Effects of Soil Type and Plant Growth Promoting Microorganism on Cabbage and *Spodoptera litura* Performance

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ABSTRACT Different soils might have various effects on the function of plant growth-promoting microorganisms (PGPMs) which could promote plant growth and foliar chemical contents. However, the interaction effects between soil types and PGPMs have not been studied. In this study, two soil types (field soil and commercial growth medium) treated with or without PGPMs (a fungus and mixed bacterial inoculants) were used to study their effects on cabbage plants. Plant growth (dry weight and leaf area), foliar nutrient contents (water and protein content), and foliar anti-nutrient chemicals (polyphenol oxidase and trypsin inhibitor) were also analyzed. Moreover, the foliage collected from different treatments was also fed to the third instar larvae of *Spodoptera litura*. The result showed that PGPMs significantly increased plant growth. Moreover, the commercial growth medium treated with PGPMs produced the highest biomass. The interaction effect between PGPMs and soil types was significant for the water content; whereas the anti-nutrient compound was affected by the soil type only. Finally, a significant combined soil type and PGPM effect was observed for the third instar performance of *S. litura*. In summary, our study suggests that the function of PGPMs might be affected by soil type. PGPMs would perform best when inoculated in the commercial growth medium which contains suitable nutrients. Therefore, the future use of PGPMs should also consider the soil nutrient status before application to obtain their appropriate efficacy.

Key Words: Soil type, PGPMs, Foliar chemistry, Insect performance.

I. Introduction

Crop's production may be affected by various environmental factors including both biotic and abiotic factors.[26] Soil type is one of the essential abiotic factors which might affect plant's growth through altering the function of plant roots and soil borne microbes (e.g. root endophytic fungi, mycorrhizal fungi, rhizobia, and plant growth-promoting microorganisms).[7,9,20,27] To alter plant performance through the interaction between plant roots and soils, several elements may be involved. Mainly functioning through the soils, nutrients in the soils might be the most important factor to affect the growth of plants and their phytochemical contents.[3,14,23,24] It has been suggested that soil organic matter (OM) may affect plant growth, and sugar beets grown in soils with high OM contents would produce higher plant biomass (leaf and root) and sugar content.[6]

Plant growth promoting microorganims (PGPMs) are another important factor to help plant to absorb nutrients from the soils.[4,16] Literatures have indicated that PGPMs could affect plant performance and nutrient uptake.[4,16] The PGPM strains *Pseudomonas alcaligenes*, *Bacillus polymyxa*, and *Mycobacterium phlei* have been found to promote plant growth more

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significantly when inoculated into the nutrient-deficient soil.[9,10] PGPMs could foster plant's nutrient uptake efficiency under poor soil conditions.[1,2,25] In addition, PGPMs could also induce plant resistance to phytopathogens (bacteria, fungi, and viruses)[4,12], insect pests[28,44] and nematodes[28,35]. For example, Zehnder [44] indicated that cucumber plants inoculated with plant growth promoting rhizobacteria (PGPR) could induce the resistance to cucumber beetle feeding. Moreover, past research also indicated that rice plants inoculated with PGPR strains could also reduce the rice leaf folder performance (*Cnaphalocrocis medinalis*).[17]

Since nutrients and PGPMs all stayed in the soil environment, the soil property could also affect their interactions. However, very little is known about the effects of soil type on functions of PGPMs. Therefore, the objective of this study was to assess the potential effects of soil type and PGPMs on plant performance and subsequently on performance of *S. litura*.

II. Materials and Methods

1. Plant

Cabbage plants (*Brassica oleracea* L. var. *capitata*) were used in this study. The cabbage seeds were sown in 104-well plates with a commercial growth medium (Know-You Seed Company, Taiwan) and watered daily. Two weeks after sowing, the seedlings were transplanted into 5-inch pots with two soil types (field soil and commercial growth medium). Chemical properties of field soil have been analyzed by the Soil Survey and Testing Center, National Chung Hsing University, Taichung, Taiwan, and commercial growth medium have been analyzed from the laboratory of Soil Environment Microbiology and Biochemistry, Department of Soil and Environmental Science, National Chung Hsing University (Table 1). The plants were placed in the greenhouse condition (25±2˚C, 16:8 h light:dark photoperiod) and watered daily. Thirty six days after sowing, the plants were used for the bioassay.

2. Insect

The eggs of *S. litura* were collected from the field in Taichung City, Taiwan and kept in the 250-mL rearing plastic cup with the moister cotton ball. After hatching, the larvae were kept in the 250-mL rearing plastic cup and fed with the artificial diet.[43] The rearing plastic cups were placed in the growth chamber (25±2˚C, 16:8 h light:dark photoperiod). The pupae were separated by the sex and were placed into 250-mL plastic rearing cup. After emerge, ten pairs of adults (male and female) were kept in the plastic cylinder (21 cm height x 14.9 cm diameter) and within the plastic cylinder tissue papers were stacked inside on which adults could deposit eggs. The adults were fed with saturated sugar solution[43] and the plastic cylinder was placed in the laboratory condition.

3. Soil and Microbial Treatments

This study was conducted to evaluate the effect of two factors; soil types and plant growth-promoting microorganisms (PGPMs) on the plant growth, insect feeding, and foliar chemistry. Two soil types (field soil and commercial growth medium) were used in this study and the soil property has been analyzed and the results were shown in Table 1. In addition, three PGPM treatments were included in this study (none, a fungus, and bacteria mixture). The fungal treatment contained

Table 1 Chemical properties of the field soil and commercial growth medium used in the study.

Soil property	Value	
	Field soil	Commercial growth medium
pH	9.21	6.6
EC (dS/m)	0.457	0.17
OM (%)	0.317	90.5
Total N (%)	0.0267	0.0500
P (mg kg^{-1})	4.07	151.455
K (mg kg^{-1})	29.9	696.363

only one fungal species *Meyerozyma guilliermondii*; the mixed bacterial inoculants consisted of three bacterial species including *Burkholderia phytofirmans, Rhizobium miluonense,* and *Rhizobium lusitanum* together. Therefore, six treatments were involved in this study: (1) field soil only, (2) field soil with the fungus, (3) field soil with the bacterial mixture, (4) commercial growth medium only, (5) commercial growth medium with the fungus, and (6) commercial growth medium with the bacterial mixture. The PGPMs were provided from the laboratory of Soil Environment Microbiology and Biochemistry, Department of Soil and Environmental Science, National Chung Hsing University. After the seeds have been sown for 2 weeks, the suspension of PGPMs [fungal suspension (>10^8 cfu ml^{-1}) and bacterial suspension (>10^8 cfu ml^{-1})] were diluted 200 times with distilled water and then poured into plastic trays. The seedlings in the 104-well plates were soaked in the microbial suspension for 15 min as the first inoculation. After 2 d, the seedlings were transplanted into 5-inch pots. Every week after the transplant, 50 mL of various microbial solutions were added into each pot, and 50 mL of water were added to plants in the control treatments. Totally, the PGPM inoculations were conducted for three times and the PGPMs were diluted 100 times in the second and third inoculations. Thirty-six day after inoculation, 4th leaves the foliage was collected for plant growth performance, foliar chemistry, and insect growth bioassay.

4. Foliar Chemistry

In this study, we measured the foliar protein content, polyphenol oxidase (PPO) activity, and trypsin inhibitor (TI) activity. The foliage (fourth leaf) was collected during the bioassay for foliar chemical analysis. For each treatment, the foliage from eight plants was used in the analysis. Leaf samples were ground using liquid nitrogen and homogenized in 7% grinding buffer (polyvinylpolypyrrolidone in potassium phosphate buffer, pH 7). The leaf extract (1 mL) was mixed with 100 µL of 10% Triton X-100 (Sigma-Aldrich, St. Louis, MO, USA) in a microtube. The crude extract solution was centrifuged at 4 ˚C, 10000 rpm for 15 min, after which the resulting supernatant was used for determining enzyme activity. To quantify the amount of protein, a standard curve was prepared using bovine serum albumin.[5,37,38] Polyphenol oxidase (PPO) activity was determined based on the procedures of Stout[36] to calculate the formation rate of melanin-like material from catechol. For this assay, 15 µL of a supernatant liquid was mixed with catechol (0.1 M potassium phosphate buffer, pH 8). After mixing for 1 min, an absorbance value at 470 nm was recorded.[8,30,39,40]

For the trypsin inhibitor (TI) assay, the leaf sample (4th leaf) was ground with liquid nitrogen and homogenized in the extraction buffer (phosphate buffer pH 7.8, 1% PVP, 1% ascorbic acid, 1 mM potassium chloride, 10 mM magnesium chloride, 50 mM EDTA-Na_2) and loaded into the 1.7-mL Eppendorf tube. The crude extract solution was centrifuged at 4 ˚C, 12000 rpm for 20 min, after which the resulting supernatant was used for determining the enzyme activity. The TI assay was conducted for three groups; sample, blank, and standard.[21,38] The TI activity was calculated using the following equation: ((OD280 of standard + OD280 of blank − OD280 of sample)/OD280 of standard) × 100%.[38]

5. Insect Growth Bioassay

This insect bioassay was conducted to evaluate the effect of soil types and PGPMs on the feeding performance of *S. litura*. The leaf sample (4th leaf) of each treatment was removed from the base of the plant by using surgical scissors. The petioles of the leaves were inserted into a 2-mL Eppendorf tube with reverse osmosis (RO) water to maintain freshness, after which the leaves were placed individually into petri dishes (9 cm in diameter). Third instar larvae of *S. litura* were weighed and individually placed on various treated leaves, and kept in the growth chamber (25 ± 2 ˚C, 16:8

h light:dark photoperiod). The larvae were allowed to feed on the foliage for 45 h before being subsequently separated, frozen, oven-dried, and weighed. Twelve replicates (larvae) were used for each treatment. At the time of the bioassay, the fresh weights of fifteen third instar larvae were measured and they were oven-dried at 45 ˚C. After 1 wk, the dry weights of the larvae were recorded. The average water content of the larvae was used to calculate the initial larval dry weight used in the feeding study. In addition, the initial leaf dry weight was calculated from five fresh-dried leaf samples from each treatment and then converted by average water content of the leaf. The initial larval and foliar dry weights were used to calculate the relative growth rate (RGR) and relative consumption rate (RCR).[11,32,42]

6. Statistical Analysis

The mean and standard error values were calculated for plant growth performance, insect feeding performance, foliar protein content, polyphenol oxidase (PPO) activity, and trypsin inhibitor (TI) activity. A two-way general linear model (GLM) and Tukey multiple range tests (Version 6.2; SAS Institute Inc., Cary, NC, USA, 1996) were conducted for comparing the interaction effects between soil type and PGPM application.

III. Results

1. Plant growth performance

The results showed that soil types and PGPMs significantly affected the dry weight of cabbage plants and their leaf area, and the interaction between PGPM and soil type application was significant. In addition, the foliar dry weight significantly differed among PGPM treatments (P=0.0001) and soil type treatments (P=0.0001) (Fig. 1). The combined PGPM and soil type application also affected the foliar dry weight (P=0.0001) that commercial growth medium and PGPM inoculation could increase 50% more dry weight than that of the commercial growth medium only treatment. Likewise, the result of leaf area showed the similar trend with that of the foliar dry weight.

2. Plant Nutrients

Our results indicated that foliar water content was influenced by the soil type and the interaction effect of PGPMs and soil types. Foliar water content differed significantly among the soil treatments (P=0.0001). Moreover, the interaction effect between PGPM and soil type also significantly influenced the foliar water content (P=0.0207) (Fig. 2). In contrast, foliar protein content was not affected by PGPM and soil type and their interaction (Fig. 2).

3. Anti-nutrient compounds

Results of the anti-nutrient compounds revealed that the PPO activity was affected by soil types and that the commercial growth medium treatment could have a

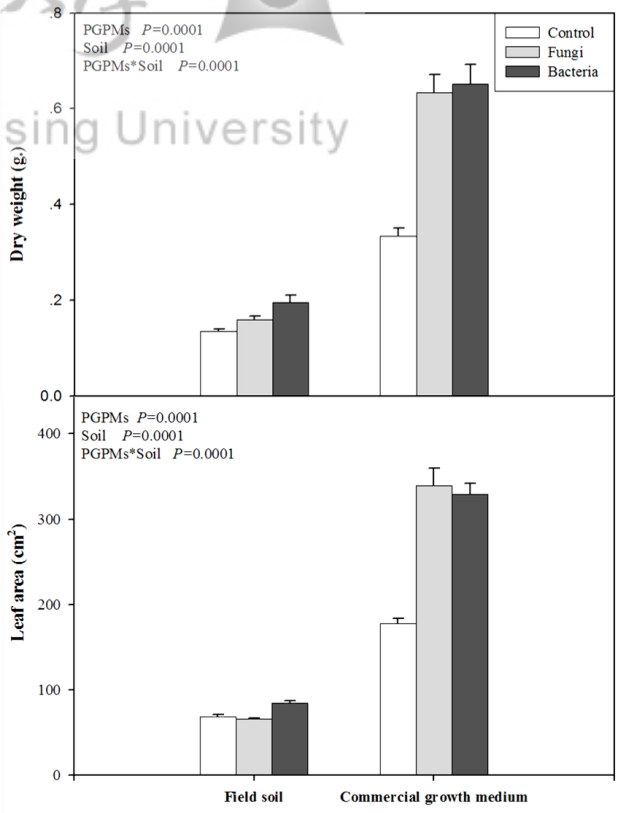

Fig. 1 Plant growth performance of cabbage plant species treated with two soil types (field soil and commercial growth medium) and PGPMs. Mean±SE (n=5) (P=0.05, Tukey's test)

higher PPO activity than that of field soil treatment (P=0.0001) (Fig. 3). However, the PGPM treatment (P=0.4041) and combined PGPMs and soil type application (P=0.2504) did not influence the PPO activity. Regarding the TI activity, our results indicated that TI activity was not affected by PGPM and soil type and their interaction (Fig. 3).

4. Insect performance

The results showed that the relative growth rate (RGR) of third instar *S. litura* was not influenced by PGPM and soil type and their interaction (Fig. 4). In contrast, the relative consumption rate (RCR) of *S. litura* was significantly affected by PGPMs (P=0.0001) and the interaction between PGPM and soil type application (P=0.0194) (Fig. 4).

IV. Discussion

The results of this study indicated that the soil type and PGPM application could significantly affected the cabbage plant' s growth performance, foliar chemistry, and insect feeding performance. In addition, the results also indicated that soil type may have some impacts on PGPM application.

Plant growth promoting microorganisms (PGPMs) have been found to promote the plant growth, plant nutrient and water uptake efficiencies, and production of plant hormones.[4,10,13,19] For example, previous studies revealed that plants inoculated with PGPMs; *B. subtilus*, *Pseudomonas* sp., *B. vietnamiensis* etc. could affect plants' shoot and root biomass, nutrient uptake efficiencies, and plant chemical contents.[18,22,29,33,34] Moreover, PGPM treatments could also influence the plant defensive responses, such as contents of plenylalanine ammonia-lyase, peroxidase, polyphenol oxidase, chitinase, phenolic, and protenase inhibitor.

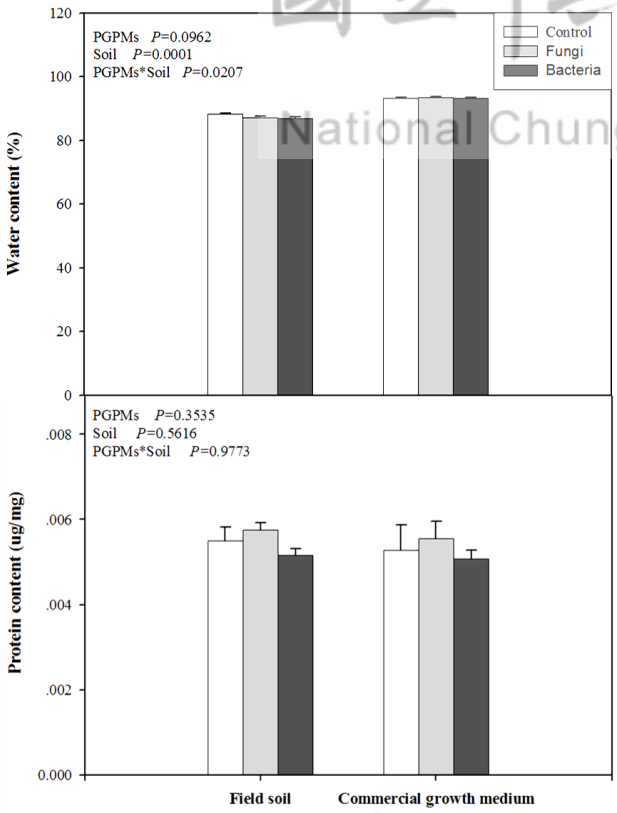

Fig. 2 Primary nutrient components of cabbage plant species treated with two soil types (field soil and commercial growth medium) and PGPMs. Mean±SE (n=5-8) (P=0.05, Tukey's test)

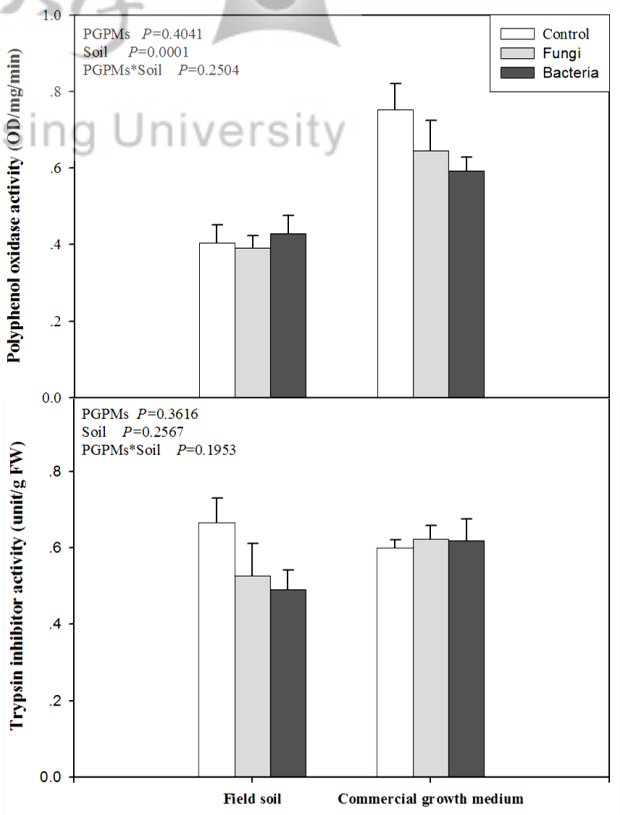

Fig. 3 Anti-nutrient components of cabbage plant species treated with two soil types (field soil and commercial growth medium) and PGPMs. Mean±SE (n=5-8) (P=0.05, Tukey's test)

[17,31,34] Our study indicated that PGPM treatments increased cabbage plant growth performance; whereas PGPM treatments did not affect the plant chemistry. Moreover, past studies have indicated that PGPMs may also induce plants' systematic resistance and that this induction response could have negative impacts on phytopathogens, insect pests, and nematode pests.[4,12,28,33,34,35,41,44] For example, Zehnder[44] have revealed that the PGPR *B. pumilus* could decrease the feeding performance of cucumber beetles (*Diabrotica undecimpunctata*) and the PGPM *Pseudomonas* sp. and *Bacillus* sp. inoculation would reduce the performance of *Helicoverpa armigera*, *C. medinalis*, and *Aproaerema modicella*.[17,31,33,34,41] Our study also found that the relative consumption rate was influenced by PGPM treatment; however, the relative growth rate did not differ among PGPM treatments. Past studies have indicated that the insect growth performance was influenced by plant nutrients like nitrogen and proteins. The literature has revealed that when plants contained higher nitrogen or protein, insect growth rate might be reduced.[32] Commercial growth medium comprised more soil nutrient (N, P, K) than that of field soil; therefore insects would increase feeding. Moreover, past studies indicated that PGPMs [fungi (*Meyerozyma guilliermondii*) and bacteria (*Burkholderia phytofirmans, Rhizobium miluonense,* and *Rhizobium lusitanum*)] inoculation could induce plants' absorbing more nutrients and minerals.[15, 25]

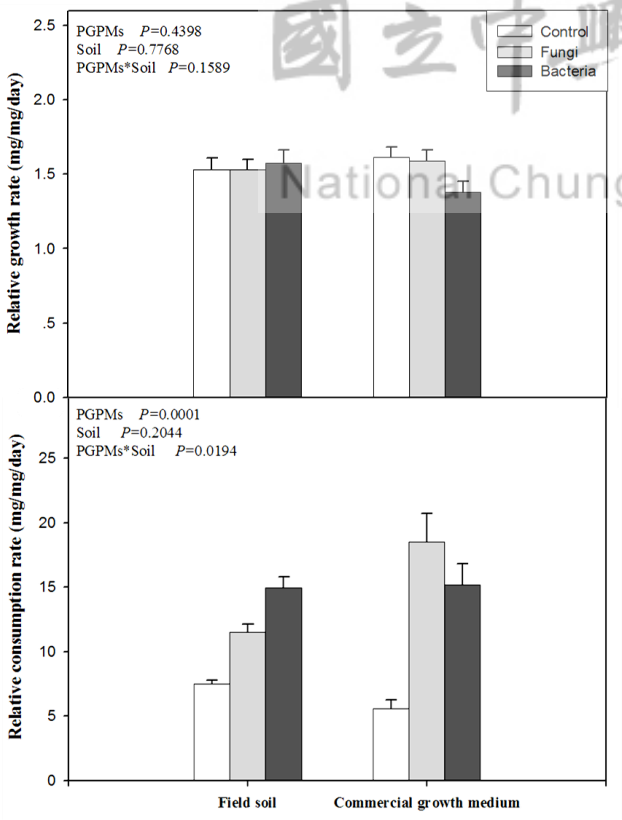

Fig. 4 The performance of third instar larvae of *Spodoptera litura* on cabbage plant species treated with two soil types (field soil and commercial growth medium) and PGPMs. (n=5-12) (P=0.05, Tukey's test)

Soil type may play an important role to affect the interaction among plant root, soil nutrient, and soil microbes.[7,9,20] Çakmakçi[6] has found that the combined effect of PGPRs and soils with high organic matter (OM) levels could significantly increase the leaf, root, and sugar yield of sugar beet. In addition, the combined PGPB and low-nutrient soil application could produce higher plant growth and nutrient (N, P, K) content than the combined PGPB and high-nutrient soil application.[9,10] Our study, however, demonstrated that PGPMs and commercial growth medium application (low pH and EC, high OM and nutrient) could produce the highest biomass and leaf area. In addition, insect performance may also be affected by this interaction. Relative little is known about the effect of soil type on PGPM application; our study, however, demonstrated some interactions may occur among these two factors. The cause for this interaction is still unclear. However, it may be related to the way PGPMs function. PGPMs work through helping plant roots' absorption efficiency; therefore, their functions would be more significant under nutritious soil environment.

In summary, our study suggests that the performance of PGPMs would be affected by soil type. PGPMs would perform best under the commercial growth medium which contains more nutrients. Therefore, further studies using PGPMs should also consider the soil nutrient status before application to

obtain the appropriate efficacy.

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2014 年 06 月 25 日 收稿
2014 年 08 月 26 日 修正
2014 年 09 月 06 日 接受