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Phosphorus Relationships in Potato Plants

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ABSTRACT

Maximum potato (*Solanum tuberosum* L.) tuber yields occur when an active plant canopy is maintained until normal plant maturation. Plant nutrient concentrations and uptake rates play a major role in maintaining an active plant top. The objectives of this study were to relate the plant P concentrations to the P and dry matter balance between tuber and total plant growth needs. Growth analysis data, plant and leaf total P concentrations and content, and the petiole soluble P concentrations were obtained on a 10-to 14-day sampling interval from P fertilization treatments in replicated field studies. The P concentration of the plant tops was significantly related to the petiole soluble P concentration and the P concentration of the active leaves. Total plant P uptake and dry matter production rates were not adequate for the tuber growth rate when the total P concentrations of the tops and active leaves were less than 2.2 g P kg^{-1}. Soluble P concentrations in the fourth petiole down from the growing tip were less than 1000 and 700 mg kg^{-1} when P uptake and dry matter production rates were not adequate for tuber growth, respectively. Final tuber yields increased from 30 to 70 Mg ha^{-1} as the number of growing days past tuber set increased from 10 to 60 days for which the P concentration of the tops was above 2.2 g P kg^{-1}. The petiole soluble P concentration decreased during the growing season following a semi-logarithmic relationship. This relationship enabled the prediction of the petiole soluble P concentration for the rest of the growing season and could be used to predict when to apply supplemental P fertilizer.

Additional index words: **P uptake, Soluble P concentration, Total P concentration, Seasonal monitoring, Tuber yields, *Solanum tuberosum* L.**

THE evaluation of a plant's nutritional status is based upon a significant relationship between the nutrient in question and plant yields. This relationship is called a nutrient response curve and can identify nutrient concentrations that are deficient, adequate, and toxic. The transition zone between deficient and adequate is the critical nutrient concentration and is generally defined as that concentration where the growth or yield is 10% less than the maximum (17,23). This concentration is dependent upon plant growth stage, plant part and its physiological age, the form of the nutrient measured, and interactions with other nutrients (2, 17, 23). Efforts to remove some of these variables have been proposed by using a critical nutrient range (6, 13, 20) or the Diagnosis and Recommendation Integrated System—DRIS (16). The first technique requires identifying a critical nutrient range from the relationship between the nutrient concentration in a plant part at a particular growth stage and final yield. This gives a band of different critical nutrient concentrations during a crop's growth and development. The critical nutrient range generally decreases with plant age, possibly being explained by the declining absolute growth rate of plants as they become larger and older (21). The DRIS approach attempts to remove the growth stage variable by identifying significant nutrient ratios between two yield levels which are then used to identify nutrient imbalances (16).

Many growers and consultants are now using crop logging techniques on crops with a high cash value. The disease incidence, insect infestations, nutritional status of the soil and plant, and plant available soil water status are usually monitored during crop growth and development. This technique should allow a grower to detect or predict, and correct a potential problem before it affects yields.

The relationships between critical nutrient ranges and final tuber yields are reported for potatoes (12, 13, 20), as well as the suitability of different plant parts and the form of plant nutrients for evaluating the P status (4, 7). The fourth petiole of the most recently matured leaf from the growing tip is usually the plant part used for nutrient analysis in potatoes (7, 13, 20). The soluble and total nutrient concentrations in the petiole are expressed on a dry weight basis.

Final potato tuber yields are a function of tuber growth rates and the duration of tuber growth, particularly for indeterminate potato varieties (9, 10, 22). Full-season tuber growth requires nutrient uptake until the start of plant maturation since the tubers function as the major nutrient sink during their growth. Nutrient uptake rates less than those required for tuber growth will cause the loss of mobile nutrients from the other plant parts to the tubers, eventually causing a premature canopy senescence. Final tuber yields could be reduced if this senescence starts too early in the growing season when the environmental conditions are still favorable for growth. Nutrient uptake rates can slow or stop during normal maturation since most tuber growth during this growth stage is from the translocation of dry matter and nutrients from the other vegetative portions of the plant (9, 14). This report relates the potato plant P concentrations to the P and dry matter balance between tuber and total plant growth.

METHODS AND MATERIALS

Data presented here come from five replicated field experiments conducted on a Portneuf silt loam soil (coarse-silty, mixed, mesic Durixerollic Calciorthid). This soil has a calcic layer starting near the 0.4 m soil depth that restricts root penetration but not water movement. These experiments were designed to evaluate different P fertilizer placement methods and to obtain soil test P correlation data for maximum potato tuber (*Solanum tuberosum* L.) yields. The effect of these treatments on the final tuber yield and total P uptake will be reported later.

Standard cultural and fertilization practices were followed in all of the field experiments (18). The P treatments in this study were established by broadcast applications of monocalcium phosphate (0-45-0) followed by plowing or discing prior to planting. Sprinkler irrigations were scheduled according to tensiometers placed in the row at the seed-piece depth (0.2 m) when the plant available soil water dropped to 50 or 60% of the soil's field capacity. A randomized complete block design was used with four or five replications for each experiment. Russet Burbank potato seed [0.06 kg (seed

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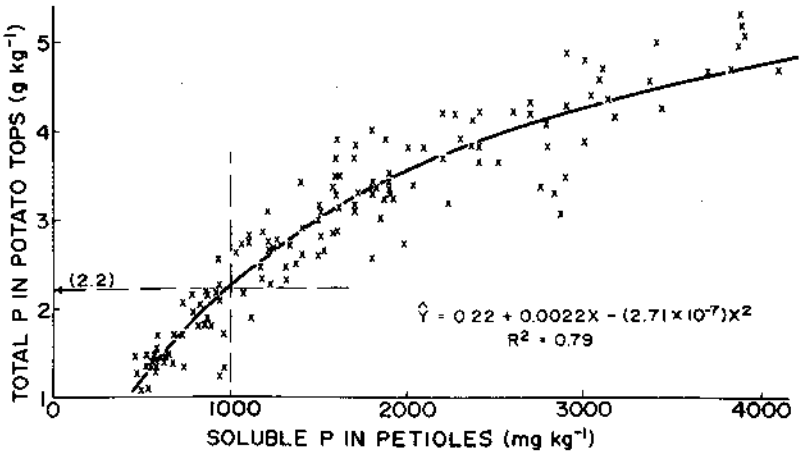

Fig. 1. The relationship between the total P concentration in the potato tops and the petiole soluble P concentration.

pieces)$^{-1}$] were planted between 19 and 25 April in 0.91 m wide rows with a 0.23 m seed spacing in all experiments. Individual plots were six rows wide and 14 or 15-m long. Metribuzin® [4-amino-6-(1,1-dimethylethyl)-(methylthio)-1,2,4-triazine-5(4H)-one] herbicide[3] and Aldicarb® [2 methyl 2-3(methylthio) propionaldehyde 0-(methylcarbamoyl) oxime] insecticide[3] were used in all experiments at 0.8 kg ha^{-1} (active ingredient, a.i.) and 3.3 kg ha^{-1} (a.i.), respectively. Seasonal N fertilizer applications were applied through the sprinklers as Solution-32 (urea-ammonium nitrate) to maintain petiole NO_3-N concentrations near 15 000 mg kg^{-1} during tuber growth.

Whole plant samples (a 1.5-m segment of row) were taken from selected treatments on a 10 to 14-day interval from mid-tuberization (about 20 June) to vine kill (about 20 September). Treatments were selected from each experiment to give a range of P nutritional levels. A sub-set of these treatments was used for leaf area measurements and their plants were separated into leaves, stems, roots, and tubers. Active leaves were defined as those that showed no visible signs of senescence. Inactive leaves were also saved for dry weight determination and chemical analysis. Leaves and stems were not separated on the remaining treatments. The 'photosynthetic active' leaf area was measured with a Li-Cor Leaf Area meter, model 3100[3]. The leaf area index (LAI) is defined as the ratio of the area of the leaf sample divided by the soil's surface area from which the sample was taken. Only those roots obtained by sampling with a potato fork were weighed and analyzed. The fresh weights of the tubers were recorded at each sampling after washing both the roots and tubers. All plant tissues were dried at 60°C, weighed for dry matter determination, ground to pass a 40-mesh screen, and analyzed for total P (8) after digestion in nitric and perchloric acids. A composite sample of 30 to 40 petioles from the fourth leaf down from the growing tip was taken from each plot at the same time as the whole plant samples, dried, ground, and analyzed for total P (g kg^{-1}) and soluble P (mg kg^{-1}) as orthophosphate (1, 8, 11).

RESULTS

The total P concentrations of potato tops and soluble P concentrations of potato petioles were highest in the early samplings and decreased as the plants became older and larger (data not shown) as reported by others (15, 21, 23). There was a significant curvilinear relationship between total and soluble P during the growing season (Fig. 1). The total P concentration of the tops increased about two-times faster than the soluble P concentration in the petiole up to about 3.0 g kg^{-1} total P in the tops. Above this concentration the petiole soluble P concentration increased at about the same rate as the total P in the potato tops.

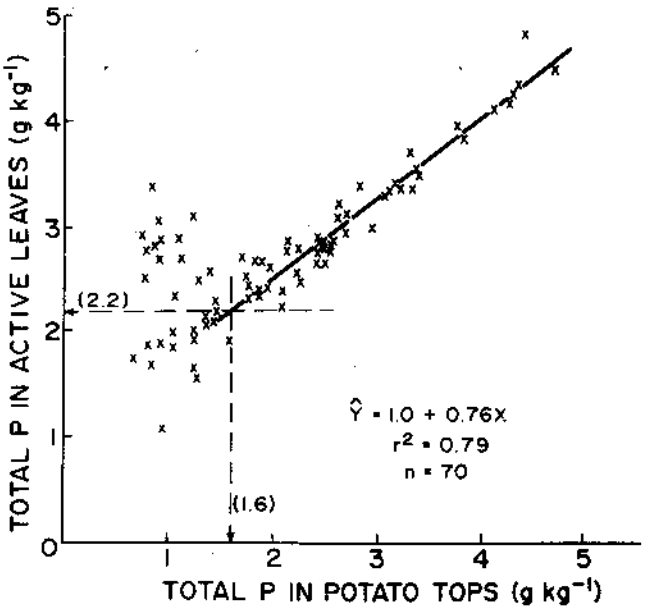

Fig. 2. The total P concentration relationship between potato tops and active leaves.

The P concentration of the tops was also related to the total P concentration of the active leaves (Fig. 2). This relation was linear above about 1.6 g P kg^{-1} in the tops, while below that concentration the data points were scattered. These lower points came from late-season samplings when many of the active leaves were growing on secondary and tertiary branches and their leaf P concentrations were high compared to those in the tops and the LAI was also generally less than three. Leaf area indexes less than three also occurred at the early season samplings but P concentrations in both the tops and the leaves were high (>3.0 g kg^{-1}).

If the total plant P uptake rate was less than that needed for tuber growth there could be a loss of P from the other vegetative portions of the plant to the tubers. An estimate of the P-balance between tuber and total plant growth needs may be provided by the

[3] Commercial names are shown for the benefit of the reader and do not imply endorsement or preferential treatment of the product listed.

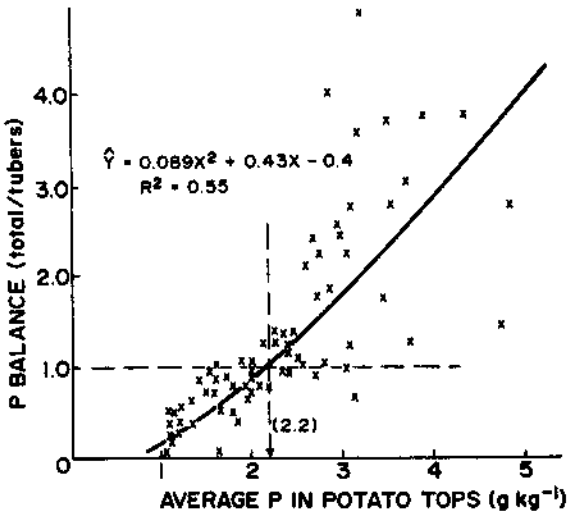

Fig. 3. The relationship between the plant's P-balance (change in the P content of the whole plant divided by the change in tubers P content between two consecutive plant samplings) and the average P concentration in the potato tops for that sampling interval.

ratio of the change in the total plant P content divided by the change in the tuber P content between two consecutive samplings. A ratio greater than one would indicate that more P was taken up by the plant than was utilized by the tubers, while a ratio less than one would indicate that tuber growth required more P than was taken up by the plant. This ratio was compared with the average P concentration of the plant top during the same sampling interval (Fig. 3). This relationship shows that those plants having a P concentration of about 2.2 g P kg^{-1} in the tops would have a P-balance ratio of about one. This would be equivalent to a soluble P concentration of about 1000 mg kg^{-1} in the petiole (Fig. 1).

The loss of P from the tops and roots to the tubers should eventually affect the plant's ability to produce dry matter. Dry matter would be lost from the vegetative portions if the plant's dry matter production rate was less than that needed for its tuber growth rate. An estimate of the balance between the total production and tuber growth needs may be provided by the ratio

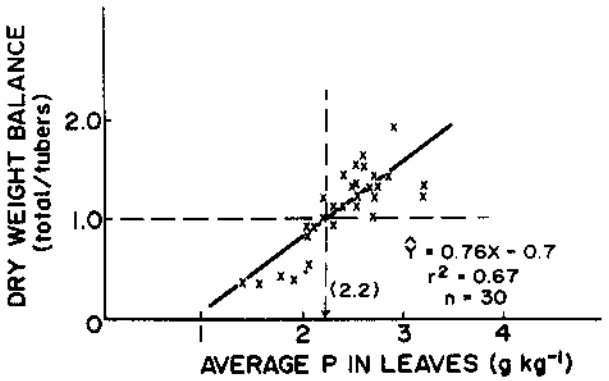

Fig. 4. The relationship between the plant's dry weight balance (the dry weight change of the whole plant divided by that of the tubers between two consecutive plant samplings) and the average P concentration in the active leaves for that sampling interval.

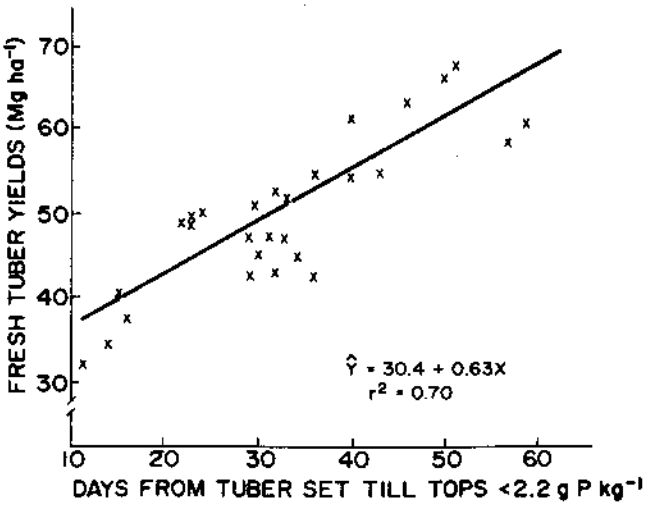

Fig. 5. The relationship between fresh tuber yields and the number of days after tuber set for which the total P concentration of the tops was greater than 2.2 g P kg^{-1}.

of the change in total plant dry weight divided by the change in the total tuber dry weight between two consecutive sampling intervals. This ratio was compared with the average P concentration in the active leaves during the same sampling interval (Fig. 4). The active leaves were used for this comparison since they are the major source of photosynthates. In addition, only data from treatments having a LAI three or greater with both plant samplings in the tuber growth stage were used. This relationship indicates that the dry matter production rate was generally sufficient for tuber growth when the P concentration of the active leaves was greater than 2.2 g P kg^{-1}. Ratios less than one could also occur from other nutrient deficiencies, diseases, or unfavorable environmental growing conditions, as well as from a smaller leaf area.

DISCUSSION AND CONCLUSIONS

These data suggest that final tuber yield may be related to the number of days for which the tops have an adequate P concentration, provided other production factors are not limiting. The final tuber yields were compared with the number of days past tuber set that the tops contained at least 2.2 g P kg^{-1} (Fig. 5). Fresh tuber yields were increased about 0.63 Mg ha^{-1} each day after tuber set that the tops contained at least 2.2 g P kg^{-1}. Tubers sufficiently supplied with P will contain about 2.0 g P kg^{-1} (14). A maximum tuber dry matter growth rate of 0.19 Mg $(ha\text{-}day)^{-1}$ was reported for the Russet Burbank variety (9) which would require a P uptake rate of 0.38 kg $(ha\text{-}day)^{-1}$. Early tuber set occurred on about 25 June in these experiments. Sixty days after tuber set would be on 24 August, which is close to the start of the normal maturation growth stage or about 20 to 30 days before vine kill at this location. This relationship (Fig. 5) would largely be a function of the experimental conditions under which the data were obtained and may not be directly applicable to other potato growing areas with different environmental conditions or production problems.

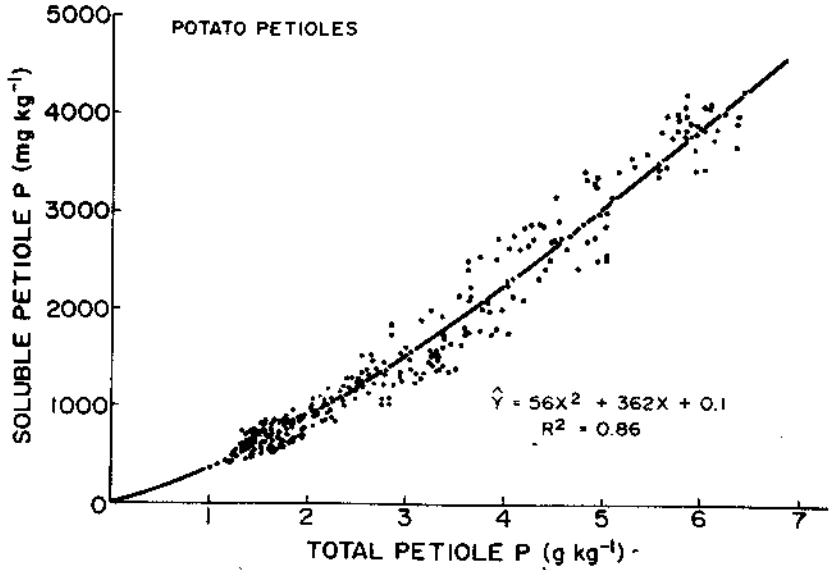

Fig. 6. The relationship between the total and soluble P concentrations of the potato petiole. (Data also obtained from reference 19).

The soluble P concentration in the petiole was a good indicator of the P status of the potato plant. These results show that the total P uptake rate was sufficient for both vegetative and tuber growth needs when the petiole soluble P concentration was greater than 1000 mg kg^{-1}. Dry matter was generally not lost from the vegetative portions of the plants to the tubers until the petiole soluble P concentration was less than 700 mg kg^{-1} (comparison of Fig. 1, 2, and 4). These soluble P concentrations are in close agreement with other published data for the late tuber - early maturation growth stage (5, 20). An excellent relationship between the total P and the soluble P in the petiole indicates that the total P concentration may also be used as a nutritional index (Fig. 6).

It should be possible to predict the time required for the petiole soluble P concentration to decrease to 1000 mg kg^{-1} if its decline follows a definite functional relationship. This approach was successful for NO_3-N concentrations in sugarbeet petioles (3). The equation used in that approach was $N = N_o e^{ct}$, where N was the NO_3-N concentration at time(t), N_o was the concentration at the first sampling date after the peak NO_3-N concentration occurred, and (c) was a constant for any treatment or grower's field. This equation was used to calculate linear regression equations using the petiole P concentrations and elapsed time from our data and published data (15, 20) where P fertilizers were not applied during the crop's growth. The coefficient of linear determination (r) ranged between −0.81 and −0.99 for the 31 data sets with a median of almost −0.99. This indicates that future petiole soluble P concentrations might be estimated by plotting the soluble P concentration on semi-logarithmic paper, with the P concentration on the log scale (y-axis) and time(t) on the linear scale (x-axis). The elapsed time interval from the first petiole sampling until the soluble P concentration reaches 1000 mg kg^{-1} would then be estimated by extrapolating a straight line from the P concentrations of the first and second petiole samplings

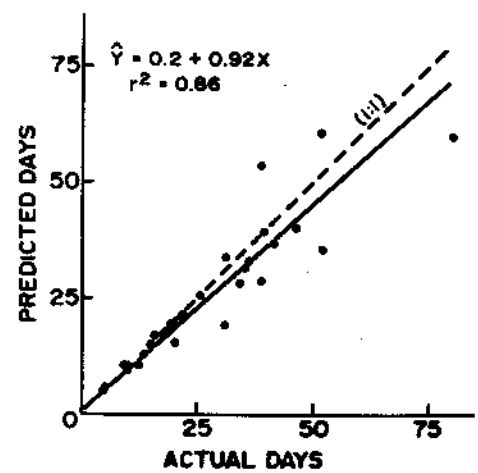

Fig. 7. Relationship between the actual days and the days predicted from the first two petiole samplings for the petiole's soluble P concentration to decline to 1000 mg kg^{-1} after the first sampling.

(both after the peak P concentration and between 10 to 20 days apart) down to 1000 mg kg^{-1} P. This predicted time was compared with the actual time interval obtained from graphing all the soluble petiole P concentrations for the entire growing season (Fig. 7). This relationship indicates that it should be possible to predict when additional P fertilizer materials may need to be applied to a growing crop. The absolute difference between the actual and predicted days averaged about 9%. Additional petiole samples past the first two samplings would shorten the predicted interval and also tend to increase the accuracy of the prediction.

Observations on potato growers' fields indicate that adequate plant P concentrations may sometimes be maintained through a foliar-feeding program or by applying a liquid or dry P fertilizer material followed by an irrigation. An additional 1-kg P ha^{-1} assimilated by the plant and used for tuber growth as a result of

these practices could increase fresh tuber yields by 2.4 Mg ha^{-1} if P was limiting. Additional studies are needed to determine the effectiveness of these practices in relationship to the plant's activity, disease infestations, and other soil factors.

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