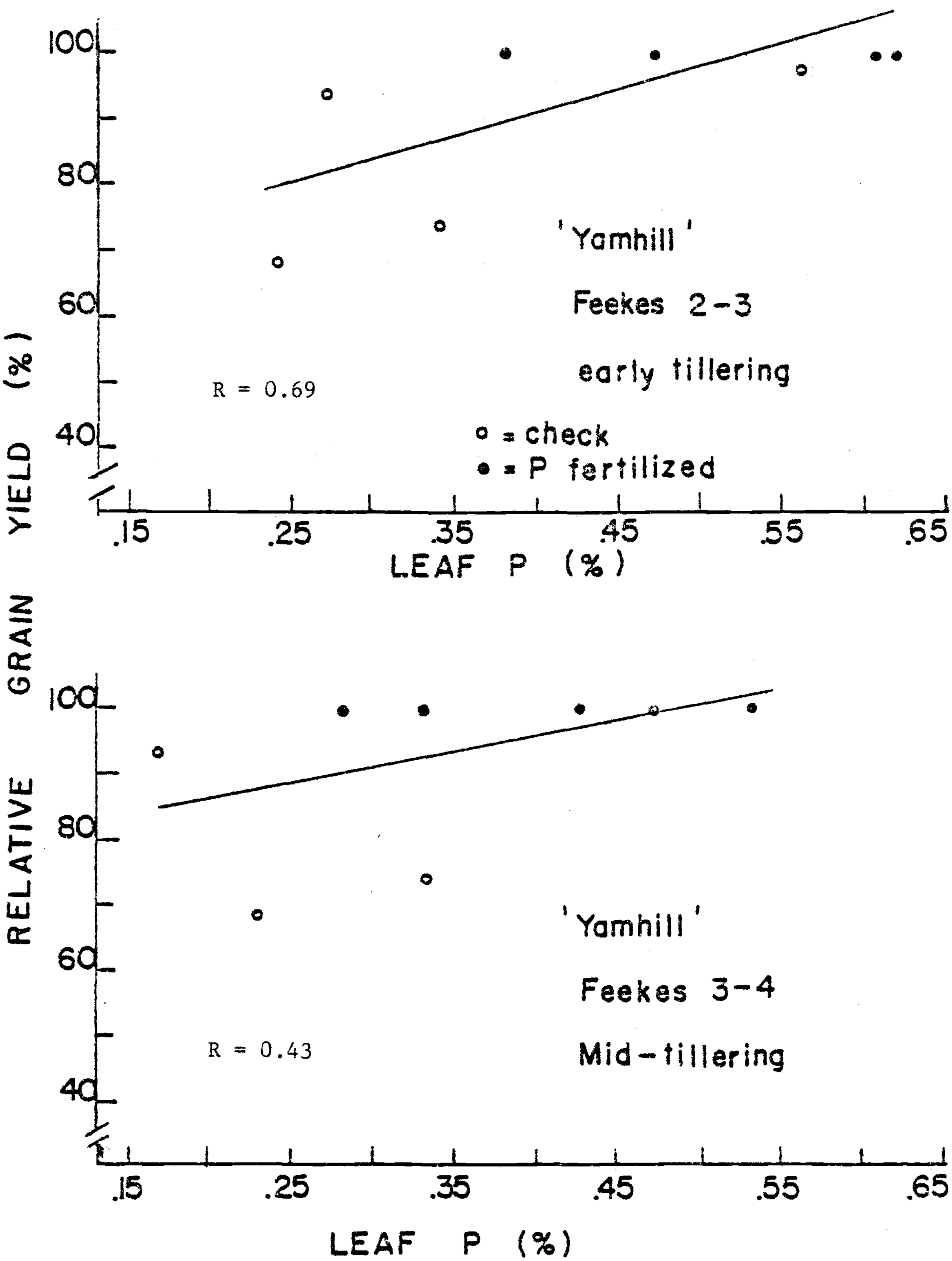

Figure 7. The relationship between leaf phosphorus concentration and relative grain yield of 'Yamhill' winter wheat at two growth stages. 1979, 1980 Western Oregon locations.

The most striking difference between 'Stephens' and 'Yamhill' in yield response at comparable leaf P concentrations was found at the 1980 Benton Co. location (Fig. 8). Variety P response was best described by parallel lines, with 'Yamhill' having a greater grain yield at P concentrations ranging from .23 to .55%. The confidence interval for the difference in yield between the varieties was 1.06 to 2.54 metric tons/ha at the 5% level.

The yield responses of five varieties ('Yamhill', 'Daws', 'Stephens', 'McDermid', and 'Hyslop') were similarly related to leaf P (r = 0.68) when leaf samples were taken at mid-tillering at the 1980 Benton Co. location (Fig. 9). The correlation was improved (r = 0.83) when the 'Stephens' P_0 plots (marked "S" in Fig. 9) were omitted, suggesting that 'Stephens' has a higher P requirement than the other varieties. The slope of the P response line was much steeper at mid-tillering than at early tillering (Fig. 8), because of the smaller range of P concentrations. Leaf P ranged from .23 to .55% at early tillering, and from .13 to .33% at mid-tillering. Grain yield increased as leaf P increased up to the highest leaf P concentration (.33%), making an estimate of the critical level impossible.

The leaf P analyses for 'Yamhill' and 'Stephens' during tillering show the importance of specifying the variety and growth stage in identifying a critical level. The variety altered the magnitude of P response at low leaf P, while growth stage affected the range between sufficient and deficient leaf P concentrations.

DRIS Nutrient Ratios

Nutrient ratios have been used as a measure of the nutritional status of plant tissue. Sumner (1977) has proposed a method (Diagnosis and Recommendation Integrated System -- DRIS) using K/P, N/P, and N/K ratios for identifying N, P, and K deficiencies in wheat plants at any stage of growth. The DRIS system operates on the assumption that N, P, and K concentrations in wheat plants decline at the same rate during the growing season.

The effect of growth stage and P fertilization on leaf K/P ratios

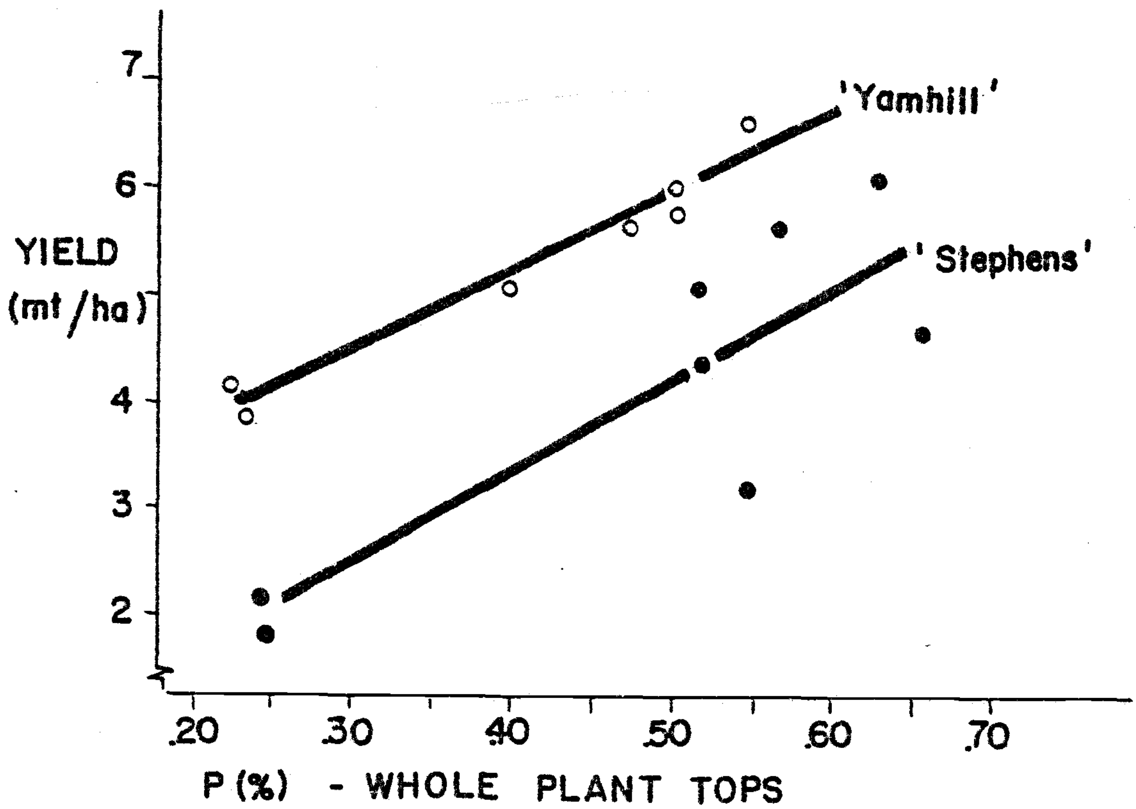

Figure 8. The relationship between the phosphorus concentration of 'Stephens' and 'Yamhill' plant tops at early tillering (Feekes 2-3) and grain yield. 1980 Benton Co. location.

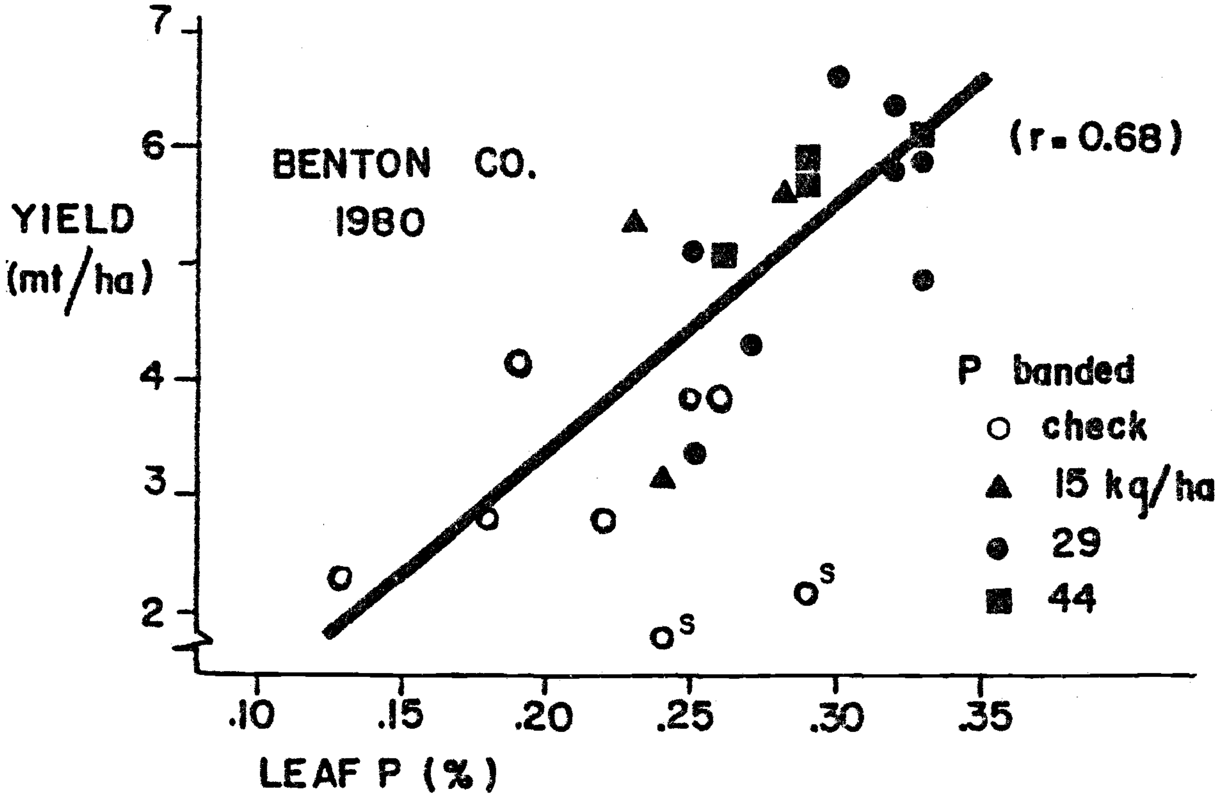

Figure 9. The relationship between the phosphorus concentration of five winter wheat varieties at mid-tillering (Feekes 3-4) and grain yield. 1980 Benton Co. location. Points marked "S" are 'Stephens' check plots.

was evaluated at three western Oregon locations: Benton Co., 1980 (Fig. 10), Linn Co. 1979 (Table 9), and Douglas Co. 1979 (Table 10). Leaf samples were not analyzed for N. The N concentration in the leaf prior to the spring N application is not related to yield under western Oregon conditions (Roberts et al., 1972).

Leaf P and K concentrations did not decline at the same rate during the growing season. Leaf P declined rapidly during tillering, while leaf K remained nearly constant. For example, leaf P dropped from .56 to .26% in P fertilized plants between early tillering and noding at the 1980 Benton Co. location (Fig. 11), while leaf K declined from 2.6 to 2.4%. Phosphorus fertilization did not affect leaf K.

Leaf K/P ratios on P fertilized plots increased during tillering as a consequence of the rapid dilution of leaf P. For example, leaf K/P ratios increased from 4.6 to 8.7 between early and mid-tillering at the 1980 Benton Co. plots (Fig. 10). Similar increases in K/P ratios on P fertilized plots were observed at Linn Co. (Table 9) and Douglas Co. (Table 10) plots.

The diagnosis of plant P and K nutrition via the DRIS system changed as leaf K/P ratios increased. Phosphorus fertilized plots were diagnosed as K deficient at early tillering, while K/P ratios at mid-tillering were in the range of optimum P and K balance (8.80 $\pm$ .90). The P_0 plots had K/P ratios closer to optimum balance than P_+ plots at early tillering.

The high P concentration found in early tillering leaf samples from P fertilized plots is probably responsible for the failure of DRIS at this growth stage. The optimum K/P ratio was derived predominantly from wheat plants sampled between jointing (Feekes 6) and heading (Feekes 10.1) with P and K concentrations ranging from .20 to .35%, and 1.5 to 3.5%, respectively (Sumner, 1977).

The most appropriate growth stage for using DRIS in western Oregon was mid-tillering (Feekes 3-4). Locations which had large P yield responses had K/P ratios on P_0 plots predicting P deficiency, and near optimum K/P ratios on P fertilized plots (Table 11). However, DRIS predicted severe K deficiency at Polk and Jackson Co. locations where P and K were not limiting yield.

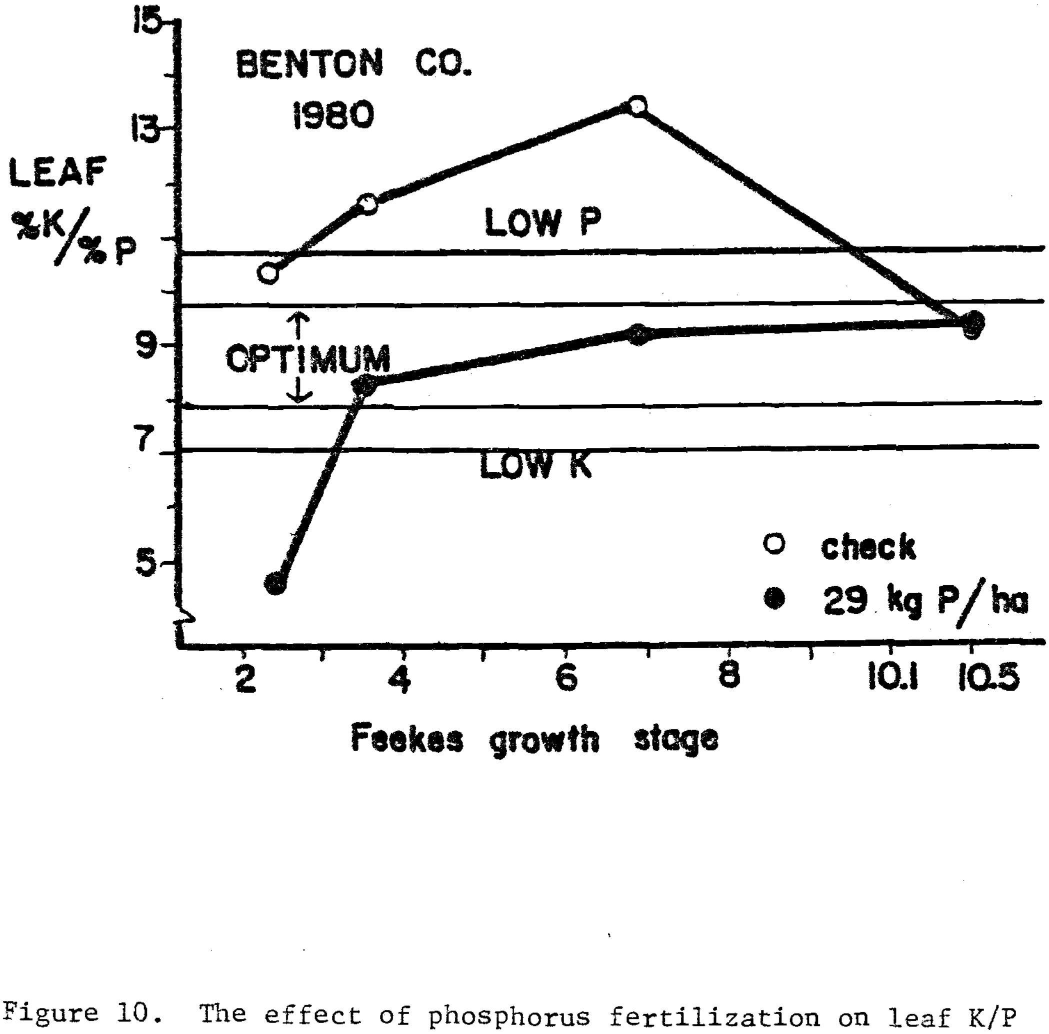

Figure 10. The effect of phosphorus fertilization on leaf K/P ratios at different Feekes growth stages. 1980 Benton Co. location.

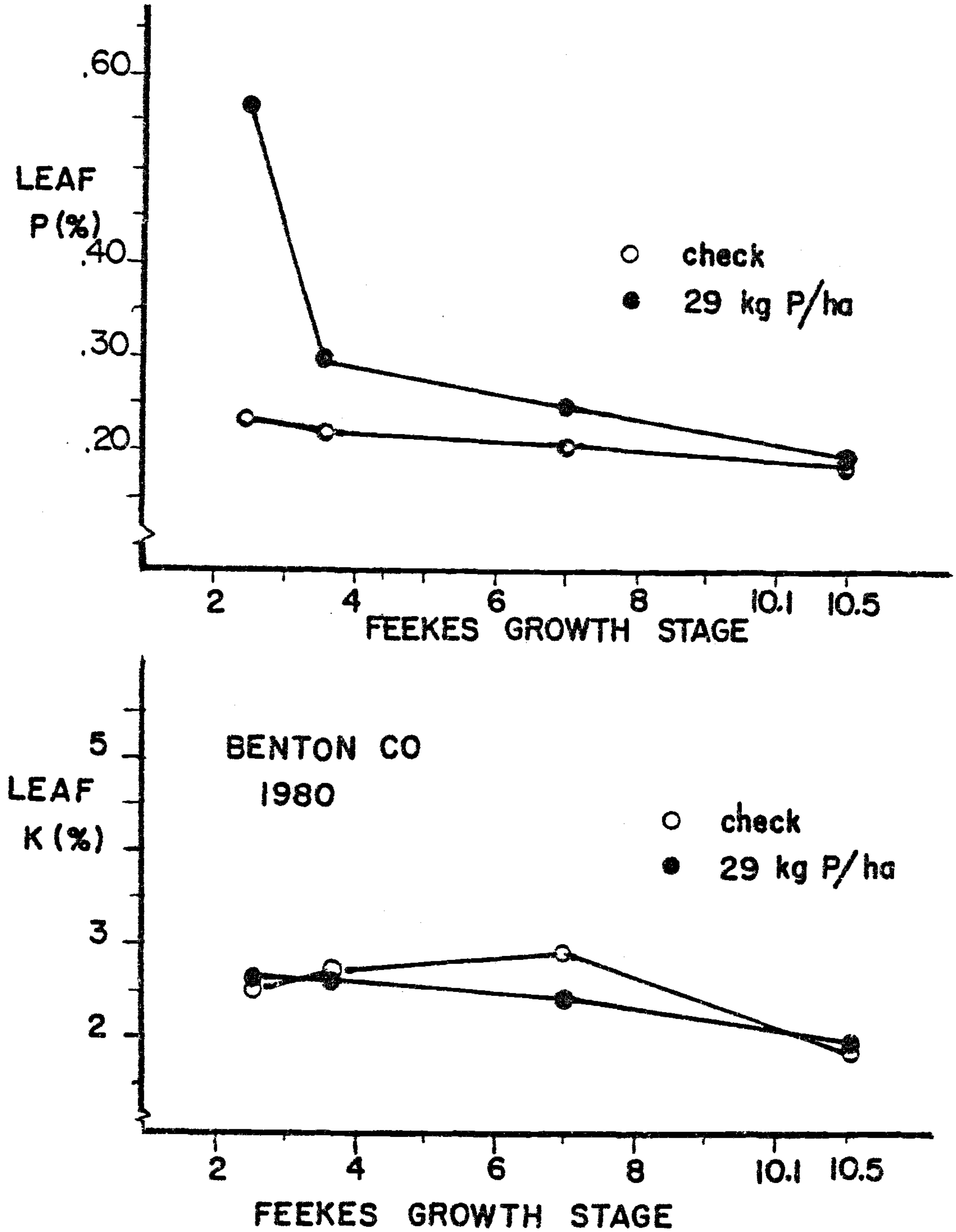

Figure 11. The effect of phosphorus fertilization on leaf P and K concentrations at different Feekes growth stages. 1980 Benton Co. location.

TABLE 9. Phosphorus Fertilization Effects on Leaf P, K, and K/P Ratios of Winter Wheat* at Three Growth Stages. Linn Co., 1979.

Fertilizer Treatment	Feekes Growth Stage		
P	2-3 early tillering	3-4 mid tillering	4-5 late tillering
- kg/ha -	----------------	K, %	----------------
0	2.2	3.3	3.7
29	2.1	3.1	3.5
	----------------	P, %	----------------
0	.27	.19	.30
29	.41	.37	.34
	----------------	K/P	----------------
0	8.2	17.4	12.3
29	5.1	8.4	10.3

* Varieties included in fertilizer treatment means: Stephens and Yamhill

TABLE 10. Lime and Phosphorus Fertilization Effects on Leaf P, K, and K/P Ratios of Winter Wheat* at Three Growth Stages. Douglas Co., 1979.

Fertilizer Treatment		Feekes Growth Stage		
Lime	P	2-3 early tillering	3-4 mid tillering	4-5 late tillering
- kg/ha -			K, %	
0	0	3.7	4.4	4.2
0	29	3.7	4.3	3.6
4480	0	3.8	4.4	4.1
4480	29	3.9	4.2	3.8
			P, %	
0	0	.35	.35	.36
0	29	.65	.41	.32
4480	0	.36	.40	.37
4480	29	.65	.43	.33
			K/P	
0	0	10.5	12.6	11.7
0	29	5.7	10.5	11.3
4480	0	10.6	11.0	11.1
4480	29	6.0	9.7	11.5

* Varieties included in fertilizer treatment means: Stephens and Yamhill.

TABLE 11. Soil and Leaf[1] Content of P, K, and Leaf K/P Ratios as Related to Grain Yield of Stephens Winter Wheat[2].

Location, Year	Fert. Trt.	Soil Test		Leaf Analysis			Yield
	P	P	K	P	K	K/P[3]	
	kg/ha	-- ppm --		------- % -------			mt/ha
Benton Co.	0	8	96	.23	2.7	11.7	3.95
80	29			.30	2.6	8.7	5.83
Douglas Co.	0	11	463	.36	4.5	12.5	2.55
79	29			.41	4.3	10.5	4.65
Polk Co.	0	110	289	.50	2.9	5.8	6.83
80	29			.52	3.0	5.8	6.80
Jackson Farm	0	37	94	.51	3.0	5.9	5.38
80	29			.57	2.8	4.9	5.51
Linn Co.	0	24	207	.20	3.3	16.5	3.47
80	29			.40	3.0	7.5	6.70

1/ Leaf samples taken at mid-tillering (Feekes 3-4)

2/ Varieties included in means for Benton Co.: Daws, McDermid, Hyslop, Stephens, Yamhill

3/ Optimum DRIS K/P ratio = 8.80 ± .90

SUMMARY AND CONCLUSIONS

A series of field experiments were conducted in 1979 and 1980 to evaluate wheat variety responses to P fertilization. The varieties 'Yamhill', 'Stephens', 'McDermid', 'Hyslop', 'Hyslop Al Tolerant', 'Nugaines', and 'Daws', and the selections Ymh/Hys 2M6 and Hyslop R9401 were chosen to give a range of P responses. Monocalcium phosphate, $Ca(H_2PO_4)_2$, was banded with the seed at planting at rates of 0 and 29 kg P/ha. Chemical analyses of leaf samples taken during tillering were used to assess the relationship between yield response, plant P, and P uptake.

The conclusions reached in this investigation were:

1. 'Stephens' and 'Yamhill' represent the extremes in variety P response on acid, low P soils in western Oregon. These varieties had comparable yields with optimum fertilization. However, 'Yamhill' outyielded 'Stephens' on plots where P and/or lime was not applied. Some possible explanations for the variety difference are: 1) greater susceptibility of 'Stephens' to Al and Mn toxicity, and 2) superior root growth and P uptake for 'Yamhill'. It was not possible to clearly separate P deficiency and Al or Mn toxicity responses under field conditions.

2. Yield responses for 'Yamhill' and Ymh/Hys 2M6 were similar, showing that tolerance to acid, low P soil conditions can be transferred from 'Yamhill' to other varieties.

3. 'Hyslop', 'Hyslop Al Tolerant', and Hyslop sel. R9401 had comparable yield responses at both locations. The similar response of these varieties can be attributed to their similar parentage.

4. 'Daws' and 'Nugaines' (from WSU) were as low yielding as 'Stephens' on P_0 plots. However, these varieties were not as responsive to P fertilization as 'Stephens'.

5. Phosphorus deficient plants maintained approximately the same P concentration throughout tillering. A rapid dilution of leaf P between early tillering (Feekes 2-3) and jointing (Feekes 6) occurred in plants well supplied with P, whether the source was banded monocalcium phosphate or native soil P. The dilution effect was not as

rapid in plants grown on high native soil P as it was with banded P on a P deficient soil.

6. The best growth stages for identifying a P critical level were early and mid-tillering (Feekes 2-4). The critical level at this stage of growth ranged from .30 to .40%.

7. 'Stephens' and 'Yamhill' had approximately the same critical level. However, below the critical level, the yield of 'Stephens' decreased more rapidly than 'Yamhill'.

8. The DRIS system did not offer any advantages over the critical level approach for diagnosing P and K deficiencies of winter wheat in western Oregon. The best relationship between the K/P ratio and yield was found at the same growth stage (mid-tillering) where leaf P and yield were best correlated. The K/P ratio was only an indirect measurement of the P concentration of the plant, since P fertilization did not affect leaf K.

This study has several practical implications for wheat producers in western Oregon. Factors such as the soil temperature at planting, the potential for Take-All root rot, and the soil pH should be considered along with P soil test results in selecting the variety to be grown and the P fertilizer program. Plant samples taken at Feekes 2-4 (early to mid-tillering) are the most useful in determining whether an adequate amount of P fertilizer has been applied. Plant samples taken after Feekes 6 (jointing) are not useful in diagnosing P nutrition, because of dilution effects.

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APPENDICES

APPENDIX TABLE 1. Analysis of Variance for Grain Yield Douglas Co., 1979

Source of Variation	df	MS	Calculated F
Blocks	3	1.26	1.07
Varieties	6	7.04	5.97**
Main plot error	18	1.18	
Lime	1	41.10	14.17**
Lime x Var.	6	4.03	1.39
Subplot error	21	2.90	
Phosphorus	1	83.70	97.28**
Lime x P	1	24.55	28.55**
Variety x P	6	1.79	2.08#
Var. x Lime x P	6	0.84	0.98
Sub/subplot error	42	0.86	
TOTAL	111		

** Significant at 1% level

Significant at 10% level

APPENDIX TABLE 2. The Effects of Lime and Phosphorus Fertilization on Yield, Stand, and Chemical Analysis of Leaf Samples at Early Tillering (Dec. 15) and Mid-Tillering (Mar. 6). Douglas Co., 1979.

Variety	Fert. Trt.		Yield	Survival	Chemical Analysis of Leaves						
					Dec. 15					March 6	
	Lime	P			P	K	Ca	Mg	Mn	P	Mn
	--kg/ha--		metric tons/ha	plants/m of row	------------- % ---------				mg/kg	%	mg/kg
Yamhill	0	0	5.00	17	.34	3.6	.20	.20	185	.33	193
	0	29	6.80	21	.60	3.7	.22	.21	160	.41	155
	4480	0	5.05	29	.34	3.8	.25	.20	136	.38	102
	4480	29	6.50	23	.62	4.0	.25	.22	131	.43	111
Hyslop sel. R9401	0	0	1.40	11	.34	4.0	.23	.22	269	.39	186
	0	29	5.00	19	.68	4.0	.23	.20	164	.42	163
	4480	0	4.60	17	.36	4.2	.26	.20	181	.39	118
	4480	29	5.80	27	.68	4.1	.27	.20	139	.43	113
Ymh/Hyslop	0	0	4.80	22	.33	3.6	.21	.19	203	.37	147
	0	29	6.05	31	.65	3.4	.21	.19	168	.43	155
	4480	0	5.50	31	.36	3.5	.23	.18	155	.39	93
	4480	29	5.90	34	.61	3.7	.23	.18	124	.42.	108
Nugaines	0	0	2.65	22	.36	4.0	.26	.23	196	.41	227
	0	29	5.36	32	.62	3.7	.25	.21	149	.41	198
	4480	0	3.90	33	.37	4.3	.27	.23	162	.38	122
	4480	29	5.34	36	.63	4.2	.25	.20	132	.43	141
Stephens	0	0	2.55	19	.36	3.7	.34	.24	245	.36	224
	0	29	4.65	20	.69	3.7	.32	.23	188	.41	209
	4480	0	6.15	25	.37	3.7	.38	.24	156	.41	123
	4480	29	5.90	32	.67	4.1	.34	.22	152	.42	126
Hyslop Al Tolerant	0	0	2.35	19	.33	4.0	.25	.21	206	.41	190
	0	29	5.60	29	.70	4.0	.24	.20	176	.40	189
	4480	0	4.90	25	.35	4.0	.29	.19	135	.40	115
	4480	29	5.85	34	.69	4.4	.29	.19	151	.41	122
McDermid	0	0	2.05	19	.32	3.9	.23	.20	221	.31	196
	0	29	5.15	22	.71	3.9	.23	.18	154	.41	207
	4480	0	4.65	31	.33	4.4	.26	.18	174	.39	122
	4480	29	6.05	34	.70	4.2	.25	.18	124	.45	122
Hyslop	0	0	2.40	22	.33	3.7	.26	.22	226	.36	207
	0	29	5.50	29	.72	3.8	.27	.21	165	.39	187
	4480	0	4.20	33	.36	3.7	.29	.21	187	.41	121
	4480	29	4.60	36	.71	3.8	.30	.20	140	.43	107

APPENDIX TABLE 3. Analysis of Variance for Grain Yield
Linn Co., 1979

Source of Variation	df	MS	Calculated F
Blocks	3	12,800	0.47
Varieties	8	66,300	2.46*
Main plot error	24	27,000	
Phosphorus	1	89,300	14.00**
P x Variety	8	13,500	2.12
Subplot error	27	6,380	

* Significant at 5% level

** Significant at 1% level

APPENDIX TABLE 4. The Effects of Phosphorus Fertilization on Grain Yield, Stand, Leaf P Concentration, and P Uptake. Linn Co., 1979.

Variety	Fert. Trt. P	Yield	Survival	Leaf P Feekes 2-3 Jan. 25	Leaf P Feekes 3-4 Mar. 2	P Uptake Feekes 8-9
	kg/ha	g/plot	plants/m of row	-------- %	------	mg P/m of row
Hyslop	0	590	21	.28	.20	116
Al Tol	29	580	36	.47	.36	191
Hyslop	0	490	33	.29	.19	138
	29	540	32	.48	.37	169
Stephens	0	290	16	.28	.20	100
	29	560	27	.44	.40	200
McDermid	0	380	37	.31	.19	131
	29	430	43	.49	.37	177
237	0	350	11	.28	.21	62
	29	570	16	.49	.42	148
Ymh/Hys	0	600	30	.27	.18	140
2M6	29	635	39	.39	.33	183
Hyslop	0	560	43	.28	.20	141
sel. R9401	29	580	47	.49	.37	209
Daws	0	370	43	.32	.21	113
	29	440	39	.44	.42	147
Nugaines	0	310	34	.27	.17	97
	29	420	41	.40	.32	121
Yamhill	0	490	26	.26	.17	128
	29	520	33	.38	.33	148
Lillifen/	0	320	16	.31	.24	66
Vogal	29	450	17	.55	.45	116
Maris	0	450	15	.32	.24	108
Hobbit	29	470	28	.49	.42	134
Faro	0	470	35	.28	.21	136
	29	410	31	.44	.39	125
Triticale	0	330	10	.33	.27	129
	29	580	14	.51	.46	172
Aspen	0	350	7	.34	.24	48
	29	520	17	.54	.44	118

APPENDIX TABLE 5. The Effects of Phosphorus Fertilization on Leaf Mn, Ca, Mg, and K Concentrations at Early Tillering (Jan. 25) and Mid-Tillering (Mar. 2).
Linn Co., 1979

Yield	Fert. trt. P	Mn 1/25	Mn 3/2	K 1/25	K 3/2	Ca 1/25	Ca 3/2	Mg 1/25	Mg 3/2
	kg/ha	mg/kg		%					
Hyslop Al Toi	0	133	156	--	3.4	--	.39	--	.11
	29	126	157	--	3.5	--	.43	--	.13
Hyslop	0	137	163	--	3.4	--	.38	--	.11
	29	131	163	--	3.4	--	.43	--	.13
Stephens	0	128	166	2.3	3.3	.42	.42	.14	.12
	29	131	169	2.1	3.0	.44	.49	.16	.14
McDermid	0	130	163	--	3.3	--	.39	--	.12
	29	112	149	--	3.4	--	.45	--	.12
237	0	138	177	--	3.6	--	.37	--	.11
	29	134	160	--	3.5	--	.39	--	.13
Ymh/Hys 2M6	0	117	136	2.0	2.7	.31	.34	.14	.10
	29	116	125	2.0	3.0	.30	.32	.12	.11
Hyslop sel. R9401	0	134	143	--	3.6	--	.37	--	.12
	29	133	130	--	3.4	--	.45	--	.13
Daws	0	100	138	--	3.2	--	.38	--	.11
	29	97	145	--	2.9	--	.45	--	.12
Nugaines	0	104	135	2.1	3.0	.29	.37	.13	.10
	29	112	137	2.2	3.3	.32	.40	.14	.12
Yamhill	0	126	136	2.0	3.3	.33	.29	.14	.10
	29	119	149	2.0	3.1	.33	.33	.13	.11
Lillifen/ Vogal	0	197	197	--	3.5	--	.44	--	.14
	29	169	158	--	2.7	--	.49	--	.14
Maris Hobbit	0	171	195	--	3.5	--	.35	--	.15
	29	157	172	--	3.4	--	.42	--	.18
Faro	0	142	190	--	3.0	--	.55	--	.14
	29	128	184	--	3.1	--	.54	--	.15
Triticale	0	205	251	--	3.4	--	.39	--	.13
	29	175	210	--	3.4	--	.46	--	.15
Aspen	0	180	156	--	3.3	--	.29	--	.13
	29	177	175	--	3.5	--	.49	--	.18

APPENDIX TABLE 6. Leaf Analysis Data for Winter Wheat
Hyslop Farm, 1980

Variety	Fert. Trt. P	Feekes Growth Stage 2-3 early tiller Nov. 30	3-4 mid tiller Jan. 18	6 joint Mar. 18	10.5 flowering June 19
	kg/ha	P, %			
Stephens	0	.53	.55	.40	.20
	29	.70	.58	.41	.19
		Mn, mg/kg			
	0	144	149	103	237
	29	149	144	100	223
		K, %			
	0	3.9	3.9	3.4	1.6
	29	3.8	4.0	3.3	1.7
		Ca, %			
	0	.45	.37	.49	.99
	29	.54	.37	.48	.96
		Mg, %			
	0	.18	.17	.12	.22
	29	.18	.17	.12	.20

Planting date: 10-11-79

APPENDIX TABLE 7. Leaf Analysis Data for Winter Wheat[1/] Benton Co., 1980

Fert. Trt. P	Feekes Growth Stage 2-3 early tillering Jan. 22	3-4 mid tillering Mar. 18	7 second stem node visible April 16	10.5 flowering June 19
kg/ha				
	P, %			
0	.24	.23	.21	.19
29	.56	.30	.26	.19
	Mn, mg/kg			
0	120	149	88	134
29	110	127	89	207
	K, %			
0	2.5	2.7	2.9	1.8
29	2.6	2.6	2.4	1.8
	Ca, %			
0	.29	.31	.26	.51
29	.37	.37	.37	.67
	Mg, %			
0	.12	.11	.12	.19
29	.13	.11	.12	.23

[1/] Varieties included in means: Daws, McDermid, Hyslop, Stephens and Yamhill.

Plating date: 11-9-79

APPENDIX TABLE 8. Leaf Analysis Data for Winter Wheat Jackson Farm, 1980

Variety	Fert. Trt. P	Feekes Growth Stage 2-3 early tiller Nov. 30	3-4 mid tiller Jan. 18	6 joint Mar. 18	10.5 flowering June 18
	kg/ha	P, %			
Yamhill	0	.56	.47	.32	.18
	29	.59	.53	.35	.17
Stephens	0	.59	.51	.33	.20
	29	.71	.57	.33	.22
		Mn, mg/kg			
Yamhill	0	119	108	75	191
	29	125	97	71	191
Stephens	0	120	104	71	258
	29	137	127	79	292
		K, %			
Yamhill	0	2.5	2.6	2.4	0.8
	29	2.1	2.5	2.3	0.8
Stephens	0	2.8	3.0	2.4	0.9
	29	3.1	2.8	2.1	0.8
		Ca, %			
Yamhill	0	.53	.34	.47	1.1
	29	.57	.34	.46	1.2
Stephens	0	.51	.51	.57	1.6
	29	.56	.53	.63	1.5
		Mg, %			
Yamhill	0	.28	.19	.16	.33
	29	.31	.20	.15	.34
Stephens	0	.26	.22	.17	.43
	29	.27	.23	.17	.47

Planting date: 10-11-79

APPENDIX TABLE 9. Leaf Analysis Data for Winter Wheat
Polk Co., 1980

Variety	Fertilizer Treatment P	Feekes Growth Stage: 3-4 mid tillering Feb. 14	6 jointing April 1	10.1 heading May 20
	kg/ha	P, %		
Stephens	0	.50	.48	.20
	29	.52	.49	.20
		Mn, mg/kg		
	0	57	52	109
	29	65	54	110
		K, %		
	0	2.9	2.6	1.8
	29	3.0	2.3	1.9
		Ca, %		
	0	.54	.78	.82
	29	.55	.78	.77
		Mg, %		
	0	.15	.13	.22
	29	.15	.13	.21

Planting date: 10-18-79