



Effect of withholding phosphorus on its distribution in wheat, (*Triticum aestivum* L.)  
by Charles Kong-Wu Wang

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of  
MASTER OF SCIENCE in Agricultural Products Utilization  
Montana State University  
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**Abstract:**

The spring wheats (*Triticum aestivum* 'Thatcher') were grown in the green house on vermiculite in pots. They were subjected to different P treatments by initial withholding of P supply for various periods of time. The yields and types of P were determined at selected growth stages.

The effect of the degree of P deficiency on total P uptake and changes of types of P by spring wheat plants were studied. Initial withholding of P supply resulted in a significant decrease in both yield and total P uptake by the plants.

The leaves and roots both showed a general decrease in total P concentration upon increasing the period for withholding P. After the milk stage, P deficiency resulted in a sharp decrease in nucleic acid P and an increase in acid-soluble and phytic acid P in the kernels, as in percentage of total P. Lipid P was found only to increase slightly in kernels at maturity.

When the plants were beyond the milk stage, the inorganic P became predominant in both the roots and leaves. Organic types of P existed only in very small amounts and the various types of P remained relatively constant regardless of the effect of the early deprivation of P.

For some unknown reasons wheat plants tend to increase total P uptake when under a P stress during the early growth stages. At maturity, the kernel showed a significant decrease in total and nucleic acid P and an increase in acid-soluble and lipid P under the influence of P deficiency. The changes in types of P may decrease the protein content of the flour as was shown by a previous study on the relationship of types of P in flour to flour quality. Therefore, changes in types of P may be expected to decrease the baking quality of wheat flour by lowering the protein content. Early P deficiency for three weeks seems to be most critical to flour quality, since maximum changes in types of P in kernels occurred at this time.

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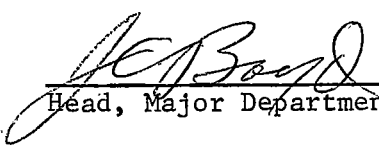
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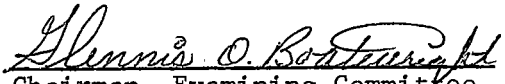
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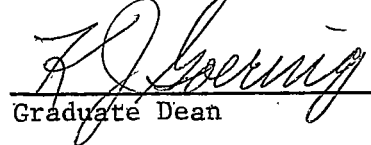
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## ABSTRACT

The spring wheats (Triticum aestivum 'Thatcher') were grown in the green house on vermiculite in pots. They were subjected to different P treatments by initial withholding of P supply for various periods of time. The yields and types of P were determined at selected growth stages.

The effect of the degree of P deficiency on total P uptake and changes of types of P by spring wheat plants were studied. Initial withholding of P supply resulted in a significant decrease in both yield and total P uptake by the plants.

The leaves and roots both showed a general decrease in total P concentration upon increasing the period for withholding P. After the milk stage, P deficiency resulted in a sharp decrease in nucleic acid P and an increase in acid-soluble and phytic acid P in the kernels, as in percentage of total P. Lipid P was found only to increase slightly in kernels at maturity.

When the plants were beyond the milk stage, the inorganic P became predominant in both the roots and leaves. Organic types of P existed only in very small amounts and the various types of P remained relatively constant regardless of the effect of the early deprivation of P.

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## INTRODUCTION

Phosphorus is one of the major elements in plant nutrition and its compounds of P have important functions in many phases of cellular metabolism and cell division.

Initial withholding of P not only significantly affects the yield of wheat but may also affect the quality of wheat flour as a result of changes in types of P under the influence of P deficiency (2,16).

The objectives of this study were mainly to elucidate the changes of total P uptake in various morphological fractions of wheat plants as well as the changes of P as influenced by initial withholding of P. These findings may enable an improved understanding of the nutritional significance of P and the possible effect of P fertilization on wheat quality.

## LITERATURE REVIEW

Wheat contains approximately 1.5 to 2 percent mineral matter. Phosphorus, one of the main mineral constituents, is present in high concentration in more than one form in the ash of the flour of the wheat (8).

Phosphorus compounds may be separated according to their chemical and physical properties into several different types (7): (1) acid soluble, which consists of phytin, inorganic, and ester type P; (2) acid labile or ester type P; (3) acid non-labile (acid-stable) in the form of phytic acid or its salts; (4) inorganic P; (5) nucleic acid P, consisting of DNA and RNA; and (6) lipid P in lecithins, cephalins, and phosphatidyl inositol.

Phytic acid is a phosphorylated myo-inositol, (hexaphosphate of myo-inositol). Phytin is the magnesium or calcium salt of phytic acid. Phytic acid and phytin occur in various plants (15). A considerable portion of the P in wheat kernels exists in the phytin form (7,13), mainly located in the bran and germ. These are stable in an acid solution.

Ester type P are considered to be the carbohydrate ester of phosphoric acid, which are acid-labile.

Pons (13) found nucleic acid P comprises an average 10.8 percent of the total P in wheat plants and found little ester type P. Andrews and Bailey (1) showed that a large proportion of the total P in flour existed in the nucleic acid forms. Analysis of plant phosphatides have revealed the presence of several additional long-chain bases in addition to the common phospholipids (13). These include phytosphyngosine, a saturated C<sub>18</sub> dihydroxysphyngosine, with the additional secondary alcohol group adjacent to that in sphingosine, and two homologues of phytosphyngosine containing 20 carbon atoms. Unsaturated sphingosines (dehydrosphyngosines) are also present in plants (18). Small quantities of phosphatidic acids and tri-phosphate are present in plant as well as animal tissues (4). Plasmalogens represent an unusual type of glycerolphosphatide which has been isolated from animal and plant tissues (4,18). Hydrolysis of these materials yields long-chain aldehydes plus monacylated 2-glycerophosphate. The distribution of phosphorus and nitrogen between the straw and the ear in wheat during growth was studied by Knowles and Watkin (9). They found a low proportion of phytin P in the ear soon after its emergence and a

relatively high proportion of inorganic P at harvest. The distribution of P was such that three-quarters of phytin and four-fifths of the inorganic P was in the ear, while four-fifths of the protein and non-protein nitrogen were transferred to the ear.

Brenchley (3) studied the phosphate requirement of barley at different periods of growth. The P supply had a high nutritional value at the early growth stage. Providing phosphate for the first six weeks, or longer, followed by the omission of P, permitted normal growth. Growth was seriously depressed in all respects with shorter initial periods of phosphate supply. Growth was steadily depressed, with longer periods of initial deprivation of P for barley. The amount of phosphate absorbed by the plant increased steadily in more or less direct proportion to the length of time it was given at the beginning of growth. However, sufficient P was taken up in the first six weeks to enable the plants to attain their maximum dry weight. The percentage of phosphate in the plants increased rapidly after six weeks. The absence of phosphate supply up to the first six weeks of growth caused an extremely rapid drop in the amount of phosphate ultimately taken up by the plant, after which a more gradual decrease occurred with lengthening periods of phosphate deprivation. Maximum dry weight was obtained when the wheat plants were grown in complete nutrient solutions for four weeks, then transferred to solutions devoid of phosphorus (3,5).

McKee and Robertson (11) found that total P increased steadily in the pea seeds over the period from 14 to 40 days from blossom, while the

hull showed a downward trend. Inorganic phosphate, which increased at a lower rate than total P, decreased slightly between the 20th and 23rd days following blossoming. This was accompanied by a corresponding increase in ester phosphate. This could have an important bearing on the synthesis of carbohydrates.

Power (14) showed that the fraction of the wheat material derived from fertilizer to be markedly influenced by moisture conditions. Uptake of soil P and total P by spring wheat was a linear function of the moisture, but the uptake of the fertilizer P was not influenced by moisture conditions once the moisture content of the surface soil had been brought to field capacity for a few days. They also found that absorption of fertilizer P by plants may be reduced considerably, unless the soil is sufficiently moist during the early stages of plant growth to keep an appreciable amount of it in solution.

Mihailovi and Hadzijev (12) investigated the P content of DNA and RNA and the ratio of the two acids in the gluten of various low-yielding and high-yielding varieties of wheat. They reported that ribonucleic acid content of wheat grain depended not only on the variety, but also on the use of nitrogen, P, and potassium fertilizers. The ratio of the nucleic acids in the grain was not specific for a wheat variety, since it was not constant.

Boatwright and Viets (2) used solution cultures to study the importance of P absorption during various growth stages of spring wheat (Triticum vulgare) and intermediate wheat grass (Agropyron intermedium).

They reported that maximum dry matter and grain production was attained when the supply of P was adequate during the first five weeks of growth.

Initially, withholding P for two weeks or more would hinder the yield of wheat and wheat grass tops and wheat grain. Maximum accumulation of P occurred when P was initially withheld, but supplied later until harvest. Watson (16) studied the relationship of P types in wheat flour and gluten to flour quality and reported that the types of P in wheat flour and gluten was influenced by the location of growth and to a lesser extent by variety. He also found that if the effect of protein content on loaf volume was removed, the total acid-soluble, inorganic, and ester-type P in the gluten and the flour showed significant relationships to the loaf volume. This relationship did not exist if the effect of protein on loaf volume was not removed. Several types of P and total P in the flour associated with the gluten were significantly related to protein content of flour.

Jennings and Morton (7) studied P types and changes of nucleic acid in the developing wheat grain under field conditions. They found the relative concentration of total P in the endosperm to decline rapidly between day 5 and 19 after flowering, remaining constant thereafter. A large portion of the total P existed in the embryo. The concentration of total P (as percent of dry weight) declined slightly in the embryo during maturation, while in the testa-pericarp, total P was fairly constant. The relative concentration of inorganic and acid-labile P declined throughout the development of the endosperm. But the relative concentration of acid stable organic P (phytic acid) declined to day 26 after flowering

then increased markedly. Similar changes were found in the testa-pericarp fraction, except for a decrease in amount of inorganic and an increase of acid-stable organic P at day 12 after flowering. Jennings and Morton (7) suggested that an enzyme system may catalyze the conversion of inorganic P to phytic acid. The relative concentration of lipid P in the endosperm declined between day 8 and 26 after flowering. The decline in the testa-pericarp started after day 20. The amount of DNA per grain in the testa-pericarp was nearly constant throughout the development after day 5, while it increased in the endosperm between day 8 and 19 then remained constant. Jennings and Morton (7) claimed that the number of cells present in the testa-pericarp were essentially constant throughout the period of development. But, if the DNA content was expressed as percent of the dry weight, then it declined until about day 26. The RNA content of the endosperm per grain increased rapidly during cell division and thereafter remained constant. If expressed as percent of the dry weight, the RNA content declined in both the testa-pericarp and the endosperm until day 20.

## MATERIALS AND METHODS

Spring wheat (Triticum aestivum 'Thatcher') was grown under green house conditions in a vermiculite media placed in plastic pots of 3,000 ml. capacity. Twenty-four seeds were evenly spread on top of the vermiculite of each pot and covered with another inch of vermiculite. Seven hundred ml. of distilled water were added to initiate germination. When the shoots were about 2 inches tall, each pot was adjusted to 22 plants by pulling out the extra plants. The plants were then subjected to a series of P treatments randomized within each of three replications. The following treatments were imposed by use of a hydroponic nutrient solution (Appendix B, Table I, page 61).

- (1) Adequate P continually (complete nutrient solution).
- (2) Initial withholding of P for two weeks, followed by adequate P thereafter.
- (3) Initial withholding of P for three weeks, followed by adequate P thereafter.
- (4) Initial withholding of P for four weeks, followed by adequate P thereafter.
- (5) Initial withholding of P for six weeks, followed by adequate P thereafter.

The pots were flushed with water to wash out all residual nutrients. Nutrient solutions were added when the plants were thinned and every four weeks thereafter. Nutrient solutions A, B, C, D, and E, described in Appendix Table I, were added at a rate of 80 ml. each. Solution C was applied only to the pots receiving phosphorus.

Plant sampling (or harvest) periods were two, three, four and six weeks after the first addition of the nutrients and at the milk, soft dough,

and maturity stages. These were separated into tops, roots, and kernels at each sampling date, then were immediately placed in a drying oven at 65°C for 48 hours to obtain the dry weights. The dried samples were ground in a Wiley Mill and analyzed for various types of P.

Total P and total acid-soluble P were determined by the reduced molybdate colorimetric method described by Pons, et. al. (13).

Inorganic P was determined colorimetrically by the modified isobutyl alcohol procedure as described by Martin and Doty (10).

Lipid P was determined by extracting the samples with a benzene-alcohol azeotropic mixture, followed by ashing of the extracted lipids.

Inorganic P was determined in the ash as described above.

Acid-labile P was determined by hydrolyzing the material in 4 ml. of 1 N HCl for seven minutes at 100°C. After cooling, 6 ml. isobutanol, 1 ml. silicotungstic acid and 1 ml. neutral molybdate reagent (17) were added, and the inorganic P was estimated (7).

Acid non-labile P (phytic acid or phytin) was estimated by difference (7), i.e., acid non-labile P equals (total acid soluble P) minus (the inorganic P plus the acid-labile P).

Nucleic acid P was estimated by the difference, i.e., nucleic acid P equals (total P) minus (total acid-soluble P plus lipid P) (13). All of these procedures are detailed in Appendix A, page 51.

Statistical analyses were made and P treatments were significantly correlated with the changes of types of P in every growth stage in wheat roots, leaves and kernels.

## RESULTS AND DISCUSSION

### Influence of P and Stage of Growth on Dry Matter Yield and Total P Percentage

Total dry matter yield of the tops was significantly affected by P stress during the early stages of plants development, (see Figures 1 and 2). Withholding of P did not cause a yield decrease when the plants were harvested at the two-week stage. However, when the plants were three weeks old, the P stress during the first two weeks resulted in a decrease in the total dry matter production. This indicates that P stress was detrimental even though growth was not influenced during the first two weeks. As the period of initial P stress increased, the dry weight of the tops decreased irrespective of growth stage. Thus, it can be concluded that a P stress during the early stages of growth decreases the yield potential of spring wheat and this detrimental effect becomes greater as the stress period increases.

Grain yield of spring wheat decreased significantly as the period for withholding initial P increased (Figure 2). Grain yields at maturity were about 10 percent less when the plants were deprived of P for the first two weeks than when they received P continuously. Grain yields decreased as the period of withholding P increased.

Root yields decreased as the period for withholding initial P increased, as shown in Figures 1 and 2. However, the magnitude of this decrease was not as great as the decrease in the yield of the tops.

Maximum root growth was achieved at the milk stage of growth. Root weights decreased as the plants approached maturity. This indicates that the translocation of carbohydrates and other nutrients from the roots to other parts of the plant may have occurred at this time.

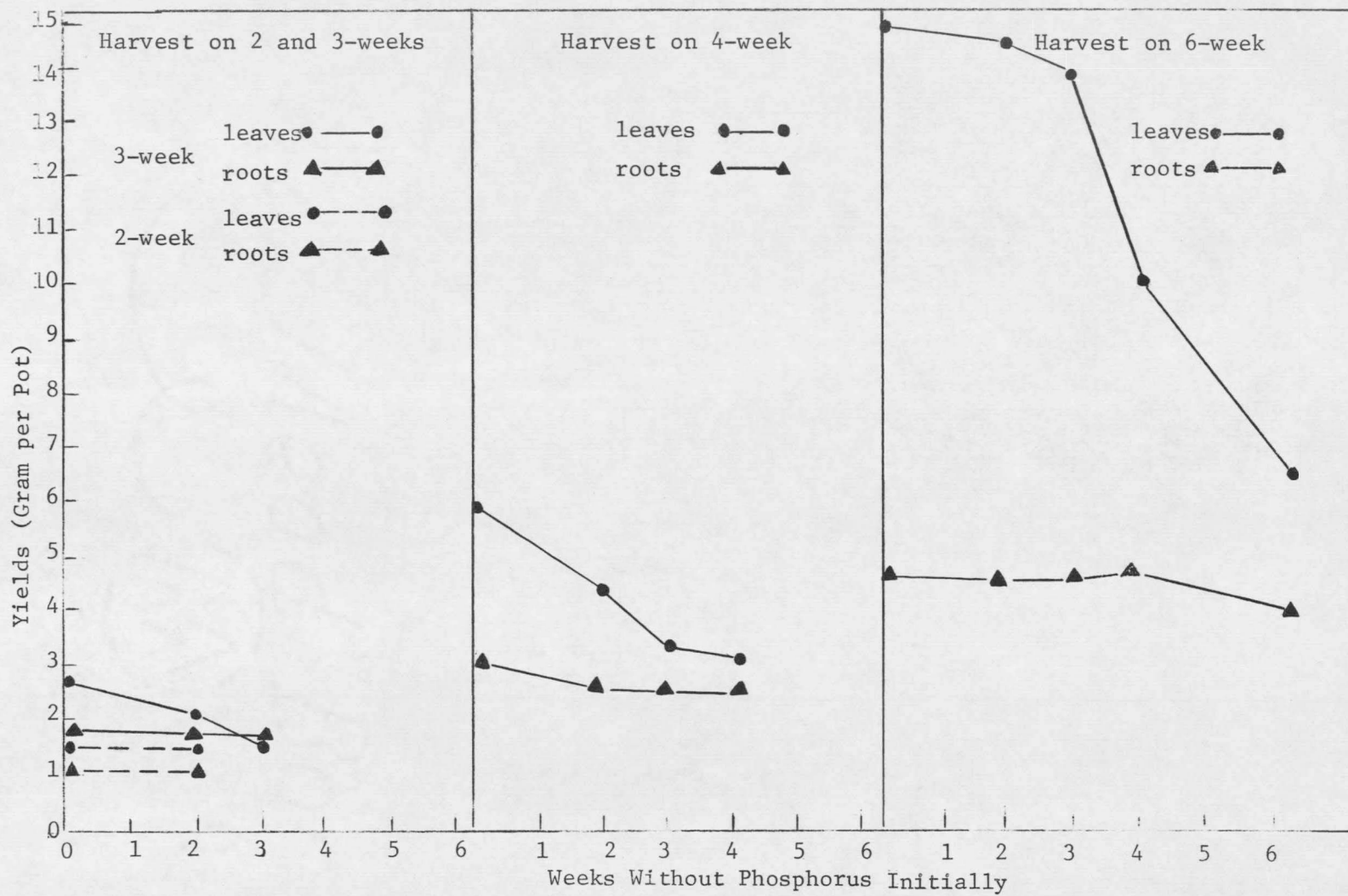


Figure 1. The Yields of Wheat Tops and Roots as Influenced by P Applications at Different Growth Stages. (up to six weeks)

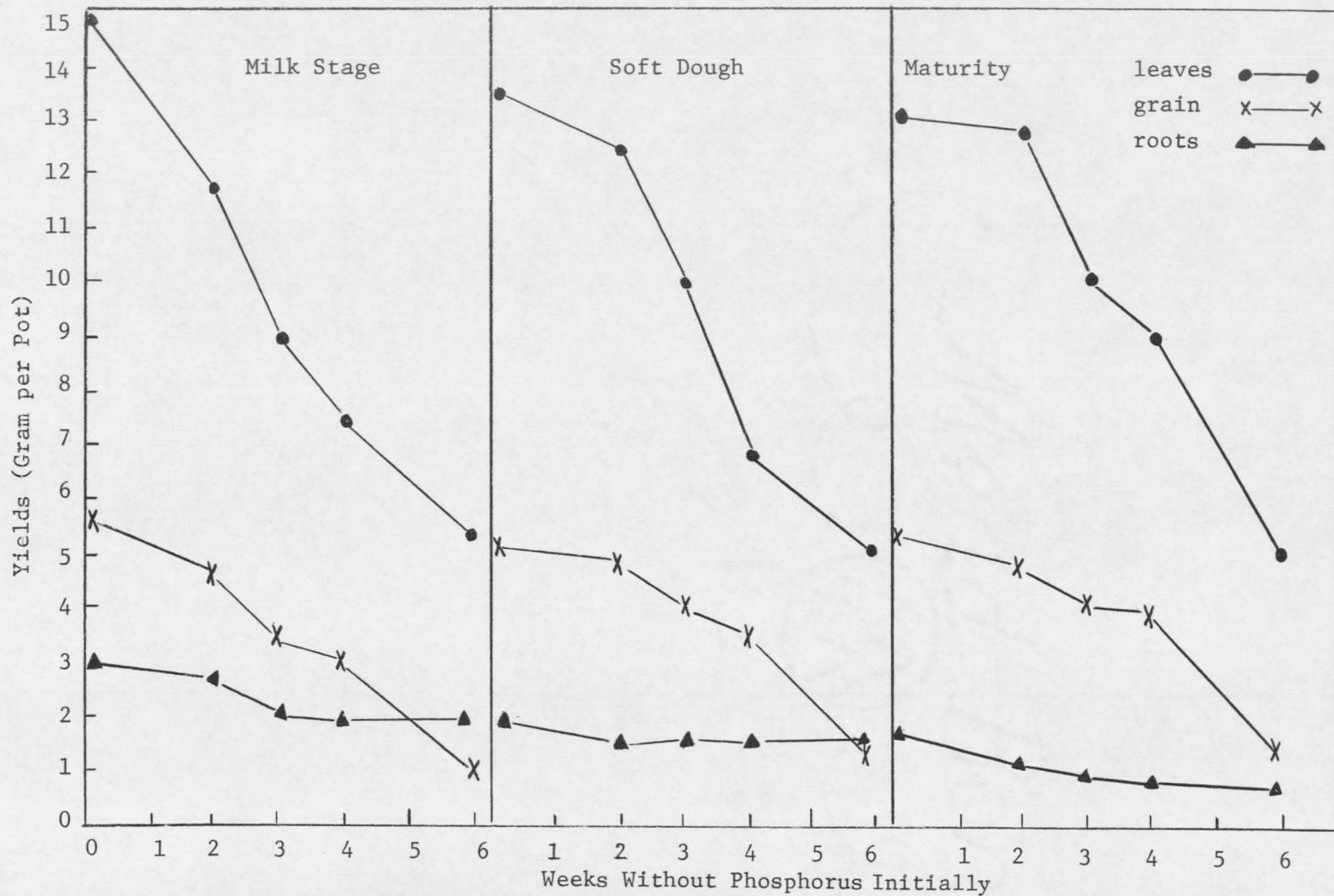


Figure 2. The Yields of Wheat Tops, Roots and Grain as Influenced by P Applications at Different Growth Stages. (milk stage to maturity)

Since the yield of all component parts of the wheat plant decreased when P was initially withheld, nucleic acid P may be involved. As the period for withholding initial P increased, nucleic acid P decreased (see pages 30-34). Reitz and Quisenberry (15) reported that P deficiency frequently resulted in an increased uptake of nitrogen by wheat plants which in turn resulted in increased accumulation of free amino acids. But the formation of protein was slowed down because of lack of P-containing enzymes. They suggested that synthesis of RNA and DNA probably would be decreased, thus restricting nuclear division and impaired the formation of protein and grain yields.

Total phosphorus concentration in the leaves of spring wheat plants as influenced by P treatments and stage of growth is illustrated in Figure 3. Total P concentration decreased in the leaves of the plants receiving no P, irrespective of the growth stage. When plants received P continuously, P concentration in the leaves decreased as the plants matured. When the plants were less than six weeks old, addition of P to plants initially deprived of it resulted in higher P concentration in the leaves than occurred when P was continuously supplied. This confirms the results of Boatwright and Viets (2). This may indicate that some mechanism for increasing uptake of P is triggered when plants that were initially deprived of P receive it thereafter. Addition of P to plants initially deprived of P for less than six weeks showed no significant decrease in total P concentration as the plants approached maturity. However, when P was withheld for six weeks, total P concentration in the leaves, at maturity, decreased.

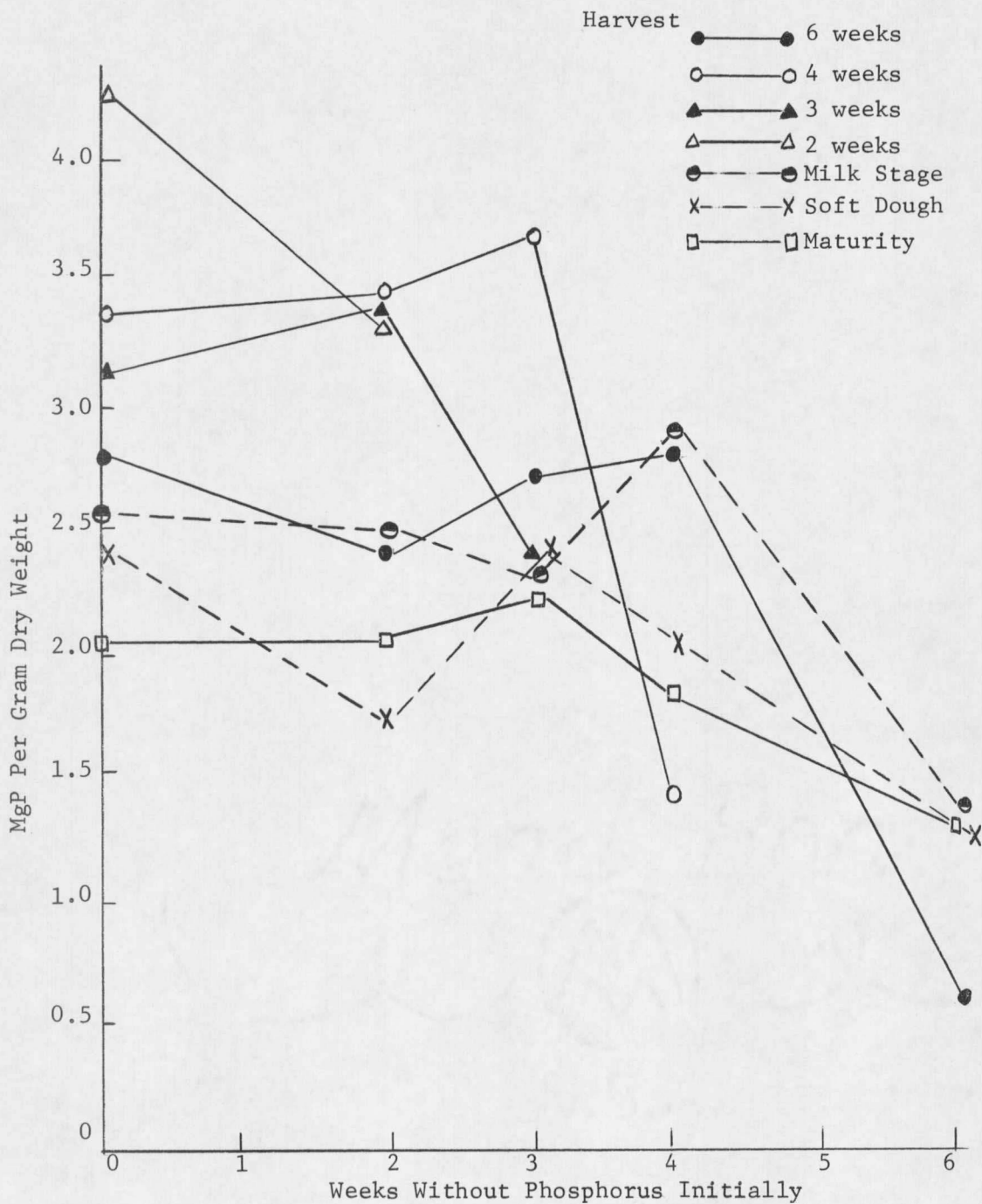


Figure 3. The Influence of Growth Stages and Time of P Applications on the Total P Concentration Present in Spring Wheat Leaves.

The total phosphorus concentration in the grain as influenced by P stress and stage of growth is shown in Figure 4. Total P concentration in the grain decreased at maturity as the period for withholding P increased from two weeks to six weeks. Initial withholding of P for two weeks did not lower the total P concentration at any stage of the grain development. Total P concentration at the soft dough and maturity stages was slightly higher in the grain when P was withheld for periods up to four weeks after emergence provided P was supplied during the later stages of growth. In all cases, plants deprived of P for the first six weeks yielded grain which was lower in total P concentration than plants which received P throughout the growth period.

The total phosphorus concentration in the roots of spring wheat plants as influenced by time of P application and stage of growth is illustrated in Figure 5. Total P concentration in the roots decreased at all stages of plant growth except the three-week stage as the period for withholding initial P supply increased, even after supplying adequate P thereafter. Plants harvested at the three-week stage yielded roots which was higher in total P content when P was omitted for the first two weeks than plants receiving P for the initial three-week period. This again indicates that some mechanism for increasing uptake of P may be triggered when the young plants are initially deprived of P but receive it thereafter. This stimulation effect of increasing of P uptake ceased when the plants grew older.

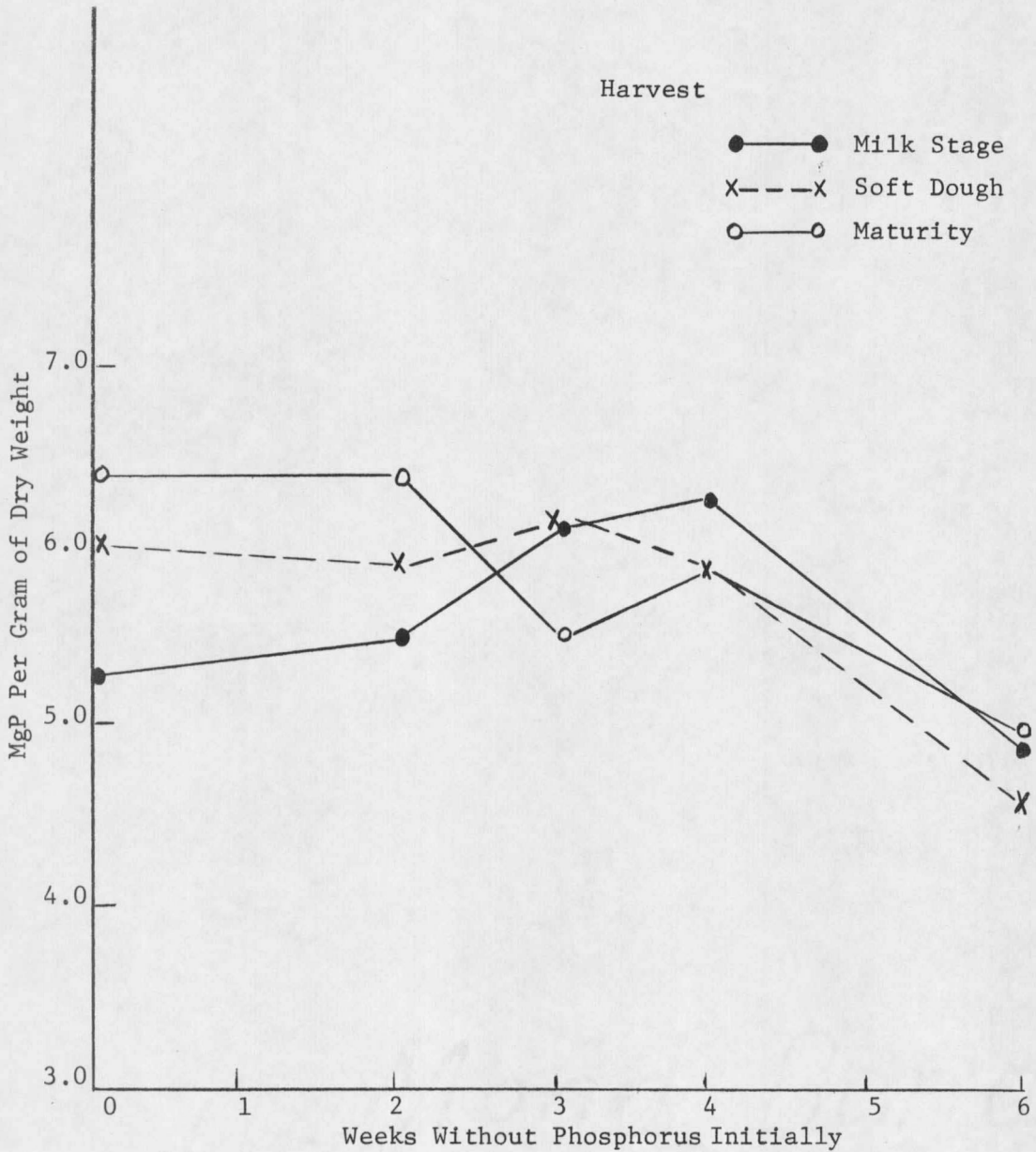


Figure 4. The Influence of Growth Stages and Time of P Applications on the Total P Concentrations Present in Spring Wheat Grains.

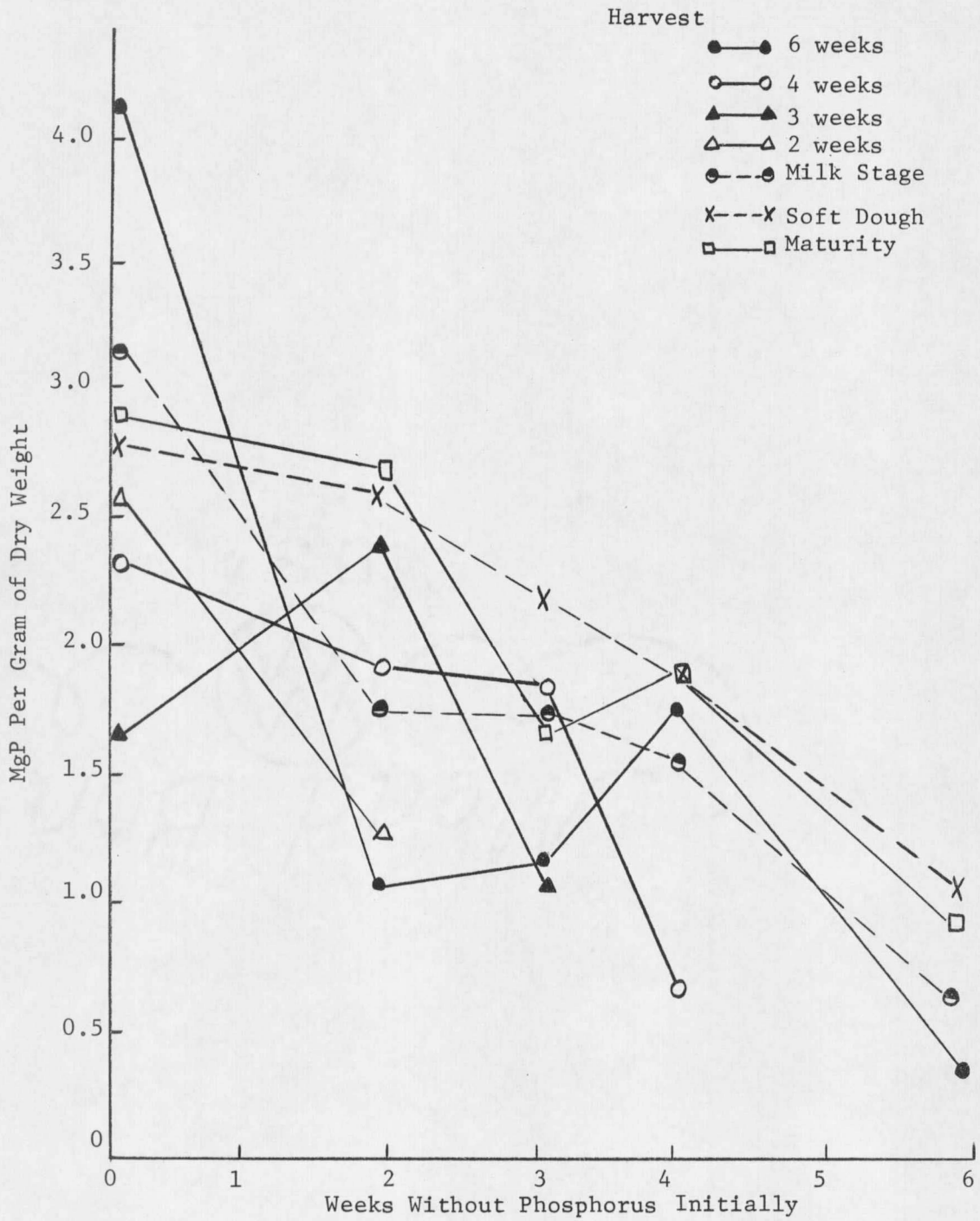


Figure 5. The Influence of Growth Stages and Time of P Applications on the Total P Concentrations Present in Spring Wheat Roots.

The total phosphorus uptake by wheat plants as influenced by initial P deficiency and growth stage is shown in Figure 6. Omitting P initially caused a significant decrease in total P uptake by plants as expressed by mg. of total P uptake per pot (one pot contains 22 plants) at various growth stages. The P uptake decreased significantly as the period for omitting initial P increased. This is due mainly to the effect of P deficiency on the yields of wheat plants as previously discussed. Secondly, when the plants were less than six weeks old, P uptake was apparently affected by the stage of growth. When the plants were harvested before the milk stage, the total P uptake increased, irrespective of the time of P application. When the plants grew older, beyond the milk stage, P uptake was not significantly affected by the stage of growth.

INFLUENCE OF PHOSPHORUS AND STAGE OF GROWTH  
ON TYPES OF PHOSPHORUS IN SPRING WHEAT LEAVES

At the two-week growth stage (Figure 7), the percentage of total P in nucleic acid and lipid P fractions decreased when P was omitted. Whereas the percentage of acid-soluble, inorganic, phytic acid, and acid-labile P increased slightly when P was omitted.

At the three-week growth stage (Figure 8), plants which received no P contained a greater percentage of the total P as nucleic acid P. This appears to be at the expense of acid-soluble, inorganic, and phytic acid P. These data are interesting since a complete reversal in the predominant types of P occurred between the second and third week. This indicates that P stress affected the metabolic activity as the plants

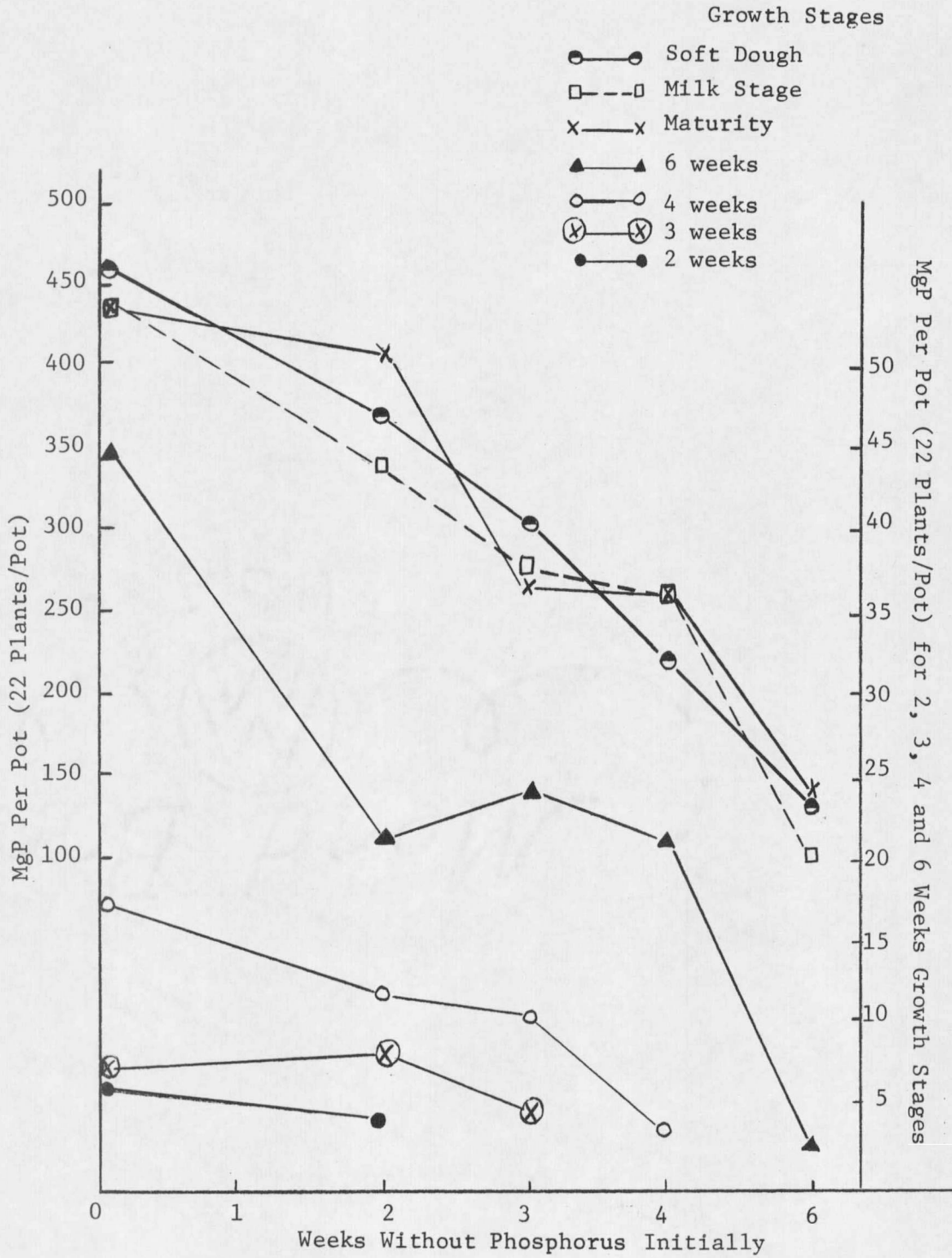


Figure 6. The Influence of Time of P Applications on Total P Uptake by the Spring Wheat at Various Growth Stages.

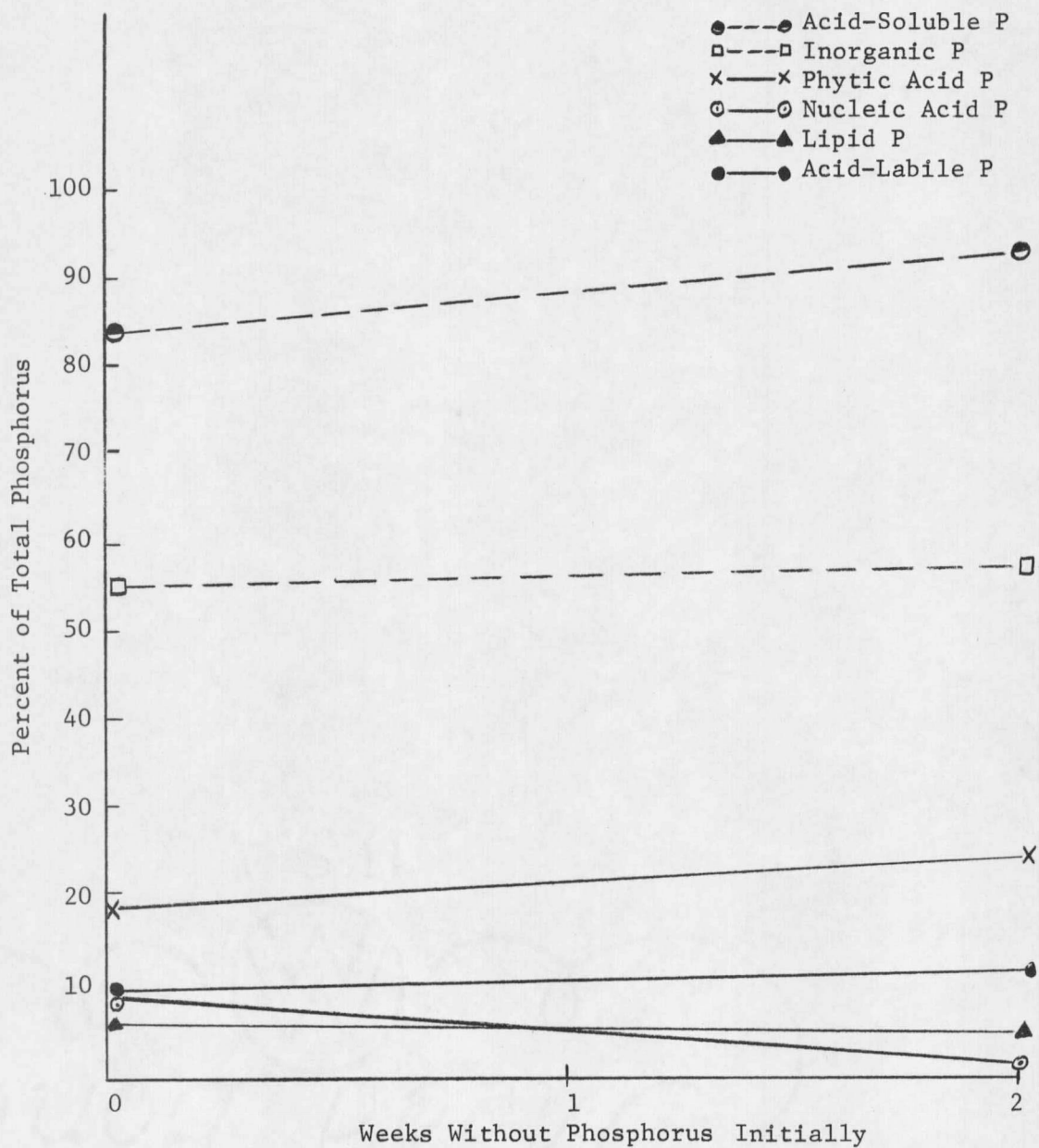


Figure 7. The Influence of Time of P Application on Different Types of P (Percentage of the Total P) in Spring Wheat Leaves at 2-week Growth Stage.

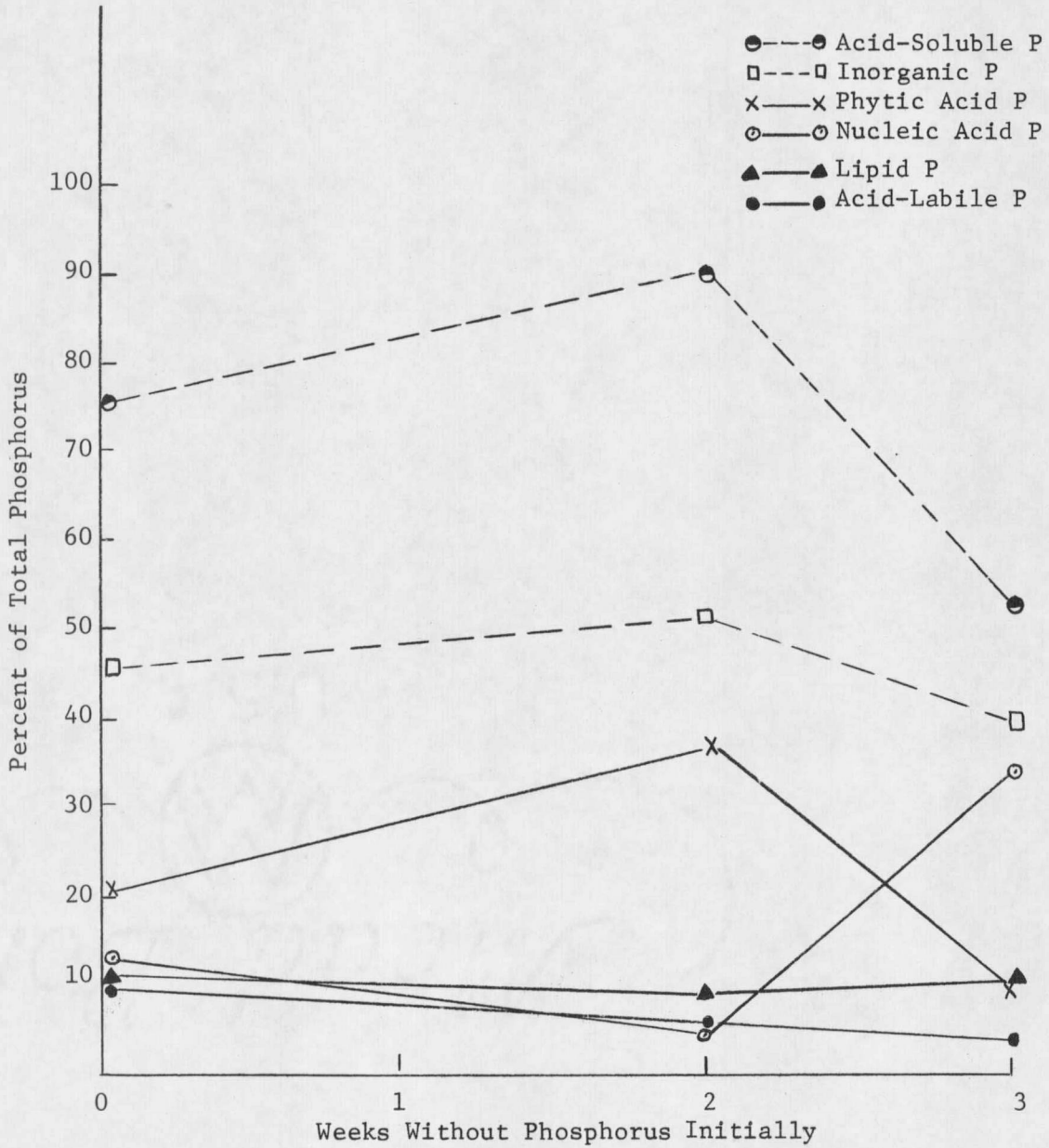


Figure 8. The Influence of Time of P Applications on Different Types of P (Percentage of the Total P) in Spring Wheat Leaves at 3-week Growth Stage.

increased in age. When P was initially omitted for two weeks, the addition of adequate P for one week resulted in a decline in the percentage of nucleic, lipid, and acid-labile P. This was accompanied by an increase in the percentage of the total P in the form of acid-soluble, inorganic, and phytic P. Nucleic acid P was not synthesized although the plants were supplied with inorganic P between the second and third weeks. This indicates that in this early stage of plant growth, a P stress altered the mechanism by which inorganic P is converted to nucleic acid P. The data also suggest that inorganic P was converted to phytic acid P.

At the four-week growth stage (Figure 9), plants that were deprived of P for the first two weeks but received P thereafter produced leaves with higher concentration of acid-soluble, inorganic, and phytic acid P but lower in nucleic acid P than plants that received P continuously. When P was applied at three weeks or entirely omitted, there was no change in acid-soluble, inorganic, and nucleic acid P in terms of percentage of total P. The data indicate that a P stress during the first two weeks causes a decrease in nucleic acid P synthesized in the leaves. However, when P was omitted for longer periods of time the plants apparently adjusted to the low P level and were able to synthesize nucleic acid when supplied with inorganic P. The low rate of nucleic acid P synthesis at the early stage of growth could be due to the enzyme system which may be responsible for this synthesis being less active at that time. The slower rate of nucleic acid P synthesis resulted in more available P for synthesis of phytic acid P.

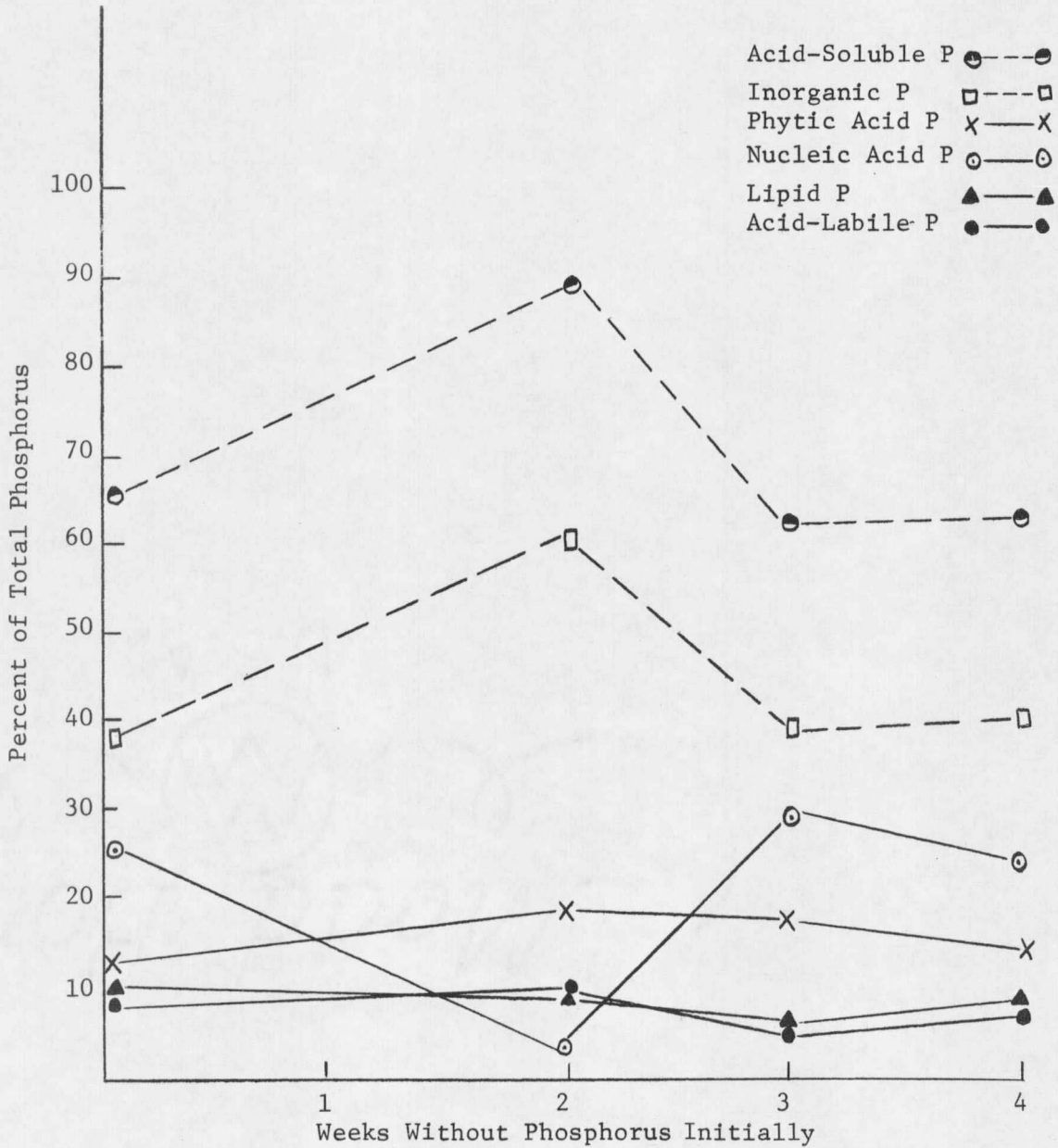


Figure 9. The Influence of Time of P Applications on Different Types of P (Percentage of the Total P) in Spring Wheat Leaves at 4-week Growth Stage.

At the six-week growth stage (Figure 10), plants that were deprived of P for the first two weeks, but received P thereafter, produced leaves that showed an increase in acid-soluble P and phytic acid P accompanied by a sharp decrease in nucleic acid P. The same suggestion which explained the sharp decrease of nucleic acid P at the four-week growth stage could be again applied here. It is interesting to note that acid-labile P, which contains ATP, decreased when P was omitted for the first two weeks. This may be responsible for the synthesis of phytic acid P. Since inorganic P is required for synthesis of ATP (adenosine 5-triphosphate), the decrease in inorganic P may indirectly account for the increased conversion of phytic acid P. When plants were initially deprived of P for three and four weeks, the leaves harvested at six weeks showed an increase in phytic acid P. All other types of P either decreased or remained about equal in amount to those when P was always present. Inorganic and acid-labile P were the two P compounds showing the greatest decrease due to a P deprivation for the first three or four weeks. These data indicate that a P stress during the period of maximum growth resulted in an increase in the synthesis of phytic acid P. Phosphorus stress during the very early stage of growth, increased the synthesis of phytic acid P and this appears to be at the expense of nucleic acid and inorganic P. Phosphorus stress during the later stages of growth resulted in increased synthesis of phytic acid P at the expense of acid-labile and inorganic P.

When P was withheld for the entire growth period, the percentage of the total P in the form of acid-soluble, nucleic acid, acid-labile,

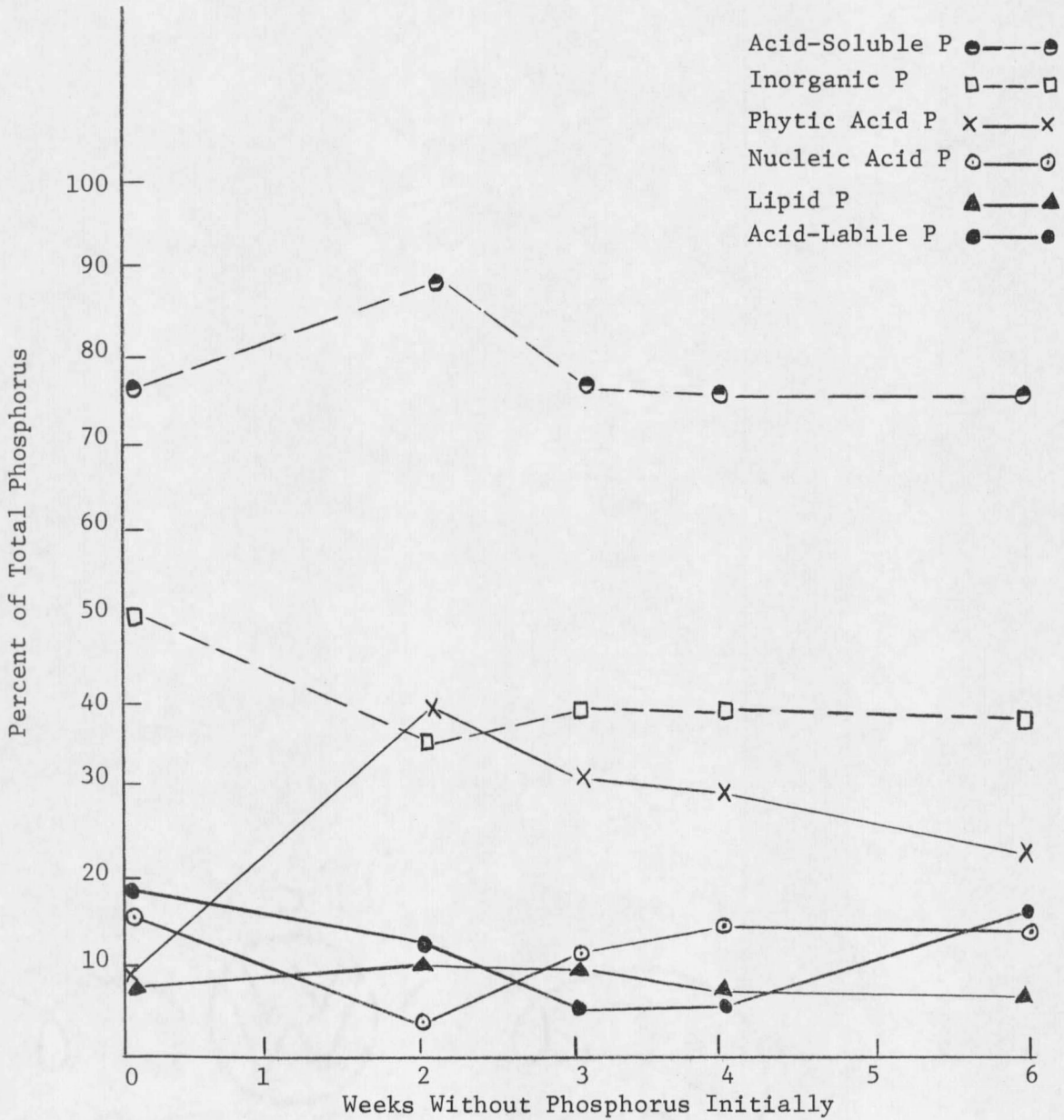


Figure 10. The Influence of Time of P Applications on Different Types of P (Percentage of the Total P) in Spring Wheat Leaves at 6-week Growth Stage.

and lipid P fractions were about equal to those when P was continuously supplied. However, the percentage of phytic acid P increased whereas inorganic P decreased.

At the milk stage or beyond (Figures 11-14), over 90 percent of the total P was in the inorganic type. Phosphorus stress for various periods of time did not significantly influence P types in the leaves at later growth stages. These data indicate that P translocation from the leaves was not influenced by the kind of P present in young leaves, because young leaves contained different amounts of the various forms of P. At the later stages of growth only total P uptake was influenced by early P stress. This indicates that the synthesis rates of the organic types of P from inorganic P were very low when the plants were old. It is suggested that the plants were unable to convert inorganic P into organic types because the enzyme systems which catalyze these conversions became inactive as the plants matured.

The influence of growth stage on the synthesis of various types of P, when it was continuously supplied, is presented in Figure 14. When the plants increased in age from two to four weeks, inorganic P decreased in the leaves. From the fourth week until the milk stage, inorganic P increased sharply up to 90 percent of the total P. From milk stage to maturity, the inorganic P remained constant.

The stage of growth influenced acid-soluble P and inorganic P similarly. The amount of P in the acid-soluble fraction was greater at all growth stages than the amount of inorganic P. This is expected because acid-soluble P includes inorganic, phytic acid and acid-labile P.

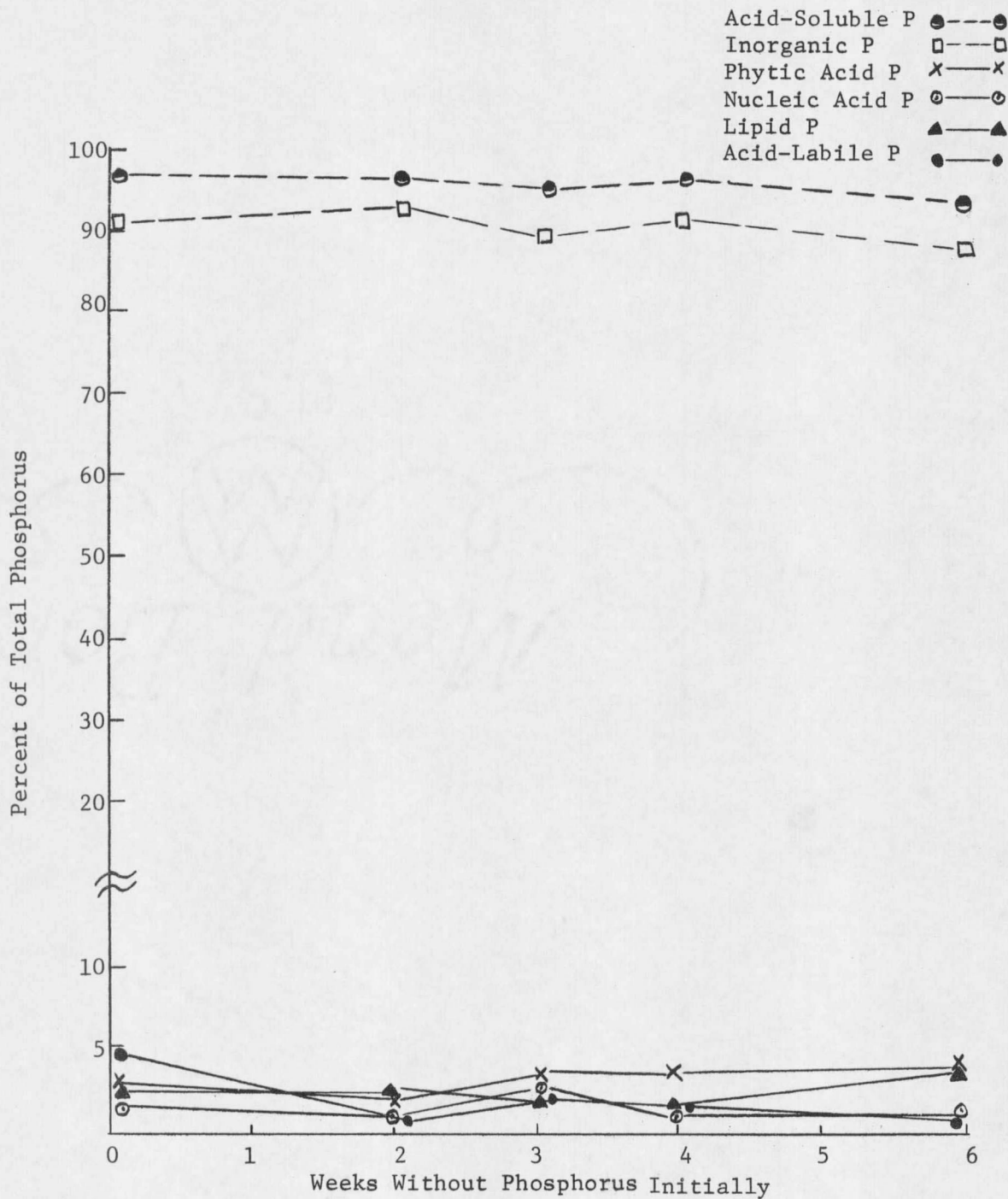


Figure 11. The Influence of Time of P Applications on Different Types of P (Percentage of the Total P) in Spring Wheat Leaves at Milk Stage.

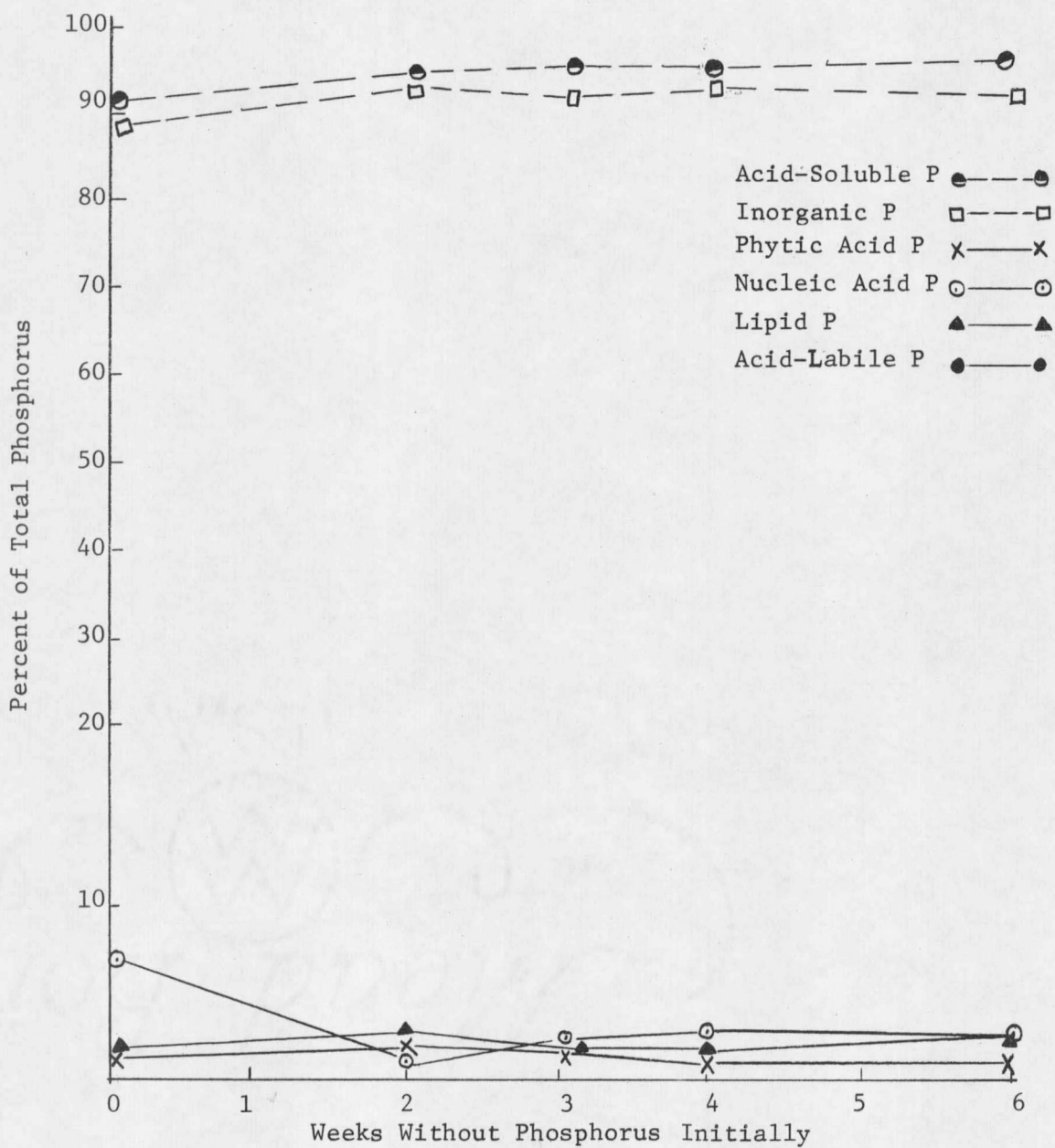


Figure 12. The Influence of Time of P Applications on Different Types of P (Percentage of the Total P) in Spring Wheat Leaves at Soft Dough Stage.

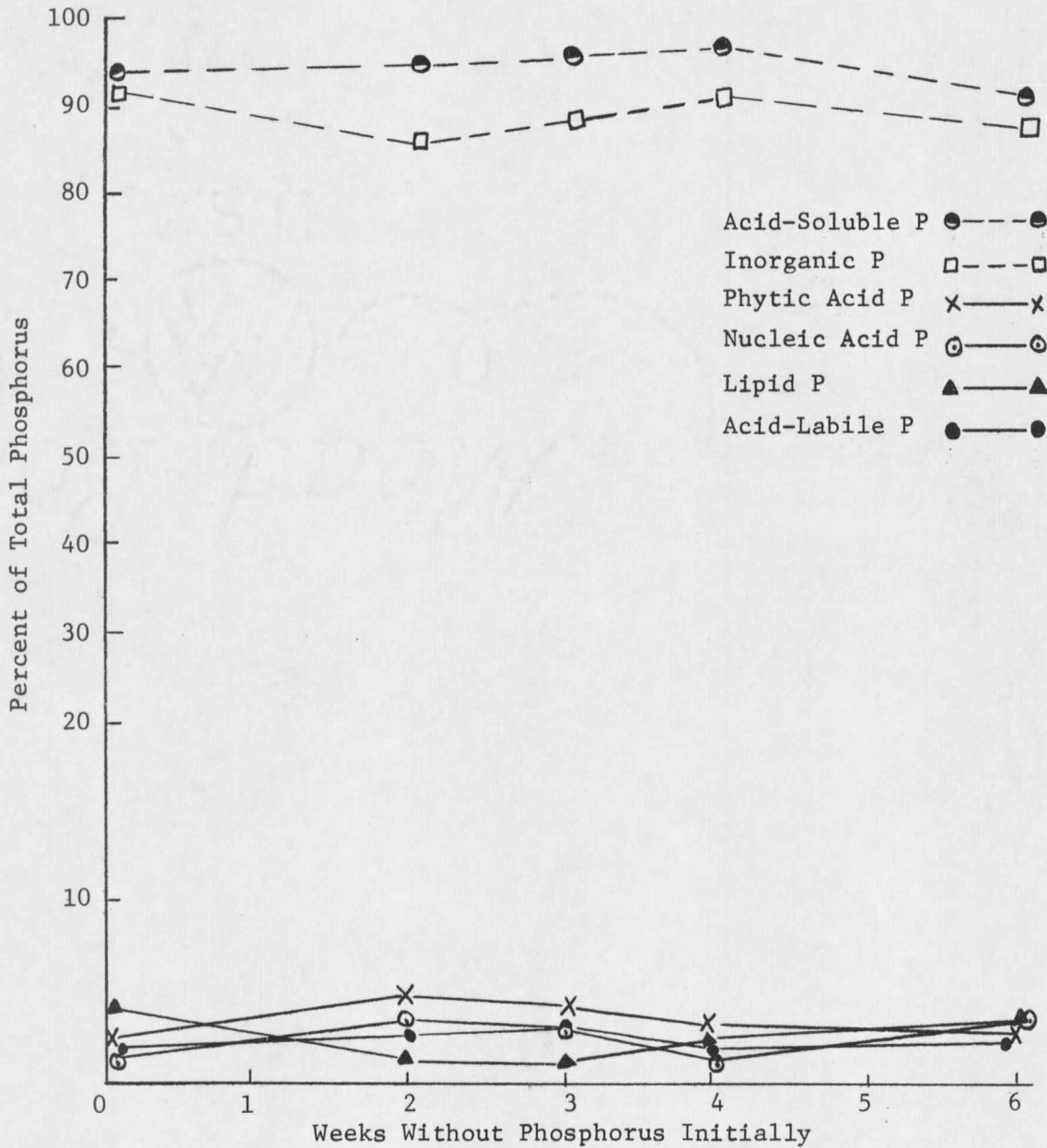


Figure 13. The Influence of Time of P Applications on Different Types of P (Percentage of the Total P) in Spring Wheat Leaves at Maturity.

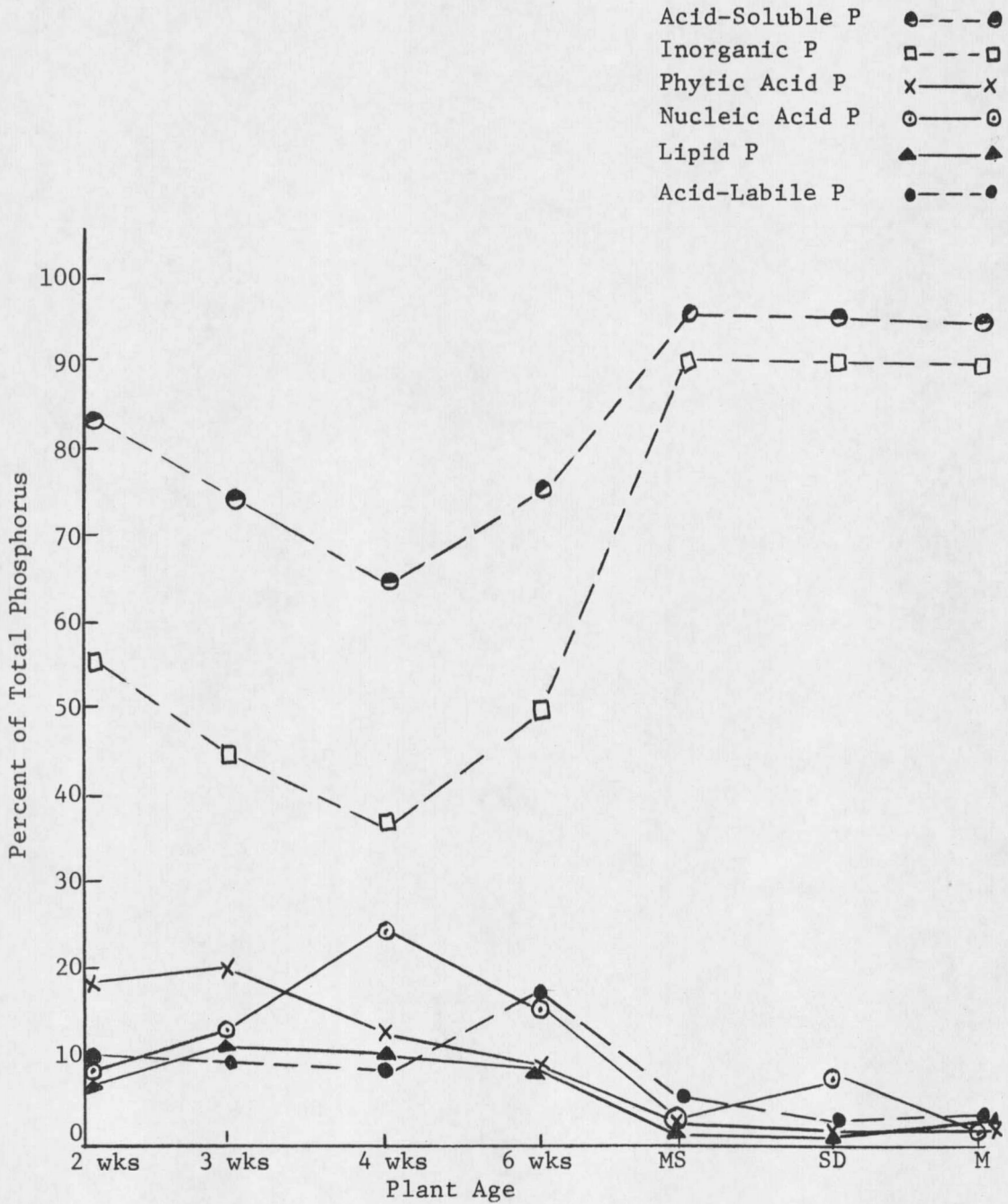


Figure 14. The Influence of Growth Stages on Different Types of P (Percentage of the Total P) in Spring Wheat Leaves when P Supply is Adequate.

The percentage of P in the nucleic acid fraction increased as the plant increased in age from two to four weeks. From four weeks to the milk stage of growth, nucleic acid P decreased. It is interesting to note that at the four-week growth stage, nucleic acid P made up 25 percent of the total P. In contrast, when plants were deprived of P for the first two weeks, then supplied with it thereafter, the plants contained only about 1 percent nucleic acid P. This indicates that a P stress for the first two weeks may restrict synthesis of nucleic acid which may be very critical for the proper development of wheat plants.

Phytic acid P represented about 20 percent of the total P up to the time of the third week in growth. From the third week until the milk stage phytic acid P decreased. In general, when P was supplied to plants initially deprived of it, phytic acid P increased in the leaves. This indicates that phytic acid P decreases in normal plants with age. However, an inverse relationship occurred when plants were initially subjected to a P stress.

#### CHANGES IN TYPES OF PHOSPHORUS IN THE WHEAT PLANT KERNELS AS INFLUENCED BY P STRESS AND GROWTH STAGES

In contrast to tops and roots (pg. 36), when plant age was between the milk and maturity stages (Figures 15-17), the kernels contained a higher percentage of organic types of P than inorganic types. As the plants approached maturity the percentage of the total P in inorganic fractions decreased. Time of P application did not significantly influence the amount of P in the inorganic fraction. The average inorganic P (for









































































