Effects of Antimicrobial Application and Non-uniform Fertilization on Maize and Potato Growth and Yield: Postprint

Authors: Li Yongxian; Zhang Xiaoyun; Zhang Leilei; Li Wang; Wu Kaixian

Date: 2018-01-05T00:00:00+00:00

Abstract

In agricultural production, fertilizer application and bacteriostatic pesticide use are two important agricultural techniques. During fertilization, spot and strip fertilization are the primary methods, which tend to result in patchy distribution of soil nutrients throughout the crop growth cycle. Under such conditions, root foraging behavior is crucial for nutrient acquisition. When bacteriostatic pesticides are applied, the chemicals can enter the soil profile through leaching and other processes, exerting direct or indirect effects on the soil ecological environment and root-soil processes. However, it remains unclear whether pesticide application influences crop root foraging behavior, thereby altering yield performance. This study selected maize and potato, major dryland food crops, as research subjects. Soil nutrient patches were established by applying equal amounts of fertilizer in alternate rows, and broad-spectrum fungicides were subsequently applied to the soil via drenching to investigate the effects of bacteriostatic pesticides on crop utilization of heterogeneous nutrients. Data from two-year field experiments demonstrated that fungicide drenching and alternate-row fertilization significantly affected crop plant biomass, yield, root biomass and distribution to a certain extent, and exhibited significant interactive effects on maize biomass, such that the significant biomass increase from alternate-row fertilization occurred under fungicide drenching conditions, whereas the fungicide-induced increase in maize biomass was primarily manifested under alternate-row fertilization conditions. Meanwhile, fungicide drenching enhanced crop foraging precision, which reached a significant level in potato, indicating that fungicide drenching has a promoting effect on crop adaptation to soil nutrient patches. Of course, the significance of bacteriostatic pesticides and nutrient patches in affecting crop growth processes is influenced by crop type and planting year, demonstrating complexity. Therefore, it is necessary to further investigate the role of bacteriostatic pesticides in crop adaptation to nutrient patches and their

mechanisms affecting crop root foraging behavior across different crops, ecological environments, and cultivation practices, which holds potential value for understanding the impact of pesticide application on fertilizer utilization.

Full Text

Effects of Fungicide Application and Heterogeneous Fertilization on the Growth and Yield of Maize and Potato

LI Yongxian, ZHANG Xiaoyun, ZHANG Leilei, LI Wang, WU Kaixian

College of Agronomy and Biotechnology, Yunnan Agricultural University, Kunming 650201, China

Abstract: In agriculture, fertilizer and fungicide application are two important techniques for high yield. For fertilization, block and strip-like fertilization are common practices that result in patchy soil nutrient distribution. In this context, root growth orientation toward soil nutrients becomes important for absorbing heterogeneous nutrients. For fungicide application, the chemicals can permeate into soil through leaching, directly or indirectly affecting the soil environment and root-soil interactions. However, it remains unclear whether pesticide application affects crop root foraging behavior and consequently alters yield performance. This study selected maize and potato—major upland food crops—as experimental subjects to investigate how fungicide application influences crop utilization of heterogeneous nutrients. Using an equal fertilizer amount, we created soil nutrient patches through inter-row fertilization and then applied broad-spectrum fungicides via watering. Two years of field experimental data demonstrated that fungicide application and inter-row fertilization significantly affected crop biomass, yield, root biomass, and distribution. Moreover, these treatments showed significant interactive effects on maize biomass, where the biomass increase from inter-row fertilization occurred primarily under fungicide application, while the fungicide effect on maize biomass was mainly expressed under inter-row fertilization conditions. Fungicide application also improved root foraging precision, with a significant effect observed in potato, indicating that fungicide application promotes crop adaptation to soil nutrient patches. However, the significance of these effects varied with crop type and planting year, demonstrating considerable complexity. Therefore, further research exploring the role of fungicides in crop adaptation to nutrient patches and their influence mechanisms on root foraging behavior is necessary, as this holds potential value for understanding how pesticide application affects fertilizer utilization.

Keywords: Nutrient heterogeneity; Fungicides; Root growth orientation toward soil nutrients; Soil microorganisms; Potato; Maize

Introduction

Fertilizer and pesticide application represent major material inputs in agricultural production and constitute an important foundation for modern agricultural development. However, inputs have become severely excessive in recent years. Statistics indicate that China' s annual fertilizer and pesticide usage has reached 60.22 million tons and 1.78 million tons, respectively—the highest globally—with nitrogen fertilizer consumption three times the world average. This overuse poses significant threats to farmland and aquatic ecosystems, reduces soil fertility and agricultural biodiversity, and creates food safety crises. Improving utilization efficiency has become a key approach to reducing these excessive inputs, and integrated fertilizer-pesticide technologies for reducing application rates while maintaining efficacy are attracting increasing attention.

In agricultural production, most pesticides applied to crop canopies can also enter the rhizosphere soil through rainwater leaching and other pathways, thereby affecting root growth. For instance, leached fungicides can influence the survival, reproduction, and community composition of soil microorganisms, which in turn regulates plant nutrient absorption. This effect may occur through two primary pathways. First, effective nutrient absorption and utilization depend on plant health; when plants suffer from pathogenic microbial infections, fertilizer use efficiency decreases substantially, leading to unnecessary fertilizer inputs. Second, soil microbial diversity and certain symbiotic microorganisms (such as mycorrhizal fungi) play crucial roles in promoting crop nutrient absorption, transformation, and transport. Consequently, research on the relationship between soil microorganisms and plant nutrition has long been a priority, with numerous studies reported in the literature.

In the crop rhizosphere environment, soil nutrients exhibit high spatial heterogeneity—nutrient patches—due to agronomic practices such as spot/strip fertilization, tillage, and irrigation. Research has confirmed that soil nutrient patches alter root nutrient absorption, utilization, and growth performance in both natural ecosystems and farmland. Soil microorganisms may regulate this process in two ways. First, to adapt to heterogeneously distributed resources, roots often selectively concentrate growth in high-nutrient patches, demonstrating foraging behavior. This process is accompanied by increased root exudation, biomass, branching, and specific root length in high-nutrient patches, which can enhance pathogenic microbial activity and proliferation, potentially making roots more susceptible to infection in these patches. Second, soil nutrient heterogeneity can increase microbial activity, driving greater microbial species and functional diversity, particularly among mycorrhizal fungi, thereby altering crop growth. Theoretically, these mechanisms suggest an interactive relationship between fungicide leaching, associated changes in soil microorganisms, and soil nutrient heterogeneity in influencing crop growth.

This study selected maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) —major upland food crops—as experimental subjects. By creating soil nutrient patches through inter-row fertilization and applying broad-spectrum fungicides via watering, we investigated whether fungicide use and associated soil microbial changes regulate crop root foraging behavior and nutrient acquisition capacity, aiming to provide theoretical guidance for optimizing fertilizer and pesticide application methods, timing, and placement in agricultural production.

1.1 Experimental Site Description

Field experiments were conducted in 2015 and 2016 at the Yunnan Agricultural University Experimental Teaching Base in Daheqiao Township, Xundian County, Kunming, Yunnan Province (25°31 07 N, 103°16 41 E). The site is located at 1,860 m altitude with an average annual temperature of 14.7°C and mean annual precipitation of 960.0 mm, concentrated primarily from May to September, representing a subtropical plateau monsoon climate. The soil is a water-improved dryland red soil, with faba bean (*Vicia faba* L.) as the previous crop. Before the experiment, soil samples from the 0–25 cm root layer were collected and analyzed using conventional methods. Soil fertility characteristics were as follows: organic matter 22.97 g · kg ¹, total nitrogen 1.09 g · kg ¹, hydrolyzable nitrogen 90.10 mg · kg ¹, total phosphorus 0.82 g · kg ¹, available phosphorus 10.74 g · kg ¹, total potassium 19.07 g · kg ¹, available potassium 143.66 mg · kg ¹, and pH 7.92.

1.2 Experimental Design

The study used maize cultivar 'Yunrui 88' and potato cultivar 'Hui-2' , both locally dominant varieties. Two factors were examined for each crop: fertilization method and fungicide application. Fertilization methods included two levels—homogeneous fertilization (every row fertilized) and heterogeneous fertilization (inter-row fertilization) [Figure 1: see original paper]. Fungicide application also comprised two levels: broad-spectrum soil microbial inhibitor application and control (equal amount of water). Each crop had four treatment combinations with three replications, totaling 24 plots arranged in a randomized block design.

Heterogeneous fertilization was implemented through inter-row trench application of controlled-release compound fertilizer (Wofute coated controlled-release fertilizer N26, P11, K11). This trenching method creates effective and persistent nutrient patches and represents a conventional practice widely adopted by farmers. During the seedling stage, narrow trenches 7–8 cm deep were dug between rows, fertilizer was applied, and then covered with 4–5 cm of surface soil. Both homogeneous and inter-row fertilization treatments received a single pre-planting application of 600 kg · hm ². Soil microbial inhibition was achieved by alternately applying broad-spectrum soil microbial inhibitors carbendazim (Guoguang, 50% wettable powder) and mancozeb (Guoguang, 70% wettable powder) at double the recommended dose every 15 days. Starting from the crop seedling stage (five-leaf stage for maize, average plant height 8 cm for potato), inhibitors were uniformly watered onto soil every 15 days (alternating between the two) until crop maturity (50% above-ground senescence for potato; dough stage for maize). Applications were performed on sunny mornings.

Each experimental plot measured 4.0 m × 5.0 m. Potato planting dates were March 18, 2015, and March 25, 2016, with row spacing of 40 cm and plant spacing of 35 cm in east-west orientation, planted in furrows at 10–12 cm depth. Maize planting dates were April 15, 2015, and April 18, 2016, with row spacing of 40 cm and plant spacing of 35 cm in east-west orientation, planted in furrows at 4–5 cm depth. During the experimental period, weeding was performed monthly, with timely irrigation and pest control as needed.

1.3 Sampling and Observations

At crop flowering stage, one-third of each plot was used for biomass and root growth observations. Fifteen plants were randomly selected from this third of each plot, and above-ground portions were harvested at ground level and oven-dried at 80°C to constant weight to determine shoot biomass. Roots (including potato tubers) were then sampled using the excavation method. A spade was used to excavate root-soil monoliths centered on each plant, bounded by midlines between rows and plants (20 cm × 16.5 cm × 25 cm for potato; 20 cm × 16.5 cm × 30 cm for maize). Initial root-soil separation was performed in the field, followed by washing with tap water to obtain root samples. To assess root foraging precision under heterogeneous fertilization (ratio of root biomass in high-nutrient zones to that in low-nutrient zones), root growth direction and nutrient zone location were marked in the field. Samples were cut along the midline between rows after being brought indoors to obtain root samples from different zones. All root samples (including potato tubers) were oven-dried at 70°C to constant weight to determine dry weight. At crop maturity, the remaining two-thirds of each plot were harvested for yield determination. Potato yield was measured as fresh weight, while maize yield was calculated based on fresh plot yield, with eight randomly selected plants from each treatment dried to determine fresh-to-dry ratio and grain extraction rate, then corrected to 14% moisture content.

1.4 Data Processing and Statistical Analysis

SPSS 19.0 was used for analysis of variance (ANOVA) on all indicators. For yield and biomass analysis, nutrient distribution and soil microbial treatment were treated as fixed factors, while for foraging precision analysis, only microbial treatment was considered as a fixed factor. The significance level was set at $= 0.05$, and variables with heterogeneous variances were natural log-transformed before analysis. Duncan's multiple range test was used for post-hoc comparisons among treatments.

Results

2.1 Effects of Fungicide Application and Fertilization Method on Crop Yield

Fungicide application and fertilization method significantly affected crop yield, though these effects varied with crop type and planting year [FIGURE:2, TABLE:1]. For potato, fungicide application significantly increased yield in 2016, while inter-row fertilization did not significantly affect yield and showed no increasing trend. In 2015, fungicide application did not significantly impact yield. Regardless of fungicide application, fertilization method significantly increased potato yield. For maize, fungicide application significantly increased yield in 2015 but not in 2016. Fertilization method did not significantly affect maize yield in either year.

2.2 Effects of Fungicide Application and Fertilization Method on Plant Biomass

To some extent, both fungicide application and fertilization method significantly affected crop biomass, with certain interactive effects, though these varied by crop type and planting year [TABLE:1, TABLE:2]. For potato, field application of soil microbial inhibitors significantly increased biomass in both years, regardless of fertilization method. Conversely, nutrient patches created by inter-row fertilization did not significantly affect plant biomass in either year, regardless of fungicide application. For maize, fungicide application significantly increased biomass in 2015 under both fertilization methods. However, in 2016, this significant promoting effect occurred primarily under heterogeneous fertilization, with no significant effect under homogeneous fertilization. Inter-row fertilization did not significantly affect maize biomass in 2015, while in 2016, it significantly increased biomass only when microbial inhibitors were applied, showing no significant effect without inhibitor application.

2.3 Effects of Fungicide Application and Fertilization Method on Root Growth and Foraging Precision

Under the interaction of nutrient patches from heterogeneous fertilization and soil microorganisms, root biomass and distribution are critical factors affecting crop productivity. In 2016, neither fungicide application nor fertilization method significantly affected root biomass in either crop [FIGURE:3, TABLE:1]. However, examining root distribution under heterogeneous fertilization revealed that fungicide application improved crop foraging precision, with a significant promoting effect observed in potato [FIGURE:4, TABLE:1]. These results suggest that soil microorganisms may inhibit the potential of crop roots to forage for nutrient patches.

Discussion

This two-year field study using maize and potato revealed interactive effects between fungicide application and fertilization method on crop growth, manifested as mutual promotion in enhancing maize biomass. Additionally, fungicide application promoted crop root foraging capacity and improved plant growth performance. These findings preliminarily indicate that broad-spectrum fungicide application can influence crop absorption and utilization of patchily distributed nutrients, offering reference value for improving fertilizer and pesticide application efficacy.

The interactive effects between fungicide application and inter-row fertilization varied with crop type and planting year, demonstrating the complexity of relationships between fertilizers and soil microbe-affecting pesticides. From a climatic perspective, numerous factors including temperature, moisture, and atmospheric conditions may contribute to this variability. For example, precipitation differences alter soil moisture content, changing the mobility of soil nutrients and fungicides, which may modify the relationship between microorganisms and nutrient patch effects. Both soil temperature and moisture content affect root activity and microbial reproduction, potentially altering how nutrient patches influence microorganisms. Fungicide degradation, volatilization, and persistence in soil are also climate-dependent. Since this study did not monitor climate parameters and their relationships with root foraging, these hypotheses require verification. Crop type differences may relate to species-specific adaptations to heterogeneous nutrients and soil microorganisms.

Root foraging capacity under heterogeneous nutrient conditions is a crucial parameter determining crop growth and yield performance. This study found that fungicide application enhanced root foraging capacity in both maize and potato. Fungicides may influence plant roots through multiple pathways, primarily via microbial inhibition, soil fauna regulation, or acting as plant growth regulators. However, limited research exists on how soil fauna and plant growth regulators modulate root foraging behavior, and their potential roles remain unclear. Regarding soil microorganisms, this study did not directly observe microbial changes, so whether fungicide application affects root foraging through microbial regulation and the underlying mechanisms can only be theoretically inferred.

If fungicide application influences root foraging through microbial regulation, one possible explanation is that root exudation and turnover accelerate during foraging, stimulating growth of specific microorganisms that cause root diseases. However, no obvious disease symptoms were observed under these conditions. Two alternative perspectives may explain this phenomenon. First, nutrient patch formation promotes beneficial microorganisms such as mycorrhizal fungi, which can function like root hairs, reduce root diseases during foraging, and thereby decrease the necessity for root growth investment. Second, nutrient patches increase rhizosphere ecological diversity, directly or indirectly promoting microbial diversity, reducing root disease incidence, enhancing root activity, and improving physiological nutrient absorption capacity. Previous research also indicates that increased foraging precision does not necessarily promote nutrient utilization, and root physiological plasticity can also alter nutrient absorption. This partially explains why crop yield and growth did not significantly increase with improved foraging precision under inter-row fertilization in this study. Therefore, further investigation into how soil microorganisms affect crop physiological characteristics when utilizing heterogeneously distributed nutrients is warranted.

Notably, plant capacity to acquire heterogeneously distributed nutrients exhibits strong species specificity. In maize production, uniform broadcasting is less common than conventional practices such as inter-row strip application, hole fertilization, or spot application on one side of plants, which are generally considered to improve nutrient absorption efficiency. This study preliminarily suggests that maize foraging precision for nutrient patches is slightly higher than that of potato, and maize shows some adaptability to inter-row fertilization, whereas traditional row-by-row fertilization may be more suitable for potato due to its roots exhibiting some nutrient avoidance behavior that limits yield potential. Based on these preliminary results, we recommend bilateral fertilization for potato, while inter-row fertilization may be appropriate for maize. This approach can not only improve nutrient utilization but also reduce labor input and promote simplified cultivation practices, offering practical value for mountainous agricultural production with low mechanization levels and increasing labor shortages. For both crops, combining conventional (heterogeneous) fertilization with soil disinfection or integrating fungicide application based on field disease conditions can promote fertilizer utilization.

Conclusion

This two-year field study using maize and potato demonstrated interactive effects between fungicide application and inter-row fertilization on maize growth, showing mutual promotion. Additionally, under inter-row fertilization conditions, fungicide application promoted root foraging capacity in both crops and improved plant growth performance to some extent. Given that treatment effects varied significantly by crop type and planting year, the influences of fungicide application and inter-row fertilization on crop growth and yield are complex. Therefore, further research is necessary to explore the role of fungicides in crop adaptation to nutrient patches across different crops, ecological environments, and cultivation practices. Investigating the mechanisms through which fungicides affect root foraging behavior—including specific microbial regulatory processes and potential roles as plant growth regulators—holds potential value for understanding how pesticide application influences fertilizer utilization.

References

[1] Xie H, Zhu L S, Tan M Y. Degradation dynamics of IPP in soil and its effects on soil microorganisms[J]. Acta Pedologica Sinica. 2016, 53(1): 232-240.

[2] Schuster E, Schröder D. Side-effects of sequentially-applied pesticides on non-target soil microorganisms: field experiments[J]. Soil Biology & Biochemistry. 1990, 22(3): 367-373.

[3] Wei L L, Lu C Y, Ding J, Yu S, et al..Functional relationships between arbuscular mycorrhizal symbionts and nutrient dynamics in plant-soil-microbe system[J]. Acta Ecologica Sinica. 2016, 36(14): 4233-4243.

[4] Weidner S, Koller R, Latz E, et al. Bacterial diversity amplifies nutrient-based plant-soil feedbacks[J]. Functional Ecology. 2015, 29(10): 1341-1349.

[5] Cavagnaro T R, Smith F A, Smith S E, et al. Functional diversity in arbuscular mycorrhizas: exploitation of soil patches with different phosphate enrichment differs among fungal species[J]. Plant, Cell and Environment. 2005, 28(5): 642-650.

[6] Hodge A. The plastic plant: root responses to heterogeneous supplies of nutrients[J]. New Phytologist. 2004, 162(1): 9-24.

[7] Smith S E, Smith F A. Roles of arbuscular mycorrhizas in plant nutrition and growth: new paradigms from cellular to ecosystem scales[J]. Annual Review of Plant Biology. 2011, 62(1): 227-250.

[8] Dodd I C, Ruiz-Lozano J M. Microbial enhancement of crop resource use efficiency[J]. Current Opinion in Biotechnology. 2012, 23(2): 236-242.

[9] Jin H, Pfeffer P E, Douds D D, et al. The uptake, metabolism, transport and transfer of nitrogen in an arbuscular mycorrhizal symbiosis[J]. New Phytologist. 2005, 168(3): 687-696.

[10] Jackson R B C. The scale of nutrient heterogeneity around individual plants and its quantification with geostatistics[J]. Ecology. 1993, 74(2): 612-614.

[11] Wijesinghe D K, John E A, Hutchings M J. Does pattern of soil resource heterogeneity determine plant community structure? An experimental investigation[J]. Journal of Ecology. 2005, 93(1): 99-112.

[12] Wu K X, An T X, Fan Z W, et al. Maize and potato growth responses to heterogeneous nitrogen and shoot competition[J]. Chinese Journal of Eco-Agriculture. 2012(12): 1571-1578.

[13] Heinze J, Gensch S, Weber E, et al. Soil temperature modifies effects of soil-biota on plant growth[J]. Journal of Plant Ecology. 2016, 10(5): 808–821.

[14] Paterson E. Root exudation from hordeum vulgare in response to localized nitrate supply[J]. Journal of Experimental Botany. 2006, 57(10): 2413-2420.

[15] Sikes B A, Cottenie K, Klironomos J N. Plant and fungal identity determines pathogen protection of plant roots by arbuscular mycorrhizas[J]. The Journal of Ecology. 2009, 97(6): 1274.

[16] Hoeksema J D, Chaudhary V B, Gehring C A, et al. A meta–analysis of context–dependency in plant response to inoculation with mycorrhizal fungi[J]. Ecology Letters. 2010, 13(3): 394-407.

[17] Delgado-baquerizo M, Reich P B, Khachane A N, et al. It is elemental: soil nutrient stoichiometry drives bacterial diversity.[J]. Environmental Microbiology. 2017, 19(3): 1176–1188.

[18] Boldt-burisch K, Naeth M A. Mycorrhization affects root distribution of Lotus corniculatus and Calamagrostis epigeios in a nutrient poor heterogeneous soil in a rhizotron experiment[J]. Rhizosphere. 2017, 4(10): 36-47.

[19] Boldt-Burisch K, Naeth M A. Heterogeneous soil conditions influence fungal alkaline phosphatase activity in roots of Lotus corniculatus[J]. Applied Soil Ecology. 2017, 116: 55-63.

[20] Du L Y, Zhang G Y, Jin W. Effects of soil water content and humic acid on degradation of organochlorine pesticides[J]. Acta Pedologica Sinica. 2006, 43(2): 332-336.

[21] Liu B, Li H, Zhu B, et al. Complementarity in nutrient foraging strategies of absorptive fine roots and arbuscular mycorrhizal fungi across 14 coexisting subtropical tree species[J]. New Phytologist. 2015, 208(1): 125-136.

[22] Newsham K K, Fitter A H, Watkinson A R. Arbuscular mycorrhiza protect an annual grass from root pathogenic fungi in the field.[J]. Journal of Ecology. 1995, 83(6): 991-1000.

[23] Maestre F T, Bradford M A, Reynolds J F. Soil heterogeneity and community composition jointly influence grassland biomass[J]. Journal of Vegetation Science. 2006, 17(3): 261.

[24] Li H, Ma Q, Li H, et al. Root morphological responses to localized nutrient supply differ among crop species with contrasting root traits[J]. Plant and Soil. 2014, 376(1-2): 151-163.

Note: Figure translations are in progress. See original paper for figures.