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Transportation Pathway of Potassium and Phosphorous in Grape Fruit

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1. Introduction

Since the balance proportion of mineral elements affects the fruit quality, reasonable fertilization is an important way to increase fruit yield and quality. With regard to N, P and K elements, K element is the largest element required by the grape. Various studies have shown that phosphorus and potassium affect the appearance of the fruit quality due to that potassium element could increase the size of grape, citrus and peach fruit, extending the shelf-life, Increasing hardness, beautiful color, and effective anti-browning (Cummings, 1980) simultaneously. P and K elements have an important role in the formation of intrinsic quality of the fruits, for instance, the soluble solid concentration in the apple fruits is in positive correlation with the potassium concentration (Tagliavini et al, 2000). Organic acid content in peach fruit is affected by the nutrition conditions of potassium and nitrogen elements, since potassium could stimulate the accumulation of acid in the fruit, while neutralizing the fruit acidity in part (Habib et al, 2000). Over the annual growth cycle of grapes, whether single application of P and K-fertilization or in coordination with nitrogen fertilizer, spraying on the surface of leaves could obtain different levels of production increase and quality improvement, As a consequence, controlling nitrogen, increasing phosphate and necessary potassium prior to the development and ripening of grapes are the essential measures to obtain superior quality grapes. However, the actual situation in China is attaching great importance on nitrogen while neglecting the application of potassium and phosphorus, which has seriously impacted the grape quality. Therefore, the rational application of P and K-fertilization has great significance in the grape production.

Ascertaining the effects of mineral elements on fruit quality, and the features of absorption, transportation, distribution of mineral elements are the premise of rational fertilization. Some scientists have applied isotope tracer technique to research the nutrient uptake and distribution, which shows that fruit is one of the centers for nutrient distribution (Hu Shi Bi et al, 1998; Huang Weidong et al, 2002; Xie Shenxi and Zhang Qiuming, 1994). Hu Shi Bi et al (1998) found that soil-applied ^{86}Rb before bloom of grape, the distribution rate at its stems, shoot tips, and leaves at the earlier stage was higher than the inflorescence; foliar application of ^{86}Rb at the same time, the absorption of ^{86}Rb by inflorescence was significantly higher than that of the soil application of ^{86}Rb ; foliar ^{86}Rb application at full bloom, the largest distribution was found at the side tip and inflorescence; additionally, the absorption of ^{86}Rb in fruit at ripening period was significantly reduced compared with the previous

periods. Fu Yu-man et al (1997) using ^{32}P tracer technique revealed that the ^{32}P uptake rate of fruit showed an increasing trend against time, accumulated in the developing fruits and roots. The uptake of ^{32}P by leaf surface rapidly involved in the metabolism process, synthesized into various organic phosphorus compounds from inorganic element, 80% of which incorporated with acid soluble components. The Research of Pei Xiaobo et al (2002) suggested that nitrogen, phosphorus and potassium were transported by stems and leaves at the earlier stage of cucumber growth, and then increased into the fruits after fruiting. Zhou Yurong and Chen Mingli (1996) utilized ^{32}P tracer study showed that the ^{32}P uptake sequence of citron daylily was autumn seedling > spring seedling > bolting > squaring > earlier bolting. The trend of ^{32}P uptake in citron daylily was high - low - high over its life. Most of the absorbed phosphorus was distributed in roots while the amount in the leaves was small. Slender roots were the major organs to absorb inorganic phosphorus and to turn it into acid soluble phosphorus. Currently, the transportation, distribution characteristics of phosphorus and potassium into the grape fruits are in need for further study. Based on the study of the absorption, transportation, distribution and regulation of P, K mineral elements, the aim of this experiment was to provide basis for the reasonable fertilization and high-quality cultivation of grapes, so as to explore approaches for improving fruit quality from the perspective of mineral nutrition.

2. Experimental materials and methods

2.1 Experimental materials

This experiment was carried out in the Science Park at the China Agricultural University from April to October in 2003. 3-year-old potted 'JingYou' grapes (*Vitis vinifera* L. × *V. labrusca* L.) were selected as the experimental samples, which were provided by the Institute of Forestry Fruit Trees, Beijing Academy of Agriculture and Forestry. In April 2003, the sprouting grapes were dug out from the exposed flowerpots and planted in a greenhouse at a spacing of 1.0 × 2.0m. Each plant remained a main vine, and two fruiting branch main tips reserved an inflorescence, while the rest were cut. 8 leaves were left at the upper part of the inflorescence and pinched at early flowering stage. 50 pieces of fruits will be reserved on each cluster after petal fall, and the management was applied according to the standard recommendation in addition to other experimental treatment. While the selected experimental elements of ^{32}P , ^{86}Rb were $\text{NaH}_2^{32}\text{PO}_4$ and $^{86}\text{RbCl}$, respectively. The selected experimental elements of ^{86}Rb , ^{32}P were $\text{NaH}_2^{32}\text{PO}_4$ and $^{86}\text{RbCl}$ respectively, which were supplied by the Institute of Atomic Energy Application, the Chinese Academy of Agricultural Sciences.

2.2 Experimental methods

The processing and determination approach for the transportation pathway of P, K mineral elements from the leaves to the fruits. (1) Carpopodium micro-girdling method: gently strip 0.5cm of the phloem with stainless steel blade 2cm at the base of the spicate peduncle. (2) 25d after full bloom, the first leaves at the upper part of 3-year-old potted 'Jingyou' grape clusters with same growth potential were selected, and uniformly coated with $1.6 \times 10^5\text{Bq}$ of $\text{NaH}_2^{32}\text{PO}_4$ or $0.77 \times 10^5\text{Bq}$ of $^{86}\text{RbCl}$ by means of micro injector facilities at 9:00 of a sunny morning, 48h later, cut the grape cluster and packaged in a brown paper bag, degrading enzyme at 105°C for 10min, drying to counter weight at 80°C , and then grinding and weighing 50mg of samples. Afterwards, BH1216 low

background α , β measuring device should be utilized to measure the activity of ^{86}Rb and ^{32}P ; adjusting the measure time to control the measurement error within 5% or less, then its mean value will be adopted for analysis. Repeat this experiment for three times, the total weight of isotope in the fruit (cpm) = total dry weight of fruit (mg) / sample weight (50mg) \times experimental sample value (cpm).

The processing and determination approach for the transportation pathway of P, K mineral elements from the roots to the fruits. 25d after full bloom, the roots of 3-year-old potted 'Jingyou' grape clusters with same growth potential were selected and placed in water for soaking, and rinsed off soil on the roots. Afterwards, $3.57 \times 10^5\text{Bq}$ of $\text{NaH}_2^{32}\text{PO}_4$ or $2.66 \times 10^5\text{Bq}$ of $^{86}\text{RbCl}$ would be added into 2L of complete nutrient solution, and then completely immersed the roots of the grapes into the $\text{NaH}_2^{32}\text{PO}_4$, $^{86}\text{RbCl}$ complete nutrient medium for 48h after mixing. Finally, the grape clusters should be cut to measure the activity of ^{86}Rb , ^{32}P by virtue of the same sampling methods and testing equipment as above-mentioned.

Study on the critical period of P, K mineral elements transporting into the fruits. The first leaves at the upper part of 3-year-old potted 'Jingyou' grape clusters with same growth potential were selected, and uniformly coated with $2.36 \times 10^5\text{Bq}$ of $\text{NaH}_2^{32}\text{PO}_4$ or $7.47 \times 10^4\text{Bq}$ of $^{86}\text{RbCl}$ by means of micro-injector at the first stage of fruit development (15d after bloom), the second stage of fruit development (25d afterbloom), veraison (50d after bloom) and the third stage of fruit development (20d before harvest) respectively, as shown in Figure 1. Selecting the grape clusters after processing for 2, 4, 8, 12, 24, 48, 72, 96 and 120h to measure the activity of ^{86}Rb , ^{32}P in the fruits by virtue of the same sampling methods and testing equipment as above-mentioned.

Study on the distribution of P, K mineral elements in the grape fruiting branches. The first leaves at the upper part of 3-year-old potted 'Jingyou' grape clusters with same growth potential were selected, and uniformly coated with $2.36 \times 10^5\text{Bq}$ of $\text{NaH}_2^{32}\text{PO}_4$ or $7.47 \times 10^4\text{Bq}$ of $^{86}\text{RbCl}$ by means of micro-injector at the first stage of fruit development (15d after bloom), the second stage of fruit development (25d afterbloom), veraison (50d after bloom) and the third stage of fruit development (20d before harvest) respectively at 9:00 of a sunny morning. Cut the whole fruit branches 5d after processing, divided into processing leaves, un-processing leaves, fruits, and stems. Measure the activity of ^{86}Rb , ^{32}P in those four parts by virtue of the same sampling methods and testing equipment as above-mentioned.

3. Results

3.1 The principal transportation pathway of P, K mineral elements from the leaves to the fruits

Through the method of ear stem girdling the transportation pathway of the phloem was blocked, then observe the amount of ^{86}Rb , ^{32}P absorbed by leaves to the fruits through the xylem. The results illustrated in Figure 1 shows that the amount of ^{86}Rb , ^{32}P transported to the fruits has been significantly reduced after girdling, which is only 5.44% (^{32}P) and 7.28% (^{86}Rb) of the control, there were extreme significant differences between treatments and control. Therefore, the principal transportation pathway for P, K mineral elements absorbed by leaves to the fruits is the phloem. It also shows that, when the phloem is blocked, a small amount of P, K mineral elements can be transported through xylem. Nonetheless, whether the P, K mineral elements that transported through the xylem are directly conducted by the xylem of petiole - stem - ear stem, or through horizontal transportation to the xylem due to the blocking of ear stem phloem, requires further testing for confirmation.

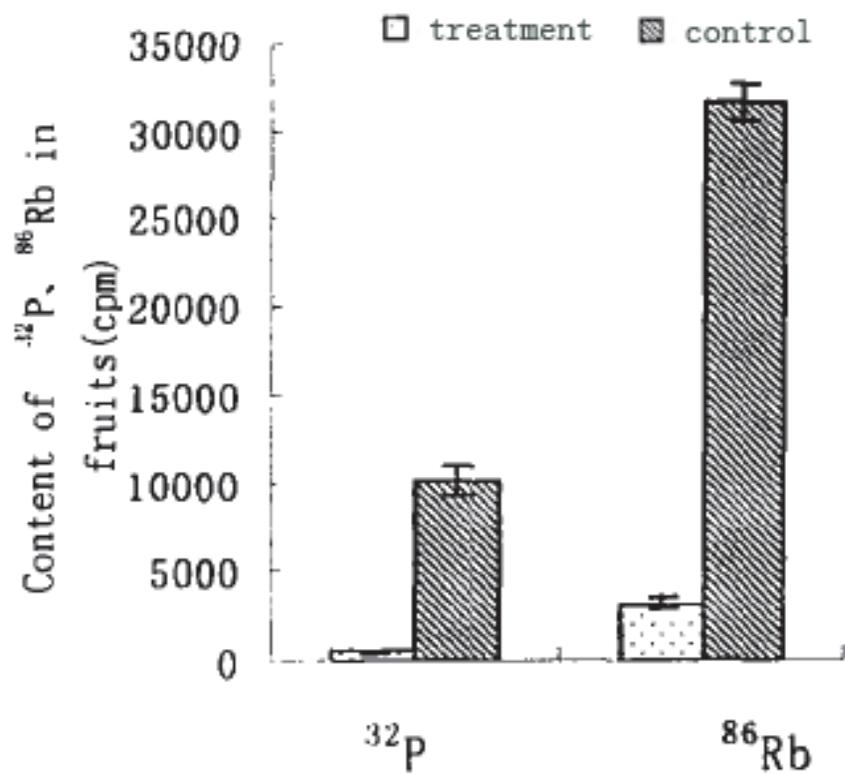


Fig. 1. Effect of fruit stalk microgirdling on influx into fruit of ^{32}P , ^{86}Rb absorbed from leaves

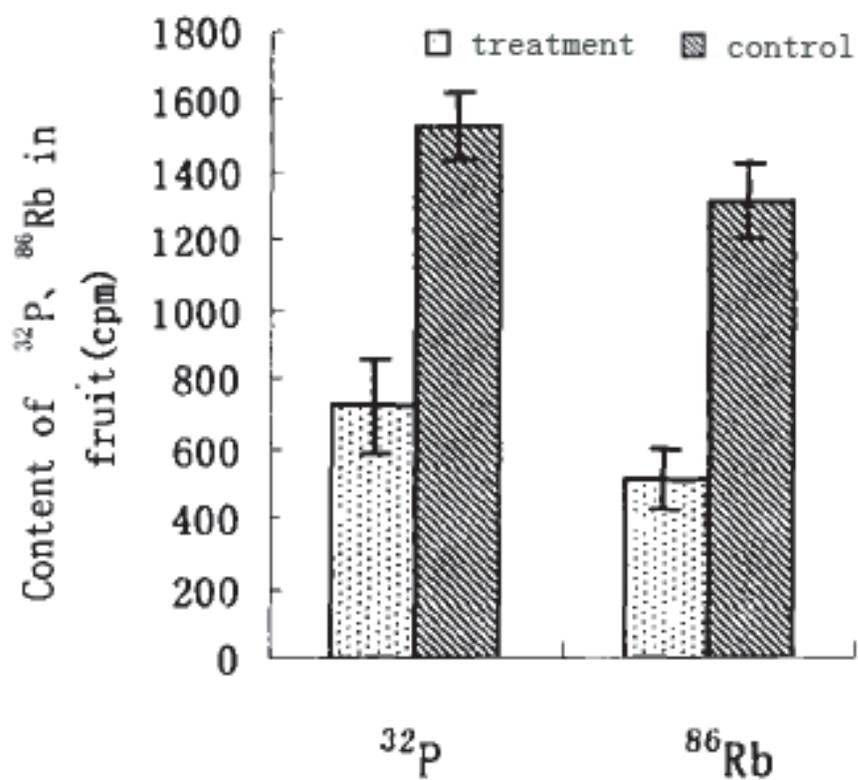


Fig. 2. Effect of fruit stalk microgirdling on influx into fruits of ^{32}P , ^{86}Rb absorbed from roots

3.2 The principal transportation Pathway of P, K mineral elements from the roots to the fruits

The principal transportation pathway for ^{86}Rb , ^{32}P absorbed by roots is ear stem phloem, and the ^{86}Rb , ^{32}P transported to the fruits will be significantly reduced ($P < 0.01$) in case of blocking of the transportation pathway at the phloem, which only accounts for 46.75% (^{32}P) and 38.67% (^{86}Rb) as compared with the control (Figure 2), it can be seen that the phloem and xylem have played an important role for the transportation of P, K mineral elements absorbed by roots to the fruits, additionally, the phloem is the principal transportation pathway, or there is more horizontal transportation between the xylem and phloem in the course of upward transportation, which is quite different from the results obtained by Zhao Jinchun (2000). Thus, it is need carry out more experimental evidence and in-depth research to further determine the principal transportation pathway of P, K mineral elements absorbed by roots to the fruits.

3.3 The P, K uptake of fruits at different developmental stages

Supplying P, K on the surface of the leaves at different growth stages of grape fruits will have a significant effect on the accumulation of P and K in the fruits (Figure 3). Foliar application of P at the first stage of fruit development (15d after bloom) will lead to the higher uptake and accumulation of P mineral element as compared with Other stages. Foliar application of P at different periods has presented a regular impact on fruits, and it shows that Supplying P at the two fast growing periods of fruit will increase P absorption in fruit. And it has demonstrated that the accumulation of P is gradually increased over time, especially 72h later, which is the fastest period of P transported into the fruit. Therefore, the results show that the earlier stage of fruit development demands the most P elements and absorbs the fastest, which is also the critical period of application of P in the production.

The absorption of K mineral elements by fruits at the ripening and young fruit stage is similar with P, The absorption was more in the two fast growing periods of fruits. K elements presented two stages of demand and efficient absorption as compared with P, namely, the first and the third stage of fruit development, while the maximum absorption was the third stage of fruit development. Thus, it should supply with potassium according to the nutrient condition in the orchard.

Figure 4 shows that the absorption efficiency of P, K fertilizer for the grape fruits at different stages had significant variation. The absorption of P at the rapid growth period of young fruit displayed a respective peak at 3d, 5d, accounting for 47.15% and 23.98% of total amount of absorption in 5d; in contrast, the 5th day had the maximum absorption at slow growth stage, accounting for 73.58% of total absorption in 5d; there was no significant difference in continuous 5d at the veraison stage of the grape fruits; supplied with P at 20d before harvest, the latest 2d showed more absorption, accounting for 36.79% and 39.80% of total absorption in 5d, respectively.

The absorption of K at the rapid growth period of young fruit displayed a peak at 3d, accounting for 47.62% of total absorption in 5d; 4d had the minimum absorption, merely accounting for 6.96% of total absorption in 5d; rebounded after the 5d, accounting for 18.74% of total absorption in 5d. In contrast, there was no significant difference for the absorption rate in the slow growth stage, the 4d had the maximum absorption at the veraison stage, accounting for 50.54% of total absorption in 5d; supplied with K at 20d before harvest, the absorption of K at 1d after treatment was low, while the peak absorption was found at the 4d, and the rest 3ds had no significant difference.

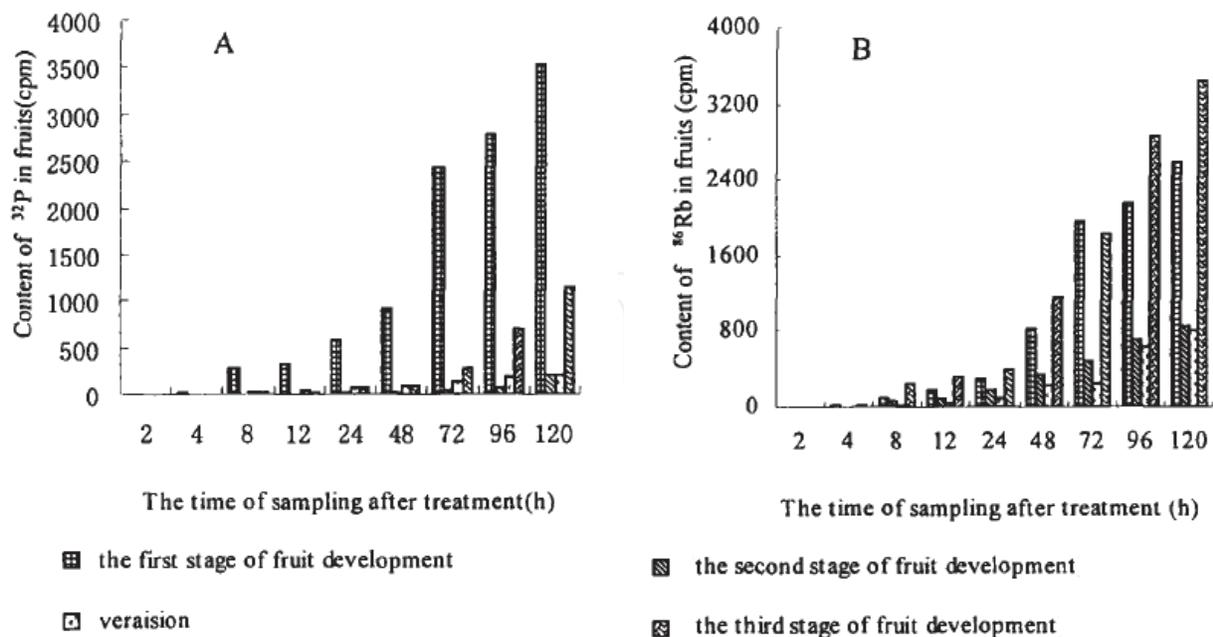


Fig. 3. Effect of different stages of fruit development on influx into fruit of ^{32}P (A), ^{86}Rb (B)

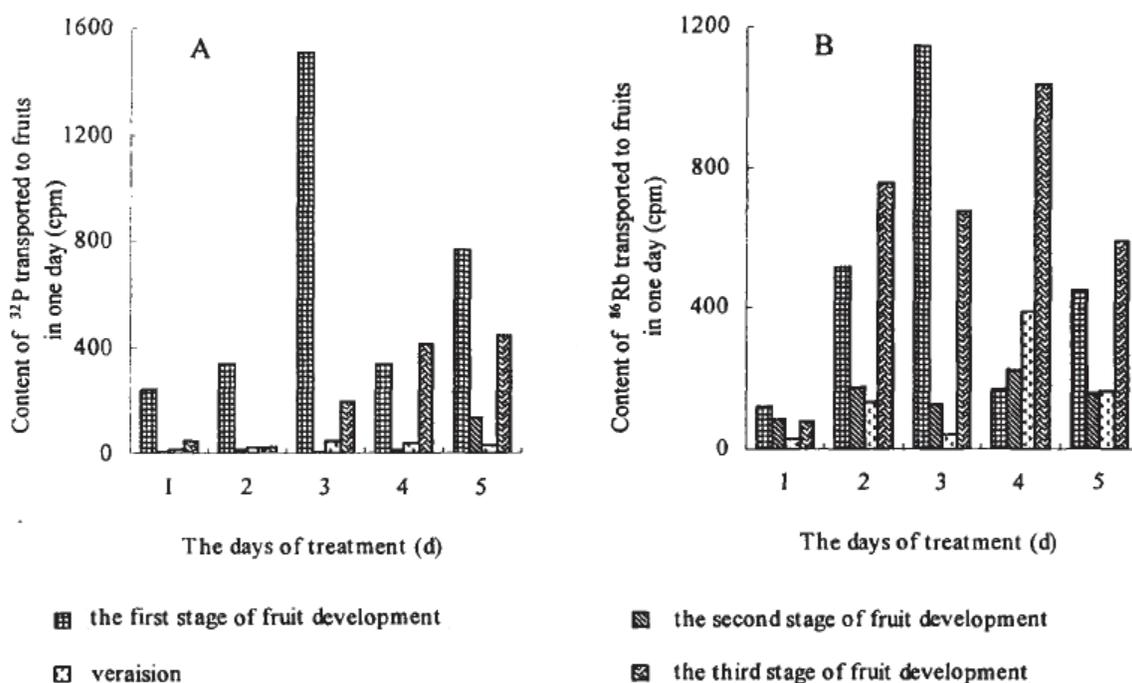


Fig. 4. Content of ^{32}P (A), ^{86}Rb (B) in fruits absorbed from leaves in one day

3.4 The distribution of P, K mineral elements in the branches of grapes

The measurement results of the 5th day after foliar application of $\text{NaH}_2^{32}\text{PO}_4$ showed that 82.90% -95.79% ^{32}P was detained in the leaves (Figure 5A). It indicated that the leaf growth itself required a certain amount of P, and ^{32}P had significantly different distribution in the fruit branches for foliar coating with ^{32}P at different stages, while the fruits were the major organs absorbing ^{32}P in addition to the leaves. The distribution of ^{32}P by virtue of foliar

spray at different stages of fruit development presented variable proportion: the first stage of fruit development (15.13%)> the third stage of fruit development (7.18%)> veraison Stage (4.87%)> the second stage of fruit development (3.53 %). The smallest proportion was in the stem, less than 1%, while the proportion of un-treated leaves was approximately 2%.

76.94%-85.58% of ^{86}Rb was detained in the leaves after 5d of the foliar application of $^{86}\text{RbCl}$ (Figure 5B). There was significant difference in distribution of ^{86}Rb in the fruit branches after treating at different stages, while the fruits were the major organs absorbing ^{86}Rb from the leaves. After foliar application of ^{86}Rb , The distribution of ^{86}Rb in fruit at different stages of fruit development presented variable proportion: the third stage of fruit development (26.86%)> the first stage of fruit development (15.44%)> the second stage of fruit development (11.40%)> veraison Stage (9.06%). The distribution proportion in the stems was 4-7%, while the proportion of un-treated leaves was approximately 1%. Compared with P element, the distribution proportion of K was higher than that of P in fruit (Figure 5B).

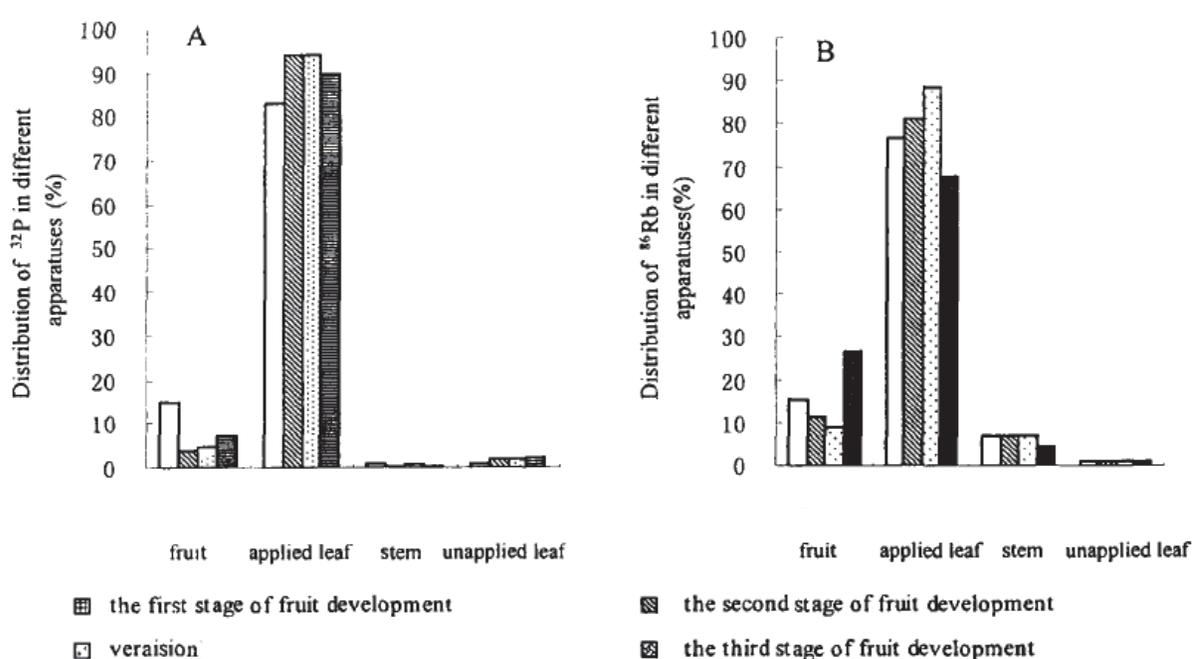


Fig. 5. Distribution of ^{32}P (A), ^{86}Rb (B) absorbed from leaves in bearing branch of grape vine

4. Discussions

4.1 The transportation pathway of P, K mineral elements in the grape fruits

At the 40s of 20th century, ^{42}K tracer technique proved that the upward channel for the transportation of inorganic nutrients is catheter, while existing active horizontal transportation from the xylem to the phloem. Circulation and redistribution process are taken place inside the plants. Literatures on the transportation pathway of nutrients showed that N, P, K mineral elements can be transported from the xylem and the phloem to apple fruits at the growing season, and the both transportation pathways came into play at the early and mid stage of apple fruit development, however, phloem sap played a major role in the fruit enlargement before harvest; with respect to peach fruits, there was still high rate of xylem sap transported to the fruits before harvest, and organic nitrogen, magnesium, potassium in the ripening leaves were transported to the fruits through the xylem

(Tagliavini et al, 2000). Zhao Jinchun (2000) applied micro-girdling stems (Han Zhenhai et al, 1995) to study the transportation pathway of apple fruits, which suggested that the absorbed K mineral element by roots was transported into the fruits mainly through the phloem in the normal development conditions of apple fruits. From the perspective of this experiment, there are two sources of P, K mineral elements for the grape fruits, namely, one is absorbed by roots and directly transported to the fruits through the xylem; the second is transported from the phloem, which may be derived from the horizontal transportation from the xylem to the phloem, and the cycling transportation from the ground leaves and so forth. However, whether P elements at the two parts are involved in the transportation to the fruit and its proportion are needed further study.

Although, it is certain that the root xylem is the important way to transport the P, K mineral elements by roots to the fruits. Taking into account that the ear stem girdling has blocked the phloem transportation pathway, it may stimulate the horizontal transportation in the plant phloem and xylem, and the transported P and K mineral elements from the xylem to the clusters in normal conditions may be less than the measured results under experimental conditions. However, according to the conclusions of this study, there is sufficient argument to deem that the transported P, K mineral elements from the xylem to the fruits cannot be ignored. Foliar application of P, K mainly transported through the phloem, also taking into account the ear stem girdling side effects, the transported P, K mineral elements from the xylem to the clusters in normal conditions may be higher than the measured results under experimental conditions. Potassium maintains a high concentration in the phloem sap, easy to juice up and down for long-distance transportation, and gives priority to supplying for the tender leaves, meristem, fruits and other parts. According to the results of this experiment, spraying P, K fertilizers on the surface of leaves are mainly transported through the phloem, hence, foliar application of P, K can meet the P, K demands at metabolic locations in a short time, thereby providing theoretical evidences to demonstrate that foliar application of P, K is able to give rapid relief of nutrient deficiency for the production.

4.2 The critical period for the grape fruit to absorb P, K mineral elements

It should be noted that this study found that young fruit at its rapid growth stage also requires a lot of potassium, however, it have paid little attention to the importance of applying K at the earlier stage of grape growth currently, and hence it is necessary to supply K for one or two times on the surface of leaves from petal full to 15d after bloom, to meet the high demand for K nutrition of rapid growth of young fruit. This study showed that the quantity demanded for P, K mineral elements of grape fruits at different developmental stages was variable, which was consistent with the research results provided by Hu Shibi et al (1998). K mineral element plays a positive effect in the late enlargement of the fruits, and thus it should timely supply K mineral element at start coloring of the grapes and meets the high demand for K mineral element at cluster late development, so as to promote the ripening of fruits and improve fruit quality of grapes and efficiency of fertilizer utilization. In the beginning of fruit ripening and slow growth period, the fruits require small amount of P, K mineral elements, and it should be supplied appropriately according to the actual nutrition situation in the orchard.

The content of nutrient elements in the fruits has an important influence on fruit quality, and rational fertilization is one of the main measures to improve grape yield and quality.

Deficiency of phosphorus element will block the protein synthesis of fruit trees, affecting cell division, thereby resulting in fruit growth retardation, and quality decline. *Vitis* liking K fruit tree has a high demand for K, thus, applying appropriate amount of P and K fertilizer will improve the nutritional balance of trees, improve fruit quality, and increase fruit resistance. In conclusion, the earlier stage of fruit development, and the stage from coloring to harvest are the critical periods for the grape to absorb P, K mineral elements, and hence it should timely apply K-fertilizer and appropriate amount of P-fertilizer. In this way, it will not only meet the requirements for a large amount of P, K mineral elements by the grape fruits, but also will increase yield and fruit quality, as well as the efficiency of fertilizer utilization.

4.3 Absorption and distribution of P, K mineral elements

On the basis of preceding studies, it indicated that the demand for K by fruits will increase as the approaching of ripening period (Tagliavini et al, 2000). According to the experimental results, the distribution ratio to P, K mineral elements into fruits by virtue of spraying on the surface of leaves showed the maximum at the rapid growth stage of young fruit and approaching the ripening stage, which were relatively consistent with the demands for P, K mineral elements by grape fruits at these stages in this study indeed. During the slow growth period, the growth rate of grape fruit slowed, the sink strength weakened, and the demand for nutrition declined. In addition, the new branch tip was still in its growth peak period, requiring relatively additional competitiveness of nutrition, and hence the distribution ratio of P, K at stems and leaves was increased accordingly.

It is noteworthy that, supplying P, K on the surface of leaves will leave some P, K mineral elements in the treated leaves after 5d. As a consequence, it can be inferred that the leaves are able to store nutrient, and the variation of vacuoles ion concentration in the leaf cells within a certain range indicates that the leaves could effectively accumulate and store P, K mineral elements. Comparison of the radioactivity of P, K elements in the leaves which had been applied at different period, it shows that the amount of external output by the leaves depends on the intensity of the pool (including the fruits, leaves and other organs). As the main metabolic pool, the changes in the strength of fruit pool will direct regulate the output volume of P, K mineral elements. At the rapid growth and near fruit ripening stage, the fruits will absorb much more P, K mineral elements, and thus the isotope detained in the leaves will be reduced accordingly. This indicates that the leaves have nutrient storage function during spraying fertilizer on the surfaces of the leaves. The measurement of nutrient variable range in the leaves by virtue of different concentrations is possible to determine the appropriate concentration of leaf fertilizer. In addition, the observation of ion content dynamics in leaves after supplying mineral elements at different developmental stages can provide reference to determine reasonable intervals of leaf fertilizer for the production.

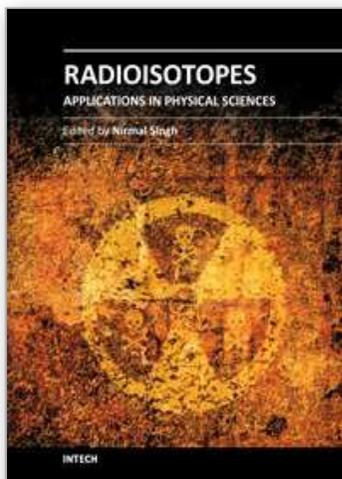
5. Acknowledgements

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The book *Radioisotopes - Applications in Physical Sciences* is divided into three sections namely: Radioisotopes and Some Physical Aspects, Radioisotopes in Environment and Radioisotopes in Power System Space Applications. Section I contains nine chapters on radioisotopes and production and their various applications in some physical and chemical processes. In Section II, ten chapters on the applications of radioisotopes in environment have been added. The interesting articles related to soil, water, environmental dosimetry/tracer and composition analyzer etc. are worth reading. Section III has three chapters on the use of radioisotopes in power systems which generate electrical power by converting heat released from the nuclear decay of radioactive isotopes. The system has to be flown in space for space exploration and radioisotopes can be a good alternative for heat-to-electrical energy conversion. The reader will very much benefit from the chapters presented in this section.

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