RUFORUM Working Document Series (ISSN 1607-9345), 2018, No. 17 (3): 1011-1017
Available from http://repository.ruforum.org

Research application summary

Effects of agronomic management practices on soil microbial communities in a maize cropping system

Nyamwange, M. M.,[1*]Njeru, E. M.,[1] Maingi, J.M.[1] & Mucheru-Muna, M.[2]

[1]Department of Microbiology, Kenyatta University, P. O. Box 43844-00100, Nairobi, Kenya
[2]Department of Environmental Sciences, Kenyatta University, P. O. Box 43844-00100, Nairobi, Kenya
Corresponding Author: nmethu1992@gmail.com

Abstract

Conventional and organic agriculture are mainstream soil agronomic management practices used by farmers in Kenya to improve crop production and soil fertility. However, long-term use of these soil management systems can have deleterious or positive effects on soil microbiota. Soil microorganisms, especially arbuscular mycorrhizal fungi colonize about eighty percent of plants promoting absorption of essential nutrients such as phosphorous (P) and nitrogen (N), and protection of plants against biotic and abiotic stresses. A 5-year field experiment was conducted at Kirege, Tharaka-Nithi County in Kenya to determine the response of soil mycorrhizal infection potential, growth of maize, uptake of N, and soil bacterial diversity to tillage, mulch and inorganic fertilizers. The study involved two tillage systems (conventional and minimum tillage), mulching (with and without) and mineral fertilizers (0 and 120 kg N/ha) set up in randomized complete block design and the test crop used was maize (*Zea mays* L.). Number of infective AMF propagules in the soil were highest at V4, intermediate at V6 and lowest at harvest stage. At maize juvenile stage, tillage, mulch and fertilization significantly ($p < 0.0001$) affected maize shoot dry matter and uptake of N. Shannon's Wiener Index (H) showed that the bacteria isolates from different treatments were genetically diverse with a genetic diversity estimate ranging from H= 0.11 to H= 0.32. Therefore, there is need for proper integration when using organic inputs such as mulch, inorganic fertilizers as well as minimum and conventional tillage so as to enhance crop growth and protection of beneficial soil microorganisms.

Keywords: *Arbuscular mycorrhizal* fungi, bacteria diversity, conventional agriculture, maize, Kenya, N uptake, organic agriculture

Résumé

Conventional and organic agriculture are mainstream soil agronomic management practices used by farmers in Kenya to improve crop production and soil fertility. However, long-term use of these soil management systems can have deleterious or positive effects on soil microbiota. Soil microorganisms, especially arbuscular mycorrhizal fungi colonize about eighty percent of plants promoting absorption of essential nutrients such as phosphorous (P) and nitrogen (N), and protection of plants against biotic and abiotic stresses. A 5-year field experiment was conducted at Kirege, Tharaka-Nithi County in Kenya to determine the response of soil mycorrhizal infection potential, growth of maize, uptake of N, and soil bacterial diversity to tillage, mulch and inorganic fertilizers. The study involved two tillage systems (conventional and minimum tillage), mulching (with and without) and mineral fertilizers (0 and 120 kg N/ha) set up in randomized complete block design and the test crop used was maize (Zea mays L.). Number of infective AMF propagules in the soil were highest at V4, intermediate at V6 and lowest at harvest stage. At maize juvenile stage, tillage, mulch and fertilization significantly ($p < 0.0001$) affected maize shoot dry matter and uptake of N. Shannon's Wiener Index (H) showed that the bacteria isolates from different treatments were genetically diverse with a genetic diversity estimate ranging from H= 0.11 to H= 0.32. Therefore, there is need of proper integration when using organic inputs such as mulch, inorganic fertilizers as well as minimum and conventional tillage so as to enhance crop growth and protection of beneficial soil microorganisms.

Keywords: Arbuscular mycorrhizal fungi, bacteria diversity, conventional agriculture, N uptake, organic agriculture

Introduction

Soil microorganisms are very important in the ecosystem as they have both direct and indirect effects on land productivity (Campiglia *et al.,* 2011). Soil microorganisms, in particular arbuscular mycorrhizal fungi (AMF), are very important in agriculture whereby they enhance crop productivity through absorption of essential nutrients like P and N (Njeru *et al.,* 2017). Soil microbes form associations with land plants, consequently increasing crop productivity (Turrini *et al.,* 2016).

The major types of microorganisms found in most soils are bacteria and fungi (Mulec and Prosser, 2011). The amount of disturbance applied to the soil, types of residues added and the amount of alikalinity or acidity in the soil determine the relative numbers of soil microorganisms found in that particular soil (Shaheen and Sabir, 2017). The region which is immediately next to the plant roots (rhizosphere) contains high amounts of microorganisms because the chemicals produced by roots act as food sources for these microorganisms. Most of the soil microorganisms are mainly decomposers of soil organic matter, but others perform roles such as nitrogen fixation, detoxification of noxious chemicals in the soil, production of plant growth promoters and suppression of disease causing microorganisms (Mulec and Prosser, 2011). The activities of soil bacteria and fungi can be affected by use of chemical fertilizers, herbicides and inappropriate agricultural management systems used by farmers.

In this study, we hypothesized that tillage, mulch and inorganic fertilization affect soil infective AMF propagules, uptake of N as well as the diversity of bacteria. The specific objectives of the study were to; (1) asses the effect of tillage, mulch and inorganic fertilization on AMF propagules in the soil, (2) evaluate the influence of tillage, mulch and inorganic fertilization on growth of maize and uptake of N, and (3) determine the influence of tillage, mulch and inorganic fertilization on bacteria diversity at maize juvenile stage.

Materials and methods

This study involved field experiments, greenhouse experiments and laboratory analyses. The experimental fields were located at Kirege, Tharaka-Nithi County in Kenya. The study involved two tillage systems (conventional and minimum tillage), mulching using dried maize stovers (with and without) and mineral fertilizers (0 and 120 kg N/ha) which were set up in randomized complete block design and replicated three times. In conventional tillage, hand hoes were used to prepare the land to a depth of about 0.15 m whereas in minimum tillage, there was manual uprooting of weeds to reduce soil disturbance. For mulch treatments, dried maize stovers from the previous cropping season were broadcasted at the rate of 4 Mg ha^{-1}, seven days after emergence. Nitrogen was applied at a rate of 120 kg N ha^{-1} in split whereby 60 kg N ha^{-1} was applied during planting while the remaining 60 kg N ha^{-1} was applied by top dressing with urea 30 days after planting. Phosphorous was supplied using TSP fertilizer at a rate of 90 kg P ha^{-1} in plots which did not receive NP fertilizer. The test crop used was maize (*Zea mays* L.) which was planted on 8th April 2013 for the first cropping season and grown in the subsequent four years. Soil from each experimental plot was sampled at four different times; before maize planting (5th April 2013), when the maize was at V4 stage (22nd November 2016), when the maize was at V6 stage (3rd January 2017) and at harvesting stage of the maize (28th March 2017). The soil samples were placed in well-labelled polythene bags and then transported to the laboratory for determination of bacteria diversity and used in the greenhouse for enumeration of AMF propagules. Four maize plants were sampled from each plot at V4 stage for determination of shoot dry matter and concentration of P and N. Data on number of infective AMF propagules, shoot dry matter and N concentration was analyzed using SAS (version 9.0) software.

Results and discussion

From the field experiments, mulch treatment produced the highest number of infective AMF propagules at V4, V6 and harvest stages compared to NP fertilizer treatment (Table 1). Organic materials increase the fertility level and water rention capacity of the soil (Bedini *et al.,* 2013), favouring growth and sporulation of AMF in the soil. Mineral fertilizers increase soil acidity which reduces the numbers of viable AMF propagules. Morever, the number of infective AMF propagules was highest at juvenile stage ($p < 0.0001$), followed by V6 stage ($p < 0.0001$), harvest stage ($p = 0.0076$) and before maize planting ($p = 0.0061$). This is because AMF species are biotrophic, thus senesce in the absence of host crops (Cavaglieri *et al.,* 2009). At V4 stage, plant tissues are growing actively hence high secretion of compounds which enhance rapid growth and sporulation of AMF. Consequently, the high number of AMF propagules at V4 stage colonizes a large number of plant roots promoting the acquisition of essential nutrients from the soil which enhance plant growth. As the plant develops towards maturity, the quantity of beneficial compounds produced in the plant rhizosphere decreases (Cavaglieri *et al.,* 2009) thus decreasing the number of infective AMF propagules at V6 and harvest stages.

This study also demonstrated that tillage ($p <0.0001$), mulch ($p = 0.0071$) and fertilizer ($p = 0.0001$) treatments had significant influence in maize shoot dry matter. Application of NP fertilizer recorded the highest shoot dry matter with an average of 5.74 g $plant^{-1}$ whereas minimum tillage produced the lowest shoot dry matter with an average of 2.51 g $plant^{-1}$ (Table 2). Application of inorganic fertilizers readily releases nutrients which favour rapid growth of the plant shoots. Moreover, N concentration in maize shoots was significantly influenced by tillage ($p = 0.0001$), mulch ($p = 0.0001$) and fertilizer ($p <0.0001$). Interestingly, mulch treatment recorded the highest N concentration of 3.21 % on average while NP treatment produced the lowest N concentration of 1.21 % (Table 2). Organic inputs enhance AMF colonization which subsequently improves uptake of N from the soil, resulting in high concentration of this beneficial nutrient in plants grown in mulch treatment (Bedini *et al.*, 2013).

Table 1. Number of infective AMF propagules in the soil as influenced by tillage, mulching and inorganic fertilizers, and their interactions. The mean standard errors are presented in parentheses

Treatments	Number of infective AMF propagules gram^{-1} of soil			
	Before planting	V4 stage	V6 stage	Harvest
ZRO	3.33 (0.14)a	95.15 (2.06)a	67.45 (1.97)a	55.23 (2.34)a
ZRF	3.24 (0.23)a	92. 34 (1.95)b	65.29 (1.50)b	52.33 (1.55)b
ZWO	3.02 (0.22)a	89.87 (2.11)c	65.19 (1.92)c	50.37(2.04)c
ZWF	3.18 (0.15)a	85.45 (2.76)d	63.74 (1.59)d	51.33 (1.99)c
CRO	3.15 (0.24)a	81.28 (2.01)e	60.26 (1.45)e	48.55 (2.43)d
CRF	3.25 (0.18)a	80.56 (1.75)ef	58.52 (2.03)f	45.25 (1.88)e
CWO	3.02 (0.13)a	81.05 (1.95)e	61.45 (1.92)e	47.21 (1.94)d
CWF	3.35 (0.12)a	75.49 (1.47)f	55.43 (1.45)g	42.23 (1.77)f
Tillage				
Conventional tillage	3.14 (0.26)a	70.34 (1.82)b	50.21 (1.42)b	42.83 (1.32)b
Minimum tillage	3.10 (0.13)a	88.49 (2.03)a	64.39 (1.93)a	55.78 (1.42)a
Mulch				
Mulch	3.33 (0.17)a	98.36 (2.16)a	68.96 (2.12)a	59.95 (2.27)a
No mulch	3.29 (0.28)a	75.34 (1.93)b	55.62 (1.97)b	50.38 (0.98)b
Fertilizer				
NP fertilizer	3.05 (0.11)a	64.74 (1.45)b	52.43 (1.59)b	41.37 (1.75)b
No NP fertilizer	3.08 (0.27)a	70.14 (1.95)a	57.05 (1.92)a	45.77 (1.54)a
P values for main factors and their interactions				
Tillage	0.7825	0.0001	0.0005	0.0001
Mulch	0.3167	<0.0001	0.0001	0.0022
Fertilizer	0.3500	<0.0001	<0.0001	0.0001
Tillage mulch	0.5116	0.0599	0.1019	0.5035
Tillage fertilizer	0.8462	0.5521	0.5095	0.4496
Mulch fertilizer	0.7523	0.3222	0.4067	0.5587
Tillage mulch fertilizer	0.7841	0.8101	0.3188	0.0602

Values followed by the same letter are not significantly different at $p < 0.05$ (Tukey's HSD test). CRF, Conventional tillage + mulch + NP fertilizer treatment; CWO, Conventional tillage + no mulch + no NP fertilizer treatment; CWF, Conventional tillage + no mulch + NP fertilizer treatment; CRO, Conventional tillage + mulch + no NP fertilizer treatment; ZRO, Minimum tillage + mulch + no NP fertilizer treatment; ZWO, Minimum tillage + no mulch + no NP fertilizer treatment; ZWF, Minimum tillage + no mulch + NP fertilizer treatment, ZRF, Minimum tillage + mulch + NP fertilizer treatment.

Table 2. Shoot dry matter and N concentration of maize plant at juvenile stage as influenced by mulch, tillage and inorganic fertilization, and their interactions

Treatments	Shoot dry matter (g plant-1)	N (%)
Minimum tillage + mulch + no NP fertilizer	2.43(0.03) e	3.47 (0.13) a
Minimum tillage + mulch + NP fertilizer	4.32 (0.65) b	2.79 (0.18) bc
Minimum tillage + no mulch + no NP fertilizer	2.11 (0.25) f	3.11 (0.28) ab
Minimum tillage + no mulch + NP fertilizer	4.11 (0.38) bc	2.43 (0.22) cd
Conventional tillage + mulch + no NP fertilizer	3.56 (0.39) d	2.35 (0.86) d
Conventional tillage + mulch + NP fertilizer	5.78 (0.63) a	1.79 (0.08) e
Conventional tillage + no mulch + no NP fertilizer	3.86 (0.33) c	2.11 (0.37) de
Conventional tillage + no mulch + NP fertilizer	5.77 (0.69) a	1.12 (0.27) f
Tillage		
Conventional tillage	4.21 (0.31) a	2.33 (0.85) b
Minimum tillage	2.51 (0.23) b	3.12 (0.32) a
Mulch		
Mulch	4.24 (0.34) a	3.21 (0.22) a
No mulch	3.02 (0.09)b	2.03 (0.09) b
Fertilizer		
NP fertilizer	5.74 (1.09) a	1.21 (2.39) b
No NP fertilizer	2.89 (0.54) b	3.41 (0.07) a
P values for main factors and their interactions		
Tillage	<0.0001	0.0201
Mulch	0.0071	0.0001
Fertilizer	0.0001	0.0081
Tillage mulch	0.1704	0.0691
Tillage fertilizer	0.2996	0.0645
Mulch fertilizer	0.5638	0.9379
Tillage mulch fertilizer	0.9342	0.2359

Values followed by the same letter are not significantly different at $p < 0.05$ (Tukey's HSD test). The mean standard errors are presented in parentheses.

In this study, seventy (70) bacteria isolates were obtained which were placed in 15 groups based on their differences in biochemical and morphological features. The Shannon's Information Index (I) showed that the bacteria isolates from the eight treatments were genetically diverse with minimum tillage + mulch + no NP fertilizer treatment having the highest genetic diversity estimate of H= 0.32 while conventional tillage + no mulch + NP fertilizer treatment had the lowest genetic diversity estimate of H= 0.11 (Table 3). Variations in bacteria diversity can be caused by factors such as land use practices used by farmers and the genotype of the host plant (Lei *et al.,* 2017). Organic inputs favor growth and survival of bacteria while other practices like mineral fertilization limit growth of soil bacteria (Cerny *et al.,* 2003), resulting in variation of bacteria isolates in different soil agronomic practices.

Table 3. Shannon's Information Index I (H), mean number of different alleles (Na) and percentage of Polymorphic Loci (% P) of bacteria isolates from the eight treatments based on ARDRA analysis

Population	CRF	CWO	CWF	ZRO	CRO	ZWO	ZWF	ZRF
I (H)	0.18 ± 0.06	0.14 ± 0.05	0.11 ± 0.02	0.32 ± 0.06	0.13 ± 0.05	0.28 ± 0.06	0.25 ± 0.06	0.26 ± 0.04
Na	0.59 ± 0.19	0.33 ± 0.15	0.46 ± 0.10	0.58 ± 0.18	1.04 ± 0.21	0.96 ± 0.21	0.88 ± 0.21	0.92 ± 0.20
% P	29.17	16.67	10.17	52.00	20.83	45.83	41.67	43.24

ICRF, Conventional tillage + mulch + NP fertilizer treatment; CWO, Conventional tillage + no mulch + no NP fertilizer treatment; CWF, Conventional tillage + no mulch + NP fertilizer treatment; CRO, Conventional tillage + mulch + no NP fertilizer treatment; ZRO, Minimum tillage + mulch + no NP fertilizer treatment; ZWO, Minimum tillage + no mulch + no NP fertilizer treatment; ZWF, Minimum tillage + no mulch + NP fertilizer treatment, ZRF, Minimum tillage + mulch + NP fertilizer treatment.

Conclusions

In this study, number of AMF propagules in the soil were negatively affected by conventional tillage using hand hoes. Our experimental findings further showed that uptake of N was positively affected by mulching using dried maize stovers. Shannon's Information Index (I) showed a considerable genetic variation within the bacteria populations from different treatments.

Acknowledgement

The authors thank International Atomic Energy Agency (IAEA, grant 16916) for their financial support in this study. This paper is a contribution to the 2018 Sixth African Higher Education Week and RUFORUM Biennial Conference held in Nairobi, Kenya.

References

Bedini, S., Avio, L., Sbrana, C., Turrini, A., Migliorini, P., Vazzana, C. and Giovannetti, M. 2013. Mycorrhizal activity and diversity in a long-term organic Mediterranean agroecosystem. *Biology Fertile Soils* 49: 781-790.

Campiglia, E., Mancinelli, R. and Radicetti, E. 2011. Influence of no-tillage and organic mulching in tomato production and nitrogen use in the Mediterranean environments of Central Italy. *Scientia Horticulture* 130: 588-598.

Cavaglieri, L., Orlando, J. and Etcheverry, M. 2009. Rhizosphere microbial community structure at different maize plant growth stages and root locations. *Microbiological Research* 164 (4): 391-399.

Cerny, J., Balik, J., Pavlíkova, D., Zitkova, M. and Sykora, K. 2003. The influence of organic and mineral nitrogen fertilizers on microbial biomass nitrogen and extractable organic nitrogen in long-term experiments with maize. *Plant Soil Environments* 49: 560-564.

Lei, Y., Xiao, Y., Li, L., Jiang, C., Zu, C., Li, T. and Cao, H. 2017. Impact of tillage practices on soil bacterial diversity and composition under the tobacco-rice rotation in China. *Journal of Microbiology* 55(5): 349-356.

Mulec, M. and Prosser, J. 2011. Diversity of endospore-forming bacteria in Soil. *Soil Biology*: 31- 38.

Njeru, E.M., Bocci, G., Avio, L., Sbrana, C., Turrini, A., Giovannetti, M. and Barberi, P. 2017. Functional identity has a stronger effect than diversity on mycorrhizal symbiosis and productivity of field grown organic tomato. *European Journal of Agronomy* 86: 1-11.

Shaheen, A. and Sabir, N. 2017. Effect of Tillage, residue and fertilizer on yields within a wheat-maize cropping system. *Sarhad Journal of Agriculture* 33 (1): 127-138.

Turrini, A., Sbrana, C., Avio, L., Njeru, E.M., Bocci, G., Bàrberi, P. and Giovannetti, M. 2016. Changes in the composition of native root arbuscular mycorrhizal fungal communities during a short-term cover crop-maize succession. *Biology and Fertility of Soils* 52 (5): 643-653.