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Arbuscular Mycorrhizal Associations and Interactions in Temperate Cropping Systems

Toshihiko KARASAWA

Summary

1. It is widely known that previously planted crops affect the growth and yield of subsequently planted crops through several mechanisms such as changes in water use efficiency and nutrient use efficiency and changes in the sizes of pest populations. However, some observations cannot be fully explained by these mechanisms. Furthermore, the effects of preceding crops are known to vary with the years when or locations where the crops are grown. It has therefore been difficult to determine an appropriate combination of preceding and succeeding crops. A better understanding of the mechanisms by which previously planted crops affect subsequently planted crops is needed for selecting the most appropriate sequence of crops in a rotation system suited to particular environmental conditions. The objectives of this study were, therefore, (i) to elucidate the mechanisms responsible for increases and decreases in the growth rates and yields of various crops after cultivation of several kinds of crops, (ii) to determine the effects of atmospheric and edaphic factors on the effects of preceding crops, and (iii) to try to establish effective methods for improving the growth rates and yields of succeeding crops.

2. A field experiment was conducted from 1991 to 1992 in a Melanudands field in Sapporo, located in the northernmost island of Japan, to determine the effects of preceding crops on the growth and yield of succeeding maize. Sunflower (*Helianthus annuus* L.), maize (*Zea mays* L.), soybean (*Glycine max* Merr.), potato (*Solanum tuberosum* L.), spring wheat (*Triticum aestivum* L.), cabbage (*Brassica oleracea* L.) and sugar beet (*Beta vulgaris* L.) crops were grown as initial crops in 1991. In 1992, a maize crop was grown in each previously planted plot and in plots that had been fallowed. All of the preceding crops had significant effects on the yield of subsequently planted maize. Both shoot weight and grain yield of subsequently planted maize varied widely depending on the crop grown in the previous season. Shoot weights and grain yields of maize after sunflower, maize, soybean, potato or wheat cropping were much higher than those after fallowing or cabbage or sugar beet cropping. The adverse effects of fallowing or cabbage or sugar beet cropping on growth and yield of maize could not be compensated for by phosphorus (P) application (87 kg P ha^{-1}). However, P deficiency was seen in subsequently planted maize after fallowing or after cabbage or sugar beet cropping. Arbuscular mycorrhizal (AM) colonization of maize roots, which is known to accelerate plant P uptake, was influenced by the crop species grown in the previous season, and AM colonization of maize roots was positively correlated with the shoot dry weight of maize. It was therefore speculated that the differences in growth rates and amounts of P uptake of subsequently planted maize were caused by differences in the AM colonization of the maize roots.

3. A pot experiment was conducted to determine whether the positive effect of AM host

cropping on the growth of succeeding maize is mainly due to the multiplication of indigenous AM fungi. Maize plants were grown in soil (Melanudands) after mustard (*Brassica alba* Boiss, non-host) cropping without AM fungal (AMF) inoculum (MD_{NI}), with inoculum from the soil after sunflower cropping (MD_{ISF}), with sterilized inoculum (MD_{SI}), and in soil after sunflower (host) cropping without inoculum (SF_{NI}). The growth of maize after mustard cropping (MD_{NI}) was inferior to that after sunflower cropping (SF_{NI}). The AMF inoculum from the soil after sunflower cropping (MD_{ISF}) improved the growth and AM colonization of maize, and shoot weight was increased from 17 to 49% of that in the SF_{NI} treatment. However, the sterilized inoculum (MD_{SI}) did not show similar effects. Similar AMF species to those increased by sunflower cropping were dominant in SF_{NI}-treated and MD_{ISF}-treated soils following maize cropping, also indicating that the AM colonization of maize was improved by multiplied AM fungi through sunflower cropping. These results suggest that the effects of preceding crops on maize growth are at least partly due to differences in AMF densities caused by various preceding crops.

4. A series of field experiments was conducted in a Melanudands field to investigate whether similar effects of preceding crops are observed in various succeeding crops other than maize. Growth and yield of kidney bean (*Phaseolus vulgaris* L.), adzuki bean (*Vigna angularis* L.), soybean, sunflower, wheat and potato (AM host) after cultivation of AM host crops were superior to those after nonhost crops. However growth and yield of radish (*Raphanus sativus* L.), cabbage, buckwheat (*Fagopyrum esculentum* Moench) and sugar beet (nonhost) were not affected by the preceding crops. Growth and yield of most AM host crops are thought to be affected by the preceding cropping in ways similar to those of maize, given that AM host crops depend on arbuscular mycorrhizae for their P uptake. However, the degrees of effects of preceding crops on AM host crops were different; the effects on adzuki bean, kidney bean, soybean, sunflower and maize crops were greater than those on wheat and potato crops.

5. The effects of preceding crops on AM formation and growth of succeeding maize were examined at different soil moisture levels. Maize was grown in pots filled with soil (Melanudands) taken from the plots in which AM host (sunflower, maize, soybean, kidney bean, adzuki bean, potato and wheat) and nonhost (mustard, radish, sugar beet and buckwheat) crops had been cultivated in the previous season. Soil water potential was adjusted to around -10 kPa (wet: W), -50 kPa (moist: M) and <-63 kPa (dry: D) from 11 days after sowing. The soils after cultivation of AM host plants in the previous season contained more AMF spores than did those after cultivation of nonhost plants. The influence of the preceding crops on AM colonization was pronounced in drier soils, in which AM colonization of maize following AM host cropping occurred more frequently than that after nonhost cropping. Arbuscular mycorrhizal colonization of maize, however, improved with increasing soil moisture status even after nonhost cropping, despite the low AMF spore population. The influence of preceding crops on maize growth was also distinct, but it declined markedly with increase in the soil moisture status. The increase in AM colonization with increase in the soil moisture status despite the low AMF spore population suggests that a higher soil moisture status improved the efficiency of AM colonization. Such effects may have, in turn, stimulated P uptake and enhanced plant growth, thereby reducing the influence of the cropping history.

6. Preceding crops have been reported to affect the growth and P uptake of succeeding crops because of their distinct effects on AM colonization. It has also been reported that low soil tem-

perature greatly reduces plant P uptake. Therefore, the effects of preceding crops on the growth, P uptake and AM colonization of succeeding maize plants were examined at three soil temperatures in order to clarify the effects of low soil temperature on the growth responses of maize plants to preceding crops. Maize plants were grown in pots in which sunflower (AM host) or mustard (nonhost) crops had been cultivated as preceding crops. Soil temperature was adjusted to 15, 20 or 25 ℃ during cultivation of maize plants. Air temperature was equally adjusted to 25 ℃ (day) and 20 ℃ (night) in each treatment. The growth rate and AM colonization of maize plants declined as the soil temperature fell. However, the growth of maize plants after cultivation of sunflower crops was superior to that after mustard cropping at each soil temperature. Shoot dry weights of maize after sunflower cropping were 5.1-times (at 15 ℃), 6.5-times (at 20 ℃) and 5.0-times (at 25 ℃) greater than those after mustard cropping. The percent AM colonization of maize roots after sunflower cropping was much greater than that after mustard cropping at each soil temperature. The results therefore suggested that the AM colonization of maize roots was affected by the preceding crops at each soil temperature and that cultivation of sunflower (AM host) crops improved the AM colonization of succeeding maize, which accelerated the P uptake and growth of maize even at low soil temperature above 15 ℃.

7. It is well known that soil-P availability affects AM colonization of plants. Thus, the effects of preceding crops may be also influenced by soil-P availability. A field experiment was conducted to determine the influence of P availability on the effects of preceding crops. After cultivation of cabbage, soybean and maize, 0, 250 and 500 kg P_2O_5 ha^{-1} of P were applied and maize crops were grown in each plot. Cabbage is a non-mycorrhizal host, and soybean and maize are AM host crops. Growth of maize differed depending on the preceding crop; the growth rate of maize after cultivation of soybean or maize (AM host) was higher than that after cultivation of cabbage (nonhost) at each level of soil-P availability. At a low available P level, the effect of the preceding crop was evident, but the effect became less evident with increase in soil-P availability level. Arbuscular mycorrhizal colonization of maize roots depended on the preceding crop, and the percent colonization of maize after cultivation of soybean or maize was higher than that after cultivation of cabbage. The percent AM colonization of maize after cultivation of each crop decreased with increase in available P level. The effects of preceding crops on the grain yield of maize were not as pronounced as the effects on early growth of maize. Differences in maize yield were observed only when no P was applied (available P level of the soil without P fertilizer being less than 103 mg P kg^{-1} soil), suggesting that the effects of preceding crops are pronounced at a low available P level in soil and that the effects are also evident at the available P level recommended in Hokkaido (44-131 mg P kg^{-1} soil).

8. The effects of the preceding crops, sunflower (AM host) and mustard (nonhost), on AM colonization and growth of succeeding maize were examined in 17 soils in an attempt to clarify the influence of soil characteristics on the effects of preceding cropping. Shoot weight of and P uptake by maize planted after sunflower cropping were much higher than those after mustard cropping in 14 soils, although the preceding cropping had little effect on soil-P availability. Percent AM colonization of maize after sunflower cropping was much higher than that after mustard cropping. The effect of preceding crops was eliminated by soil sterilization. These results suggested that the differences in maize growth were caused by differences in AM colonization. Correlation analysis of the effect of preceding cropping and soil properties

showed that the difference in the effects on maize growth could not be explained by soil chemical properties but only by the AM colonization of the preceding sunflower. In one of the 17 soils, however, the effect was not evident despite the fact that the percent AM colonization of the preceding sunflower was high. This soil was sterilized, and the effect of inoculation of AM fungi on maize was examined. However, it was found that the inoculation increased AM colonization but did not improve maize growth at any P level, suggesting that the effect of AM fungi was unusually inhibited in this soil by unknown soil physicochemical properties. In most soils, however, the preceding AM host crop, sunflower, increased the AM colonization of the succeeding maize and improved its growth.

9. It has been suggested that cultivation of some crops with little arbuscular mycorrhiza results in a decline in AM colonization and growth of succeeding crops. However, such crops also need to be cultivated in rotation. To try to establish an effective method for improving the growth of succeeding crops, therefore, green manure crops (AM host crops) were grown immediately after harvesting of crops with little mycorrhiza, and the effects on succeeding maize were examined under field conditions. After oat *(Avena sativa* L.) cropping, sunflower, vetch (*Vicia* sp.) or mustard seeds were sown as green manure on August 7, 1996. Sunflower seeds were also sown on September 9 and October 11. Each green manure crop was harvested (unincorporated) or incorporated on November 5. In the following season, maize was grown in the plots after sunflower, vetch or mustard cropping and in a plot after fallowing. The percent AM colonization, shoot weight and yield of maize grown after AM host (sunflower and vetch) cropping were much greater than those after fallowing and nonhost (mustard) cropping. Furthermore, the growth of succeeding maize was not affected by incorporation of the green manure crops. These results suggest that the increases in AMF populations during cultivation of AM host crops improved the efficiency of AM colonization in the following season and that this brought about positive effects of sunflower and vetch cropping. Effects of sunflower cropping on the growth of maize were not observed in the plots in which sunflower seeds were sown after September. Since there was little AM colonization of sunflowers for which the seeds had been sown after September, it is thought that sunflower cropping after September did not increase sizes of AMF populations in the soil. Therefore, AM host crops must be sown in August (in case of sunflower) to improve AM colonization, growth and yield of succeeding crops when crops with little mycorrhiza are grown in the field.

10. The results of this series of studies suggested that the differences between growth rates of succeeding crops were mainly caused by fluctuation in sizes of indigenous AMF populations due to different preceding crops. These results indicate that AM dependency of crops and the associations of crops with AM fungi are important factors for selection of an appropriate combination of preceding crops and succeeding crops. The effects of preceding crops were evident in dry soil and in low-P soils but not in wet soil and in high-P soil. These effects were observed over relatively wide ranges of soil temperature and soil type. Information on these effects is useful for determining the most appropriate sequence of crops in a rotation system suited to particular environmental conditions. The results of this series of studies indicate that the selection of a combination of preceding crops and succeeding crops should be based on the AMF status in soil when crops are grown in dry soil (especially drier than field capacity) or low-P soil (especially less than 110 mg P kg^{-1}). The results also suggest that the productivity of crops after cultivation of nonhost crops is improved by the introduction of AM

host crops as green manure. Improvement in crop sequences and introduction of green manure crops are thought to be useful means for manipulating indigenous AM fungi so as to improve field crop production in crop rotations.