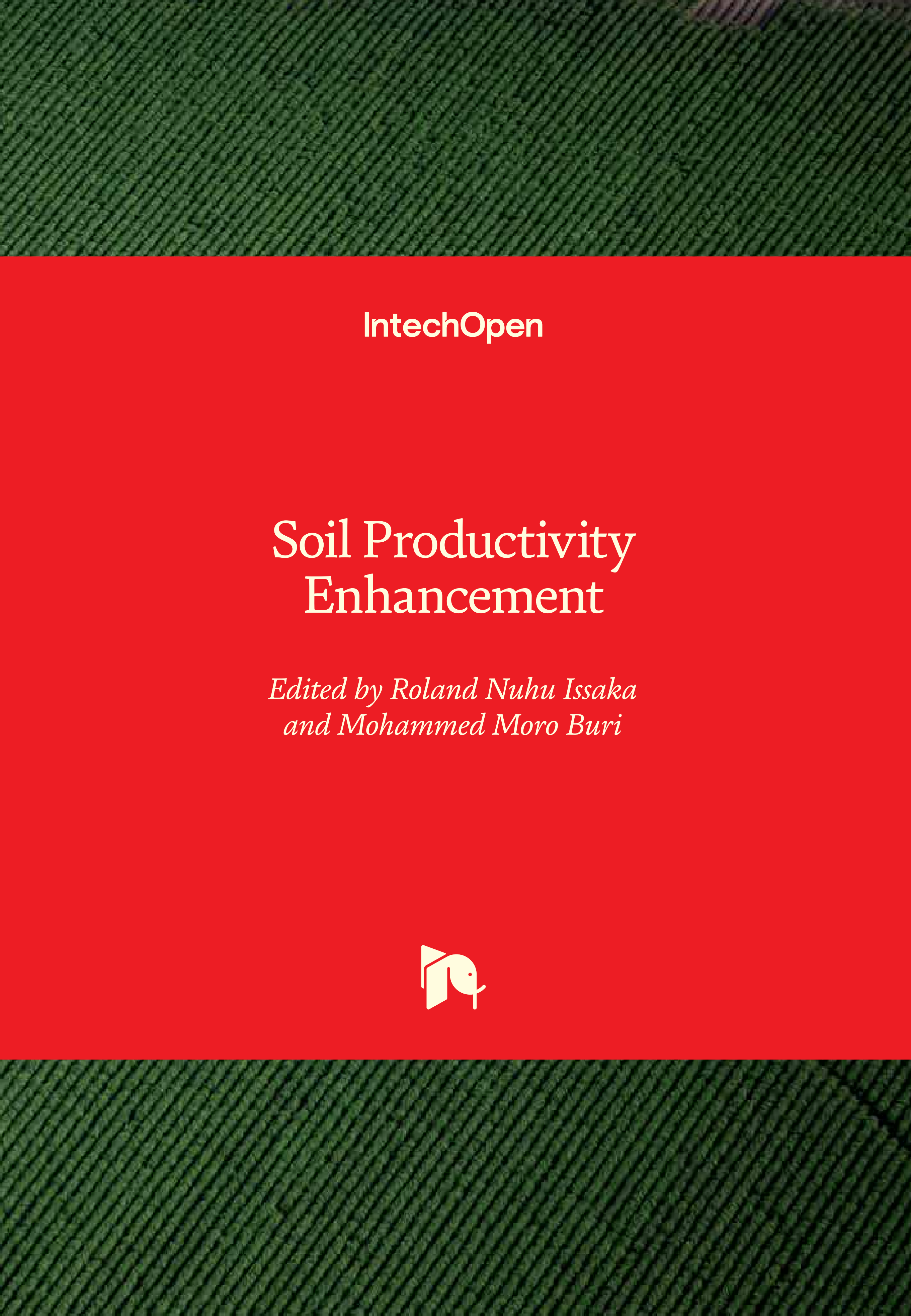


IntechOpen

Soil Productivity Enhancement

Edited by Roland Nuhu Issaka
and Mohammed Moro Buri

SOIL PRODUCTIVITY ENHANCEMENT

Edited by **Roland Nuhu Issaka**
and **Mohammed Moro Buri**

Soil Productivity Enhancement
http://dx.doi.org/10.5772/intechopen.74124
Edited by Roland Nuhu Issaka and Mohammed Moro Buri

Contributors

Bente Foereid, Lutengano Mwinuka, Hani Mohamed Awad Abdelzaher, Shaima Moustafa, Haifa Alhaithloul, Muhammad Khalid Iqbal, Congming Zou

© The Editor(s) and the Author(s) 2018
The rights of the editor(s) and the author(s) have been asserted in accordance with the Copyright, Designs and Patents Act 1988. All rights to the book as a whole are reserved by INTECHOPEN LIMITED. The book as a whole (compilation) cannot be reproduced, distributed or used for commercial or non-commercial purposes without INTECHOPEN LIMITED's written permission. Enquiries concerning the use of the book should be directed to INTECHOPEN LIMITED rights and permissions department (permissions@intechopen.com).
Violations are liable to prosecution under the governing Copyright Law.

Individual chapters of this publication are distributed under the terms of the Creative Commons Attribution 3.0 Unported License which permits commercial use, distribution and reproduction of the individual chapters, provided the original author(s) and source publication are appropriately acknowledged. If so indicated, certain images may not be included under the Creative Commons license. In such cases users will need to obtain permission from the license holder to reproduce the material. More details and guidelines concerning content reuse and adaptation can be foundat http://www.intechopen.com/copyright-policy.html.

Notice

Statements and opinions expressed in the chapters are these of the individual contributors and not necessarily those of the editors or publisher. No responsibility is accepted for the accuracy of information contained in the published chapters. The publisher assumes no responsibility for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained in the book.

First published in London, United Kingdom, 2018 by IntechOpen
eBook (PDF) Published by IntechOpen, 2019
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, The Shard, 25th floor, 32 London Bridge Street
London, SE19SG – United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

Soil Productivity Enhancement
Edited by Roland Nuhu Issaka and Mohammed Moro Buri

p. cm.

Print ISBN 978-1-78984-678-2

Online ISBN 978-1-78984-679-9

eBook (PDF) ISBN 978-1-83881-772-5

Meet the editors

Dr. Roland Nuhu Issaka was a Principal Research Scientist at the CSIR-Soil Research Institute of Ghana. He is currently with Africa Rice-Liberia. He holds a Doctorate Degree in Soil Science from Tottori University, Japan. He was at the Japan International Research Center for Agricultural Sciences in Ishigaki for a one-year post-doctoral study. Dr. Issaka is a soil fertility agronomist. His research focuses on soil fertility, erosion control, and water management. He has published more than 30 peer-reviewed scientific publications, over 50 technical reports, and several chapters in books. He has edited three books, including Soil Fertility published by IntechOpen.

Dr. Mohammed Moro Buri is a chief research scientist and current Director of the CSIR-Soil Research Institute, Ghana. He has over 25 years' work experience. He is a product of KNUST, Ghana, and Shimane and Tottori universities in Japan. He has expertise in soil resource management, water management, environmental management, soil nutrient management, and plant nutrition. He has either worked for or collaborated with international organizations such as IITA, Africa Rice, IWMI, JIRCAS, and several universities in Japan and Ghana. He has over 100 publications (journal papers, conference papers, books, book chapters, manuals, and research reports) to his credit. He is also a lecturer for postgraduate students on Soil Health and Environmental Resources Management (SHEM) at the CSIR College of Science and Technology, Ghana, and mentors young scientists at the CSIR-Soil Research Institute, Ghana.

Contents

Preface

An increasing world population means higher demand for food and fiber. These demands can only be met through increased and sustained soil productivity, which is linked to proper soil and crop management practices with the provision of soil nutrients being an important factor. In most poor countries, particularly in Africa, agriculture is the main source of income, hence improving crop production has a positive effect on the socioeconomic status of farmers and their families. Most soils in Africa and Latin America are inherently poor or have been degraded due to crop production (uptake of nutrients by plants, soil erosion, and leaching of nutrients) with little or no fertilizer input. The availability of cheap and good organic fertilizers and the integrated use of these with mineral fertilizers are key to increasing crop production.

Soil Productivity Enhancement examines various sources of fertilizer materials and their effects on crop production. It further describes the practices and possible nutrient management methods to improve production. The book has five chapters written by scientists from various parts of the world. It is divided into three sections. Section 1: Conversion of Environmentally Polluting Waste into Fertilizer. Waste water and other by-products from factories have serious environmental issues. This section offers suggestions as to the conversion of these pollutants to organic fertilizers that can be used for crop production. An added advantage of these processes is the maintenance of environmental sanity through the conversion of these waste products to useful materials. Section 2: Practices for Improving Nutrient Availability. Good nutrient management and proper composting of organic materials are options that can be used to enhance and/or increase the productivity of the soil. Section 3: Policy on Fertilizer Use. Use of fertilizers may be effective in increasing crop production. Adequate policies regarding the management and use of fertilizers not only promote and encourage efficiency in crop production but also help to reduce pollution and improve environmental sanity.

Dr. Roland Nuhu Issaka and Dr. Mohammed Moro Buri
CSIR-Soil Research Institute
Kwadaso-Kumasi, Ghana

Section 1

Conversion of Environmentally Polluting Waste into Fertilizer

Chapter 1

Organic Fertilizers and Nutrient Recycling from Diluted Waste Streams

Bente Foereid

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78042

Abstract

To develop a circular economy, nutrients from waste streams need to be recovered and brought back to agricultural production as much as possible. Liquid waste streams pose a specific problem because high water content makes transport expensive. Treatment of wastewater and diluted waste streams to recover nutrients are briefly discussed, and two options that are not much used are discussed: sorption to increase the fraction of nutrients found in the solid phase and nitrification of liquid to reduce nitrogen losses. Then, availability of nutrients to plants and environmental effects are discussed. It is concluded that there is little information on how treatment options affect how bioavailable the nutrients are and that this should be taken into account when treatment option is chosen.

Keywords: biofertilizer, nutrients, liquid waste, bioavailability, environmental effects

1. Introduction

Many organic waste streams have high nutrient content, and can, if treated properly, become good fertilizers and soil improvers. There are many reasons to promote this use:

1. Resource efficiency: Nutrients in waste resource can replace mineral fertilizers and therefore reduce resource mining and energy use.
2. Organic agriculture cannot use mineral fertilizers and needs to use organic fertilizers to get nutrients for crop growth.

3. Organic fertilizers also contain organic matter as well as organically bound nutrients. Organic matter can improve soil fertility and reduce soil degradation in some cases, and organically bound nutrients are released slowly.
4. Carbon can be sequestered in the soil and reduce atmospheric build-up.

The benefits of organic matter additions to soil have been stated by many authors [1–4]; however, the evidence suggests that mineral fertilizers usually are better at supplying plants with nutrients and avoid leaching losses, at least in the short term. However, in the longer term, building organic matter in the soil can improve nutrient retention. Slow release of nutrients may be beneficial for some crops (with long-period nutrient uptake e.g. root crops) and under some conditions (humid conditions with leaching losses early in the season), but less beneficial for other crops and conditions [5].

Many organic waste streams contain a lot of water, making transport difficult and expensive in economic and environmental terms. Examples of diluted waste streams can be sewage, biogas digestate, animal manure, various industrial waste streams, animal manure and fish sludge from aquaculture.

An overview of wastewater treatment can be found in textbooks, for example, [6–8]. Choice of treatment has so far almost exclusively focused on cleaning the water sufficiently to be discharged to the recipient; the resource recovery perspective has not received much attention. However, this is now changing because of concern of resource mining, particularly for phosphorus [9, 10] and high-energy consumption in nitrogen fertilizer production [11].

Options for concentration (alone or in combination) can be:

- dewatering (by centrifuge or press)
- flocculation, settling
- precipitation
- drying, evaporation
- biological stabilization, wet composting

In most cases, liquid waste streams are left to let whatever can settle do so. There are also methods to increase settling and flocculation. Some form of stabilization is also common, either aerobic by use of oxygen or by anaerobic digestion for biogas production.

Dewatering leaves an organic rest with relatively low water content and a liquid residue with dissolved substances. As soluble nutrients are the most readily plant available, that means that a large fraction of the plant available nutrients will be found in the liquid phase. Often no good use of the liquid phase can be found, and it enters into sewage treatment systems. In many cases also some chemicals (polymers) are required to give proper separation [12]. This is costly, and chemicals can also have potentially negative environmental effects.

Dissolved nutrients can be precipitated out of solution. This is commonly done to get phosphorus out of wastewater before discharge to the recipient. Unfortunately, an almost insoluble salt results, and plant availability is very low [13, 14], although different for different precipitation chemicals [15].

Drying or water reduction by evaporation can be good options if cheap or waste heat is available. However, most liquid waste streams contain most of the nitrogen on ammonium form, and some measures must be applied to prevent losses of nitrogen as ammonia [16]. This is commonly achieved by acidifying the solution first or collecting the ammonia in biofilter acid trap afterwards.

Fertilizer products developed from organic residues can be called organic fertilizers or biofertilizers. This chapter deals with biofertilizers developed from liquid waste streams and discusses how biofertilizer quality in agricultural and environmental terms depend on treatment.

2. New treatment option to increase fraction in the solid phase and make liquid waste stable

Some newer options to increase recycling are discussed before Sorption is a physical and chemical process by which one substance becomes attached to another. By adding cheap sorbents to a liquid waste stream prior to dewatering, the fraction of nutrients found in the solid phase after dewatering can be increased. Nitrification is a microbial process where ammonium is transferred to nitrate. This leaves a stable solution that can be applied and evaporated without losses of ammonia.

2.1. Sorption

Some sorbents can be used to remove nutrients from liquid waste streams and concentrate them in a solid phase that can be separated by dewatering. Sorption is a physical and chemical process by which one substance becomes attached to another. Sorbents are the solid substances they attach to, sorbate are the substances (dissolved or gaseous) that attach. Organic material is a weak sorbent, sorption properties can be greatly increased by charring [17]. The sorbents can be charred organic material (e.g. biochar, hydrochar, activated carbon) or some clay or other minerals (bentonite, zeolite, vermiculite). Cation exchange is the most common; there are reports on removal of ammonium ([18–24]. Some authors also report potassium removal [22, 23]. Sorption of anions appears to be more difficult, but there are some reports of phosphorous sorption [18, 20, 22–26]. Sorption of nitrate is difficult, but it appears that it can be achieved on some biochars produced at high temperature [27, 28]. There are also reports of sorption of hydrogen sulfide (reviewed by [29]) and also one report on ammonia removal from the gas phase [30].

2.2. Nitrification

It is possible to reduce or eliminate losses of ammonia from liquid waste by reducing pH, or nitrogen can be collected in biofilters or by stripping afterwards [31].

Losses of ammonia from liquid waste can also be eliminated by transforming ammonium to nitrate by a microbial process prior to storage and/or evaporation and application. The process also lowers pH, and that will also reduce ammonia volatilization, so that a small free and stable product will be the result. There are reports on tests on this for digestate and urine [32–34]. This process happens naturally in soil, and it can also be made to happen in an aerated reactor, this is done in many sewage treatment plants [35, 36]. It is also similar to wet-composting where nitrogen transformations happen as well as carbon consumption and stabilization [37].

Nitrification has two steps; both are microbially mediated [35]. In the first step, ammonia is oxidized to nitrite (NO_2-) by bacteria belonging to the genus *Nitrosomonas*. In the second step, nitrite is oxidized to nitrate (NO_3-), mostly by *Nitrospira* and *Nitrobacter* microorganisms [35, 38, 39]. However, high nitrite concentrations inhibit both processes, and it is therefore important to control the processes so that the intermediate products do not accumulate. This means process parameters must be controlled so that both steps can proceed at the same rate [40]. As ammonia oxidizing bacteria use ammonia as a substrate, not ammonium, this generally means controlling parameters of the concentration of free ammonia in solution is kept relatively low, for example, moderate pH and temperature [40].

3. What do we know about how treatment options affect plant availability?

It is known from numerous studies that not all nutrients in biofertilizers based on organic residues are available to crop plants, and sometimes also become available only after some time, and predicting the availability over time can be challenging [41, 42]. Plants take up dissolved nutrients, and nutrients that are dissolved or readily soluble will usually be 100% plant available. This is the case for mineral fertilizers. Most studies of plant availability of nutrient have assessed final products, for example, [43–47]. There are few studies assessing the same waste residue treated in different ways. This makes it difficult to disentangle the effect of feedstock from the effect of treatment option.

Dissolved nutrients in liquid organic waste will usually be bioavailable. Dewatering will therefore usually mean that most of the readily plant available nutrients are found in the liquid phase. How well plant nutrients are recycled will then depend on what happens to the liquid phase. Often it is not recycled optimally because transport costs are too high.

Precipitation can make nutrients less available, or even almost unavailable. This is well known for phosphorus removal from sewage treatment [15, 48]. The most common precipitation agents are aluminum and iron salts, leaving phosphorous almost unavailable to crop plants. Excess precipitation chemicals may even make soil phosphorus less available.

It is usually assumed that drying does not affect nutrient quality, so that plant availability remains unaltered. However, there is very little experimental evidence confirming that this is actually true. Knoop et al. [49] compared composting and drying as treatment options. They found that the content of plant available nitrogen decreased during drying although less than during composting, probably because the most plant available nitrogen is lost as ammonia. The fraction of phosphorus that was plant available also decreased during drying. There was no difference between air (20–30°C) and own dried (70°C). However, phosphorus availability was measured chemically; it is not certain that this corresponded exactly to actual plant availability measured in plant growth experiments. We have some indications that drying at high temperature at least may make phosphorus more plant available. This requires further study.

Most biological stabilization options will make the nutrients more available as they are decomposition processes, which mineralize the nutrients. However, during aerobic treatment (composting), some of the nitrogen is lost, more the more open the process is [50–52]. Anaerobic treatment will also usually make nutrients more available [53], an exception is phosphorus during anaerobic digestion of precipitated sewage sludge [54], probably because excess precipitation chemicals are used, which precipitate mineralized phosphorus.

Adding sorbents before dewatering can be a way to increase the fraction of nutrients found in the liquid phase as discussed in Section 2. The authors usually state that solid product can be applied in agriculture as a fertilizer, but there are surprisingly few studies that investigate if sorbed nutrients are as bioavailable as nutrients added the conventional way. One study found that ammonia sorbed as gas was bioavailable, but the degree of availability was not compared to conventional fertilizer application [55]. Another study found that sorbed nutrients were slowly desorbed in soil [56]. Our own unpublished studies suggest that ammonium sorbed to zeolite is less plant available than conventionally added ammonium. A recent study [57] found that at least some nitrogen sorbed to zeolite from urine was plant available. They also suggest that nitrification could be an important driver of release of nitrogen from zeolite, as liming increased the recovery of mineral nitrogen. It is possible that zeolite and other sorbents provide surface area for biofilm development, and it could therefore stimulate nitrification. This requires further study.

Nitrification has also been discussed as a possible way to treat liquid waste. The question if nitrate or ammonium is the preferable fertilizer is a complicated one. Usually nitrate is preferred, because it can be taken up faster and only ammonium as a fertilizer can be harmful to some plants [58, 59]. However, nitrate is also more easily leached and can be lost from the soil profile before plants can take it up. As such, ammonium can be regarded as a slow release fertilizer, as it is usually quite quickly nitrified in agricultural soil.

4. How does treatment affect environmental performance of biofertilizers?

Most environmental problems related to fertilizer use, either mineral or organic, are related to losses to the environment, as leaching and runoff and as gas. Loss of nitrogen and phosphorus to waterways and coastal areas can result in eutrophication and algal blooms [60]. Losses of ammonia gas can also lead to over-fertilization and acidification [61]. In addition, a small fraction of the nitrogen lost as gas is lost as nitrous oxide, a powerful greenhouse gas and as NOx [62, 63]. The best way to avoid losses is therefore to time fertilizer application or availability with crop demand, so that the crop can take it up before it is lost, this will be a win-win situation. Losses can also be reduced by reducing application rates, but this will also reduce yield.

Biofertilizers usually induce larger losses per unit nutrients added than mineral fertilizers. This is partly because not all nutrients in organic fertilizers are immediately available and may become available later when plants cannot take them up. However, this depends on crop type as well, some crops take up nutrients throughout the growing season, and then slow-release fertilizers may be an advantage [5].

The environmental effect of acidification has not been much studied. Particularly the effect on losses of nitrogen a nitrous oxide would be an interesting field of study, as the effect of pH on emissions of this gas is particularly complicated [62–66]. Denitrification rate increases with pH up to above neutral, but the fraction that is nitrous oxide rather than dinitrogen gas is higher at acidic pH. The effect on emission of the greenhouse gas nitrous oxide is therefore difficult to predict.

Addition of sorbents to increase the fraction of nutrients found in the solid phase has been discussed in Section 2. There is also some evidence that sorbents could reduce gaseous losses from soils, including greenhouse gases. Vermiculite and bentonite have been shown to decrease emissions of ammonia and nitrous oxide when mixed with manure prior to [67, 68] and increase nutrient retention after application [69]. However, Dietrich [70] did not find any effect of bentonite additions to digestate on nitrous oxide emission, so this also requires further study.

Nitrification as treatment option was also discussed in Section 2. Most environmental effects are related to losses; as mentioned in the previous section, nitrate is more easily lost by leaching. However, it is also more easily taken up by plants, and if application is timed with demand, losses can be low. As greenhouse gases can be emitted by a number of processes [62, 63, 71], it is difficult to predict if nitrification prior to application will increase or decrease emissions. However, a review found lower emissions from nitrate-based fertilizers [62], suggesting that nitrification may be favorable.

5. Conclusion and outlook

Sorption can be a good way to get a larger fraction of available nutrients in the solid phase prior to dewatering. Nitrification prior to storage and application may be a good way to reduce losses of nitrogen. However, little is known about if these and other treatments affect how plant available the nutrients are. More effort should be directed at understanding how treatment options affect plant availability, to be able to choose the best options.

Acknowledgements

The author wishes to thank Dr. Marianna Makadi, Maria Dietrich and Dr. Nataliia Kasian for help and discussions around the topics of digestate treatment and sorption. The review work was funded by SIS: Sustainable recycling of organic waste resources in the future bioeconomy.

Conflict of interest

The author declares no conflict of interest.

Author details

Bente Foereid

Address all correspondence to: bente.foreid@nibio.no

Norwegian Institute of Bioeconomy Research, Ås, Norway

References

[1] Christensen BT, Johnston AE. Soil organic matter and soil quality – Lessons learned from long-term experiments at Askov and Rothamsted. In: Gregorich EG, Carter MR, editors. Soil Quality for Crop Production and Ecosystem Health. Amsterdam, The Netherlands: Elsevier; 1997. pp. 399-430

[2] Reeves DW. The role of soil organic matter in maintaining soil quality in continous cropping systems. Soil and Tillage Research. 1997;**43**:131-167

[3] Lal R, Griffin M, Apt J, Lave LM, Morgan G. Managing Soil Carbon. Science. 2004;**304**:393

[4] Lal R. Challenges and opportunities in soil organic matter research. European Journal of Soil Science. 2009;**60**:158-169

[5] Research R. Guide to the Classical and Other Long-Term Experiments. Rothamsted Research, Harpenden, Herts, UK: Datasets and Sample Archive; 2008

[6] Pfaffin JR. Ziegler EN, editors. LLC, Taylor and Francis Group: Encyclopedia of Environmental Science and Engineering; 2006

[7] Crini G, Badot P-M. Sorption Processes and Pollution: Conventional and Non-conventional Sorbents for Pollutant Removal from Wastewaters. Besançon: Presses universitaires de Franche-Comté; 2010

[8] Perry RH. Green DW, editors. Perry's Chemical Engineer's Handbook. New York, USA: McGraw-Hill Companies; 1999

[9] Cordell D, Drangert J-O, White S. The story of phosphorous: Global food security and food for thought. Global Environmental Change. 2009;**19**:292-305

[10] Cordell D, Rosmarin A, Schröder JJ, Smit AL. Towards global phosphorous security: A system framework for phosphorous recovery and reuse options. Chemosphere. 2011;**84**:747-758

[11] Gellings CW, Parmenter. In: Gellings CW, editor. KE energy efficiency in fertilizer production and use. In: Efficient Use and Conservation of Energy. Oxford, UK: EOLSS Publishing Co. Ltd.; 2016

[12] Alvarenga E, Hayrapetyan S, Govasmark E, Hayrapetyan L, Salbu B. Study of the flocculation of anaerobically digested residue and filtration properties of bentonite based mineral conditioners. Journal of Environmental Chemical Engineering. 2016;**3**: 1399-1407

[13] Maguire RO, Sims JT, Coale FJ. Phosphorus fractionation in biosolids-amended soils: Relationship to soluble and desorbable phosphorus. Soil Science Society of America Journal. 2000;**64**:2018-2024

[14] Maguire RO, Sims JT, Dentel SK, Coale FJ, Mah JT. Relationships between biosolids treatment process and soil phosphorus availability. Journal of Environmental Qualality. 2001;**30**:1023-1033

[15] Øgaard AF, Brod E. Efficient phosphorus cycling in food production: Predicting the phosphorus fertilization effect of sludge from chemical wastewater treatment. Agricultural and Food Chemistry. 2016;**64**:4821-4829

[16] Amon B, Kryvoruchko V, Amon T, Zechmeister-Boltenstern S. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. Agriculture, Ecosystems & Environment. 2006;**112**:153-162

[17] Bhatnagar A, Sillanpaa M. Utilization of agro-industrial and municipal waste materials as potential adsorbents for water treatment – A review. Chemical Engineering Journal. 2010;**157**:277-296

[18] Hollister CC, Bisogni JJ, Lehmann J. Ammonium, nitrate, and phosphate sorption to and solute leaching from biochars prepared from corn Stover (*Zea mays* L.) and oak wood (Quercus spp.). Journal of Environmental Quality. 2012;**1**:137-144

[19] Kucic S, Cosic I, Vukovic M, Briski F. Sorption kinetic studies of ammonium from aqueous solution on different inorganic and organic media. Acta Chimica Slovenia. 2013;**60**:109-119

[20] Estevez MM, Sapci Z, Linjordet R, Morken J. Incorporation of fish by-product into the semi-continuous anaerobic co-digestion of pre-treated lignocellulose and cow manure, with recovery of digestate's nutrients. Renewable Energy. 2014;**66**:550-558

[21] Mazeikiene A, Valentukrvicirne M. Removal of ammonium ions from digested sludge fugate by using natual zeolite. Journal of Environmental Engineering and Landscape Management. 2016;**24**:176-184

[22] Guaya D, Hermassi M, Valderrama C, Farran A, Cortina JL. Recovery of ammonium and phosphate from treated urban wastewater by using potassium clinoptilolite impregnated hydrated metal oxides as N-P-K fertilizer. Journal Environmental Chemical Engineering. 2016;**4**:3519-3526

[23] Guaya D, Hermassi M, Valderrama C, Gibert O, Moreno N, Querol X, Batis NH, Cortina JL. Recovery of nutrients (N-P-K) from potassium-rich sludge anaerobic digestion side-streams by integration of a hybrid sorption-membrane ultrafiltration process: Use of powder reactive sorbents as nutrient carriers. Science of the Total Environment. 2017;**599-600**:422-430

[24] Takaya CA, Fletcher LA, Singh S, Anyikude KU, Ross AB. Phosphates and ammonium sorption of biochar and hydrochar from different wastes. Chemosphere. 2016;**145**:518-527

[25] Yao Y, Gao B, Inyang M, Zimmermann AR, Cao X, Pullammanappallil P, Yang L. Biochar derived from anaerobically digested sugar beet tailings: Characterization and phosphate removal potential. Bioresource Technology. 2011;**102**:6273-6278

[26] Kizito S, Luo H, Wu S, Ajmal Z, Lv T, Dong R. Phosphate recovery from liquid fraction of anaerobic digestate using four slow pyrolysed biochars: Dynamics of adsorption, desorption and regeneration. Journal of Environmental Management. 2017;**201**:260-267

[27] Mizuta K, Matsumoto T, Hatate Y, Nishihara K, Nakanishi T. Removal of nitrate-nitrogen from drinking water using bamboo powder charcoal. Bioresource Technology. 2004;**95**:255-257

[28] Yao Y, Gao B, Zhang M, Inyang M, Zimmermann AR. Effect of biochar amendment on sorption and leaching of nitrate, ammonium, and phosphate in a sandy soil. Chemosphere. 2012;**89**:1467-1471

[29] Ozekmekci M, Salkic G, Fellah MF. Use of zeolites for removal of H2S: A mini-review. Fuel Process Technology. 2015;**139**:49-60

[30] Taghizadeh-Toosi A, Clough TJ, Sherlock RR, Condron LM. A wood based low temperature biochar captures NH_3-N generated from ruminant urine-N, retaining its bioavailability. Plant and Soil. 2012;**353**:73-84

[31] Drosg B, Fuchs W, Al Seadi T, Madsen M, Linke B. IEA Bioenergy: Nutrient Recovery by Biogas Digestate Processing. 2015

[32] Botheju D, Svalheim Ø, Bakke R. Digestate nitrification for nutrient recovery. The Open Waste Management Journal. 2010;**3**:1-12

[33] Sun FY, Dong WY, Shao MF, Li J, Peng LY. Stabilization of source-separated urine by biological nitrification process: Treatment performance and nitrite accumulation. Water Science Technology. 2012;**66**:1491-1497

[34] Udert KM, Wächter M. Complete nutrient recovery from source-separated urine by nitrification and distillation. Water Research. 2012;**46**:453-464

[35] Koops H-P, Pommerening-Röser A. Distribution and ecophysiology of the nitrifying bacteria emphasizing cultured species. FEMS Microbiological Ecology. 2001;**37**:1-9

[36] Massara TM, Malamis S, Guisasola A, Baeza JA, Noutsopoulos C, Katsoua E. A review on nitrous oxide (N_2O) emissions during biological nutrient removal from

municipal wastewater and sludge reject water. Science of the Total Environment. 2017;**596-597**:106-123

[37] Carceres R, Malinska K, Marfa O. Nitrification within composting: A review. Waste Management. 2018;**72**:119-137

[38] Wagner M, Loy A. Bacterial community composition and function in sewage treatment system. Environmental Biotechnology. 2002;**13**:218-227

[39] Moussa MS, Sumanasekera DU, Ibrahim SH, Lubberding HJ, Hooijmans CM, Gijzen HJ, van Loosdrecht MCM. Long term effects of salt on activity, population structure and floc characteristics in enriched bacterial cultures of nitrifiers. Water Research. 2006;**40**:1377-1388

[40] Udert KM, Fux C, Münster M, Larsen TA, Siegrist H, Gujer W. Nitrification and autotrophic denitrification of source-separated urine. Water Science Technology. 2003;**48**:119-130

[41] Delin S, Stenberg B, Nyberg A, Brohede L. Potential methods for estimating nitrogen fertilizer value of organic residues. Soil Use and Management. 2012;**28**:283-291

[42] Brod E, Øgaard AF, Haraldsen TK, Krogstad T. Waste products as alternative phosphorus fertilisers part II: Predicting P fertilisation effects by chemical extraction. Nutrient Cycling in Agroecosystems. 2015;**103**:187-199

[43] Odlare M, Pell M, Arthurson JV, Abubaker J, Nehrenheim E. Combined mineral N and organic waste fertilization – Effect on crop growth and soil properties. Journal of Agricultural Science. 2014;**152**:134-145

[44] Kristoffersen AØ, Skretting J, Bergjord AK, Haraldsen TK. Gjødselvirkning av organisk avfall fra storsamfunnet (in Norwegian). Bioforsk FOKUS. 2013;**8**:1

[45] Haraldsen TK, Andersen U, Krogstad T, Sørheim R. Liquid digestate from anaerobic treatment of source-separated household waste as fertilizer to barley. Waste Management Research. 2011;**29**:1271-1276

[46] Brod E, Øgaard AF, Hansen E, Wragg D, Haraldsen TK, Krogstad K. Waste products as alternative phosphorus fertilisers part I: Inorganic P species affect fertilisation effects depending on soil pH. Nutrient Cycling in Agroecosystems. 2015;**103**:167-185

[47] Foereid B. Phosphorus availability in residues as fertilizers in organic agriculture. Agricultural and Food Science. 2017;**26**:25-33

[48] Bøen A, Haraldsen TK, Krogstad T. Large differences in soil phosphorus solubility after the application of compost and biosolids at high rates. Acta Agriculture Scandinavica, Section B – Soil and Plant Sciences. 2013;**63**:473-482

[49] Knoop C, Dornack C, Raab T. Effect of drying, composting and subsequent impurity removal by sieving on the properties of digestates from municipal organic waste. Waste Management. 2018;**72**:168-177

[50] Boldrin A, Andersen JK, Møller J, Christensen FE. Compost and compost utilization: Accounting of greenhouse gases and global warming contributions. Waste Management & Research. 2009;**27**:800-812

[51] Hao X, Chang C, Larney FJ. Carbon, nitrogen balances and greenhouse gas emission during cattle feedlot manure composting. Journal of Environmental Quality. 2004;**33**:37-44

[52] Wang J, Hu Z, Xu X, Jiang X, Zheng B, Liu X, Pan X, Kardol P. Emissions of ammonia and greenhouse gases during combined pre-composting and vermicomposting of duck manure. Waste Management. 2014;**34**:1546-1552

[53] Möller K, Müller T. Effects of anaerobic digestion on digestate nutrient availability and crop growth: A review. Engineering in Life Science. 2012;**12**:242-257

[54] Alvarenga E, Øgaard AF, Vråle L. Effect of anaerobic digestion and liming on plant availability of phosporus in iron- and aluminum-precipitated sludge from primary wastewater treatment plants. Water Science and Technology. 2017;**75**:1743-1752

[55] Taghizadeh-Toosi A, Clough TJ, Sherlock RR, Condron LM. Biochar adsorbed ammonia is bioavailable. Plant and Soil. 2012b;**350**:57-69

[56] Guaya D, Valderrama C, Farran A, Sauras T, Cortina JL. Valorisation of N and P from waste water by using natural reactive hybrid sorbents: Nutrients (N,P,K) release evaluation in amended soils by dynamic experiments. Science of the Total Environment. 2018;**612**:728-738

[57] Caspersen S, Ganot Z. Closing the loop on human urine: Plant availability of zeolite-recovered nutrients in a peat-based substrate. Journl of Environmental Management. 2018;**211**:177-190

[58] Magalhaes JR, Huber DM. Ammonium assimilation in different plant-species as affectet by nitrogen form an pH control in solution culture. Fertilizer Research. 1989;**21**:1-6

[59] Havlin JL, Tisdale SL, Beaton JD, Nelson WL. Soil fertility and fertilizers. In: Yarnell, D. editor. New Yersey: Pearson Education; pp. 137-141

[60] Camargo JA, Alonso A. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International. 2006;**32**:831-849

[61] Guo JH, Liu XJ, Zhang Y, Shen JL, Han WX, Zhang WF, Christie P, Goulding KWT, Vitousek PM, Zhang FS. Significant acidification in major Chinese croplands. Science. 2010;**327**:5968

[62] Bouwman AF, Boumans LJM, Batjes NH. Emissions of N_2O and NO from fertilized fields: Summary of available measurement data. Global Biogeochemical Cycles. 2002;**16**:1058. DOI: 10.1029/2001GB001811

[63] Butterbach-Bahl K, Baggs EM, Dannenmann M, Kiese R, Zechmeister- Boltenstern S. Nitrous oxide emissions from soils: How well do we understand the processes and their controls? Philosophical Transactions of the Royal Society. B. 2013;**368**:20130122

[64] Simek M, Cooper JE. The influence of soil pH on denitrification: Progress towards the understanding of this interaction over the last 50 year. European Journal of Soil Science. 2002;**53**:345-354

[65] Stehfest E, Bouwman L. N_2O and NO emission from agricultural fields and soils under natural vegetation: Summarizing available measurement data and modelling of annual emissions. Nutrient Cycling in Agroecosystems. 2006;**74**:207-228

[66] Liu B, Mørkved PT, Frostegård Å, Bakken L. Denitrification gene pools, transcription and kinetics of NO, N_2O and N_2 production as affected by soil pH. FEMS Microbiological Ecology. 2010;**72**:407-417

[67] Redding MR. Bentonite can decrease ammonia volatilisation losses from poultry litter: Laboratory studies. Animal Production Science. 2013;**53**:1115-1118

[68] Hill J, Redding M, Pratt C. A novel and effective technology for mitigating nitrous oxide emissions from land-applied manure. Animal Production Science. 2016;**56**:362-369

[69] Redding MR, Lewis R, Kearton T, Smith O. Manure and sorbent fertilisers increase on-going nutrient availability relative to conventional fertilisers. Science of the Total Environment. 2016;**569-570**:927-936

[70] Dietrich M, Greenhouse Gas Emission from Digestate in Soil [master thesis]. Zurich: ETH; 2017

[71] Firestone MK, Davidson EA. Microbial basis of NO and N_2O production and consumption in soil. In: Andrcac MO, Schimel DS, editors. Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere. 1989. pp. 7-21

Chapter 2

Olive-Pressed Solid Residues as a Medium for Growing Mushrooms and Increasing Soil Fertility

Hani Mohamed Awad Abdelzaher,
Haifa Abdulaziz S. Alhaithloul and
Shaima Mohamed Nabil Moustafa

Additional information is available at the end of the chapter

http://dx.doi.org/ 10.5772/intechopen.78562

Abstract

Organic fertilizer is the core of organic farming, which represents the most important way to provide crops and agricultural products that are safe and free of any chemical components and pesticides. From this point of view, the purpose of this study is to provide a source of organic fertilizers which was formerly an environmental problem. The northwestern region of Saudi Arabia is flourishing with olive production, leaving huge amounts of residues called olive press cake (OPC). These wastes are a major environmental pollution despite their good content of carbohydrates, protein, oil and cellulose alongside phenols and lignin. We tested the cultivation of *Gliocladium roseum*, *Pythium oligandrum* and *Trichoderma harzianum* and the mushroom *Pleurotus ostreatus* on OPC in order to reduce the high percentage of phenols that impede the germination of some plant seeds. *Gliocladium roseum*, *Pythium oligandrum* and *Pleurotus ostreatus* were able to reduce the percentage of phenols to more than 40% and thus support germination of seeds of *Eruca sativa*. This study gave than one benefit: firstly, reducing phenols that impede the germination of seeds. Secondly, *Gliocladium roseum* and *Pythium oligandrum* work against some plant diseases and also produce plant-like hormones that increase growth of plants.

Keywords: biofertilizer, *Eruca sativa*, *Gliocladium roseum*, *Pythium oligandrum*, *Trichoderma harzianum* and *Pleurotus ostreatus*, northwestern region of Saudi Arabia, olive press cake

1. Introduction

Olive trees are widespread in the Mediterranean countries, where the climate is in line with the pattern and physiology of the growth of these trees. There is almost no Mediterranean

Figure 1. Mediterranean countries distributed in Africa, Asia, and Europe.

country without thousands of hectares of olive trees, where the majority of people thrive on their products, fruits, and oil [1, 2]. Olive is one of the most important horticultural crops, both for direct consumption of fruit and for oil extraction which has nutritional value and a high historical reputation. The scientific name of the olive plant is *Olea europaea* L. and follows the family of Oleaceae. Olive trees grow wild in many parts of the world, especially in southern France, Syria, Palestine, Jordan, Morocco, Algeria, and India and also grow wildly in the southwest of Saudi Arabia. Olive trees are durable and can live for centuries. They are strong, energetic, and resistant to various conditions, including water shortage. The tallest tree reaches 15 m and the average height is 5–8 m. Leaves are spear shape, covered with a thick cutin and some disc hairs. Trees bear two types of flowers: bisexual and male flowers, according to the variety. Pollination is done by wind, and the fruit is drupe, rounded, or oval, depending on the variety and turns to black color when matured. Olive trees are subtropical. During winter, most varieties need low temperatures until flowering buds are formed. Trees thrive in the spring. If temperatures are high in winter, flowering is greatly reduced. Olive trees can withstand summer temperatures up to 48°C. Small olive trees need to be irrigated on a regular basis during the first 3 years of planting. After that, they can tolerate very little irrigation. Olive trees are cultivated in many areas in Spain, Tunisia, and Libya, relying on rain only without the need for artificial irrigation when rainfall is up to 300 mm per year. Small olive trees also need little fertilization but respond to good fertilization later, where it is necessary to add organic and chemical fertilizers, especially nitrogen, potash, and phosphates (www.fao.org).

Most of the world's olive production is concentrated in Mediterranean countries, as well as some countries outside the Mediterranean basin such as Peru, Australia, Chile, Iran, Albania, Argentina, USA, and Saudi Arabia (**Figure 1**). Since 2010, there have been significant variations in production from year to year until 2018 (www.fao.org). This may be due to:

- Development of new varieties characterized by their high production;
- Unusual temperature change
- Recent climate changes on earth
- Political problems and wars in some countries

It should also be noted that the level of global consumption of olive products, especially olive oil, has increased steadily in parallel with increasing awareness of the strong role of olive products in human health as well as increasing world population. For this reason, global demand for olive products in general and olive oil in particular has increased. All modern methods have been used to increase production and increase the efficiency of olive squeeze operations (**Figure 2**).

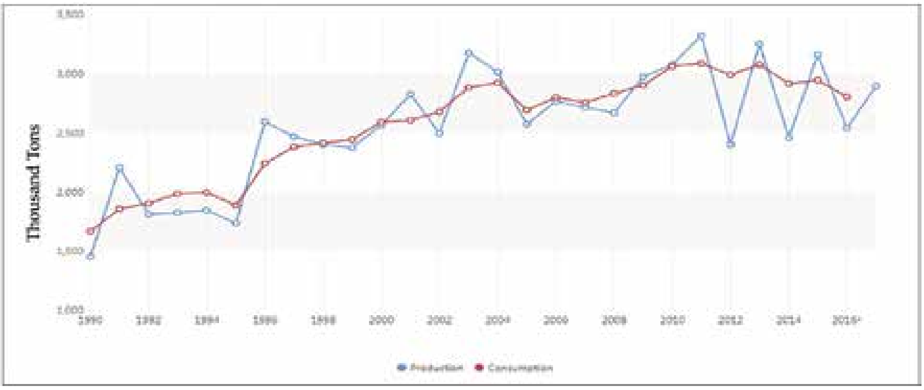


Figure 2. World olive oil production and consumption, 2016/2017, in years (www.fao.org).

Ranking of countries in terms of olive production, as shown in **Table 1**:

Country	2017/2018 (average)
Greece	260–280 (270)
Italy	300–318 (309)
Spain	1.100–1.250 (1.175)
Portugal	90–100 (95)
Morocco	100–110 (105)
Tunisia	250–270 (260)
Turkey	230–250 (240)
Syria*	100–150 (125)
Total	**2.430–2.730 (2.580)**

Production (1.000 tm). *Affected by war.

Table 1. Latest production in the eight leading olive oil producers that make up to 90% of the world's olive oil production (www.fao.org).

2. A research on the presence conversion of the solid waste of pressing olives to soil fertilizers using some useful fungi [part of this work has been reported elsewhere]:

It is important to outline the stages of oil production from olive. Olive fruits must be purified from all impurities, either by manual method or by special sieves, and then washed with hot water to eliminate the effect of some substances on taste and quality of olive oil [1, 2]. Processing olive fruits for the mechanical stages in the production line are as follows:

- After washing the fruits well, they are ground by different crushing processes. This is the first process designed to compress the fruits and separate largest amount of liquids in them.
- This process is carried out accurately and at suitable temperatures, until the oil is assembled together to facilitate separation from other components, especially water, where the temperature directed plays an important role in affecting the viscosity of the oil. Temperature is about 30°C. The aim is not to affect the viscosity of the water but to prevent the mixing of water with oil and influence its density, as well as to protect the oil material from being affected by temperature change of its physical properties such as changing its color to red, or its acidity.
- Separation of the components:

  The previous phase contributes to some degree in the separation of oil molecules from milled materials, but they are without the end filter work because some oil particles are stuck in the mixture. They need a more precise separation process such as process of separation of liquids from solids, separation of oil from liquid materials, and the process of refining it more than once depending on the value of its standard density. This process is affected by a number of factors:

  1. Density: It plays an important role in separating oil from other liquids. This depends on the speed at which the material is removed due to the force, resulting from the rotational movement of the center of motion.
  2. Size: The small size of the oil molecules increases the difficulty of collecting and removing them from the mix.
  3. Viscosity: Differences in the degree of viscosity between components of the mixture contribute to the speed and ease of separating oil from rest of the materials, as well as temperature that was previously mentioned.
- After the oil is separated by centrifugation, solid and liquid residues are discarded, and the oil is finally obtained.

What concerns us here is the solid remains that are the residues of grinding seeds and cellulosic cell walls and organelles of olive fruit cells, as well. This mixture is called olive press cake (OPC) (**Figure 3**).

The huge quantities of waste produced from olive mills have the following properties:

- These residues contain cellulose, protein, carbohydrate, and oil, and they represent a good medium for use as soil fertilizers.

- High content of phenols may cause inhibitors of plant seed germination.
- High content of nutrients in these residues may be an appropriate environment for hordes of insects, spiders, bacteria, and fungi, and some of them may be harmful.

Therefore, we have conducted studies on the abovementioned topics, focusing on the use of these residues as organic fertilizers that can be used to improve mechanical, natural, chemical, and biological soil properties.

The importance of organic agriculture in many areas is of interest to farmers, consumers, society, and the environment. Farmers benefit from the adoption of organic means to increase the production and quality of their crops, due to improved soil fertility and productivity over a long term. Organic agriculture also prohibits the use of insecticides, fungicides, herbicides, nematocides, and other chemicals, reducing dependence on off-farm inputs, thereby reducing production costs and improving health and vitality of animals and plants, while preserving biological and environmental diversity. For the consumer, it increases their confidence in high-quality organic agricultural products, ensuring that they are free of pesticide residues, chemical fertilizers, and genetically modified organisms. All this makes the community healthy, reduces the risk of soil and water contamination with chemical residues, and promotes the sustainability of natural resources and the ecosystem. For soil fertility, there is no accepted concept that includes or is known specifically and clearly. Some soil scientists have pointed out that soil fertility means "the state of nutrients in the soil, in terms of quantity, availability, equilibrium,

Figure 3. A, B: a large pile of solid olive residues (olive press cake, OPC) from olive presses in Sakaka, Jouf, Saudi Arabia. C: amount of OPC in a pail in preparation for some laboratory experiments.

and other nutrients." According to this definition, it has a well-balanced source of nutrients in a soft form to meet its needs during various stages of its growth. Soil may contain necessary essential nutrients in a readily available form. However, their production capacity is low, or unproductive, due to the negative impact of physical, chemical, and biological soil properties. In other words, soil fertility, whether physical or chemical, refers to "the ability of the soil to supply the plant with nutrients." In these two ideas, soil fertility is only an estimate, since the biological effects and their relation to certain aquatic or hydrothermal factors are not considered important, making this interpretation non-exhaustive, although it is used by most soil fertility researchers. Soil fertility is also indicated by its ability to meet the needs of the entire crop of nutrients and water. Soil fertility is sometimes defined as an expression of the state of the nutrient soil, that is, the amount of nutrients it contains in a prepared, adequate, and balanced form for optimal production of a particular crop. In general, soil fertility is a cumulative estimate that can deteriorate as a result of continuous agricultural exploitation and can be developed, maintained, and sustained through good fertilization programs and appropriate soil management.

2.1. Biofertilizers

Modern scientific progress has allowed many processes to take place in nature, prompting scientists to develop new technologies and introduce them into agriculture to protect the environment and increase crop productivity. Using of microorganisms in agriculture was proven to take advantage in processing nutrients needed by the plant in its growth and productivity, and in increasing its biological ability to control pathogens. Biofertilizers can be used to improve soil properties when applying organic farming systems as a natural catalyst for plant growth and productivity. Many studies have shown that some added microorganisms produce antibiotics to protect themselves, killing many pathogenic fungi. At the same time, these microorganisms secrete stimulant-like substances such as auxins to increase seed germination rate as well as increasing root and vegetative growth of the plant. In addition, these stimulants increase the surface area of the root hairs, which contributes to increase the ability of the plant to absorb water, salts, and nutrients. For the previous mentioned reasons, these microorganisms contribute to improving physical and chemical properties of agricultural soils and thus their fertility and productivity. Therefore, some countries have been interested in settling organic agriculture in many parts of the country. This is done by converting organic waste and agricultural products to organic fertilizers, especially in countries characterized by drought due to lack of rainfall, scarcity of vegetation, and high temperatures. In desert countries, lack of intensive cultivation methods resulted in a decrease in biofertilizers and low organic matter, resulting in reduced soil fertility, http://www.fao.org/organicag/oa-faq/oa-faq1/ar.

From this point of view, one of the main objectives of this study is the use of olive press cake (OPC) from many olive mills spread in Jouf region in the northern part of Saudi Arabia, as biofertilizers in organic agriculture. The number of fruitful olive trees in such area was estimated to be more than 15,000,000 trees, produced more than 12,000,000 l of olive oil.

The agricultural land of the city of Sakaka and its suburbs, belonging to the Jouf region, of the northern part of Saudi Arabia is characterized by the lack of suitable physical, chemical, and biological properties. Therefore, we have considered using enormous amount of residual OPC in raising efficiency of agricultural soil through a number of successive researches in this field.

As a result of the huge quantities of the remnants of the process of refining olives, large quantities of waste are formed with other pollutants from the wastewater of these processes [2, 3]. These pollutants are of big environmental problem because of their high organic load [4]. The addition of OPC to agricultural soil increases organic matter and inorganic elements essential for plant growth [5]. By contrast, the application of OPC to the soil causes phytotoxic properties due to the high content of phenolic compounds [4, 6, 7]. Generally, the mushroom fungus (*Pleurotus*) can grow well on organic residues containing lignin and lignocellulose, since these fungi are able to analyze these substances and produce simpler, more nutritious residues, and more benefits to plants. Previous studies indicate that the first stage of mycelial growth of the mushroom and some terrestrial fungi is to be biomass, followed by a decrease in the concentration of harmful phenolics, which turns waste into organic residues enriched and useful for agricultural soil [8, 9].

Analysis of components of OPC is found to contain ash, lipids, minerals, polyphenols, polysaccharides, proteins, sugars, and tannins [10]. The concentration of phenolic compounds reaches up to 10 g/L [11], which causes high plant toxicity and antibacterial properties.

We have benefited from these data that we designed researches based on the use of certain fungi in the withdrawal of high phenols of OPC and then converted it into organic fertilizers added to agricultural soil. Useful fungus of *Gliocladium roseum*, *Pythium oligandrum* and *Trichoderma harzianum,* and the mushroom of *Pleurotus ostreatus* were used in this respect. It is well known and noted through many previous studies that *G. roseum*, *P. oligandrum,* and *T. harzianum* have a long history of biological control of many fungal plant diseases [10]. The mushroom of *P. ostreatus* mushroom is also known for its high nutritional value and a good source of protein for many people. Therefore, the use of *G. roseum*, *P. oligandrum,* and *T. harzianum* has more than one benefit. The first is the withdrawal of the high concentration of phenolic materials from OPC to be suitable for agriculture. The second that these fungi are important in the biological control constitutes a wonderful medium to exist within these organic fertilizers. It is worth mentioning that *G. roseum*, *P. oligandrum,* and *T. harzianum* have the ability to secrete substances similar to plant hormones (auxins) that cause increased vegetative growth and productivity of plant crops [12].

The overall aim of this study was to use *P. ostreatus* mushrooms as well as *G. roseum*, *P. oligandrum,* and *T. harzianum* to grow on OPC to benefit from the productivity of mushrooms and make it suitable as a biofertilizer.

2.2. Materials and methods

G. roseum (JU 121, Jouf University, Saudi Arabia), *P. oligandrum* (JU 221, Jouf University, Saudi Arabia), and *T. Harzianum* (JU 321, Jouf University, Saudi Arabia) were isolated from 25 agriculture fields distributed in Khoaa village, Sakaka (29° 48′ 6′ N, 40° 26′ 27″), Jouf Governorate, located in the northern part of Saudi Arabia [1]. *P. ostreatus* (MUAGRI 1102, Egypt) fungus was kindly obtained from the Ministry of Agriculture, Egypt, as a ready spawn grown on grains of sorghum; afterward the spawn prepared by subculturing the fungus on the medium of Malt Extract Agar) was used (**Figure 4**).

OPC was obtained from an olive mill located in Sakaka city, Jouf, Saudi Arabia, and used spontaneously after sterilization by autoclaving.

Figure 4. Spawn of mushroom of *P. ostreatus* grown on grains of sorghum.

2.3. Mushroom (*P. ostreatus*) cultivation

Experiments were performed in a glass house, and two treatments were used (control + five replicates). Subsequently, results were statistically arranged and all treatments were compared using Duncan Multiple Range test. Ninety-five percent vermiculite and five percent gypsum were the only components of the control. Treatments were prepared as 95% olive press cake and 5% gypsum (dry weight).

2.4. Substrate medium sterilization for cultivation of *P. ostreatus*

Gypsum was added to each treatment and mixed thoroughly and then placed in a cloth bag. Autoclaving was done for two successive days at 121°C for 1 h and left 3 days before use. The glasshouse was disinfected using sodium hypochlorite. The medium was re-placed in big plastic bags in order to allow the manipulation of mixing the spawn with the substrate by thoroughly shaking. Subsequently, medium was inoculated with 5% (dry weight) spawn of *P. ostreatus*. The bags were sealed tightly with a strong thread and punctured with a sterile metal screwdriver.

2.5. Adjustment of culture circumstances

Substrates were incubated at 20–25°C, under 80–95% (R.H.) humidity in the dark during starting days until the emergence of white mycelial growth. The colonized substrates were subjected to a cold shock at 5°C for 48 h to stimulate the emergence of first flush. It is worth mentioning that ventilation was very important during the fruiting period; therefore, the upper side of the bags was opened. Precautions must be taken for the temperature to be around 25°C and the relative humidity was between 80 and 90% by watering the bags twice daily and placing vast water containers on the floor.

2.6. Harvesting mushroom crop

Basidiocarps (fruiting bodies) of *P. ostreatus* had been collected when pilei were matured and just before started to curl up. Residues attached on stipes of mushrooms were gently disposed of by wiping them with a tissue paper before weighing. After harvesting mushroom, the average weight of singular basidiomata calculated as the quotient of the total weight of fresh bodies collected by their total number, the average production for each parameter and diameter of the pilei, and the average diameter were measured.

2.7. Culturing *G. roseum*, *P. oligandrum*, and *T. harzianum* on OPC

Olive press cake (OPC) was collected from an olive mill (Aljouba, Sakaka city, Jouf, Saudi Arabia). Fungi were developed and preserved in potato dextrose agar (PDA) (part of this work has been reported elsewhere [1]). Potato dextrose agar discs containing fungal growth were used for OPC inoculation and subculturing, as well. Incubation procedure was performed in 1-L Erlenmeyer flasks, each containing 200 g of OPC and 150 ml distilled water at 28°C for a time course of 1–4 weeks (**Figure 5**).

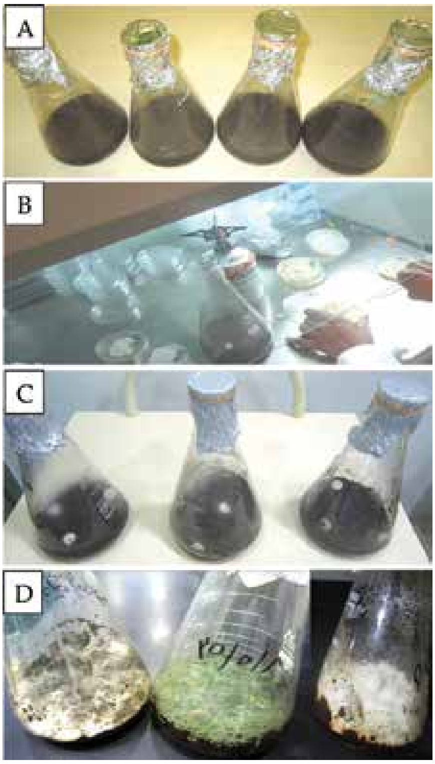


Figure 5. A. OPC and water in flasks after sterilization in the autoclave. B. Flasks during inoculation by fungi. C. Flasks after inoculation. D. Fungal growth after incubation for 2 weeks at 28°C in the dark.

2.8. Effect of growth of *G. roseum*, *P. oligandrum*, *T. harzianum,* and *P. ostreatus* on the amount of phenols in OPC

The total phenolic contents of OPC were estimated according to the method of [13], via tannic acid as a standard, and expressed as grams per kilogram of OPC. Analyses were done for each treatment before and after growth of tested four fungi within 1–4 weeks.

2.9. Testing the ability of *Eruca sativa* seeds to grow in the waste before and after the growth of fungi

The OPC before and after culturing with each of the tested four fungi was analyzed for their appropriateness for growing seeds of *E. sativa*. Quantities of every 100 g of OPC were added to plastic pots. Fifty *E. sativa* seeds were distributed on the surface of each pot containing tested OPC. Pots were incubated in an illuminated growth cabinet at 25°C with 12 h photoperiod (91 μmol m^{-2} s^{-1}). Emergence seedlings were counted in the course of 5–20 days.

2.10. Statistical analysis

Data were analyzed using one-way analysis of variance (ANOVA) through Minitab statistical software (version 12) unless elsewhere mentioned.

3. Results

3.1. The effect of different amounts of OPC on growth parameters (incubation period, yield, average weight, and average diameter of pilei) of *P. ostreatus*

Table 2 shows that that period required for incubation of OPC substrate was around 13 days compared with the control treatment which needed 5 extra days. Highest mushroom production was recorded in control, but in OPC it showed significant differences between them and the yield fell by almost half. In control, the average weight was 25.26 (g/cap), whereas it decreased to 17.99 (g/cap) in OPC. There were no significant differences between control treatment and OPC in their average diameter of fungal pileus.

3.2. Culturing *G. roseum, P. oligandrum, T. harzianum,* and *P. ostreatus* on OPC

G. roseum, P. oligandrum, T. harzianum, and *P. ostreatus* showed excellent growth on OPC, which began from the first week of cultivation and more intense growth between the second and the third week of the incubation period (**Figure 5**).

3.3. Total phenols of OPC before and after the growth of *G. roseum, P. oligandrum, T. harzianum,* and *P. ostreatus*

Total phenols significantly decreased when *G. roseum, P. oligandrum,* and *P. ostreatus* grew on OPC from the first week up to the fourth week of growth. On the other hand, *T. harzianum* did not show any significant decrease in phenol content of OPC before and after growth on OPC (**Figure 6**).

Treatments	Incubation period (days)	Yield (g/0.5 kg)	Average weight (g/cap)	Average diameter (cm/cap)
Control	18a[1]	588.69a	25.26a	8.31a
OPC	13b	270.16c	17.99c	7.28a

[1] Means within each column followed by the same letter were not significantly different according to Duncan's Multiple range test (P = 0.05).

Table 2. Effect of adding olive press cake on incubation period, yield, average weight, and average diameter of *P. ostreatus.*

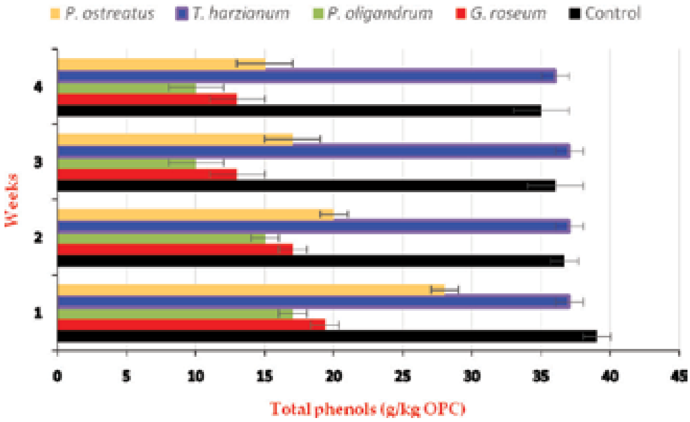


Figure 6. Phenol content (g/kg OPC) of OPC treated with each of *G. roseum*, *P. oligandrum*, *T. harzianum*, and *P. ostreatus* during different treatment times (1–4 weeks). Data are averages (±S.E.) of five replicates and significant values against control represent **highly significant at $p < 0.01$, ***very significant at $p < 0.001$.

Treatments	Time of incubation (days)			
	5	10	15	20
Vermiculite	42*	42**	42	42
OPC	0	0	0	0
OPC previously incubated with *G. roseum* for 1 week	29c	33c	33c	33c
OPC previously incubated with *G. roseum* for 2 week	38c	41c	41c	41c
OPC previously incubated with *G. roseum* for 3 week	37c	40c	40c	40c
OPC previously incubated with *G. roseum* for 4 week	39c	41c	41c	41c
OPC previously incubated with *P. ostreatus* for 1 week	22c	28c	30c	31c
OPC previously incubated with *P. ostreatus* for 2 week	32c	38c	40c	41c
OPC previously incubated with *P. ostreatus* for 3 week	35c	38c	39c	40c
OPC previously incubated with *P. ostreatus* for 4 week	35c	43c	40c	42c
OPC previously incubated with *T. harzianum* for 1 week	0	0	0	0
OPC previously incubated with *T. harzianum* for 2 week	0	0	0	0
OPC previously incubated with *T. harzianum* for 3 week	0	0	0	0
OPC previously incubated with *T. harzianum* for 4 week	0	0	0	0
OPC previously incubated with *P. oligandrum* for 1 week	33c	33c	31c	31c
OPC previously incubated with *P. oligandrum* for 2 week	35c	40c	42c	42c
OPC previously incubated with *P. oligandrum* for 3 week	43c	45c	45c	45c
OPC previously incubated with *P. oligandrum* for 4 week	45c	46c	46c	46c

*Number of emerged *Eruca sativa* seeds out of 50.

**Means within each column followed by the same letter were not significantly different (compared with the control in OPC) according to Duncan's Multiple range test (P = 0.05).

Table 3. Emergency of 50 *Eruca sativa* seeds inoculated or not with *G. roseum*, *P. oligandrum*, *T. harzianum*, and *P. ostreatus* in the presence or absence of olive press cake (OPC) incubated within 20 days.

3.4. Germination of *E. sativa* seeds on OPC previously cultured with *G. roseum*, *P. oligandrum*, *T. harzianum*, and *P. ostreatus*

OPC previously cultured with each of *G. roseum*, *P. oligandrum*, *T. harzianum*, and *P. ostreatus* during 1–4 weeks increased the emergency of *E. sativa* seedling, whereas seeds never germinated in crude OPC (**Table 3**, **Figures 7** and **8**).

Ability of Eruca sativa seeds to grow on OPC before and after the growth of *P. oligandrum* after 30 and 40 days

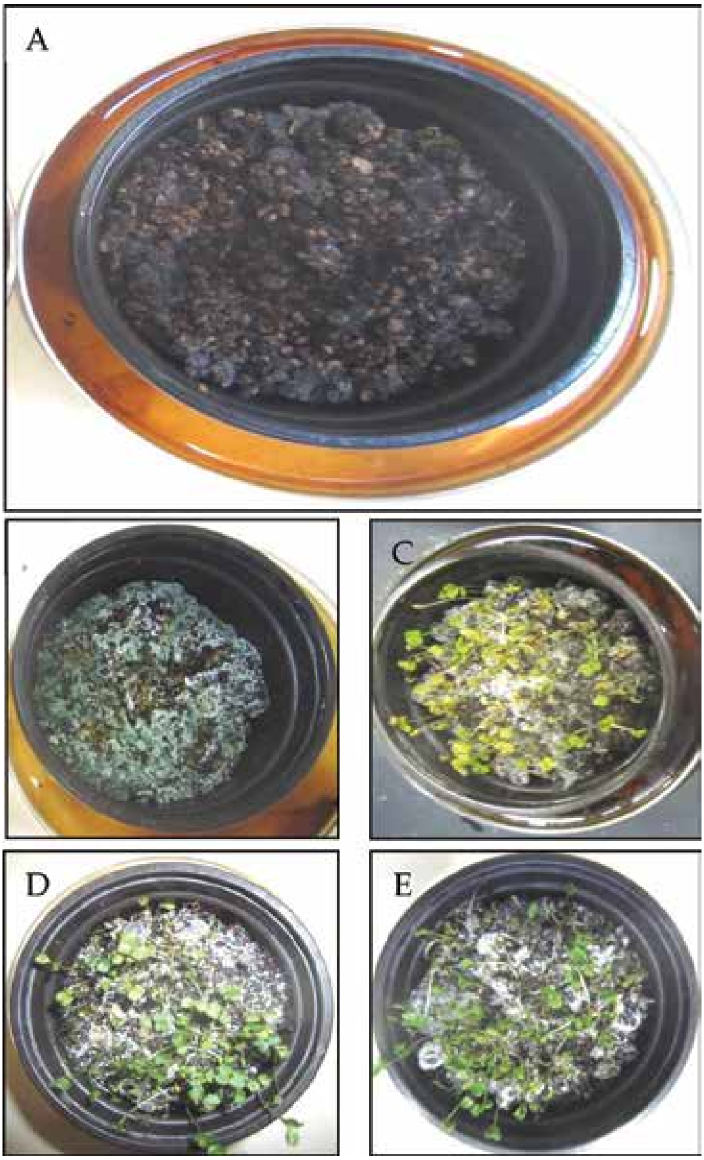


Figure 7. (A–E) Germination of *Eruca sativa* seeds on OPC after 2 weeks culturing with *G. roseum* (B), *T. harzianum* (C), *T. harzianum* (D), *P. oligandrum* (E), *P. ostreatus*, and control (A) whereas seeds were seeded on crude OPC after 7 days at 25°C under 12 h photoperiod (91 μmol m^{-2} s^{-1}).

Figure 8. (A–E) Germination of *Eruca sativa* seeds on OPC after 30 and 40 days culturing with *P. oligandrum*. Control represents seeds on crude OPC after 7 days at 25°C under 12 h photoperiod (91 μmol m^{-2} s^{-1}).

4. Discussion

Experimental data show that the phytotoxic properties of OPC were responsible for inhibiting the growth of plant seeds used in this study. The olive press cake used in our study inhibited *E. sativa* seed germination. Many high concentrations of phenolic compounds were considered one of the main reasons of the toxicant effect of OPC on plant seed germination and subsequent growth [14]. For this reason, a high phenolic content of OPC could be responsible for phytotoxicity. Most of phenolic acids began to exhibit their phytotoxicity at high concentrations [15]. In this research, OPC were 40 g kg^{-1} of total phenolic compounds. The application of OPC to agricultural soil causes the inhibition of plant seeds and retards the growth of many growing plants.

It is worth mentioning that many fungi can grow and flourish in food environments containing high concentrations of phenols. From the previous point, this phenomenon can be used to withdraw or even reduce the high percentage of phenols in any medium [16].

From the study, many *Aspergillus* spp. are capable of decomposing phenolics in OPC. Subsequently, many isolates of *A. niger* were observed to flourish and produce dense growth on OPC [17]. One of the methods used by some fungi to remove the toxic effect of high concentrations of phenols had been attributed to their capacity to metabolize phenols [14]. Earlier results showed that *Coriolopsis rigida* decreases phenolics of OPC [4]. In addition, the same fungus increased the dry weight of tomato fruits [18].

Results of this study showed that some of the tested fungi, which were *G. roseum*, *P. oligandrum,* and *P. ostreatus*, had the ability to grow on OPC and withdraw a large amount of phenols up to 75% of the main concentration. By contrast, *T. harzianum* was able to grow on OPC while it could not affect the level of phenols and therefore remained the amount of phenols as they were throughout the incubation period. This may be explained by the ability of *G. roseum*, *P. oligandrum,* and *P. ostreatus* to metabolize the phenols while *T. harzianum* cannot. It is therefore very important to test the ability of fungi (even in the level of isolates) for analyzing phenols after testing their ability to grow on OPC to be used in the clearance OPC from the high concentration of phenols.

Fortunately, a high level of nutrients in OPC strengthened and helped to grow tested fungi intensively without any dietary additives. Therefore, we have used environmentally friendly fungi and have benefits in the biological control and production of plant-like auxins for plant growth in addition to its ability to reduce the high concentration of phenols. So we hit two birds with one stone, which is that we have made OPC suitable to add to the agricultural soil to improve their properties and at the same time add fungi that resist plant diseases and increase the vegetative growth and productivity of plants.

Another useful dimension is the extent to which OPCs are used as a medium for growth of an edible species of mushrooms (*P. ostreatus*). After mushroom cultivation course, OPC can then be used as high-value organic fertilizers. Mushrooms were recently used for decreasing phenolics in OPC. Other basidiomycota belonging to white rots were proved to be efficient metabolizers of phenolics in OPC [19]. *Pleurotus* was able to grow on OPC and reduced total phenols. It has been evidenced that the development of normal basidiomata on OPC cultured with *P. ostreatus* and *P. eryngii* [20]. They further postulated that the residual toxicity of OPC was significantly reduced. Our experiments showed that by growing *P. ostreatus* on OPC, the percentage of phenols decreased by about 40% of the ratio in the raw OPC after 4 weeks of mushroom cultivation.

It is worth mentioning that each of *G. roseum*, *P. oligandrum,* and *P. ostreatus,* which gave positive results toward the reduction of high phenols and make the residues suitable for seed germination and then used in organic agriculture as fertilizer for agricultural soil, was used separately from each other.

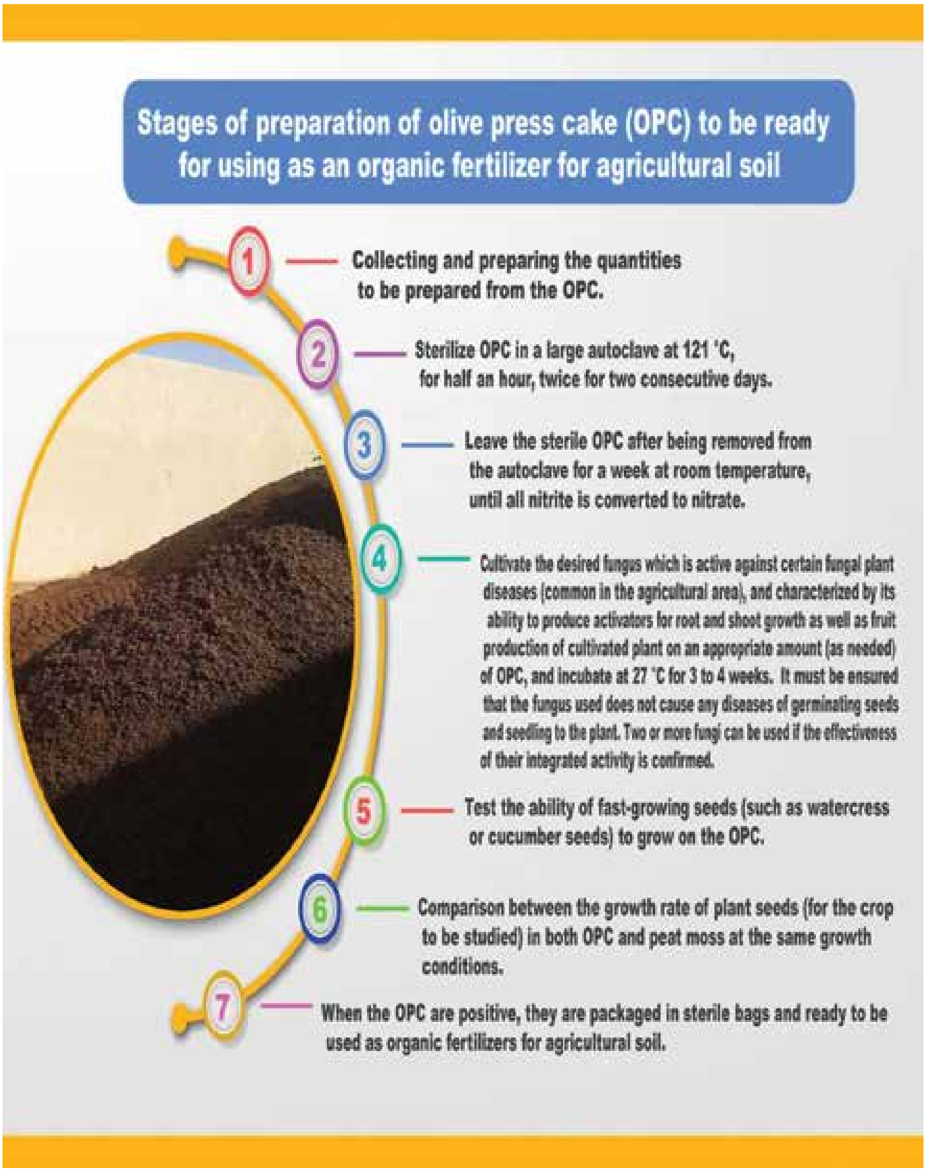
It is therefore very appropriate to test the integration of *G. roseum* and *P. oligandrum* in their work as depressants of the high concentration of phenols and their ability as biological controls. There have been no experiments on this integration in this study here, and therefore we recommend further studies in this regard.

This study is a nucleus of similar studies using other useful fungi that have antifungal properties and can eliminate the OPC of the high concentrations of phenols.

5. Conclusion

It is known that there are many sources of organic fertilizers that man has dealt with throughout the ages. The basic contents of organic fertilizers contain plant and animal residues moistened and left for a certain period of time until microbial degradation occurs and eventually produce organic fertilizers containing organic sources in a simple form that the plant can benefit from. What is new here is that we used OPC as a vital source of organic fertilizer. Olive press cake contains cellulose, protein, carbohydrate, oil, and phenol. This shows the good content of the necessary compounds to ensure seed germination, plant growth, and prosperity. The problem is the high content of phenols that have hindered the germination of plant seeds in some crop plants. In this context, research studies have been conducted to benefit from the high nutritional content of OPC and to withdraw the high concentration of phenols in order to prepare these wastes as a good source of organic fertilizers .It has been found that using some of the saprophytic fungi can reduce the level of phenols in OPC. The idea was to use saprophytic fungi with the ability to control some plant diseases, in addition to their ability to increase plant growth by producing plant-like hormones (auxins) that are responsible for increasing vegetative growth and fruit production. Therefore, we have used *G. roseum, P. oligandrum, T. harzianum,* and *P. ostreatus* known to have the ability to control fungal plant diseases and produce plant-like hormones. Our studies have shown that *G. roseum, P. oligandrum,* and *P. ostreatus* can play a positive role in reducing the rate of phenols and the foundation of OPC to be a good source of organic fertilizers.

Steps of preparing OPC to be a suitable medium for organic fertilizers can be illustrated in the following infographic illustration:



Stages of preparation of olive press cake (OPC) to be ready for using as an organic fertilizer for agricultural soil

1. Collecting and preparing the quantities to be prepared from the OPC.
2. Sterilize OPC in a large autoclave at 121 °C, for half an hour, twice for two consecutive days.
3. Leave the sterile OPC after being removed from the autoclave for a week at room temperature, until all nitrite is converted to nitrate.
4. Cultivate the desired fungus which is active against certain fungal plant diseases (common in the agricultural area), and characterized by its ability to produce activators for root and shoot growth as well as fruit production of cultivated plant on an appropriate amount (as needed) of OPC, and incubate at 27 °C for 3 to 4 weeks. It must be ensured that the fungus used does not cause any diseases of germinating seeds and seedling to the plant. Two or more fungi can be used if the effectiveness of their integrated activity is confirmed.
5. Test the ability of fast-growing seeds (such as watercress or cucumber seeds) to grow on the OPC.
6. Comparison between the growth rate of plant seeds (for the crop to be studied) in both OPC and peat moss at the same growth conditions.
7. When the OPC are positive, they are packaged in sterile bags and ready to be used as organic fertilizers for agricultural soil.

Author details

Hani Mohamed Awad Abdelzaher[1,2]*, Haifa Abdulaziz S. Alhaithloul[1] and Shaima Mohamed Nabil Moustafa[1,2]

*Address all correspondence to: abdelzaher1963@yahoo.com

1 Department of Biology, College of Science, Jouf University, Sakaka, Saudi Arabia

2 Department of Botany and Microbiology, Faculty of Science, Minia University, El-Minia, Egypt

References

[1] Abdelzaher HMA, Albahrawi AZ, Moustafa SMN. Isolation of some biocontrol fungi from Saudi soil and their beneficial role as bio-fertilizers. Journal of Pure and Applied Microbiology. 2015;**9**:541-549

[2] Roberta S, Giuseppe I. Environmental impacts of olive oil production: A life cycle assessment case study in the province of Messina (Sicily). Journal of Cleaner Production. 2012;**28**:88-100

[3] Maria CC, Anna MG, Angela V. Soil amendment with olive mill wastes: Impact on groundwater. Journal of Environmental Management. 2013;**131**:216-221

[4] Sampedro I, Aranda E, Martin J, Garcia-Garrido JM, Garcia Romera I, Ocampo JA. Saprobic fungi decrease plant toxicity caused by olive mill residues. Applied Soil Ecology. 2004a;**26**:149-156

[5] Paredes C, Ceggara J, Roing A, Sanchez-Monedero MA, Bernal MP. Characterization of olive mill wastewater (alpechin) and its sludge for agricultural purposes. Bioresource Technology. 1999;**67**:111-115

[6] Martin J, Sampedro I, Garcia-Romera I, Garcia-Garrido JM, Ocampo JA. Arbuscular mycorrhizal colonization and growth of soybean (*Glycine max*) and lettuce (*Lactuca sativa*) and phytotoxic effects of olive mill residues. Soil Biology and Biochemistry. 2002;**34**:1769-1775

[7] Roig A, Cayuela ML, Sanchez-Monedero MA. An overview on olive mill wastes and their valorisation methods. Waste Management. 2006;**9**:960-969

[8] Aranda A, Sampedro I, Ocampo JA, Garcia-Romera I. Phenolic removal of olive-mill dry residues by laccase activity of white-rot fungi and its impact on tomato plant growth. International Biodeterioration and Biodegradation. 2006;**58**:176-179

[9] Tomati U, Galli E, di Lena G, Buffone R. Induction of laccase of *Pleurotus ostreatus* mycelium grown in olive mill waste waters. Agrochimica. 1991;**35**:275-279

[10] Hafidi M, Amir S, Revel JC. Structural characterization of olive mill waste-water after aerobic digestion using elemental analysis, FTIR and 13C NMR. Process Biochemistry. 2005;(8):2615-2622

[11] Borja R, Martin A, Maestro R, Alba J, Fiestas JA. Enhancement of the anaerobic digestion of olive mill wastewater by the removal of phenolic inhibitors. Process Biochemistry. 1992;(4):231-237

[12] Moustafa SMN, Abdelzaher HMA. Increasing of tomato yield grown in hydroponic system using *Pythium oligandrum* isolated from Khoaa, Aljouf, Saudi Arabia. Egyptian Journal of Microbiology. 2018;**53**:1-8

[13] Ribereau-Gayon P. Les Composes Phenoliques des Vegetaux. Paris: Dumond; 1968

[14] Wang X, Yu J, Wang Y, Wang L. Mechanism-based quantitative structure-activity relationships for the inhibition of substituted phenols on germination rate of *Cucumis sativus*. Chemosphere. 2002;**46**:241-250

[15] Wang TSC, Yang T, Chuang T. Soil phenolic acids as plant growth inhibitors. Soil Science. 1967;**103**:239-246

[16] Moreno E, Quevedo-Sarmiento J, Ramos-Cormenzana A. Antibacterial activity of waste waters from olive oil mills. In: Cheremisinoff PN, editor. Encyclopedia of Environmental Control Technology. Houston: Gulf Publishing Co.; 1990. pp. 731-757

[17] Hamdi M, Ellouz R. Use of *Aspergillus niger* to improve filtration of olive mill wastewaters. Journal of Chemical Technology and Biotechnology. 1992;**53**:195-200

[18] Sampedro I, Romero C, Ocampo JA, Brenes M, Garcia-Romera I. Removal of monomeric phenols in dry olive residue by saprobic fungi. Journal of Agricultural and Food Chemistry. 2004b;**52**:4487-4492

[19] Hammel KE. Organopollutants degradation by ligninolytic fungi. Enzyme and Microbial Technology. 1989;**11**:776-777

[20] Sanjust E, Pompel R, Rescigano A, Rinaldi A, Ballero M. Olive milling wastewater as a medium for growth of four *Pleurotus* species. Applied Biochemistry and Biotechnology. 1991;**31**:223-235

Section 2

Practices for Improving Nutrient Availability

Chapter 3

Composing of Municipal Solid Waste and Its Use as Fertilizer

Muhammad Khalid Iqbal

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.81729

Abstract

The high generation of waste in Pakistan (estimated at 55,000 tons/day) has resulted in serious environmental problems. Collected solid waste material are left in depressions and on vacant plots, buried, burned, and dumped in the ocean. To improve this situation, the material was composted and evaluated as a fertilizing material and its effect on the environment. Composting of these waste resulted in the production of good quality materials that can be used as soil amendments and source of plant nutrients. Large amounts of N and K are usually generated and very effective in crop production. Leaching of nutrients was less when compost was applied than mineral fertilizer. The composting of solid municipal waste was observed to be a better option to open disposition.

Keywords: MSW, compost, aeration

1. Introduction

Pakistan urbanization has increased drastically in recent decades. The migration of people in urban areas leads to problems like poverty, housing and transportation, water and sanitation, and solid waste generation. In Pakistan, the solid waste generation in urban areas is estimated at 55,000 tons/day [1]. Waste management generally comprises primary and secondary collection and open dumping of more than 90% of the collected waste. Only 60% of the waste generated is actually collected in most cities of Pakistan. The uncollected waste lies in topographic depressions, vacant plots along the street, roads and railway line, drains, storm drains, and open sewers within overall urban limits [2]. Burial, burning, and ocean dumping strategies for the management of MSW lead to contamination of land, air, and sea [3]. It poses serious health hazards by causing considerable increase in the environmental pollution [4]. In Lahore, Pakistan, the existing system of solid waste management is inadequate and insufficient to manage the present and future need.

2. Materials and methods

In MSW, the organic matter is an important parameter to determine the method for its treatment. Typically, MSW is treated by two different methods: (i) by anaerobic digestion and (ii) aerobic process (composting). Both methods have their own specific advantages and disadvantages, with aerobic process very rapid compared to anaerobic treatment [5]. Composting is the process whereby thermophilic, aerobic microorganisms transform organic materials into hygienic, biostable products [6].

Composting methods differ in duration of decomposition and potency of stability and maturity. Aerobic composting physically breaks up organic matter yielding a texturally and chemically homogeneous end product in less time than anaerobic methods.

Composting process is affected by some environmental conditions (temperature, moisture contents, pH, and aeration) and substrate characteristics (C/N ratios, particles size, nutrient contents, and free air space) [7]. Moisture content greatly influences the changes in physical and chemical properties of waste material in the course of degradation of organic matter. MSW comprises high proportion of moisture (80–90%) and organic matters (70–80%) that give raise the odor during decomposition [8]. When the optimum moisture level (60%) is not easily accessible to the microorganism, their microbial activity abates the composting process, and temperature (40–70°C) will not be accomplished [9]. Most favorable moisture level for biodegradation of different compost mixtures varied from 50 to 70% [10]. Excessive moisture content of MSW results in significant leachate formation during composting and collapse of the composting matrix leading to reduction in porosity and oxygen availability. If the oxygen apportioning is not homogenous, it causes CO_2 accumulation and brings forth anaerobic condition inside the piles. According to Haug [9], oxygen concentration within the composting matrix should not be lower than 5–7%, and proper aeration of the composting material will only be possible if enough porosity and FAS are around 30% in composting piles. To control the moisture contents and to optimize the C/N ratio, bulking agents (BA) are added in the composting process for an effective degradation of MSW.

However, the main requirement for the safe use or application of compost to agricultural lands is its degree of stability and maturity, which implies stable organic matter content [11, 12]. Stability prevents nutrients from becoming tied up in rapid microbial growth, allowing them to be available for plant needs [13]. Application of immature compost may inhibit seed germination, reduce plant growth, and damage crops by competing for oxygen or causing phytotoxicity to plants due to insufficient biodegradation of organic matter [14]. Due to these concerns, extensive research has been conducted to study the composting process and to evaluate methods to describe the stability and maturity of compost prior to its agricultural use [15]. The most common indicators that have been used in other composting studies include C/N ratio, cation exchange capacity (CEC), humic substances, $NH_4^+ - N$ and $NO_3^- - N$ ratio of

$NH_4^+ - N/NO_3^- - N$, and CO_2 evaluation [13]. It should be noted that no single maturity indicator could be applied to all composts because of differences in feedstock used.

The compost prepared by mechanical composting plants is generally low in plant nutrients, and therefore their acceptability by farmers is poor [16]. The loss of nutrients is responsible for a decrease in soil fertility. The most common practice to preserve or restore the soil fertility is to add the organic matter to this soil.

Compost as fertilizer or soil conditioner improves the soil quality by enhancing aeration, water status, macro- and micronutrients, and aggregate stability, which perk up plant growth [17]. Plant establishment and maintenance of high crop yield are possible only by the use of compost.

Compost material improves the soil health and plant growth. It has also been found that compost suppresses the pathogens and plant diseases. Compost increases the organic matter in soil, improve tilth and water holding capacity, and provide a long-term supply of nutrients as the organic material decomposes [18].

3. Results

3.1. Comparing treated and untreated compost

The uptake of nutrients by plants depends upon the rate of applications of compost and availability of nutrients in soil. Thus, available forms of nutrients in soil solution depend on the release of nutrients from fertilizer materials in soil solution.

The treated and untreated composts are incubated in a specific pot volume to study the mineralization of nitrogen in controlled environmental conditions. The treated and untreated composts are applied at different rates, and soil is analyzed before putting the pot in the incubator. The chemical analysis of soil is given in Table 4.14, and the quantity of nitrogen untreated composts (**Table 1**).

In the incubation study, trace amounts of ammonium are found while the nitrification process is very rapid. The net N mineralization is presented in terms of the sum of the ammonium-N and total oxides of nitrogen (nitrate) (**Table 2**).

The net N mineralization rate of the control soil throughout the incubation period ranged from 67.47 to 85.20 mg/kg with a mean of 81.51 mg/kg. Soil mineral N is shown to increase with the incubation time. Considering each sampling time, the treated compost application resulted in

Sand (%)	Silt (%)	Clay (%)	pH	Total P (mg/kg)	Total K (mg/kg)	Total N (mg/kg)	C/N
53.12 ± 8.93	19.25 ± 4.06	27.63 ± 5.65	7.5 ± 0.12	6.5 ± 0.53	117.6 ± 0.61	0.06 ± 0.01	6.0 ± 0.8

±SE of three replicates.

Table 1. Initial soil properties used in the study.

Compost application pate (kg-N/ha)	Compost (g)	
	Treated	Untreated
30	54.94	64
60	109.88	128
90	164.82	192

Table 2. Application rate of N to the soil.

higher amounts of soil mineral N than the control and the untreated compost-amended soil. The soil mineral N of the different treatments is presented in **Figure 1**, with reference to incubation time.

The effect of compost application rate (30, 60, 90 kg N/ha) on soil mineral N contents is found not to be important for any given time, which is attributed to the fact that the increase in the amount of mineral N is not significantly different between the treatments, except T-90.

Flavel and Murphy [19] found also in his study that the N-mineralization is not much different between treatments, but there is difference in total N mineralization rates that are different in magnitude of N.

The mean mineral N over the whole duration of the incubation experiment increased with the increase of the treated compost application rate (**Figure 2**). The untreated compost applications at the highest rate increased the mean soil mineral N contents as compared to control. The N mineralization depends upon the rate of N amended in soil. As the regression value R^2 (0.979) in treated compost indicates that 98% of the variability in N mineralization is dependent on the

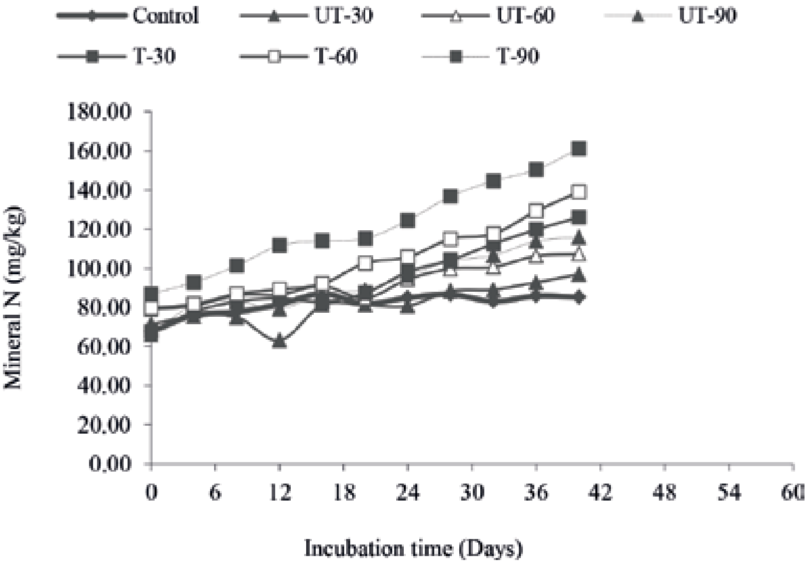


Figure 1. Mineralization of treated and untreated compost in soil. T, treated compost; UT, untreated compost.

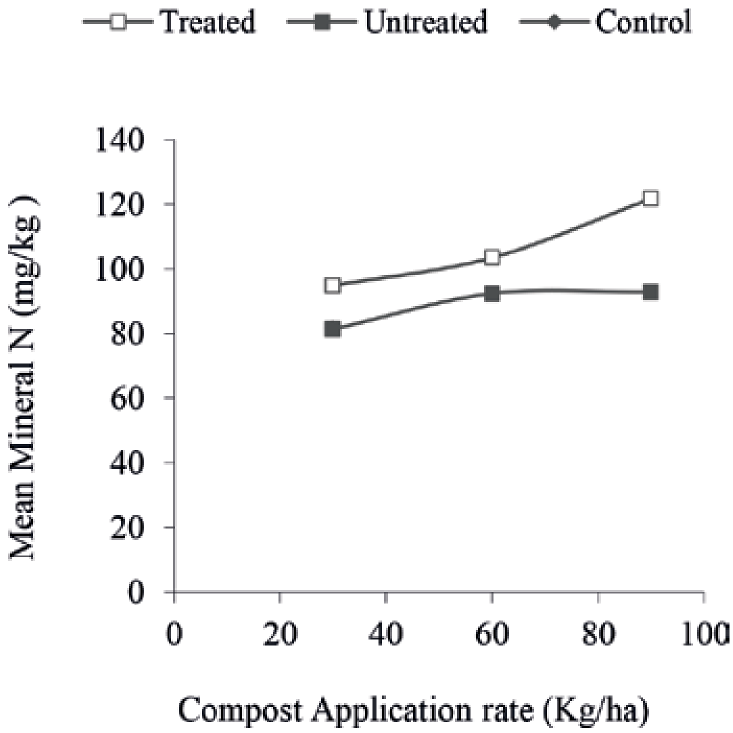


Figure 2. Mineralization of nitrogen of treated and untreated compost in soil. T, treated compost; UT, untreated compost.

rate of the N added. In untreated compost, 88% of the N mineralization depended on the N addition.

The amount of gross N mineralization depends upon the total C, N, lignin, ash, and NO_3^-. The composts used in the study are characterized by relatively low C/N ratios. The treated compost has a C/N ratio of 11:40 and untreated of 15:33. Treated compost application results in significantly higher net N mineralization by 76.26% than untreated compost. The same observation is noted by Kokkora [20] and Chaves et al. [21].

The $\text{NMR}_{\text{total}}$ of the treated compost remained fairly constant from days 4 to 14 and then increased from days 24 to 44 constantly. The $\text{NMR}_{\text{total}}$ of the untreated compost remained constant till day 2, then decreased in day 8, and increased in day 15 and from that point till day 24 (**Figure 3**).

Both compost showed a net mineral N release in incubation. This finding is in good agreement with other incubation work using organic materials with low C/N ratio [21, 22].

The mineralization rate in the study revealed that CO_2 released from the soil amendments is higher than the control (soil), because the amendments increased the soil biomass in relation to control [23, 24]. The presence of high concentration of easily degradable organic C in the amendments led to a larger growth of the microbial population in the soil [25]. The highest CO_2 evolution is recorded at day 15 of incubation, and afterwards it shapely declined in the

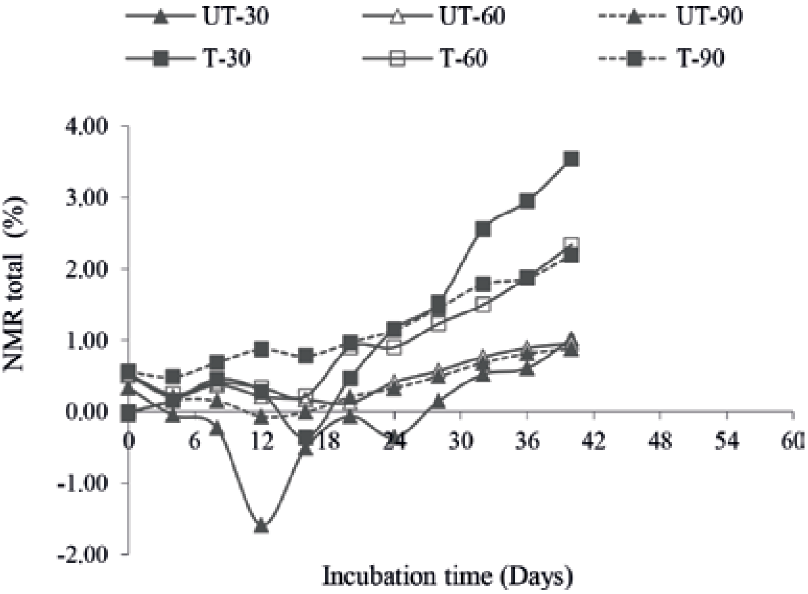


Figure 3. Mineralization of treated and untreated compost in soil. T, treated compost; UT, untreated compost.

treated compost, whereas after 20 days, both composts showed steady CO_2 evolution. This suggests that after this period the amendments are mature for plant growth (**Figure 4**). The increased application rate of amendments affects the large increase in C mineralization in matured compost. Similar results are found by (Pedra et al. [26] and Busby et al. [27]). The low C/N ratio of the experimental amendments induced their stability and showed a higher rate of mineralization due to N contents which promote microbial activity to some extent. Hence, the results of mineralization in both composts are not considerably different at the end of the incubation.

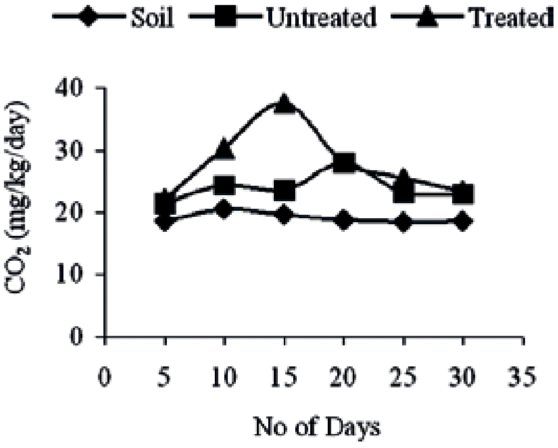


Figure 4. Mineralization of $CO_2 - C$ of treated and untreated compost in soil.

4. Lysimeter study of compost

The lysimeter experiment was conducted to study the effect of N leaching of two different composts, in poor quality sandy soil under controlled drainage system. This aim is used to note the nitrate leaching and subsequent effects of excessive leaching on sandy soil. In this study the potential of treated and untreated composts and mineral fertilizer on quality of sand and tomato plant is also evaluated. The study also covers phosphate and potassium nutrients at different depths of lysimeter sand and from different parts of the plant at the end of the experiment. The analysis of sand, which is used in lysimeter study, is given in Table 4.16. The sand is mixed with compost in lysimeter, and their application rate of compost nutrients is given in **Table 3**.

4.1. Mineral nitrogen leaching experiment

Nitrogen is an essential nutrient required to increase and maintain agricultural production. However, nitrogen leaching can impact water bodies. The mineral nitrogen results are different due to each treatment nutrients leachibility and phytoavailability. In the initial stage of the experiment, leaching of N in treated and untreated composts is parallel to control. The mineral fertilizer treatments (200, 400, 600 kg N/ha) are notably different from all other treatments. It is also noted that there is no considerable difference between treated and untreated composts throughout the study period. The mineral fertilizer produces an excessive quantity of mineral N in the leachate. The increase of application rate of mineral fertilizer increased the N in the leachate. Due to the increase of mineral N leachate from the mineral fertilizer treatments, a limited amount of mineral N is found in the tomato crop. At the end of the leaching, an increase of about 60.5 and 67% of the initial (30.91 and 28.76%) leaching is increased in untreated and treated compost, respectively. Ahmad et al. [28] results are inlined with the present study.

Mineral fertilizer had notably higher N in leachate than compost (treated and untreated) shown in tomato plant growth in irrigated sandy soil, which indicates an environmental benefits from water quality perspective as compared to mineral fertilization. The amount of N leaching agrees with Xiaoxin et al. [29] report that increased application rate increased N leaching.

Figure 5 shows the effect of the compost type on the total mineral N leached during the lysimeter study as compared to mineral fertilizer treatments. Treated compost is not considerably higher in the amount of N leaching than untreated compost. However, the mineral N leached from both compost-amended sandy soil is higher than the control and lower than the mineral fertilizer treatment. The effect of compost application rate on total N leaching is

	Sand (%)	Silt (%)	Clay (%)	O.M (%)	Tot. N (%)	T.P (mg/kg)	K (mg/kg)
Fine sand	98.2	1.5	0.3	1.29	0.017	0.7	23.9
Coarse sand	97.8	1.6	0.6	1.23	0.02	0.65	20.5

Table 3. Mechanical analysis of the soil used in the lysimeter experiment.

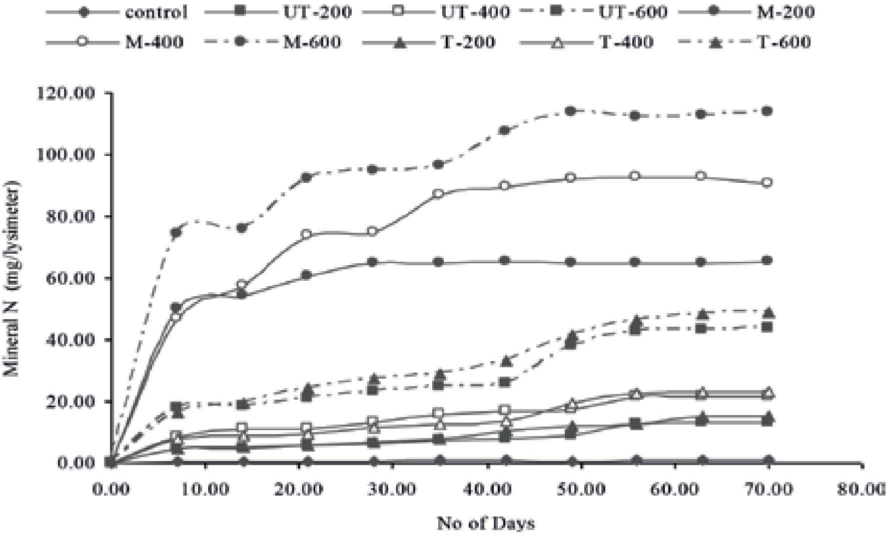


Figure 5. Mineral N leached from different treatments. UT, untreated compost; T, treated compost; M, mineral fertilizer.

different from each treatment. The amount of $NH_4^+ - N$ leached is 3.5%, and the remaining is the 96.5% $NO_3^- - N$ of the total mineral N leached. The same observation was found by the Kokkora [20] in his study of biowaste and onion waste.

The amount of mineral N leached from mineral fertilizer-amended sand is calculated as a percentage of the mineral fertilizer N applied. It is found to be 19.33% at the rate of 200 kg N / ha, 12.45% at the rate of 400 kg N/ha, and 10.34% at the rate of 600 kg N/ha. The amount of mineral N leached from both compost-amended sand was calculated as a percentage of the total compost N applied. The average of all treatments is 2.8% for untreated compost and 3.04% for the treated compost.

Kokkora [20] found that compost with low C/N ratio leached more than compost with the high C/N ratio. The same observation is found in the present study (**Figure 6**).

Compost application to poor quality and well-drained sandy soil is found capable of increasing tomato production by increasing the supply of nutrients. The soil properties and crop production are dependent on the application of compost rate and its C/N ratio. The residual mineral N in sandy soil is found to be low for all treatments except mineral fertilizer. The effect of depth is found not to be considerable in all lysimeter treatments. The residual total mineral N contents resulted from all depths of mineral fertilizers are found to be higher than from all compost-amended soil, while the compost application rate is not found to be different in total mineral N for both treated and untreated composts (**Figure 7**).

The treated compost (C/N, 11:40) appreciably increased the N uptake in the tomato plant. The increase in N uptake is due to the increase of compost application rate, which is in accordance with Iglesias-Jimenez and Alvarez [30], who used compost with a C/N ratio lower than 12.

The untreated compost has a poor response to the immobilization of N due to C/N ratio of 15:33. Sullivan et al.'s [31] results are in accordance with the present study.

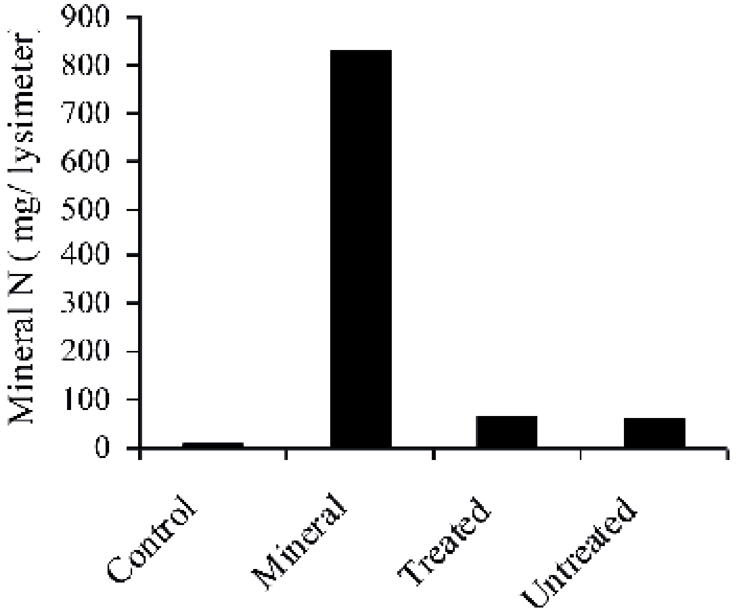


Figure 6. Comparison of total mineral N leached from mineral fertilizers and composts.

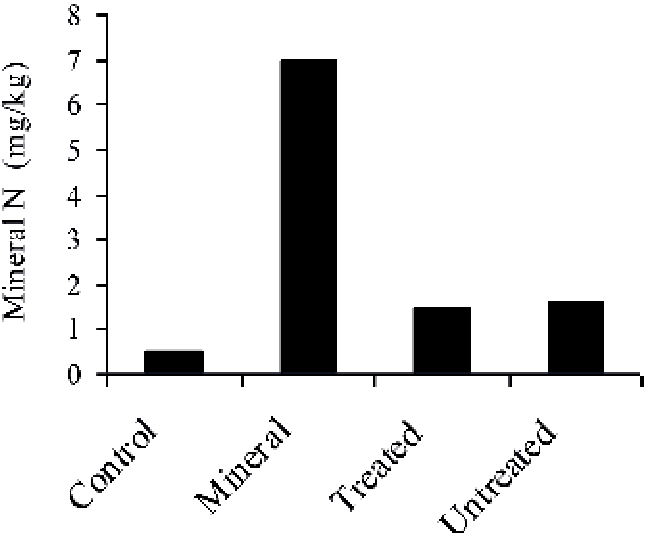


Figure 7. Uptake of mineral N by soil from mineral fertilizer and compost.

The study results show that about 16.1 and 19.66% in 600 kg N/ha is more than 200 kg N/ha. The N recovery in mineral fertilizers is very low in all treatments compared to both composts. This low recovery means that excessive quantity of N is leached during the experiment, which is shown in Figure 4.35.

4.2. Nitrogen uptake by tomato plant from mineral fertilizer and composts

4.2.1. Mineral potassium leaching

The effect of compost application is important in tomato crop uptake of K and P, but no considerable difference is found between treated and untreated composts. However, the treated compost shows higher K uptake than untreated compost. The rate of K uptake is directly correlated with the application rate of composts (**Figure 8**). The rise of compost application rate raised the quantity of K by plant. Abdelhamid et al. [32] reported that the addition of compost prepared with rice straw along with oilseed rape cake and poultry manure improves soil chemical and biological properties. The increased availability of nutrients in enriched compost enhanced root proliferation, which resulted in greater uptake of K by the crop (**Figure 9**).

The extractable K from sand is notably higher due to application of composts than the control. The K concentration is 83.6 and 82% more than the control in treated and untreated compost-amended soil.

Similar results of extractable K are also found by both treated and untreated composts. The release of nutrients is more in treated compost than in untreated compost due to low C/N ratio. The same observations are found by Nishanth and Biswas [33] in their study (**Figure 10**).

4.2.2. Phosphorous leaching

Incorporation of enriched compost (treated) in sandy soil resulted in notably higher total P uptake by tomato plant in all the growth stages than the control. A 99.6% increase in P uptake

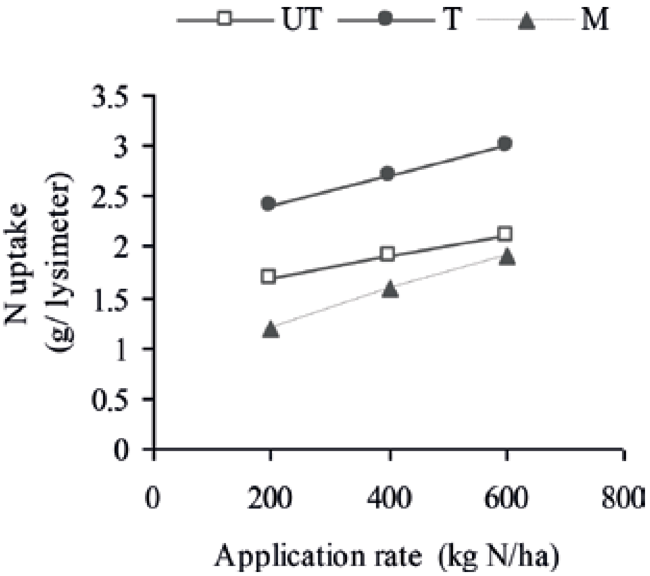


Figure 8. Nitrogen uptake by plant from mineral fertilizer and composts. UT, untreated compost; T, treated compost; M, mineral fertilizer.

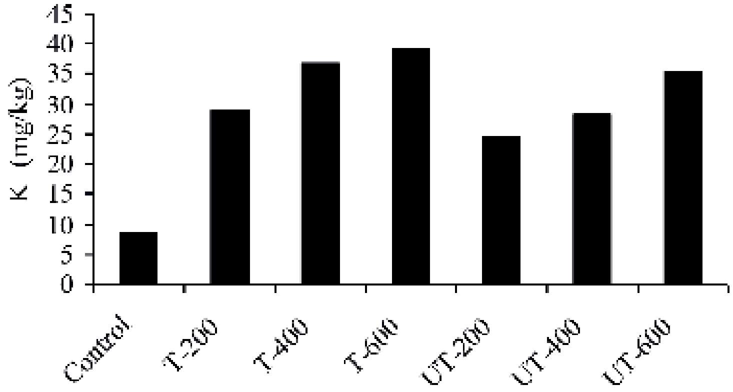


Figure 9. Comparison of K uptake by tomato plant from treated and untreated composts. T, treated compost; UT, untreated compost.

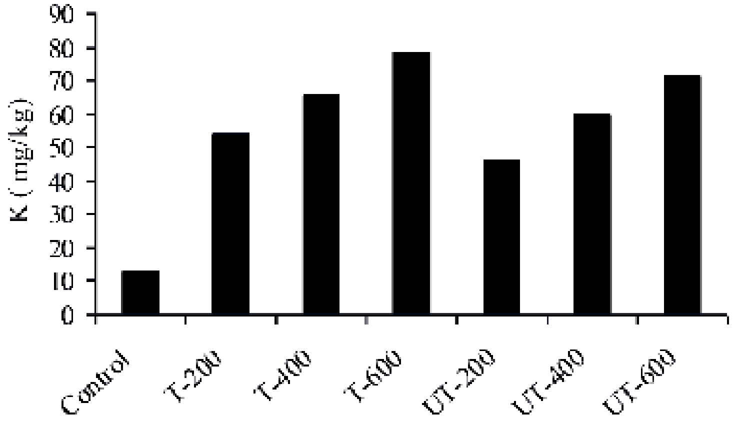


Figure 10. Concentration of K in sand after the harvest of tomato crop by the application of treated and untreated compost. C, control; T, treated compost; UT, untreated compost.

over control is also recorded for both composts. The P uptake increases substantially in both composts with increased application rate (**Figure 11**). The treated compost resulted in higher P uptake than the untreated compost. It was also reported by Nishanth Biswas [33] that phosphate-solubilizing microorganisms can mineralize organic and inorganic P into soluble forms in the root rhizosphere, and because the microorganisms render more P in solution form than that required for their growth and metabolism, the surplus is available for plants resulting in increasing P uptake.

The amount of available P in sand is greatly influenced by the addition of compost. The rate of addition of compost increased the concentration of P in both compost-amended sand. The analysis of sand at the end of the experiment shows that compost application had considerably higher available P in sand than the control. The treated compost sand retained greater P by

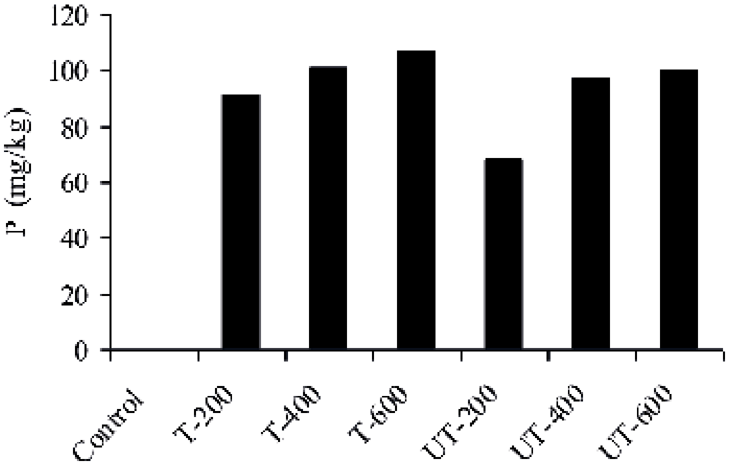


Figure 11. Comparison of P uptake by tomato plant from treated and untreated compost applications. T, treated compost; UT, untreated compost.

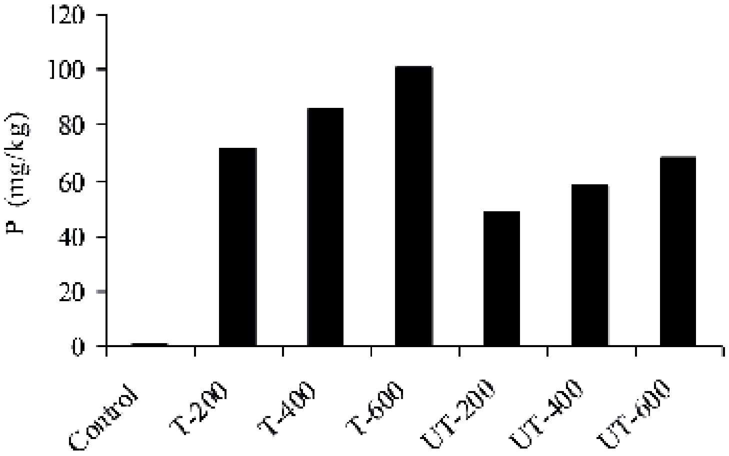


Figure 12. Concentration of P in sand after the harvest of tomato crop by the application of treated and untreated compost. T, treated compost; UT, untreated compost.

about 99.46% and the untreated by about 99% than the control, while the treated compost has 32.5% higher P in the sand than untreated compost-amended sand (**Figure 12**).

5. Pot study

The pot study is conducted to compare the efficiency of inorganic fertilizer and enriched composts with different percentages of inorganic nitrogen (urea) for improving the growth of tomato plants and to document their performance as soil amendments. The treated composts and inorganic fertilizers are mixed with loamy sandy soil in individual pots, which are applied at different rates.

The treated compost along with different percentages (20 and 40%) of chemical fertilizer (urea) is described for the agronomic and environmental effects of the compost in pot study of tomato plant.

5.1. Effect of treatments on physical characteristics of tomato plant

With regard to root length, the highest value was observed with the application of composts enriched with 40% N, (T_4) that is 32.97% greater than the control. It is found that the root length is significantly greater (25.58%) by the addition of full dose of N (110 kg N/ha) than the control and no significant difference is noted between the cases of T_1, T_2, and T_3 treatments to tomato plants. Root length recorded in case of T_4 is also significantly different compared to T_1.

The application of T_1 resulted in significantly greater (14.51, 50.26%) root dry weight than T_2 and control, respectively. The maximum plant root dry weight is observed by the application of T_4, which is more (54%) than the control (P and K only), and no difference in results between T_1, T_3, and T_4 is noted. There is also a significant difference between T_2 and T_3. A significant greater root dry weight of T_4 (21%) than T_2 was observed. The root dry weight recorded as a result of T_4 is greater than that obtained by control.

The maximum shoot dry weight is also observed by the application of T_3 which differs significantly from the control, T_1, T_2, and T_4. But it is higher in T_3 and T_4 than the full dose of the mineral N fertilizer (110 kg N/ha), whereas a difference in their weight between T_4 and T_2 is also present. T_1 is greater (31.45%) than the control. The leaching of N in the soil is greater in

Application rate (kg N/ha)	Compost/lysimeter (kg)	Total N (g)	K (g)	P (g)	C/N ratio
Treated compost					11.40
200	0.15	3.2	2.46	1.75	
400	0.30	6.4	4.92	3.51	
600	0.46	9.6	7.5	5.38	
Untreated compost					15.33
200	0.18	3.2	2.71	0.52	
400	0.35	6.4	5.28	1.01	
600	0.53	9.6	8.0	1.53	
Mineral fertilizer					
200	0.0069	3.2			
400	0.0139	6.4			
600	0.0208	9.6			

Table 4. Application rate of treated and untreated composts and mineral fertilizer.

the mineral N than in the compost combinations. The tomato plant needs not only the N but also all other nutrients (P and K), which affect the growth of the fruit (**Table 4**).

The pots treated with T_4 produced the maximum number of fruits, while the pots treated with T_1, T_2, and T_3 also give the maximum number of fruits compared to control (**Table 5**). The recital of the pots fertilized with T_4 is considerably healthier than fertilized with T_1. The average number of fruits per pot varied among the compost types (T_2–T_4) and mineral fertilizer (T_1) with an increase in order of $T_4 > T_3 > T_1 > T_2$. It is also noted that T_1 and T_3 do not show a significant difference between their results and are lower in values than T_4 but higher than the control.

All the composts (T_2–T_4) and mineral fertilizers (T_1) produce an acceptable degree of fruits, whose chemical composition depends upon the contribution of nutrients, which are supplemented to plants during their growth period. The application of composts, supplemented with 40% N (T_4), has a number of fruits significantly higher (36.90%) than the control. Similarly, T_2 is significantly lower (0.67%) than T_1. The weight of fresh fruit per plant is statistically similar between T_1 and T_3. The results reveal that the application of T_4 significantly increases the weight of fresh fruit up to average of 0.97% over T_1. Garcia-Gomez et al. [34] also found the same results in their study.

The compost type affected the tomato growth parameters such as stem height, stem girth, leaves per plant, number of branches per plant, and dry matter per plant. Atiyeh et al. [35] describe the same idea; better growth is proportional to the higher nutritional input by the vermicompost. The tomato plant needs other nutrients (P and K) for effective plant growth, which is in line with the report that okra gave an upbeat and healthier fruit yield due to the availability of P and K not only N [36].

Stem height is affected by the application of different ratios of compost and mineral fertilizer. Compost T_4 shows the superiority over T_2 and T_3 composts and also on control. This superiority up to 16.45, 9.6, and 3.9%, more in stem height over control, T_2 and T_3, respectively, is noted. T_1 is significantly higher (14.56%) in stem height of tomato plant than the control. Similarly, no significant difference is found between T_1 and T_3 and in between T_1 and T_4, whereas a significant difference is found between T_4 and T_2.

Treatments	Root length (cm)	Root dry weight (g/pot)	Shoot dry weight (g/pot)
T_1	34.12 b	15.02 c	104.07 c
T_2	32.95 b	12.84 b	101.13 b
T_3	33.71 b	14.74 c	113.79 e
T_4	37.88 c	16.26 c	109.76 d
Control	25.39 a	7.47 a	71.34 a

Values having same letters in column do not differ significantly at $P < 0.05$, according to Duncan's Multiple Range Test.

Table 5. Effect of treatments on root length, root dry weight, and shoot dry weight.

In the case of stem girth, a nonsignificant difference is observed between T_1, T_2, T_3, T_4, and control. This result is different from the pattern of other growth parameters decreased in the present study. T_4 in all growth showed the maximum result, whereas in stem girth, T_4 shows the average maximum but lower than T_3. Stem girth did not show a remarkable difference between T_3 and control. Togun et al. [37] also noted the same observation by the application of different composts on the tomato plant in plots (**Table 6**).

The maximum number of leaves per plant is recorded when enriched compost T_4 is supplemented and has a nonsignificant difference with full dose of N (T_1). All composts (T_2–T_4) and mineral fertilizer (T_1) improved the number of leaves significantly over control. It is also noted that there is no significant difference between T_2 and T_3 and the T_1 produced more leaves per plant than T_2 and T_3, while T_4 is more than T_3.

The rate of compost and enrichment significantly influenced the number of branches per plant but no significant influence by N rate (T_1) over T_3 and T_4. When compost is added with N addition, the maximum number of branches is not produced by the T_3 and T_4 compared to control, and T_1 may not have much more than the control.

Regarding the dry mass per plant, all treatments differed significantly compared to control. The highest rate of N addition (T_1) increased the dry mass per plant 39.92% compared to control. Statistically, similar results are obtained by the treatments T_1, T_2, and T_3. Enriched compost T_4 is higher than T_1, T_2, and T_3. The present study results were in line with Levy and Taylor [38] and Meunchang et al. [39] (**Table 7**).

Treatments	No. of fruit	Fresh fruit weight/pot (g)	Stem height (cm)	Stem girth (cm)
T_1	31.0 c	816.9 c	75.2 dc	2.16 NS
T_2	29.0 b	811.4 b	69.48 b	2.0
T_3	32.10 c	817.5 c	73.9 c	3.15
T_4	35.4 d	824.9 d	76.9 d	2.13
Control	26.5 a	520.5 a	64.26 a	1.57

Values having same letters in column do not differ significantly at $P < 0.05$, according to Duncan's Multiple Range Test.

Table 6. Effect of treatments on the number of fruit/pot, fresh fruit weight/pot, stem height, and stem girth.

Treatments	No. of leaves/plant	Branches/plant	DM/plant (g)
T_1	22.7 c	4.31 N.S	11.2 b
T_2	19.0 b	3.67	11.10 b
T_3	19 b	4.11	12.10 b
T_4	23 c	4.54	14.23 c
Control	14.0 a	3.42	7.4 a

Values having same letters in column do not differ significantly at $P < 0.05$, according to Duncan's Multiple Range Test.

Table 7. Effect of treatments on the number of leaves per plant, branches/plant, and DM/plant.

5.2. Effect of treatments on nutrient uptake in soil and plant

The addition of both composts and inorganic fertilizer has positive impacts on the growth of the tomato plant, and no negative effect is found throughout the study, whereas the growth rate is maximum in compost treatments compared to control and inorganic treatment. The same kind of observation is found in the study of the Martinez-Blanco et al. [40]. The tomato plant needs the N, P, and K in great amount for their growth. The maximum concentration of N is observed in plants growing in pure compost T_2, which is higher than T_1, T_4, and control. The T_1 treatment has N concentration greater than the control, whereas no significant difference is found between T_1 and T_4. T_3 and T_2 had N significantly higher in plant than T_1, but the N quantity is higher in soil in T_1, T_2, T_3, and T_4 than the control. The greater concentration of N in soil is due to leaching of N in the soil, and plant uptake of N is less in all treatments than T_2 and T_3 (**Tables 8** and **9**). T_2 is pure compost, and T_3 (compost enriched with 20% urea) releases the N and other nutrients slowly as compared to the inorganic N, which are more soluble and more leached, as already studied in the Lysimeter experiment that the N leaching is maximum and plant uptake is less in sandy soil. The N leaching or denitrification might have reduced in soil by mixing N-fertilizer with organic compost resulting in better utilization of N by plants. Some scientists described that the compost releases the nutrients slowly and reduced the loss of N.

The compost affects the physical and chemical properties of the soil and reduces the soil acidification due to the basic nature of the compost. In the present study, the addition of

Treatments	Nitrogen (g/plant)	Phosphate (g/plant)	Potassium (g/plant)
T_1	2.8 b	1.98 b	2.1 b
T_2	5.2 c	4.14 c	3.93 c
T_3	4.9 c	4.3 c	4.10 c
T_4	2.78 b	2.06 b	2.03 b
Control	0.90 a	0.25 a	0.32 a

Values having same letters in column do not differ significantly at $P < 0.05$, according to Duncan's Multiple Range Test.

Table 8. Effect of treatments on nutrient uptake by plant.

Treatments	Nitrogen (g/kg)	Phosphate (g/kg)	Potassium (g/kg)	O.M (%)
T_1	3.5 b	2.91b	4.59 b	8.68 b
T_2	5.8 c	4.74 c	7.53 c	13.11d
T_3	6.25 c	3.38 bc	5.09 b	11.5 dc
T_4	3.63 b	2.68 b	4.37 b	10.7 c
Control	0.37 a	0.38 a	1.12 a	5.36 a

Values having same letters in column do not differ significantly at $P < 0.05$, according to Duncan's Multiple Range Test.

Table 9. Effect of treatments on nutrient uptake by soil.

compost (T_2) shows maximum OM in soil. But T_2 and T_3 have great significant difference compared to control. The concentration of OM was greater in T_2 and T_3 than T_1 and T_4, whereas T_1 shows the variation with control in values because T_1 does not contain the compost, but the inorganic N is only added. OM increases with increasing compost application rate.

The application of compost improves the fertility of nutrients in depleted soil because compost increases the OM, soil porosity, water holding capacity, and nutrients contents [41]. With the addition of higher rates of compost, the quantity of C is increased, which ultimately increases the ratio of OM. The low level of soil organic matter may lead to reduced crop productivity, even when sufficient nutrients are present in inorganic fertilizers [42].The present study results are in line with Evanylo et al. [43] (**Table 9**).

Application of compost has a significant effect on P uptake in plants and on soil. The soils treated with T_2 and T_3 compost produce tomato plants with the maximum P uptake compared to the other enriched compost (T_4) and mineral fertilizer (T_1).

Similar observations are made for T_1, which is higher in P concentration than the control. The significant difference is found in P uptake by plant between compost T_1 and T_4 as compared to T_2 and T_3. Similarly, P concentration is also found to be greater in soil. With the increased application rate of compost, the quantity of P in soil is increased. The highest P in soil is present in compost T_2 and T_3, because the compost releases the nutrients in the soil slower than mineral fertilizers. The concentration of P in lysimeter is also studied and found that P in soil is higher than plant uptake. P in soil is higher than K because P makes the bonding with Ca, which is present in the compost. The present study results are strongly related with Mbarki et al. [44].

The same type of behavior is found in the case of K that the compost contains higher concentrations of K than mineral fertilizer. K is also present in higher amount in soil than plant, which is in accord with other scientists. The higher concentration of K is responsible for the higher growth of the plant.

Author details

Muhammad Khalid Iqbal

Address all correspondence to: drkhichi75@gmail.com

PCSIR Lahore, Pakistan

References

[1] JICA, (Japan International Cooperation Agency) and Pak-EPA (Pakistan Environmental Protection Agency). Guideline for Solid Waste Management. Pakistan: Pak-EPA; 2005

[2] Batool SA, Chaudhry N. Municipal solid waste management in Lahore city district, Pakistan. Waste Management. 2009;**29**:1971-1981

[3] Earle JFK, Chynoweth DP, Nordstedt RA. Anaerobic Bioconversion: Biogasification of Municipal Solid Waste. Florida Cooperative Extension Service, Institute of Food and Agricultural Science, University of Florida, Bulletin; 1995. p. 267

[4] Khan AM. Lahorites generating 6000 ton garbage daily. In: The Nation. 2010

[5] Lopes WS, Leite VD, Prasad S. Influence of inoculum on performance of anaerobic reactors for treating municipal solid waste. Bioresource Technology. 2004;**94**:261-266

[6] Agnew JM, Leonard JJ. Literature review—The physical properties of compost. Compost Science and Utilization. 2003;**11**:238-264

[7] Kulcu R, Yaldiz O. Determination of aeration rate and kinetics of composting some agricultural wastes. Bioresource Technology. 2004;**93**:49-57

[8] Jolanun B, Towprayoon S, Chiemchaisri C. Aeration improvement in fed batch composting of vegetable and fruit wastes. Environmental Progress. 2008;**27**:250-256

[9] Haug RT. The Practical Handbook of Compost Engineering. Boca Raton, Florida, USA: CRC Publishers Ltd.; 1993

[10] Richard TL, Hamelers HVM, Veeken A, Silva T. Moisture relationship in composting process. Compost Science and Utilization. 2002;**10**:286-302

[11] Castaldi P, Garau G, Melis P. Influence of compost from sea weeds on heavy metal dynamics in the soil-plant system. Fresenius Environmental Bulletin. 2004;**13**:1322-1328

[12] Castaldi P, Garau G, Melis P. Maturity assessment of compost from municipal solid waste through the study of enzyme activities and water-soluble fractions. Waste Management. 2008;**28**:534-540

[13] Kalamdhad AS, Pasha M, Kazmi AA. Stability evaluation of compost by respiration techniques in rotary drum composter. Resources, Conservation and Recycling. 2008;**52**: 829-834

[14] Brewer LJ, Sullivan DM. Maturity and stability evaluation of composted yard trimmings. Compost Science and Utilization. 2003;**11**:96-112

[15] ZmoraNahum SO, Markovitch O, Tarchitzky J, Chen Y. Dissolved organic carbon (DOC) as a parameter of compost maturity. Soil Biology and Biochemistry. 2005;**37**:2109-2116

[16] Gaur AC, Singh G. Role of integrated plant nutrient system in sustainable and environmentally sound agricultural development. In: RAPA Publication: 1993/13. Bangkok: FAO; 1993. pp. 110-130

[17] Amlinger F, Peyr S, Geszit J, Dreher P, Weinfurtner K, Nortcliff S. Beneficial Effects of Compost Application on Fertility and Productivity of Soil: A Literature Study. Vienna:

Federal Ministry for Agricultural and Forestry. Environment and Water Management; 2007. p. 235

[18] Tahir M, Arshad M, Naveed M, Zahir ZA, Shaharoona B, Ahmad R. Enrichment of recycled organic waste with N fertilizer and PGPR containing ACC-deaminase for improving growth and yield of tomato. Soil and Environment. 2006;**25**:105-112

[19] Flavel TC, Murphy DV. Carbon and nitrogen mineralization rates after application of organic amendments to soil. Journal of Environmental Quality. 2006;**35**:183-193

[20] Kokkora MI. Bio waste and vegetable waste compost application to agriculture [PhD thesis]. Greece: School of Applied Sciences, National Soil Resource Institute, Cranfield University; 2008

[21] Chaves B, DeNeve S, Hofman G, Boeckx P, Van Cleemput O. Nitrogen mineralization of vegetable root residues and green manures as related to their biochemical composition. European Journal of Agronomy. 2004;**21**:161-170

[22] Rogers BF, Krogmann U, Boyles LS. Nitrogen mineralization rates of soils amended with nontraditional organic wastes. Soil Science. 2001;**166**:353-363

[23] Calderon FJ, McCarty GW, VanKessel JS, Reeves JB III. Carbon and nitrogen dynamics during incubation of manured soil. Soil Science Society of America Journal. 2004;**68**: 1592-1599

[24] Naher UA, Hashem MA, Uddin MK, Ahmed M, Saleque MA. Carbon mineralization and carbon dioxide evolution rate of cow dung and poultry manure along with rice straw and lime under covered condition in the tropical environment. Pakistan Journal of Biological Sciences. 2004;**7**:155-158

[25] Stemmer M, Roth K, Kandeler E. Carbon mineralization and microbial activity in a field site trail used for ^{14}C turnover experiments over a period of 30 years. Biology and Fertility of Soils. 2000;**31**:294-302

[26] Pedra F, Polo A, Ribeiro A, Domingues H. Effect of municipal solid waste compost and sewage sludge on mineralization of soil organic matter. Soil Biology and Biochemistry. 2007;**39**:1375-1382

[27] Busby RR, Torbert HA, Gebhart DL. Carbon and nitrogen mineralization of non-composted and composted municipal solid waste in sandy soils. Soil Biology and Biochemistry. 2007;**39**:1277-1283

[28] Ahmad Z, Yamamoto S, Honna T. Leaching and phyto-availability of nitrogen, phosphorus and potassium from different bio-compost under chloride- and sulphate-dominated irrigation water. Journal of Environmental Quality. 2008;**37**:1288-1298

[29] Xiaoxin L, Chunsheng H, Delgado JA, Zhang Y, Ouyang Z. Increased nitrogen use efficiencies as a key mitigation alternative to reduce nitrate leaching in north China plain. Agriculture Water Management. 2007;**98**:137-147

[30] Iglesias-Jimenez E, Alvarez CE. Apparent availability of nitrogen in composted municipal refuse. Biology and Fertility of Soils. 1993;**16**:313-318

[31] Sullivan DM, Bary AL, Thomas DR, Fransen SC, Cogger CG. Food waste compost effects on fertilizer nitrogen efficiency, available nitrogen, and tall fescue yield. Soil Science American Journal. 2002;**66**:154-161

[32] Abdelhamid MT, Horiuchia T, Oba S. Composing of rice straw with oilseed rape cake and poultry manure and its effects on faba bean (*Vicia faba L*) growth and soil properties. Bioresource Technology. 2004;**93**:183-189

[33] Nishanth D, Biswas DR. Kinetics of phosphorus and potassium release from rock phosphate and waste mica enriched compost and their effect on yield and nutrient uptake by wheat (*Triticum aestivum*). Bioresource Technology. 2008;**99**:3342-3353

[34] Garcia-Gomez A, Bernal MP, Roig A. Growth of ornamental plants in two composts prepared from agro industrial wastes. Bioresource Technology. 2002;**83**:81-87

[35] Atiyeh RM, Edwards CA, Subler S, Metzger JD. Pigmanure vermicompost as a component of a horticultural bedding plant medium: effect on physicochemical properties and plant growth. Bioresource Technology. 2001;**78**:11-20

[36] Togun AO, Akanbi WB, Dris R. Influence of compost and nitrogen fertilizer on growth, nutrient uptake and fruit yield of tomato (*Lycoersicon esculentum*). Crop Research. 2003;**26**: 98-105

[37] Togun AO, Akanbi WB, Adediran JA. Growth, nutrient uptake and yield of tomato in response to different plant residue compost. Food Agriculture and Environment. 2004;**2**: 310-316

[38] Levy JS, Taylor BR. Effects of pulp mill solids and three composts on early growth of tomatoes. Bioresource Technology. 2003;**89**:297-305

[39] Meunchang S, Panichsakpatana S, Weaver RW. Tomato growth in soil amended with sugar mill by-products compost. Plant and Soil. 2006;**280**:171-176

[40] Martinez-Blanco J, Munoz P, Anton A, Rieradevall J. Life cycle assessment of the use of compost from municipal organic waste for fertilization of tomato crops. Resources, Conservation and Recycling. 2009;**53**:340-351

[41] Broken W, Muhs A, Meese F. Changes in microbial and soil properties following compost treatment of degrade temperate forest soils. Soil Biology and Biochemistry. 2002;**34**: 403-412

[42] Aref S, Wander MM. Long term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments. In: Sparks DL, editor. Advances in Agronomy. Vol. 62. San Diego, CA: Academic Press; 1997. pp. 153-197

[43] Evanylo G, Sherony C, Spargo J, Starner D, Brosius M, Haering K. Soil and water environmental effects of fertilizer-, manure-, and compost-based fertility practices in an organic vegetable cropping system. Agricultural Ecosystem and Environment. 2008;**127**:50-58

[44] Mbarki S, Labidi N, Mahmoudi H, Jedidi N, Abdelly C. Contrasting effects of municipal compost on alfalfa growth in clay and sandy soils: N, P, K, content and heavy metals toxicity. Bioresource Technology. 2008;**99**:6745-6750

Chapter 4

Relationship of Agronomic Practices to Soil Nitrogen Dynamics

Congming Zou, Robert C Pearce, John H Grove,
Yan Li, Xiaodong Hu, Jie Chen, Junying Li and
Yan Jin

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.77229

Abstract

Soil nitrogen (N) dynamics are a major concern of soil nutrient status and its supply for crop uptake and growth. They are a central focus of agroecosystems. Agronomic practices play a central role in regulating soil N dynamics; the methodologies for investigating soil N mineralization are diverse, but debatable. This chapter discusses the pros and cons of different methods for measuring soil N mineralization, including laboratory, *in-situ,* and modeling procedures. This chapter illustrates the influence of agronomic practices on root architecture that potentially affects crop nutrient uptake. The relationship between agronomic practices and soil N dynamics were fully discussed, which can substantially inform soil fertility and crop nutrition management.

Keywords: agronomic management, nitrogen dynamics, methodology,
N mineralization, crop N uptake

1. Agronomic practices reflect the history of managing soil N dynamics

Nitrogen (N) is the most important plant mineral nutrient [1]. It was first discovered in the late eighteenth century, and N's role in improving crop production was widely recognized by the mid-nineteenth century [2]. Long before these discoveries, ancient farmers often unknowingly employed agronomic practices that resulted in managing soil N availability, thereby helping to ensure the human food supply and nutrition. There were two major sources of N

IntechOpen

in agroecosystems before synthetic N fertilizers—soil N and legume-based biological N fixation. Ancient farmers constructively developed tillage schemes and rotated nonlegume and legume crops to manage both N sources for millennia. Because the appearance of commercial synthetic N fertilizers in the early twentieth century brought significant changes to traditional agronomic practices, the history of agronomic practices from the perspective of managing soil and biologically fixed N dynamics would seem to be a fruitful review.

Plow tillage is a form of soil N management. Much of the soil N is in complex organic forms, such as decomposing plant and animal residues [3]. Most plants can only take up inorganic N (NH_4^+ and NO_3^-) [4] although the basic amino acids are absorbed by some plant species (e.g., *Picea abies*) [5]. Inorganic N and basic amino acids in soil are mainly derived from N mineralization processes. Tillage practices can promote mineralization because disturbance exposes naturally protected (i.e., aggregate-protected) soil organic matter (SOM) to microbes, enhancing microbial activity and N mineralization (Tisdall and Oades [6]). Therefore, plow tillage was considered a great agricultural advance and, from the archeological evidence, has had a very long history. Foot plows [7] also called "digging sticks" are shown in Egyptian tomb paintings [8]. A wooden model of oxen and plow was found in an Egyptian tomb dating from 2000 BCE [8]. In Asia, one of the oldest existing Chinese books titled "Lü Shi Chun Qiu" (compiled in 239 BCE) or "The Annals of Lu Buwei" [9] demonstrated the details of when and how to till according to soil and weather conditions and served as an early example of a practical farming guide.

Rotation can also be a tool to manage soil N through legume bio-fixation of N, depending on the crop species. Monocropping, especially with nonlegumes and heavy-nutrient-using crops (e.g., tobacco and corn) can deplete soil N [10]. Rotation practices, even simple fallow, help to restore soil N [11]. This practice was evident in early Roman times. One of the Rome's greatest poets, Virgil (70–19 BCE), wrote in his poem Georgics (from the Greek, "On Working the Earth") "For the field is drained by flax-harvest and wheat-harvest, drained by the slumber-steeped poppy of Lethe, but yet rotation lightens the labour." This emphasizes that fallow was necessary to rotate with those crops requiring more nutrients. On the other hand, rotations that include a legume crop can bring biological N fixation into agricultural production systems. Although ancient farmers knew nothing of the biological N fixation process, and nothing about the importance of mineral N to plant growth, they intentionally included legume crops into crop sequences. This was evident in the Pliny the Elder's (23–79 CE) book on natural history that mentioned several legume successions as alternatives to conditions that forbade fallowing [12].

Synthetic fertilizer N application in agricultural production has a relatively short history compared to tillage and rotation practices because knowledge regarding N in plant nutrition and N synthesis techniques is recent. In 1836, Jean-Baptiste Boussingault (1801–1887) investigated manure, crop rotation, and N sources and for the first time concluded that N was a major component of plants and that the nutritional value of fertilizer was proportional to its N content [13]. However, ammonia could not be easily synthesized from constituent elements until 1908, when the Haber-Bosch process was developed. After that, synthetic fertilizer N started to play a greater role in agricultural production, helping to improve global food security [14].

2. Influence of synthetic fertilizer N on traditional agronomic practices

The appearance of synthetic fertilizer N brought a huge increase in the global food supply. Erisman et al. [14] estimated that around 50% of the world population's food requirements are currently met by using synthetic fertilizer N. However, synthetic fertilizer N fundamentally disturbed the soil N cycling balance in agro-ecosystems and brought significant changes to traditional agronomic practices. Our unpublished data (Zou et al. [91]) show that synthetic fertilizer N can promote or prime soil N mineralization depending on the indigenous SOM level and the amount of synthetic N.

Synthetic fertilizer N played a role in developing modern no-tillage farming. Agriculture derives numerous benefits from no-tillage, including fuel and labor savings, increased soil C stocks and erosion resistance. But few people recognized the fertilizer N contribution to no-tillage until early Kentucky no-tillage × N fertility trials revealed its importance [15]. No-tillage without N fertilizer significantly lowered yield compared to conventional tillage without N fertilizer. However, no-tillage with N fertilizer produced yields comparable to those of conventional tillage with fertilizer N. From this perspective, one can speculate that added fertilizer N compensated for reduced soil N mineralization in no-tillage. Other factors, including herbicide and equipment development, also made no-tillage farming feasible in Kentucky and the rest of the Southeast and mid-Atlantic states in the USA, beginning in the 1960s [16]. At the time, the move away from tillage was viewed with much skepticism, but eventually no-tillage was accepted as a revolution in farming. By 2009, approximately 36% of U.S. cropland, planted to eight major crops, was in no-tillage soil management [17].

Although ancient farmers knew nothing of biological N fixation, legume crops had been an important cropping system component worldwide before synthetic N became available [12]. However, crop rotation was discouraged during the Green Revolution, partially because pest control benefits from crop rotation could be replaced by chemical crop protectants [18]. Also, the N credits from biological N fixation could be easily replaced by synthetic fertilizer N. However, soon after the height of the Green Revolution, many studies reported that no amount of chemical fertilizer or pesticide could fully compensate for crop rotation benefits [19]. Rotation systems then came back into fashion. Currently, 80% of all corn, soybean, and wheat planted acres in the United States are in rotation.

3. Systematic understanding of agronomic practices and soil N dynamics

This brief review of agricultural history shows that managing N dynamics is one of the central reasons farmers developed and implemented specific agronomic practices. Furthermore, in the last few decades, new knowledge indicates how transient N can have negative impacts on global environments and human health [20]. A systematic understanding of "How does soil and crop sequence management influence nitrogen dynamics?" will significantly influence agronomic practice development but also has global meaning for the quality of human life. The aim of optimal agricultural N management is to enhance net N mineralization at times when crops need N, to synchronize soil N mineralization with crop N uptake, and to minimize N loss. To systematically understand this topic, three sequential steps need clarification:

1. How do agronomic practices affect soil organic matter pools?
2. How do soil organic matter pools contribute to soil N availability?
3. How do agronomic practices influence crop N uptake capacity?

Soil organic and crop residue N pools provide the organic N for N mineralization. This microbial process, primarily heterotrophic, also requires soil organic C (SOC) as an energy source [21, 22]. Thus, to understand how soil and crop management affect mineralized soil N, it is critical to first evaluate whether and how tillage, rotation, and fertilizer N application affect SOC and N sequestration. Soil organic matter sequestration has been reported to be linked with soil aggregate formation. The dominant concept that explains SOC and N sequestration is based on the aggregation-SOM model [23]. Zou et al. [24] reported that using NT and/or rotation practices in burley tobacco production maintained desirable soil physical and chemical properties by macroaggregate stabilization, which led to conserving SOC and TSN stocks [24]. The basic idea is that soil organic matter functions as a nucleus/binding agent for aggregate formation. Aggregates are important reservoirs of SOC and N that are protected from microbial access and less subject to physical, chemical, microbial, and enzymatic degradation (Six et al. [25]).

Appropriate and precise estimation of soil N mineralization has been a challenge since the early 1900s [26]. Temporal and spatial variability are large because this process is determined by internal soil factors (e.g., SOM level, labile C and N pools, soil microbial community) and external environment factors (e.g., temperature, precipitation and aeration) [27–29]. Agronomic management, such as plant species and N fertilizer application, may also affect N mineralization [30, 31]. With current technologies, it is impossible to predict N mineralization by taking these factors into consideration simultaneously. Instead of being a measure of available N supply, N mineralization estimates by current methods should be considered an index of N availability [32].

Isotopic tracers and incubation methods are the two main approaches used to estimate N mineralization. The isotopic tracer method can measure gross N mineralization, but isotope methods are expensive and can also have methodological problems with mineralization rate estimates and other assumption violations [33]. Although incubation methods can only measure net soil N mineralization (net soil N mineralization = gross N mineralization–N immobilization), incubation can fairly estimate the available N pool, which has a practical value for efficient N management in agroecosystems. Therefore, long-term biological mineralization has been considered the most suitable soil N availability index and is often used to validate other indices derived from more rapid chemical or biological assays [4, 34]. There are, however, many variations to incubation methods, including environment, sample pretreatment, and incubation time, and each variation has advantages and disadvantages. To use incubation to meet research objectives, assumptions, benefits, and liabilities of each variation should be considered.

An experimentally derived N availability index might not necessarily reflect total crop N uptake. Besides the amount of available soil N, crop N accumulation also depends on N uptake capacity. Crop N uptake capacity might be determined by either/both genetic and environmental controls. Genetics can control crop growth rate and biomass accumulation, which would result in different N demands at different growth stages [35]. Crop species have different root architectures, mostly controlled by genetics [36]. However, roots, the dominant nutrient uptake organ directly exposed to the soil, interact with a wide array of soil physical, chemical, and biological factors that vary in time and space [37]. To understand the impact of agronomic management practices on crop N uptake or yield, both soil N availability and root architecture must be considered.

For this review, literature concerning the effect of agronomic practices on crop N uptake or yield is reviewed in three sequential steps. First, the mechanism and effect of agronomic practices on SOC and STN sequestration are described. Second, the pros and cons of long-term incubation methodologies for estimating N mineralization are described. Finally, the potential effects of soil and crop management on root architecture are discussed.

4. Mechanisms and effect of agronomic practices on soil C and N sequestration

The link between SOC and total soil N (STN) decomposition and stabilization and soil aggregate dynamics has been developed, recognized, and intensively studied since the 1900s [23]. Soil organic C and N dynamics are important to agricultural production because these affect soil nutrient cycling and plant productivity [38]. The C and N dynamics are also important to the environment because they can affect greenhouse gas emissions and water quality [39, 40]. These processes happen in a heterogeneous soil matrix and have multiple interactions with soil biota [23]. The task of elucidation is complex. Aggregate-SOM models can explain some of these complexities. Aggregates not only physically protect SOC and SON, but also influence soil microbe community structure [41], limit oxygen diffusion [42], regulate water flow [43], determine nutrient adsorption and desorption [44, 45], and reduce surface runoff and erosion [46]. All these processes have fundamental effects on soil C and N sequestration and stabilization.

More current studies to understand the impact of agronomic practices on soil C and N sequestration have been based on the aggregate hierarchy concept proposed and developed by Tisdall and Oades [47, 48]. To apply the theoretical aggregate-SOM models, the first consideration is the physical separation of soil into different aggregate size classes. Two main methods to separate soil aggregates are widely used by researchers: dry and wet sieving [49]. The disruption of aggregates is mainly due to slaking and microcracking when the soil is initially dry. Dry sieving of air-dried samples is used to characterize the aggregate size distribution with minimum destruction. Wet sieving is used to simulate microcracking and slaking [50]. Water-stable aggregate stability from wet sieving procedures was reported to be closely correlated with SOM stabilization because SOM can act as a transient binding agent (Tisdall and Oades [6]) and has served as an effective early indicator of soil C change in numerous studies (e.g., [51]). The wet sieving procedure has been frequently used to evaluate the agronomic practice effects on both SOM sequestration and soil structural stability [52, 53]. In the wet sieving procedure, sample pretreatment is important [46]. The rewetting pretreatments for soils can cause different results when comparing soils and management history treatments [46]. Cambardella and Elliott [54] showed that capillary-wetted soils retained more macroaggregates (>250 μm) than slaked soils. Bissonnais [46] demonstrated that the different aggregate breakdown methods and frequency of crusting soil samples can dramatically affect soil aggregate stability within the same soil management system. Adopting minimum breakdown aggregates in the sieving procedure keeps comparisons between treatments relative to the natural field conditions.

The effect of agronomic practices (including tillage, rotation, and fertilizer N application) on SOC and STN, according to aggregate-SOM models, has been studied intensively in grass and grain crop production systems [55–59], but not in leaf harvest crop production systems. In these studies, no-tillage increased or maintained SOC and STN compared to conventional tillage. With aggregate separation, conventional tillage can increase large aggregate turnover rate, diminishing the macroaggregate proportion and SOC and STN concentrations [54]. In contrast, no-tillage increases macroaggregates and SOC and STN accumulation.

Most studies show that rotation increases SOC and STN sequestration, compared to monocropping [57, 60]. Crops in rotation schemes have different impacts on SOM stabilization, depending on the quantity and quality of crop residues. Wright and Hons [61] found that crop residue production was similar among wheat, sorghum, and soybean fields, but the wheat field had significantly higher SOC and STN in surface soil than the other two fields, which indicates that the higher C:N ratio in wheat residue can play a role in SOM stabilization. Kong et al. [57] reported that the quantity of crop residue/carbon production had a linear relationship with SOC sequestration in sustainable cropping systems. Therefore, when evaluating crop rotation schemes on SOM sequestration, examining crop residue quantity and quality is important.

Studies on the effect of fertilizer N application on SOM sequestration have produced the most controversial results. Some studies report that fertilizer N application increases SOM because higher fertilizer N input causes more crop residue to be returned to soil [56]. Mulvaney et al. [62] reported that fertilizer N application decreased soil N in the long-term Morrow plot study and argued that synthetic N application enhanced soil microbial decomposition due to the decreasing C:N ratio. Others have found no effect of N fertilizer application on SOM sequestration [63, 64].

5. Methodologies of soil N mineralization measurement

There are many different methods available for long-term aerobic incubation, in laboratory and field, depending on soil sample pretreatment and other incubation conditions [65].

5.1. Laboratory incubation methods

Most aerobic laboratory incubation methods have common features, including maintenance of optimal soil water status (typically with 60% water-filled pore space), constant temperature (commonly 25, 30, or 35°C), and periodic sampling to estimate N mineralization rates [34]. Although there have been several standardized protocols (e.g., [26, 66]), there is significant variation in aerobic incubation details.

5.1.1. Leaching versus non-leaching processes

In early studies with long-term N mineralization incubation, samples were usually incubated continuously in a container without periodic leaching of the accumulated inorganic N. The merit of this method was convenience, but there could be cumulative inhibitory effects, such as pH decline, on mineralization during the incubation [67]. Thus, nonleaching approaches were not recommended for long incubation periods. Stanford and Hanway [68] proposed a periodic leaching approach during incubation. Briefly, 0.01 M $CaCl_2$ was used to leach mineralized N from the sample at the end of each incubation period [69]. The merit of leaching would be avoidance of accumulation of unspecified toxins. While being a time-consuming and apparatus-requiring process, there was also an additional technical concern with potential leaching of soluble organic N during the incubation [65, 70].

5.1.2. Excluded crop residue versus included crop residue

Crop residue can contribute to the soil inorganic N pool by N mineralization or immobilization, depending on the residue C:N ratio. Most laboratory incubation methods exclude such contributions by discarding visible pieces of residue in the pretreatment sieving process [33]. Some laboratory methods cut entrained residues into pieces that are mixed with soil for incubation [71]. Certainly, discarding large portions of residue might influence estimates of the N credit from the previous crop because soil fertility guidelines usually recommend a different fertilizer N rate for the current crop that depends on the previous crop.

5.1.3. Field-moist soil sample versus dried and/or ground soil sample

Using dried and/or ground soil is convenient for a large amount of soil samples that require time to process or for cooperative projects where soil samples come from multiple locations at different times. However, several days are needed to rewet soil for preincubation, which also causes an N mineralization flush during the first weeks of incubation. Numerous studies report that sample sieving and drying-rewetting causes rapid microbial death and enhances microbial respiration and activity, producing an N mineralization bloom [72–75]. Using field-moist samples might cause less physical damage during preincubation protocols and cause a better transition from field to lab conditions than dried and/or ground soil samples. However, field-moist soil samples intended for incubation need to be gently crushed through the sieve (usually 2–4 mm) immediately after sample collection.

5.1.4. Homogenized soil versus undisturbed soil cores

Most laboratory incubation methods utilize a homogenized sample created by sieving. However, there are reports that homogenized samples do not well represent the effects of field soil tillage. Laboratory soil should have a physical structure similar to that of the field environment the sample represents, but sieving artificially "tills" soil from undisturbed/no-tillage environments. This can expose aggregate-protected SOM and enhance the microbial activity, over-estimating the N mineralization. Undisturbed cores may be a better option for laboratory incubations intended to differentiate the impact of tillage on N mineralization [76].

5.1.5. Constant temperature versus variable temperature

Most laboratory incubation methods use a constant temperature, which does not reflect temperature fluctuation in field conditions. Carpenter-Boggs et al. [77] proposed a variable temperature method for laboratory incubation in which soil samples are incubated in a variable temperature incubator (VTI) that mimicked field soil temperatures under a growing corn canopy. They reported that the VTI technique provided a lower sample variance and a smaller initial flush of N mineralization than constant incubation temperature (35°C).

5.2. Field (*in-situ*) incubation methods

Due to the uncertainty about the extrapolation of laboratory N mineralization values in the field, estimating N mineralization from SOM and crop residues in field conditions would be a compelling research topic for investigators because more efficient N fertilization practices could be hastened if a reliable *in-situ* N mineralization method was developed. So far, there have been three dominant *in-situ* research techniques: buried polyethylene bags, covered cylinders, or resin-trap core methods.

5.2.1. Buried polyethylene bag method

The buried polyethylene bag method for *in-situ* N mineralization was proposed by Eno [78]. The main driving force behind this technical development was the realization that soil temperature variance results in considerable changes in the soil NO_3^- production rate. In that preliminary laboratory study, soil in sealed polyethylene bags had an equal nitrification rate compared to soil contained in ventilated bottles. Polyethylene is permeable to oxygen and carbon dioxide, but no NO_3^- diffused through the polyethylene bag during the 24-week incubation period. The preliminary results and polyethylene characteristics mean this technique has the potential to estimate aerobic *in-situ* soil N mineralization.

Although this technique mimics field temperature conditions at a low cost, the technique does not reflect transient field moisture conditions [79]. Elevated NO_3^- and carbon dioxide concentrations inside the bags may promote denitrification [80]. Physical damage to the bags by insects or plant roots may result in loss of mineralized N into the field soil via diffusion and mass flow [77, 78]. Another major limitation of this technique is the inevitable disturbance of soil, which does not allow a valid comparison of tillage effects on N mineralization in field conditions [76].

5.2.2. *Covered cylinder method*

The covered cylinder method was developed as a more durable alternative to the buried bag. This technique allows incubation of intact soil cores [81]. Covered cylinders are usually constructed from PVC or metal pipes that are capped to exclude rainfall, which is also assumed to stop inorganic N leaching [82]. Although the tubes are open at the bottom, aeration is less than that in field soil, which might result in higher denitrification potential. Modifications such as using gas permeable caps or perforations in the tube sidewall were often added to promote air exchange and reduce denitrification potential [83, 84]. However, sidewall aeration holes could potentially allow mineralized N loss. Water may enter the soil tubes through aeration holes, causing N leaching at the bottom of the soil column. Furthermore, plant roots may potentially grow into the soil column via aeration holes or the open bottom, absorbing mineralized soil from the tubes. Another major limitation of this technique is that the soil in the tube usually has a lower soil moisture content than the surrounding field [79].

The basic principle of the covered cylinder method was to limit N leaching by sheltering incubating soil from precipitation. Based on the same principle, there was another *in-situ* method called the “rain shelter” [76, 85], which simply used a shelter over the sampled area to prevent leaching. Except for considerations regarding the quality and durability of the rain shelter and surface water run-on during intense rainfall, the major drawback of this technique is a lack of ability to reflect field soil moisture fluctuations.

5.2.3. *Resin-trap soil core method*

Buried polyethylene bags and covered cylinder methods can capture variation in field temperature, while failing to reflect moisture and aeration conditions, which are reported to play a large role in soil N mineralization [28]. An alternative *in-situ* method was proposed that employs ion exchange resins to capture mineralized N leaching from undisturbed soil cylinders [86, 87]. The major modification of this technique is an open cylinder top, which allows precipitation and air to freely enter the intact soil column, and a resin trap at the bottom to capture inorganic N that might otherwise leach from the tube. There are some concerns about whether the soil tube causes abiotic differences between soil in the tube and the surrounding field soil. Wienhold et al. [88] reported that soil inside the cylinders was slightly wetter and warmer than adjacent soil, which likely increases soil N mineralization. They pointed out that the magnitude of change in soil N mineralization was likely much less than the normally observed field core-to-core variation. This method was found to better track true field conditions [79] and has the potential to become a standard procedure [89].

The drawback with intact cores and resin bags is a large resource demand. This technique requires preliminary studies to ensure leached ions are efficiently trapped under field conditions. Resin duality, adsorption capacity, and bypass flow are all factors that can potentially influence resin effectiveness in capturing leached N. The extraction of adsorbed N from the resin is also time-consuming. Kolberg et al. [87] reported that five extractions with KCl were required to completely release adsorbed N.

5.2.4. Other modifications to in-situ incubation methods

Except for the major design developments mentioned above, some minor modifications to *in-situ* incubation methods have been suggested. Hatch et al. [90] proposed a method to combine the soil core with acetylene inhibition, which would limit N loss by nitrification due to uncontrolled soil *in-situ* incubation conditions. The big concern with this modification is that the tube must be sealed at the top, causing a loss in practical application to the field environment if rainfall is a concern. Given consideration on different drainage characteristics in resin-trap soil cores relative to the surrounding soil, Hanselman et al. [79] developed a "new" type of resin-trap soil core method in which resin is mixed with soil to create an artificial uniform soil column. This method is impractical when undisturbed soil structure is a research concern, as in a comparison of conventional and conservation tillage [76].

5.3. Method selection

As discussed above, each method, including laboratory and *in-situ* methods, has unique assumptions, advantages, and disadvantages. There is no standard method that will work for every situation. The selection of method depends on the nature of the study, available resources, and site-specific factors. Although laboratory methods might not reflect natural field conditions, they can provide reasonable relative values to estimate differences due to soil type and certain management practices. Zou et al. [91] reported that discarding plant residue in the laboratory incubation method neglects the potential effect of plant residue on soil N mineralization. The primary merit to field incubation is a more practical estimation of N mineralization, which might be more useful in management decision making. However, the substantial time and apparatus requirement for the *in-situ* incubation methods must be considered. Zou et al. [92] reported that soil C and N fractions contribute variably to predict soil N mineralization in different rotation systems, but SOC (which can be calculated from soil organic matter, a common index in the routine test package of many soil testing laboratories) was the best overall NSNM predictor in their study. The principle is that both biotic and abiotic factors control the soil N mineralization process. Knowing the advantage and disadvantage of each method can help the investigator choose the best method while reducing misinterpretation.

6. The influence of agronomic practices on root architecture

Plant roots are a fundamental component of terrestrial ecosystems and function to maintain nutrient and water supply to the plant [92]. Although root system architecture is controlled mainly by genetic factors [93], plant root systems exhibit high developmental plasticity. This plasticity is possible because root development results from continuous propagation of new meristems. In a heterogeneous soil matrix, a wide array of physical, chemical, and biological factors can affect the initiation and activity of root meristems [37]. Previous studies have reported that certain crop root traits enhance productivity in resource-limited environments due to improved nutrient and water scavenging abilities [94–96]. Agronomic practices can influence crop nutrient uptake capacity by affecting the root growth environment.

Tillage affects root growth mainly by changing soil structure, strength, and penetration resistance. Any particular root increases its length through primary growth when cells of the meristem divide, elongate, and push the root tip forward through surrounding materials. Turgor pressure in the elongating cells is the driving force and must be sufficient to overcome cell wall constraints and other additional constraints imposed by the surrounding environment [97]. Compared to conventional plow tillage, numerous studies on grain crops report that no-tillage increases mechanical impedance, which can result in reduced root length density, root surface density, and lower biomass production [98–100]. Similar results were found in a no-tillage burley tobacco study [91, 101]. Furthermore, greater mechanical impedance with no-tillage not only restricts root growth but also changes root morphology, restricting main root axis elongation, stimulating lateral root branching and root thickening [102, 103].

Nutrient supply and distribution (or fertilizer application) can affect root system architecture mainly by signaling [104, 105]. Typically, roots proliferate in volumes where nutrients are most concentrated [106]. However, the mechanisms of plant root response to the different nutrient elements might be controlled by different pathways and signals [107–110].

There have been few studies on the effect of crop rotation on plant root architecture. Given the basic factors controlling root development, the hypothesis is crop rotation may differentially influence root architecture compared to monocropping systems, if rotated with residue-rich or deep-rooted crops that can increase SOM levels and soil structure. In this case, rotation affects root proliferation by changing soil structure in a manner similar to that observed with no-tillage. If rotation involves legumes, more N nutrition is provided than found with monocropping. In this case, rotation could affect root architecture by changing soil nutrient supply in a manner similar to that found with fertilizer application.

The effects of agronomic practices on crop N uptake not only affect SOM sequestration and soil N mineralization but also alter the soil environment for plant root proliferation. Similarly, in a paper titled “A New Worldview of Soils” [111], soil productivity is broadly defined as the soil’s unique ability to supply water, nutrients, air, and heat, among other life-sustaining resources, adjusting that supply to the demands of plants and microbes. Soil resources fall into two main components: (a) nutrients and moisture and (b) an environment suited for root growth and microbial activity.

7. Conclusion

Agronomic practices reflect agriculture’s N management history. Current agronomic practices have two major responsibilities: (1) promote global food production and (2) maintain the agroecosystem environment. This review shows that soil N dynamics have the potential to provide a framework to understand how agronomic practices connect these two responsibilities. Systematically understanding N cycling in the context of a suite of soil and crop management practices provides a foundation to understand, develop, evaluate, and reshape those agronomic practices.

Acknowledgements

This work publication was supported in part by the National Natural Science Foundation of China Grant (41601330), and the Yunnan Applied Basic Research Project (2017FB074), and the Yunnan Provincial Tobacco Monopoly Bureau Grants (2016YN28,2017YN06,2017YN09). Authors thank Dr. Mark S Coyne for offering the helpful advice and countless reviews on this manuscript.

Author details

Congming Zou[1,2], Robert C Pearce[2], John H Grove[2], Yan Li[1], Xiaodong Hu[1], Jie Chen[1], Junying Li[1]* and Yan Jin[1]*

*Address all correspondence to: zoucongmingzcm@163.com and jinyan2017ziran@163.com

1 Yunnan Academy of Tobacco Agricultural Sciences, Kunming, China

2 Department of Plant and Soil Sciences, University of Kentucky, Lexington, Kentucky USA

References

[1] Epstein E. Mineral Nutrition of Plants: Principles and Perspectives. Sunderland (Massachusetts): Sinauer Associates; 1972. DOI: 10.2307/2484208

[2] Galloway JN, Cowling EB. Reactive nitrogen and the world: 200 years of change. Ambio: A Journal of the Human Environment. 2002;**31**:64-71. DOI: 10.1579/0044-7447-31.2.64

[3] Marschner H, Marschner P. Marschner's Mineral Nutrition of Higher Plants. Academic Press; 2012

[4] Keeney DR. Nitrogen availability indices. In: Page AL, et al, editors, Methods of Soil Analysis. Part 2. Agronomy Monograph No. 9. Madison, WI: ASA; 1982. pp. 711-733

[5] Boukcim H, Plassard C. Juvenile nitrogen uptake capacities and root architecture of two open-pollinated families of *Picea abies*. Effects of nitrogen source and ectomycorrhizal symbiosis. Journal of Plant Physiology. 2003;**160**:1211-1218. DOI: 10.1078/0176-1617-00973

[6] Tisdall J, Oades JM. Organic matter and water-stable aggregates in soils. Journal of Soil Science. 1982;**33**:141-163. DOI: 10.1111/j.1365-2389.1982.tb01755.x

[7] Curwen EC. Prehistoric Farming of Europe and the Near East. Pt. I., Plough and Pasture, the Early History of Farming. New York: Henry Schuman; 1953. pp. 3-147

[8] Burke J. Connections. Boston: Brown and Company; 1978

[9] Lü B, Knoblock J, Riegel JK. Lü Shi Chun Qiu. California: Stanford University Press; 2000

[10] Bationo A. Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. Nairobi: Afnet-CIAT; 2004. pp. 127-136

[11] Giller KE, Cadisch G, Ehaliotis C, Adams E, Sakala WD, Mafongoya PL. Building soil nitrogen capital in Africa. In: Buresh RJ, Sanchez PA, Calhoun F, editors. Replenishing Soil Fertility in Africa. Madison, WI: Soil Science Society of America and American Society of Agronomy; 1997. pp. 151-192

[12] White KD. Fallowing, crop rotation, and crop yields in roman times. Agricultural History. 1970;**44**(3):281-290

[13] Smil V. Enriching the earth: Fritz Haber, Carl Bosch, and the transformation of world food production. MIT press; 2004. DOI: 10.2307/3985938

[14] Erisman JW, Sutton MA, Galloway J, Klimont Z, Winiwarter W. How a century of ammonia synthesis changed the world. Nature Geoscience. 2008;**1**:636-639. DOI: 10.1038/ngeo325

[15] Rice C, Smith M, Blevins R. Soil nitrogen availability after long-term continuous no-tillage and conventional tillage corn production. Soil Science Society of America Journal. 1986;**50**:1206-1210. DOI: 10.2136/sssaj1986.03615995005000050023x

[16] Phillips SH, Young H Jr. No-Tillage Farming. Indianapolis, IN, USA: Reiman Associates; 1973

[17] Horowitz J, Ebel R, Ueda K. "No-till" Farming Is a Growing Practice. USDA Report. 2010

[18] Bruns HA. Concepts in Crop Rotations. Croatia: InTech Open Access Publisher; 2012

[19] Karlen DL, Varvel GE, Bullock DG, Cruse RM. Crop rotations for the 21st century. In: Donald LS, editor. Advances in agronomy. Academic Press; 1994. pp. 1-45

[20] Townsend AR, Howarth RW, Bazzaz FA, Booth MS, Cleveland CC, Collinge SK, et al. Human health effects of a changing global nitrogen cycle. Frontiers in Ecology and the Environment. 2003;**1**:240-246. DOI: 10.2307/3868011

[21] Chen R, Senbayram M, Blagodatsky S, Myachina O, Dittert K, Lin X, et al. Soil C and N availability determine the priming effect: Microbial N mining and stoichiometric decomposition theories. Global Change Biology. 2014;**20**:2356-2367. DOI: 10.1111/gcb.12475

[22] Sollins P, Spycher G, Glassman C. Net nitrogen mineralization from light-and heavy-fraction forest soil organic matter. Soil Biology and Biochemistry. 1984;**16**:31-37. DOI: 10.1016/0038-0717(84)90122-6

[23] Six J, Bossuyt H, Degryze S, Denef K. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil and Tillage Research. 2004;**79**:7-31. DOI: 10.1016/j.still.2004.03.008

[24] Zou C, Pearce RC, Grove JH, Coyne MS. Conservation practices in tobacco production increase large aggregates and associated carbon and nitrogen. Soil Science Society of America Journal. 2015;**79**:1760-1770. DOI: 10.2136/sssaj2015.06.0235

[25] Six J, Elliott E, Paustian K. Soil macroaggregate turnover and microaggregate formation: A mechanism for C sequestration under notillage agriculture. Soil Biology and Biochemistry. 2000;**32**:2099-2103. DOI:10.1016/S0038-0717(00)00179-6

[26] Bundy L, Meisinger J. Nitrogen availability indices. In: Weaver RW, Angle JS, Bottomley P S, editors. Methods of Soil Analysis: Part 2. SSSA, Madison, WI, USA: Microbiological and Biochemical Properties; 1994. pp. 951-984

[27] Goncalves J, Carlyle J. Modelling the influence of moisture and temperature on net nitrogen mineralization in a forested sandy soil. Soil Biology and Biochemistry. 1994;**26**: 1557-1564. DOI: 10.1016/0038-0717(94)90098-1

[28] Sierra J. Temperature and soil moisture dependence of N mineralization in intact soil cores. Soil Biology and Biochemistry. 1997;**29**:1557-1563. DOI: 10.1016/S0038-0717(96)00288-X

[29] Zech W, Senesi N, Guggenberger G, Kaiser K, Lehmann J, Miano TM, et al. Factors controlling humification and mineralization of soil organic matter in the tropics. Geoderma. 1997;**79**:117-161. DOI: 10.1016/S0016-7061(97)00040-2

[30] Gill K, Jarvis S, Hatch D. Mineralization of nitrogen in long-term pasture soils: Effects of management. Plant and Soil. 1995;**172**:153-162. DOI: 10.1007/BF00020869

[31] Van Der Krift TA, Berendse V. The effect of plant species on soil nitrogen mineralization. Journal of Ecology. 2001;**89**:555-561. DOI: 10.1046/j.0022-0477.2001.00580.x

[32] Binkley D, Hart SC. The components of nitrogen availability assessments in forest soils. Advances in Soil Science. Springer; 1989. pp. 57-112. DOI: 10.1007/978-1-4613-8847-0_2

[33] Hart SC, Stark JM, Davidson EA, Firestone MK. Nitrogen mineralization, immobilization, and nitrification. In: Weaver RW, Angle JS, Bottomley PS, editors. Methods of Soil Analysis: Part 2. SSSA, Madison, WI, USA: Microbiological and Biochemical Properties; 1994. pp. 985-1018

[34] Griffin T, Honeycutt C, Albrecht S, Sistani K, Torbert H, Wienhold B, et al. Nationally coordinated evaluation of soil nitrogen mineralization rate using a standardized aerobic incubation protocol. Communications in Soil Science and Plant Analysis. 2007;**39**:257-268. DOI: 10.1080/00103620701759285

[35] Gastal F, Lemaire G. N uptake and distribution in crops: An agronomical and ecophysiological perspective. Journal of Experimental Botany. 2002;**53**:789-799. DOI: 10.1093/jexbot/53.370.789

[36] Clark RT, MacCurdy RB, Jung JK, Shaff JE, McCouch SR, Aneshansley DJ, et al. Three-dimensional root phenotyping with a novel imaging and software platform. Plant Physiology. 2011;**156**:455-465. DOI: 10.1104/pp.110.169102

[37] Lynch J. Root architecture and plant productivity. Plant Physiology. 1995;**109**(1):7

[38] Bauer A, Black A. Quantification of the effect of soil organic matter content on soil productivity. Soil Science Society of America Journal. 1994;**58**:185-193. DOI: 10.2136/sssaj1994.03615995005800010027x

[39] Cole C, Duxbury J, Freney J, Heinemeyer O, Minami K, Mosier A, et al. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutrient Cycling in Agroecosystems. 1997;**49**:221-228. DOI: 10.1023/a:1009731711346

[40] Spalding RF, Exner ME. Occurrence of nitrate in groundwater—A review. Journal of Environmental Quality. 1993;**22**:392-402. DOI: 10.2134/jeq1993.00472425002200030002x

[41] Lupwayi N, Arshad M, Rice W, Clayton G. Bacterial diversity in water-stable aggregates of soils under conventional and zero tillage management. Applied Soil Ecology. 2001;**16**:251-261. DOI: 10.1016/S0929-1393(00)00123-2

[42] Sullivan L. Soil organic matter, air encapsulation and water-stable aggregation. Journal of Soil Science. 1990;**41**:529-534. DOI: 10.1111/j.1365-2389.1990.tb00084.x

[43] Prove B, Loch R, Foley J, Anderson V, Younger D. Improvements in aggregation and infiltration characteristics of a krasnozem under maize with direct drill and stubble retention. Soil Research. 1990;**28**:577-590. DOI: 10.1071/SR9900577

[44] Linquist B, Singleton P, Yost R, Cassman K. Aggregate size effects on the sorption and release of phosphorus in an Ultisol. Soil Science Society of America Journal. 1997;**61**(1):160-166. DOI: 10.2136/sssaj1997.03615995006100010024x

[45] Zhang W, Yao Y, Sullivan N, Chen Y. Modeling the primary size effects of citrate-coated silver nanoparticles on their ion release kinetics. Environmental Science and Technology. 2011;**45**:4422-4428. DOI: 10.1021/es104205a

[46] Bissonnais Yl. Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. European Journal of Soil Science. 1996;**47**:425-437. DOI: 10.1111/j.1365-2389.1996.tb01843.x

[47] Tisdall J, Oades J. The effect of crop rotation on aggregation in a red-brown earth. Soil Research. 1980a;**18**:423-433

[48] Tisdall J, Oades JM. Organic matter and water-stable aggregates in soils. Journal of Soil Science. 1982;**33**:141-163

[49] Kemper W, Rosenau R. Aggregate stability and size distribution. In: Klute A, editor. Methods of Soil Analysis. Part 1. Agronomy Monograph. 9. 2nd ed. Madison.WI: ASA and SSSA; 1986. pp. 425-442

[50] Puget P, Chenu C, Balesdent J. Total and young organic matter distributions in aggregates of silty cultivated soils. European Journal of Soil Science. 1995;**46**:449-459. DOI: 10.1111/j.1365-2389.1995.tb01341.x

[51] Veum KS, Goyne KW, Kremer R, Motavalli PP. Relationships among water stable aggregates and organic matter fractions under conservation management. Soil Science Society of America Journal. 2012;**76**:2143-2153. DOI: 10.2136/sssaj2012.0089

[52] Angers DA, Giroux M. Recently deposited organic matter in soil water-stable aggregates. Soil Science Society of America Journal. 1996;**60**:1547-1551. DOI: 10.2136/sssaj1996.03615995006000050037x

[53] Beare M, Hendrix P, Coleman D. Water-stable aggregates and organic matter fractions in conventional-and no-tillage soils. Soil Science Society of America Journal. 1994;**58**: 777-786. DOI: 10.2136/sssaj1994.03615995005800030020x

[54] Cambardella C, Elliott E. Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. Soil Science Society of America Journal. 1993;**57**:1071-1076. DOI: 10.2136/sssaj1993.03615995005700040032x

[55] Brye K, Olk DC, Schmid BT. Rice rotation and tillage effects on soil aggregation and aggregate carbon and nitrogen dynamics. Soil Science Society of America Journal. 2012;**76**: 994-1004. DOI: 10.2136/sssaj2010.0436

[56] Haynes R, Naidu R. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review. Nutrient Cycling in Agroecosystems. 1998;**51**:123-137. DOI: 10.1023/A:1009738307837

[57] Kong AY, Six J, Bryant DC, Denison RF, Van Kessel C. The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. Soil Science Society of America Journal. 2005;**69**:1078-1085. DOI: 10.2136/sssaj2004.0215

[58] Sainju UM, Caesar-Tonthat T, Jabro JD. Carbon and nitrogen fractions in dryland soil aggregates affected by long-term tillage and cropping sequence. Soil Science Society of America Journal. 2009;**73**:1488-1495. DOI: 10.2136/sssaj2008-0405

[59] Six J, Elliott E, Paustian K, Doran J. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Science Society of America Journal. 1998;**62**:1367-1377. DOI: 10.2136/sssaj1998.03615995006200050032x

[60] West TO, Post WM. Soil organic carbon sequestration rates by tillage and crop rotation. Soil Science Society of America Journal. 2002;**66**:1930-1946. DOI: 10.2136/sssaj2002.1930

[61] Wright AL, Hons FM. Soil carbon and nitrogen storage in aggregates from different tillage and crop regimes. Soil Science Society of America Journal. 2005;**69**:141-147. DOI: 10.1002/9780470777923.ch16

[62] Mulvaney R, Khan S, Ellsworth T. Synthetic nitrogen fertilizers deplete soil nitrogen: A global dilemma for sustainable cereal production. Journal of Environmental Quality. 2009;**38**:2295-2314. DOI: 10.2134/jeq2008.0527

[63] Brown KH, Bach EM, Drijber RA, Hofmockel KS, Jeske ES, Sawyer JE, et al. A long-term nitrogen fertilizer gradient has little effect on soil organic matter in a high-intensity maize production system. Global Change Biology. 2014;**20**:1339-1350. DOI: 10.1111/gcb.12519

[64] Su YZ, Wang F, Suo DR, Zhang ZH, Du MW. Long-term effect of fertilizer and manure application on soil-carbon sequestration and soil fertility under the wheat–wheat–maize cropping system in Northwest China. Nutrient Cycling in Agroecosystems. 2006;**75**: 285-295. DOI: 10.1007/s10705-006-9034-x

[65] Beauchamp E, Reynolds W, Brasche-Villeneuve D, Kirby K. Nitrogen mineralization kinetics with different soil pretreatments and cropping histories. Soil Science Society of America Journal. 1986;**50**:1478-1483. DOI: 10.2136/sssaj1986.03615995005000060020x

[66] Honeycutt C, Griffin T, Wienhold BJ, Eghball B, Albrecht S, Powell JM, et al. Protocols for nationally coordinated laboratory and field research on manure nitrogen mineralization. Communications in Soil Science and Plant Analysis. 2005;**36**:2807-2822. DOI: 10.1080/00103620500304184

[67] Allison F, Sterling LD. Nitrate formation from soil organic matter in relation to total nitrogen and cropping practices. Soil Science. 1949;**67**:239-252. DOI: 10.1097/00010694-194903000-00005

[68] Stanford G, Hanway J. Predicting nitrogen fertilizer needs of Iowa soils: II. A simplified technique for determining relative nitrate production in soils. Soil Science Society of America Journal. 1955;**19**:74-77. DOI: 10.2136/sssaj1955.03615995001900010018x

[69] Stanford G, Smith S. Nitrogen mineralization potentials of soils. Soil Science Society of America Journal. 1972;**36**:465-472

[70] Smith JL, Schnabel R, McNeal B, Campbell G. Potential errors in the first-order model for estimating soil nitrogen mineralization potentials. Soil Science Society of America Journal. 1980;**44**:996-1000. DOI: 10.2136/sssaj1980.03615995004400050025x

[71] Heumann S, Böttcher J, Springob G. N mineralization parameters of sandy arable soils. Journal of Plant Nutrition and Soil Science. 2002;**165**:441-450. DOI: 10.1002/1522-2624(200208)165:43.0.CO;2-F

[72] Mikha MM, Rice CW, Milliken GA. Carbon and nitrogen mineralization as affected by drying and wetting cycles. Soil Biology and Biochemistry. 2005;**37**:339-347. DOI: 10.1016/j.soilbio.2004.08.003

[73] Miller AE, Schimel JP, Meixner T, Sickman JO, Melack JM. Episodic rewetting enhances carbon and nitrogen release from chaparral soils. Soil Biology and Biochemistry. 2005;**37**:2195-2204. DOI: 10.1016/j.soilbio.2005.03.021

[74] Wu J, Brookes PC. The proportional mineralisation of microbial biomass and organic matter caused by air-drying and rewetting of a grassland soil. Soil Biology and Biochemistry. 2005;**37**:507-515. DOI: 10.1016/j.soilbio.2004.07.043

[75] Xiang SR, Doyle A, Holden PA, Schimel JP. Drying and rewetting effects on C and N mineralization and microbial activity in surface and subsurface California grassland soils. Soil Biology and Biochemistry. 2008;**40**:2281-2289. DOI: 10.1016/j.soilbio.2008.05.004

[76] Rice C, Grove J, Smith M. Estimating soil net nitrogen mineralization as affected by tillage and soil drainage due to topographic position. Canadian Journal of Soil Science. 1987;**67**:513-520. DOI: 10.4141/cjss87-048

[77] Carpenter-Boggs L, Pikul JL, Vigil MF, Riedell WE. Soil nitrogen mineralization influenced by crop rotation and nitrogen fertilization. Soil Science Society of America Journal. 2000;**64**:2038-2045. DOI: 10.2136/sssaj2000.6462038x

[78] Eno CF. Nitrate production in the field by incubating the soil in polyethylene bags. Soil Science Society of America Journal. 1960;**24**:277-279. DOI: 10.2136/sssaj1960.03615995002400040019x

[79] Hanselman TA, Graetz DA, Obreza TA. A comparison of *in situ* methods for measuring net nitrogen mineralization rates of organic soil amendments. Journal of Environmental Quality. 2004;**33**:1098-1105. DOI: 10.2134/jeq2004.1098

[80] Subler S, Parmelee R, Allen M. Comparison of buried bag and PVC core methods for in situ measurement of nitrogen mineralization rates in an agricultural soil. Communications in Soil Science and Plant Analysis. 1995;**26**:2369-2381. DOI: 10.1080/00103629509369454

[81] Raison R, Connell M, Khanna P. Methodology for studying fluxes of soil mineral-N *in situ*. Soil Biology and Biochemistry. 1987;**19**:521-530. DOI: 10.1016/0038-0717(87)90094-0

[82] Adams M, Attiwill P. Nutrient cycling and nitrogen mineralization in eucalypt forests of South-Eastern Australia. Plant and Soil. 1986;**92**:341-362. DOI: 10.1007/BF02372483

[83] Dou H, Alva A, Khakural B. Nitrogen mineralization from citrus tree residues under different production conditions. Soil Science Society of America Journal. 1997;**61**:1226-1232. DOI: 10.2136/sssaj1997.03615995006100040031x

[84] Rapp M, Leclerc MC, Lossaint P. The nitrogen economy in a *Pinus pinea* L. stand. Forest Ecology and Management. 1979;**2**:221-231. DOI: 10.1016/0378-1127(79)90048-3

[85] Powlson D. Effect of cultivation on the mineralization of nitrogen in soil. Plant and Soil. 1980;**57**:151-153. DOI: 10.1007/BF02139653

[86] DiStefano JF, Gholz H. A proposed use of ion exchange resins to measure nitrogen mineralization and nitrification in intact soil cores. Communications in Soil Science and Plant Analysis. 1986;**17**:989-998. DOI: 10.1080/00103628609367767

[87] Kolberg R, Rouppet B, Westfall D, Peterson G. Evaluation of an *in situ* net soil nitrogen mineralization method in dryland agroecosystems. Soil Science Society of America Journal. 1997;**61**:504-508. DOI: 10.2136/sssaj1997.03615995006100020019x

[88] Wienhold BJ, Varvel GE, Wilhelm WW. Container and installation time effects on soil moisture, temperature, and inorganic nitrogen retention for an *in situ* nitrogen mineralization method. Communications in Soil Science and Plant Analysis. 2009;**40**:2044-2057. DOI: 10.1080/00103620902960575

[89] Khanna PK, Raison RJ. *In situ* core methods for estimating soil mineral-N fluxes: Re-evaluation based on 25 years of application and experience. Soil Biology and Biochemistry. 2013;**64**:203-210. DOI: 10.1016/j.soilbio.2012.09.004

[90] Hatch D, Jarvis S, Philipps L. Field measurement of nitrogen mineralization using soil core incubation and acetylene inhibition of nitrification. Plant and Soil. 1990;**124**:97-107. DOI: 10.1007/BF00010937

[91] Zou C, Pearce RC, Grove JH, Coyne MS. Laboratory vs. *in situ* resin-core methods to estimate net nitrogen mineralization for comparison of rotation and tillage practices. Journal of Plant Nutrition and Soil Science. 2017;**180**:294-301. DOI: 10.1002/jpln.201600571

[92] Zou C, Pearce RC, Grove JH, Coyne MS, Roualdes EA, Li Y. Stability of indicators for net soil nitrogen mineralization in tobacco rotation and tillage systems. Soil Science Society of America Journal. 2018;**82**:483-492. DOI:10.2136/sssaj2017.08.0263

[93] de Dorlodot S, Forster B, Pagès L, Price A, Tuberosa R, Draye X. Root system architecture: Opportunities and constraints for genetic improvement of crops. Trends in Plant Science. 2007;**12**:474-481. DOI: 10.1016/j.tplants.2007.08.012

[94] Liao H, Rubio G, Yan X, Cao A, Brown KM, Lynch JP. Effect of phosphorus availability on basal root shallowness in common bean. Plant and Soil. 2001;**232**:69-79. DOI: 10.1023/A:1010381919003

[95] Lynch JP. Root phenes for enhanced soil exploration and phosphorus acquisition: Tools for future crops. Plant Physiology. 2011;**156**:1041-1049. DOI: 10.1104/pp.111.175414

[96] Ribaut JM, Betran J, Monneveux P, Setter T. Drought tolerance in maize. In: Bennetzen JL, Hake SC, editors. Handbook of Maize: Its Biology. New York: Springer; 2009. pp. 311-344. DOI: 10.1007/978-0-387-79418-1_16

[97] Foy C, Carson E. The plant root and its environment. In: Carson EW, editor. Proceedings of an Institute Sponsored by the Southern Regional Education Board, held at Virginia Polytechnic Institute and State University, July 5-16, 1971. 1974

[98] Gajri P, Arora V, Prihar S. Tillage management for efficient water and nitrogen use in wheat following rice. Soil and Tillage Research. 1992;**24**:167-182. DOI: 10.1016/0167-1987(92)90099-W

[99] Guan D, Al-Kaisi MM, Zhang Y, Duan L, Tan W, Zhang M, et al. Tillage practices affect biomass and grain yield through regulating root growth, root-bleeding sap and nutrients uptake in summer maize. Field Crops Research. 2014;**157**:89-97. DOI: 10.1016/j.fcr.2013.12.015

[100] Mosaddeghi M, Mahboubi A, Safadoust A. Short-term effects of tillage and manure on some soil physical properties and maize root growth in a sandy loam soil in western Iran. Soil and Tillage Research. 2009;**104**:173-179. DOI: 10.1016/j.still.2008.10.011

[101] Zartman R, Phillips R, Atkinson W. Tillage and nitrogen influence on root densities and yield of burley tobacco. Tobacco International. 1976;**178**(18):35-38

[102] Cook A, Marriott C, Seel W, Mullins C. Effects of soil mechanical impedance on root and shoot growth of *Lolium perenne* L. *Agrostis capillaris* and *Trifolium repens* L. Journal of Experimental Botany. 1996;**47**:1075-1084. DOI: 10.1093/jxb/47.8.1075

[103] Griffith DR, Mannering JV, Moldenhauer WC. Conservation tillage in the eastern Corn Belt [United States]. Journal of Soil and Water Conservation. 1977;**32**:20-28

[104] López-Bucio J, Cruz Ramírez A, Herrera-Estrella L. The role of nutrient availability in regulating root architecture. Current Opinion in Plant Biology. 2003;**6**:280-287. DOI: 10.1016/S1369-5266(03)00035-9

[105] Robinson D. Resource capture by localized root proliferation: Why do plants bother? Annals of Botany. 1996;**77**:179-186. DOI: 10.1006/anbo.1996.0020

[106] Robinson D. The responses of plants to non-uniform supplies of nutrients. New Phytologist. 1994;**127**:635-674. DOI: 10.1111/j.1469-8137.1994.tb02969.x

[107] Mantelin S, Touraine B. Plant growth-promoting bacteria and nitrate availability: Impacts on root development and nitrate uptake. Journal of Experimental Botany. 2004;**55**:27-34. DOI: 10.1093/jxb/erh010

[108] Williamson LC, Ribrioux SP, Fitter AH, Leyser HO. Phosphate availability regulates root system architecture in Arabidopsis. Plant Physiology. 2001;**126**:875-882. DOI: 10.1104/pp.126.2.875

[109] Zhang H, Forde BG. An Arabidopsis MADS box gene that controls nutrient-induced changes in root architecture. Science. 1998;**279**:407-409. DOI: 10.1126/science.279.5349.407

[110] Zhang H, Jennings A, Barlow PW, Forde BG. Dual pathways for regulation of root branching by nitrate. Proceedings of the National Academy of Sciences. 1999;**96**:6529-6534. DOI: 10.1073/pnas.96.11.6529

[111] Lin H. A new worldview of soils. Soil Science Society of America Journal. 2014;**78**:1831-1844. DOI: 10.2136/sssaj2014.04.0162

Section 3

Policy on Fertilizer Use

Fostering Fertilizer Use and Welfare Distribution in Tanzania: Implications for Policy and Practice

Lutengano Mwinuka

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78043

Abstract

This chapter attempts to assess the way the welfare effect is distributed among various players of the fertilizer supply chain and how fertilizer use can be promoted using micro fertilization technology. As policy debates over fertilizer use promotion have not yet come full circle, this chapter derives important implications for policy and practice. In particular, illustrations and economic-surplus effects framework were used to indicate expected impacts of fertilizer microdosing on crop yields and welfare. Low-dimension diagrammatic analysis using supply and demand curves was used together with detailed assessment of actors' interactions in the fertilizer supply chain. In terms of welfare, crop producers, consumers and other market agents gain more if fertilizer microdosing is adopted by farmers. However, the magnitude of welfare effects varies as the slope of demand and supply curves change due to marginal fertilizer costs, crop prices and yield responses. Other influencing factors are soil moisture, the microdose rate, cropping system and general farm management practices. Thus, fertilizer microdosing can easily foster fertilizer use if the country elites implement a rational consistent policy, hence improving the welfare of players if adoption of the technology is reinforced with an efficient fertilizer supply chain.

Keywords: welfare distribution, economic-surplus model, fertilizer microdosing, supply chain, Tanzania

1. Introduction

A plethora of scientific literature indicates that hunger is caused by poor soil fertility. In Sub-Saharan Africa, the gap between cereal consumption and production is the largest compared to other continents. The productivity of most food crops is not as good as expected [1, 2]. Thus, it is possible to secure food in African countries if soil fertility is improved as well as if there is an understanding of what works for smallholder farmers in rural areas [3]. Although small-scale farmers are a potential source of economic growth [4], more efforts are needed to rescue them from operating under low inputs and rain-fed agricultural conditions, which result in low yields and profits [5, 6]. It is worth noting that fertilizers account for the largest proportion of production costs component when compared with other farm inputs. Nevertheless, farmers in Tanzania have low levels of fertilizer use, hence low productivity [7, 8]. In this light, fertilizer use should be encouraged in order to improve productivity among farmers.

Investing on fertilizer use by smallholder farmers, including the application of recommended rates has been risky due to the scarcity of fertilizers and the unpredictability of rainfall [9, 10]. Fertilizer microdosing is likely to be a unique initiative that can encourage fertilizer use among the farmers community. The fertilizer microdosing technique is based on localized placement of small doses of mineral fertilizers ranging from 25–75% of the common rates at the base of the plants at sowing or shortly after seed germination instead of spreading fertilizers evenly across the field [9, 11]. This chapter focuses on how fertilizer use can be fostered to improve welfare among potential stakeholders of the fertilizer supply chain. Tanzania has been used as the fertilizer microdosing technology is rather new within the country and more understanding is needed associated with its impacts on fertilizer supply chain [12, 13]. In view of this, key implications are derived for policy and practice with the emphasis on fertilizer microdosing as an innovative low input technology that can replenish soil nutrients.

Some studies, although limited, seem to confirm that yields do relatively increase when fertilizer microdosing is applied [9, 14, 15]. However, in such studies, the issue of welfare distribution effects was rarely included to consider the benefits of fertilizer microdosing to producers and consumers [2, 11, 16]. In this regard, a separate welfare effects analysis urgently needs to be undertaken, targeting this farm-level technology [17], as it can easily be adopted by smallholder farmers in rural areas [18]. The available literature seems to be inapplicable as it mainly presents the impact of fertilizer microdosing in terms of yield responses. Actual impacts, indicating interactions between demand and supply and the role of price mechanisms have been marginally featured in the available literature. Likewise, the coverage on interactions of fertilizer supply chain actors at the national level seems to be scanty. Some of the key questions that remain unanswered include the following: what could be the impact of adopting fertilizer microdosing on the supply side and produced food prices? What are the likely changes in demand/supply of food crop produce, and to what extent is the resulting impact likely to differ from the cost of fertilizer used or return on investment?

While reviewing past economic studies related to fertilizer use, the researcher found inadequate information on welfare effects distributions of farm input use [15, 19]. In view of this, in the present chapter, the researcher build on the earlier studies to assess the welfare effects of fertilizer microdosing based on yield and prices. Based on this objective of the chapter, the contributions are twofold: first, little attention was noted on issues associated with crop responses and welfare in the on-going policy debates over modern input promotion [3, 20]. Thus, the researcher sought to learn from the economic theory and provide insights into the welfare effects that are likely to occur if fertilizer microdosing is adopted. In the same vein, the researcher sought to ascertain whether key actors, particularly farmers, are better off than before, and what factors are important for determining the outcomes, hence promote the technology. Second, in addition to contributing to the growing knowledge base on the welfare effects as prices of commodities change, the researcher extended the role of price analysis on welfare, beyond the output by considering the input (fertilizer) prices [21] and inter-temporal effects [22]. This study focuses on the way market functioning can affect the incentives of fertilizer supply chain actors using the available information gathered from previous studies. An investigation of how the input market should be improved is pertinent in understanding the underlying causes of low modern input use among producers and recommending best practice and policy for implementation [19, 23, 24].

2. Methods

The agricultural sector is controlled by market fundamentals such as forces of supply and demand. However, in reality, this is not always the case, as the market alone is not enough to allow equitable, sustained and stable growth [13]. In this regard, the demonstration of the partial equilibrium model using forces of supply and demand was used in this chapter, and a relevant literature review was undertaken to determine whether the supply chain performance and fertilizer markets functioning can improve through policy associated actions and government interventions. However, the main disadvantage of the economic-surplus approaches as reported is that the reliability of the findings usually depends on the extent to which the underlying parameters represent local conditions [25]. Keeping this constraint in mind, economic-surplus effects were determined and augmented with a thorough assessment of the fertilizer supply chain using Tanzania as a case. Integration of related approaches may be useful in support decisions, for instance, about better allocation of resources for promoting fertilizer use and investments [2].

2.1. Economic-surplus model for welfare analysis

As suggested by [26], this chapter uses fertilizer microdosing as an opportunity available for upgrading the agri-food value chains in Tanzania, targeting potential food crops [27]. It is the upgrading option that is within the reach of the weakest actor, i.e., the smallholder farmers [28]. An illustration and framework development of economic surplus (welfare and distribution) effects of the farm-level technology is of great importance for understanding the likely spillover of the new innovation [29]. Low-dimension diagrammatic analysis of expected impacts was used, based on the basic economic theory of supply and demand. In addition, a downward sloping demand curve and an upward sloping supply curve were used to characterize the domestic market for food crop produce. Thus, the choice of this methodological line comes from the fact that the economic-surplus approach requires the least information, is relatively easier to use and gives reliable results. According to [30], this method provides a relatively simple and flexible approach to understanding the value of adopting new technology by allowing for the comparison of the situations of with and without the use of the new technology. Details of the welfare impact results are portrayed in **Figure 1** and are further explained in the subsequent sections.

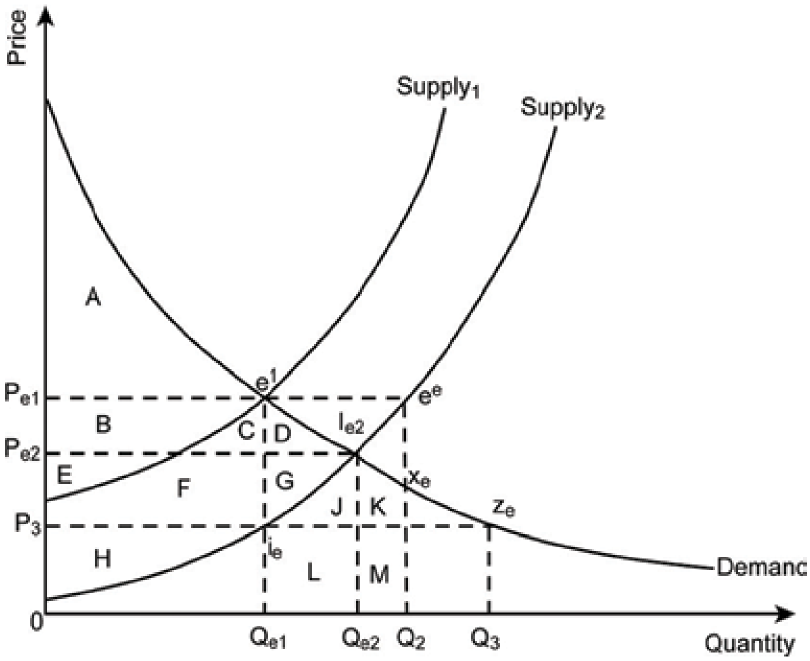


Figure 1. Impacts of fertilizer microdosing in supply.

2.2. The law of one price and its application

The law of one price is an economic theory that states that there is only one prevailing price for each product in a perfectly competitive market. Theoretically, price arbitrage works to dissipate price wedges between domestic and world or external market so that there is a stable tendency of domestic prices of a commodity to align with external prices [21]. In the context of this chapter, it is assumed that the movement of fertilizers from one market to the other will continue until the supply and demand forces equate the prices in both markets. It is further assumed that domestic fertilizer prices are embedded in the impact of domestic market and trade policies and actual functioning of farm-inputs markets. Therefore, the researcher has considered the law of one price as a relevant theory in underpinning the theoretical foundation of the chapter. In this regard, it has been noted that fertilizer microdosing, as an intermediary traded input, can transform the production process, given the availability of the primary factors of production, such as land, labor and capital. The value that is added through the production process, over and above the value (cost) of traded inputs (fertilizer), is value added [13]. Economic returns to the primary factors of production after the fertilizer microdosing has been applied by smallholder farmers are part and parcel of the welfare analysis presented. Moreover, additional reviews were undertaken to understand policy issues and conditions that prevent the law of one price from perfecting fertilizer supply chain as well as distribution, using Tanzania as a case.

3. Results

3.1. Response of fertilizer microdosing in supply

Here, the researcher analyses the economic impacts of fertilizer microdosing on a partial equilibrium model. **Figure 1** shows the market forces for a crop produce, with a standard upward sloping supply curve and downward sloping demand curve. Initially, the equilibrium is attained at point e^1 due to the price mechanism that ensures that demand and supply is equal. At this point, the price is Pe^1, and the quantity traded is Qe^1. The interpretation of this depicted situation can involve other intermediate activities of the supply chain, including transportation and storage. However, in the context of the chapter, they are hidden. For instance, better market functioning that result in favorable fertilizer prices to farmers is likely to encourage fertilizer use among producers; hence improve crop production [13].

Let us assume the scenario that smallholder farmers adopt fertilizer microdosing, which is a new farm-level technology in Tanzania. The supply curve (socially optimal supply curve) of the crop that would use fertilizer microdosing lies below the original supply curve, as shown in **Figure 1** by Supply^2. Given the original price Pe^1, more can actually be produced and supplied to the market (Q^2), or the original quantity Qe^1 can actually be produced at a much lower cost (P^3) if fertilizer microdosing is adopted. It should be noted that the new supply curve (Supply^2) due to fertilizer microdosing technology does not necessarily have to be parallel to the original supply curve (Supply^1). Comparatively, the extent of response due to fertilizer microdosing may vary with the scale of production, microdose rate and price [16]. Variation of yield responses due to fertilizer use also depends on the amount of moisture in the soil [31]. Access to adequate amount of soil moisture in semi-arid areas is a necessary condition for having a positive effect of fertilizer application [32]. Thus, the assumed scenario was used as a guide for providing required insights of the fertilizer microdosing and elucidating on its associated impacts.

3.2. Fertilizer microdosing impact on price, yields and welfare

As highlighted above, soil infertility poses the greatest threat in Tanzanian agriculture, and most of the farmers do not use fertilizers on their farms. What occurs in terms of supply if innovative low input technology such as fertilizer microdosing that replenishes soil nutrients is accepted by farmers for their cash and food crop production? Agro-dealers and other fertilizer suppliers/producers may, for example, be motivated to supply this farm input. This is particularly important considering that it is a new technology that makes business possible and worth undertaking and the emergence of new policies (regulations, taxes and subsidies) that penalize and/or incentivize players of the fertilizer supply chain. It is worth noting that increasing crop production due to fertilizer use surges, given the original demand curve and the underlying motivation of doing so. Such a situation results in a lower price, P_{e2}, and a higher equilibrium quantity, Q_{e2}, in the market, as given by point $e2$. At this new equilibrium point, consumers can buy more crop commodities/food at a lower price, resulting in a welfare gain to consumers as measured in the area (B + C + D). Similarly, producers can sell more, but at a lower price, resulting in the PS of the area (E + F + G + H) minus area (B + E), which is also positive (**Figure 1**). The overall welfare gain due to fertilizer microdosing equals the sum of the change in the producer and the consumer surplus, which amounts to the area (C + D + F + G + H), the area between the new and old supply curves and under the demand curve, whereby, CS increased by C + D and a significant share of the welfare is favoring crop producers, presented by the area (F + G + H).

Note: Supply$_1$ and Supply$_2$ are the supply curves without and with fertilizer microdosing technology intervention respectively. Supply$_1$ represents the without fertilizer microdosing scenario, whereby, consumer surplus (CS) = area A, producer surplus (PS) = area (B + E), and total surplus (TS) = area (A + B + E). Supply$_2$ represents the with fertilizer microdosing scenario, whereby CS = area (A + B + C + D), PS = area (E + F + G + H), and TS = area (A + B + C + D + E + F + G + H). Therefore, welfare effects due to fertilizer microdosing in supply are represented by the area (C + D + F + G + H).

Welfare gains for both producers and consumers and other associated impacts such as a lower equilibrium price and higher quantity of food produced and consumed seem to be in line with other quantitative and qualitative studies undertaken on the impacts of farm-level technologies [11, 16]. The associated impacts of fertilizer microdosing can encourage fertilizer use in the perspective of low-income countries such as Tanzania, where insufficient crop productivity is a fundamental constraint. Based on **Figure 1**, it can also be noted that the magnitude of the impacts will depend, among others, on how crop yield (supply) effects are relative to the size of the market, which as reported earlier, varies by type of crop and farming system. Whatever the extent of the impact is, in terms of the quantity of crop produced due to fertilizer microdosing application, the size of the impact, $Q_{e1}Q_{e2}$, however, is smaller than the original size of the farm-level technology potentials, $Q_{e1}Q_{2}$, which is due to the change in the price. Farm technologies are output-increasing in nature. The observed impacts are supported by the recent literature and ex-ante approaches of various technologies along the agri-food value chain [33].

3.3. Inter-temporal welfare effects

The size of the welfare effects depends on the slope of the demand and supply curves. Let the assumption be that the extent of yield responses due to fertilizer microdosing application is the same as before, that is, the shift in the supply or demand curve is of the same distance as before, and independent of scale and/or price. The scenario considered and discussed in the context of this chapter focused on impacts on the outcomes of crop yields increase in supply. For instance, in the presence of a perfectly inelastic, that is, vertical demand curve, the new equilibrium is at point i_e (same quantity, lower price), with consumers receiving all the gains from increased yields in the form of a lower price and a welfare gain of $P_{e1}e^{1}i_{e}P_{3}$, which is equivalent to the area (B + C + E + F). In the presence of a perfectly elastic, that is, horizontal demand curve, additional crop yields in supply result in a new equilibrium at point e^{e}, where all the gains translate into an increase in the equilibrium quantity supplied and demanded. This implies that there is no change in price. As a result, this leads to welfare gain to producers of the area (C + D + F + G + H + I).

Distribution of welfare gains over producers and consumers can be influenced by varying the slope of the demand curve. Moreover, the sign does not change due to this slope change. As the demand for food is generally fairly inelastic (not perfectly), the actual scenario is likely to lie in between the two extreme cases shown. Less than one in absolute value (inelastic) estimates of elasticity of demand for food most of the time vary by type of food, and many also vary by income level [34]. Because basic food commodities such as staple foods were considered by our case, the demand will be more inelastic. Likewise, if supply is perfectly inelastic (i.e., a vertical supply curve), the equilibrium is at point x_e, resulting in a lower equilibrium price and higher equilibrium quantity compared to what was analyzed before. This implies that consumers gain and producers lose. However, the overall welfare result is positive under $e^1x_eQ_2Q_{e1}$, which is the area (D + G + J + K + L + M). Finally, a completely elastic (i.e., horizontal supply curve) results in equilibrium at point z_e, whereby demand increases the most to Q_3 as the price also falls the most to P_3, and all welfare gains end up with the consumers who benefit to the maximum extent possible, by the area under $P_{e1}e^1z_eP_3$.

A vertical supply curve is representative of the short-run, where it is generally difficult for farmers to respond to price changes, whereas the horizontal supply curve corresponds to a long-run situation, where producers of agri-food commodities can respond. However, farmers in this situation are price takers in a highly competitive market. The actual representation is likely to lie somewhere in between, with the short-run and long-run situations being closer to inelastic and more elastic, respectively. These findings imply the importance of inter-temporal effects, which seem to have been ignored in the available literature [29]. To be more specific, the overall welfare and the welfare of consumers in particular improve while that of producers declines, implying that the supply is relatively inelastic. Thus, in the short-run situation, the increase in sales from extra yields due to fertilizer microdosing could be insufficient to compensate for the price decrease on existing sales. In the long-run situation, the supply of crop produce is more elastic. In view of this, welfare gains are likely to occur, and most of the gains end up with consumers.

3.4. Fertilizer microdosing interactions and performance of the fertilizer supply chain

Some assumptions were made to arrive at the presented results. Variations of the findings could result from the influence of other factors. At this point, discussions of various impressions on the viability of fertilizer microdosing technology have been presented. The focus has been on how the impacts of fertilizer microdosing technology can be sustained by considering other interactions of fertilizer supply chain. The researcher has also identified some factors that may alter the anticipated impact of fertilizer microdosing, hence improved welfare.

3.4.1. Impact of fertilizer microdosing on economic returns

Development of low-input soil fertility management practice for crops is vital [35] in a wider range of cropping systems in semi-arid and sub-humid areas [12]. Fertilizer microdosing can be a better option that can be relied upon by smallholder farmers in rural areas [9]. However, before the adoption of technology is cascaded, there was a need to undertake a comprehensive economic analysis, by taking into account the associated risks [19, 36]. It was reported in sub-humid farming system that fertilizer microdosing (25, 50 and 75% of recommended rates) can be applied to maize farms and result in positive net return distributions [16]. Because soil moisture is a problem in semi-arid areas, fertilizer microdosing was found to be more effective if and when combined with rainwater harvesting technology. A potential economic gain was further noted from sunflower compared to other crops such as pearl millet and groundnuts. Direct impacts of fertilizer microdosing technology on yields and profit changes with the level of moisture in the soil, micro-dose rate, cropping system and general farm management practices.

3.4.2. Enhancing fertilizer microdosing impacts

There are costs associated with access and the application of a farm-input, and for this case, fertilizers. While the underlying causes for low fertilizer use are still debatable [37], the main notion behind fertilizer microdosing technology is to encourage farmers to use fertilizer after experiencing the associated benefits, including higher yields [9]. This farm technology is more feasible if costs associated with its use would be reduced to the level affordable by farmers [16], considering that fertilizer can account for up to 35% of the total crop production costs [8]. The government and other partners can play an important role in improving the distribution of farm inputs, rendering extension services on how best fertilizers can be applied to different cropping systems and stimulating adoption of the technology. Comparatively, the net welfare gains may be lower if there are excess costs related to fertilizer use, incurred by producers, which counteract the original shift of the supply curve [20]. However, farmers can organize themselves into strong groups and use them as platforms for collective farm-inputs procurement.

3.4.3. Interactions within the fertilizer supply chain

The economic-surplus framework presented earlier cannot suffice to describe concerns emanating from the fertilizer supply chain. Measures to address issues in the fertilizer supply chain may vary significantly. For example, there could be no problem in the beginning of the supply chain, but costs and benefits may occur later in the chain and affect potential players. Fertilizer subsidy can stimulate the supply side and encourage fertilizer application to the lowest fertilizer users in the world, including Tanzania [8, 38]. However, fertilizer subsidy schemes that are convenient, transferable, and sustainable are needed for farmers who are not using fertilizers at all [39]. It should be noted that following the subsidy removal and devaluation in Tanzania, sharp declines in fertilizer use were observed [37], implying that any structural adjustment should not be detrimental to fertilizer markets in the country. Thus, improvement in inputs market functioning with a strategic investment in public goods is a potential way forward for countries such as Tanzania [24].

It should be noted that structural adjustment is the only factor that affects fertilizer prices among other factors, and fertilizer prices, however, are one of the several factors that influence fertilizer use [40]. As far as welfare distribution is concerned, fertilizer subsidies cannot only lower food prices in favor of consumers but also increase rural wages to key players of the supply chain. In general, market infrastructure, similar to other factors such as soil moisture conditions, cropping systems and extension systems, has a great role to play, and it must be considered as far as fertilizer use is concerned [20]. For example, when the fertilizer-crop price ratio is not favorable to farmers due to market failures, government intervention is inevitable for incentives and welfare enhancing [8, 13, 21]. Fertilizer distribution systems need to be improved for farmers in marginal areas, as they are less likely to use fertilizer and adopt new technology than those in higher potential areas. This is also an indication that agricultural input markets, particularly those for fertilizers and seeds, require more rigorous policy actions that are location based and context-specific [20].

3.4.4. Interactions with other commodity markets and players

A contrasting assumption that all factors remain constant was considered in the analysis. For instance, higher crop yields due to fertilizer microdosing application result in lower prices of the crop commodity in the market, which could also increase demand elsewhere in the system and hypothetically lead to second-order impacts. To be more explicit, higher cereal yields from crops, such as maize, which are used as chicken feed, become cheaper if fertilizer is used in the farm. Nevertheless, if the supply of the chicken feed declines due to changes in price, the local chicken meat demand is likely to rise, and prices for the same will essentially rise. The idea is that local chicken are less efficient in the use of resources such as water and land compared to crops [41]. Moreover, the effects of fertilizer can be boosted by manures because when they are used together, they tend to be more effective on crop yields [42]. However, the use of manures in rural areas is limited by the availability of sufficient quantities. From this observation, it would seem that crop-livestock integration could be further enhanced for more food and income diversification.

Although soil water is a necessary condition for realizing a significant impact of fertilizer use, improved seeds are similarly a key constituent. It should be noted that soil moisture is not a serious problem in sub-humid farming system as in semi-arid areas. In this light, fertilizer microdosing can be applied effectively in sub-humid areas and have the desired impact realized [16, 32]. Thus, there is need of introducing rainwater harvesting or irrigation technologies in semi-arid areas for fertilizer use technology to be employed and cope with climatic

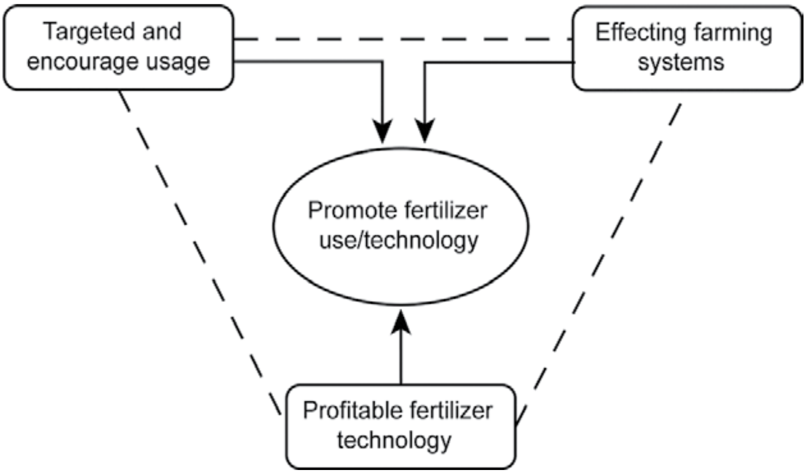


Figure 2. Promoting fertilizer use and microdosing technology in Tanzania.

variability conditions [31, 43]. In Tanzania, there is an effective locally manufactured fertilizer known as Minjingu Mazao. This fertilizer use technology can be featured in the government input subsidy programs, as experience has shown that the imported fertilizers meant for subsidizing crop production do not reach farmers. It has been reported that the imported fertilizers are being sold to unintended people, hence affecting the intended farmers [20]. Farmers are unlikely to benefit from the current yield gains as their depleted soils are non-responsive to fertilizer application [44]. In view of this, an understanding of the possible marginal yield/income responses across different agro-ecological zones of a country is needed before investing much in soil nutrient inputs such as fertilizer microdosing. In addition, more can be done to promote fertilizer use related technologies in Tanzania and beyond (**Figure 2**).

4. Discussion

4.1. A synthesis

An economic theory shows that the impacts of crop yields due to fertilizer microdosing, application as a farm-level technology in supply and in terms of quantity are different from the original size of the yields. In other words, the extent of the yields obtained is influenced by the amount and the way fertilizer was applied, costs associated with fertilizers, level of food prices, size of the fertilizer market and interactions within the fertilizer supply chain and with other players and markets. It is also evident that impacts change with the slope of the demand and supply curve and consumer preference or level of the technology adoption, which play an important role in the demand size of fertilizers. If all of these influencing factors are considered, one cannot be sure of the likely impact of the fertilizer application in the context of welfare and food security.

Table 1 presents the results of the supply and demand side analyses of applying fertilizer microdosing on infertile soil that has an appropriate amount of soil moisture. It summarizes

Increasing yields in supply	**Impact on market equilibrium**		**Welfare impacts in the commodity market**			**Factor of influence and impacts**
	Price	Quantity	Consumers	Producers	Total	Extent of yields increase relative to the size of the fertilizer market
Perfectly elastic supply curve	–ve	+ve	+ve	Constant	+ve	Interactions within the fertilizer supply chain and with other players
Perfectly inelastic supply curve	–ve	+ve	+ve	–ve in example	+ve	If fertilizer use involves costs, then welfare impacts will be lower.
Perfectly elastic demand curve	Constant	+ve	Constant	+ve	+ve	Impacts may be smaller if costs associated with technology are high.
Perfectly inelastic demand curve	–ve	Constant	+ve	Constant	+ve	If fertilizer use decreases, the impacts are larger at a lower scale and price.

Table 1. Overview of the impacts of increasing yields in the market as fertilizer microdosing is applied in a food commodity.

what happens to the market equilibrium. Whereas the second and third columns show the price and quantity of food commodity, respectively, consumer and producer welfare are shown in the fourth and fifth columns, respectively. The overall effect of the welfare is presented in the sixth column. This scenario was assumed to occur in the market for the food commodity in question and for varying assumptions regarding demand and supply curves, providing the boundaries by rows for what might occur. The last column indicates the impact of other factors that are of influence, where possible, relaxing some of the simplifying assumptions made throughout the analyses. The following subsections present the implications for policy and in practice, and briefly highlight the aforementioned studies on the farm-level economic impacts of fertilizer microdosing in Tanzania.

4.2. Promoting fertilizer microdosing technology

Promoting the farm-level technology that can encourage farmers to use fertilizers in a country is a key for improving crop productivity [12]. However, there are some factors that need consideration before adopting and promoting technology such as fertilizer microdosing. First, the starting point for encouraging fertilizer use among farmers should be identified. Farmers in a country such as Tanzania are of different scales, and for this reason, fertilizer microdosing can target small-scale farmers who cultivate farms of less than a hectare. The technology is useful to farmers who do not use fertilizers, as they are motivated to use more after finding it is profitable. Because smallholder farmers are resource poor, the government can reduce the cost of the technology by appropriately subsidizing the fertilizers and improve access of fertilizers at the village level [16, 45].

Fertilizer microdosing can be more cost-effective if the government addresses potential market failures within the fertilizer supplier chain. [46] Suggested focusing on a holistic approach by addressing five pillars of market development and supporting conditions for effective functioning fertilizer markets. The pillars include policy, human capital, finance, market information and regulation. Crop yields can be improved with the efficient use of the technology, which goes hand in hand with the provision of opportunities for acquiring necessary knowledge and skills to targeted farmers and linking them with input suppliers [20].

In addition, after the adoption of the fertilizer microdosing technology by farmers with or without subsidization, the technology should have positive impacts on country farming systems. Testing the effectiveness of technology for upgrading agri-food value chains in sub-humid and semi-arid farming systems was important in Tanzania [12, 27]. For instance, marginal yields due to fertilizer microdosing should be high enough to motivate farmers to use fertilizers and adopt the technology. Moreover, better yields in semi-arid areas can be obtained if the fertilizer microdosing is combined with rainwater harvesting technology, particularly through tied-ridges.

The second factor is related to the third one, that is, the technology contributes significantly economic returns, hence being profitable to farmers. It is envisaged that farm-level technology should increase the output. However, additional crop yield due to fertilizer microdosing is a necessary but not sufficient condition for obtaining net returns. Empirical evidence shows that fertilizer microdosing can have significant impacts on both yield and income in sub-humid rather than in semi-arid farming systems. Variability in soil quality, soil moisture, and fertilizer market costs influence considerably the response and distribution of crop yields and rewards [16]. This type of technology can be promoted at the country level, as it can improve agricultural growth and alleviate poverty [31, [47], **Figure 1**. **Figure 2** presents a summary of the described factors and the way they are related to the promotion of fertilizer use and technology, in this case, fertilizer microdosing.

4.3. Implication for policy

At this point, it is evident that the microdosing strategy can inspire farmers to use more fertilizers. As policy debates on fertilizer use promotion are on-going [20], issues related to crop responses due to fertilizer microdosing have been presented from the context of localized application. Key messages that can be considered for policy actions have been highlighted to guide policy makers in re-shaping the existing policies or formulate new ones with a view of improving soil fertility as a key input for increased crop yields and profitability. It has been noted that fertilizer microdosing is a cost-effective farm-level technology that requires more resource attention.

Moreover, fertilizer-output price rations were found to be unfavorable due to market failure, including inadequate provision of necessary market linked infrastructures [12, 24]. The government can intervene and enhance the welfare of all key players in the fertilizer supply chain and markets by balancing the outcome of the trade-offs, including reducing the tax level of locally manufactured fertilizers. For example, as shown in **Figure 2**, smart fertilizer subsidies that are effective and sustainable can be used to support the application of fertilizer microdosing technology for pro-poor growth in Tanzania. However, policy measures from the government side should be predictable to enable farmers to make proper choices for farm inputs.

4.4. Implication for practice

Fertilizer microdosing can provide solutions to farmers and other players of the fertilizer supply chain. The outcome of the applied research that works on innovative solutions can benefit a wide range of supply chain actors. For example, farmers are likely to have higher returns on investment if they adopt fertilizer microdosing in the production of important crops, such as maize [16]. It is expected that with the adoption of technology, the demand for associated farm-inputs will be triggered, hence profitable to input producers, trades and other market agents.

Based on this, future studies and policy makers will be provided with information on how to improve soil quality and the modern input supply chains. The information will also be useful in understanding constraints, such as soil infertility and ineffective supply chains and possible solutions for addressing these issues. Moreover, detailed information at the national level about the composition of soil micronutrients would determine appropriate ways of using fertilizers, hence ensuring high productivity and profitability.

In this regard, policy, practice and future research tend to inform and benefit one another. If people's knowledge on the causal-impact of fertilizer microdosing is enhanced, it will enable the refinement of policies and result in better outcomes among the essential players in the fertilizer supply chain.

5. Concluding remarks

This review has revealed how economic theory can be used to provide intuitions of the welfare effects to various players of the supply chain if fertilizer microdosing technology is adopted. The overall welfare gains to crop producers, consumers and other market agents due to fertilizer microdosing application have been found to be positive. Moreover, the size of the welfare impacts changes as the slope of the demand and supply curves change, given the crop yield responses as a result of fertilizer use and micro fertilization application. This implies the importance of inter-temporal effects in the market where farmers are considered as price takers. Other factors that seem to influence crop yield and profit responses have been highlighted. These include soil moisture, the micro-dose rate, cropping system and general farm management practices. In addition, interventions that can be undertaken by the government and other players for improving the efficiency of the fertilizer supply chain have been highlighted.

This chapter has important policy and practice implications. The findings suggest that in a country such as Tanzania, where investment in physical infrastructures are limited, more is supposed to be done in terms of investing in functional seed and fertilizer markets, road networks, storage facilities and market information systems. Thus, a rational policy choice for a country should promote fertilizer use through embracing farm-level technologies such as fertilizer microdosing by considering the entire fertilizer supply chain. More resources can then be allocated in order to improve the welfare and living conditions of key players, particularly in rural areas. At this juncture, it could be concluded that fertilizer microdosing technology is worth adopting as it enhances agricultural growth and reduces poverty.

Acknowledgements

The author gratefully acknowledges the useful suggestions provided by anonymous reviewers. This publication is a product of the Trans-SEC project (www.trans-sec.org). The German Federal Ministry of Education and Research (BMBF) funded the project, and the German Federal Ministry for Economic Cooperation and Development (BMZ) co-financed the Trans-SEC project. The views expressed in this chapter are solely those of the author and may not, in any circumstance, be regarded as stating an official position of the BMBF or BMZ.

Author details

Lutengano Mwinuka

Address all correspondence to: mwinuka.lutengano@gmail.com

Department of Economics and Statistics, The University of Dodoma (UDOM), Dodoma, Tanzania

References

[1] Matshe I. Boosting smallholder production for food security: Some approaches and evidence from studies in sub-Saharan African. Agrekon. 2009;**48**(4):483-511

[2] Mourice SK, Rweyemamu CL, Nyambilila AA, Tumbo SD. Narrowing maize yield gaps under rain-fed conditions in Tanzania: Effects of small nitrogen dose. Tanzania Journal of Agricultural Sciences. 2014;**12**(2):55-65

[3] Gilbert N. African agriculture: Dirt poor. Nature. 2012;**483**:525-527

[4] Cairns JE, Hellin J, Sonder K, Araus JL, MacRobert JF, Thierfelder C, Prasanna BM. Adapting maize production to climate change in sub-Saharan Africa. Food Security. 2013;**5**:345-360

[5] Kalhapure AH, Shete BT, Dhonde MB. Integrated nutrient management in maize (Zea mays L.) for increasing production with sustainability. International Journal of Agriculture and Food Science Technology. 2013;**4**(3):195-206

[6] Kristjanson P, Neufeldt H, Gassner A, Mango J, Kyazze FB, Desta S, et al. Are food insecure smallholder households making changes in their farming practices ? Evidence from East Africa. Food Security. 2012;**4**:381-397

[7] URT (United Republic of Tanzania). National Sample Census of Agriculture 2007/2008 Vol. 5e: Morogoro Regional Report. Dar es Salaam: National Bureau of Statistics; 2012

[8] Wilson RT, Lewis J. The Maize Value Chain in Tanzania. A Report from the Southern Highlands Food Systems Program. Rome: FAO; 2015

[9] Camara BS, Camara F, Berthe A, Oswald A. Micro-dosing of fertilizer – A technology for farmers' needs and resources. International Journal of AgriScience. 2013;**3**(5):387-399

[10] de Graaff J, Kessler A, Nibbering JW. Agriculture and food security in selected countries in sub-Saharan Africa: Diversity in trends and opportunities. Food Security. 2011;**3**:195-213

[11] Twomlow S, Rohrbach D, Dimes J, Rusike J, Mupangwa W, Ncube B, et al. Micro-dosing as a pathway to Africa's green revolution: Evidence from broad-scale on-farm trials. Nutrient Cycling in Agroecosystems. 2010;**88**:3-15

[12] Graef F, Sieber S, Mutabazi K, Asch F, Biesalski HK, Bitegeko J, et al. Framework for participatory food security research in rural food value chains. Global Food Security. 2014;**3**(1):8-15

[13] MAFAP. Review of food and agricultural policies in the United Republic of Tanzania 2005–2011, (July). MAFAP Country Report Series. Rome: FAO; 2013

[14] Hayashi K, Abdoulaye T, Gerard B, Bationo A. Evaluation of application timing in fertilizer micro-dosing technology on millet production in Niger, West Africa. Nutrient Cycling in Agroecosystems. 2008;**80**:257-265

[15] Tabo R, Bationo A, DialloMaimouna K, Kassane O, Koala S. Fertilizer Microdosing for the Prosperity of Small Scale Farmers in the Sahel: Final Report. Sadore, Niger: International Crop Research Institute for the Semiarid Tropics (ICRISAT); 2005

[16] Mwinuka L, Mutabazi KD, Makindara J, Sieber S. Reckoning the risks and rewards of fertilizer micro-dosing in a sub-humid farming system in Tanzania. African Journal of Science, Technology, Innovation and Development. 2016;**8**(5–6):497-508

[17] Farquharson RJ, Martin RJ, Mccorkell B, Scott JF, Sotheary E, Phaloeun C, et al. Characteristics of an agricultural innovation and incentives for adoption: Rhizobium in Cambodia. International Journal of Environmental and Rural Development. 2013;**4**(2):44-39

[18] Mwinuka L, Mutabazi KD, Graef F, Sieber S, Makindara J, Kimaro A, Uckert G. Simulated willingness of farmers to adopt fertilizer micro-dosing and rainwater harvesting technologies in semi-arid and sub-humid farming systems in Tanzania. Food Security. 2017;**9**(6): 1237-1253

[19] Asci S, Borisova T, VanSickle JJ. Role of economics in developing fertilizer best management practices. Agricultural Water Management. 2015;**152**:251-261

[20] Jayne TS, Mather D, Mason N, Ricker-Gilbert J. How do fertilizer subsidy programs affect total fertilizer use in sub-Saharan Africa? Crowding out, diversion, and benefit/cost assessments. Agricultural Economics. 2013;**44**:687-703

[21] Short C, Barreiro-Hurlé J, Balie J. Policy or markets? An analysis of price incentives and disincentives for rice and cotton in selected African countries. Canadian Journal of Agricultural Economics. 2014;**62**(4):441-469

[22] Rutten MM. What economic theory tells us about the impacts of reducing food losses and/or waste: Implications for research, policy and practice. Agriculture and Food Security. 2013;**2**:13

[23] Mghenyi E, Myers RJ, Jayne TS. The effects of a large discrete maize price increase on the distribution of household welfare and poverty in rural Kenya. Agricultural Economics. 2011;**42**:343-356

[24] von Braun J. Addressing the food crisis: Governance, market functioning, and investment in public goods. Food Security. 2009;**1**:9-15

[25] Falck-Zepeda J, Horna D, Smale M. Betting on cotton: Potential payoffs and economic risks of adopting transgenic cotton in West Africa. The African Journal of Agricultural and Resource Economics. 2008;**2**(2):188-207

[26] Gibbons P. Commodities, Donors and Value-Chain Analysis and Upgrading. DIIS Paper Prepared for UNCTAD; 2003

[27] Mwinuka L, Mutabazi KD, Graef F, Maeda C, Makoko B, Swai E. Agri-Food Value Chains Upgrading Strategies Choices: A Participatory Smallholder Farmer Centred Approach. Plant2030 Status Seminar. Berlin 4th–6th March 2015;2015a

[28] Sanogo I. How to Conduct a Food Commodity Value Chain Analysis? Technical Guidance Sheet (TGS) Prepared under ENCAP-Enhance Capacities in Food Security and Response Analysis. World Food Program; 2010

[29] Cook DC, Carrasco LR, Paini DR, Fraser RW. Estimating the social welfare effects of New Zealand apple imports. The Australian Journal of Agricultural and Resource Economics. 2011;**55**:599-620

[30] Mensah EC, Wohlgenant MK. A market impact analysis of soybean technology adoption. Research in Business and Economic Journal. 2010;**1**:142-159

[31] Reynolds TW, Waddington SR, Anderson CL, Chew A, True Z, Cullen A. Environmental impacts and constraints associated with the production of major food crops in sub-Saharan Africa and South Asia. Food Security. 2015;**7**:795-822

[32] Fufa B, Hassan RM. Determinants of fertilizer use on maize in eastern Ethiopia: A weighted endogenous sampling analysis of the extent and intensity of adoption. Agrekon. 2006;**45**(1):38-49

[33] Graef F, Uckert G, Schindler J, König HJ, Mbwana HA, Fasse A, et al. Expert-based ex-ante assessment of potential social, ecological, and economic impacts of upgrading strategies for improving food security in rural Tanzania using the ScalA-FS approach. Food Security. 2017. DOI: 10.1007/s12571-016-0639-x

[34] Andreyeva T, Long M, Brownell K. The impact of food prices on consumption: A systematic review of research on the price elasticity of demand for food. American Journal of Public Health. 2010;**100**:216-219

[35] Mwinuka L, Schneider I, Maeda C, Mutabazi KD, Makindara J, Graef F, et al. Comparing stakeholder views for mutual acceptable food value chain upgrading strategies in Tanzania. African Journal of Agricultural Research. 2015b;**10**(12):1376-1385

[36] Richardson JW, Herbst BK, Outlaw JL, Gill RC II. Including risk in economic feasibility analyses: The case of ethanol production in Texas. Journal of Agribusiness. 2007;**25**(2):115-132

[37] Rashid S, Jayne TS, Minot N. Modern Input Promotion in Africa: Overview of Evidence and Future Policy Direction. Prepared as the Background Paper for the Annual Trend and Outlook Report (ATOR) of the Regional Strategic Analysis and Knowledge Support Systems (ReSAKSS); 2015

[38] Benson T, Kirama SL, Selejio O. The Supply of Inorganic Fertilizer to Smallholder Farmers in Tanzania. IFPRI Policy Note 17. Washington, DC: International Food Policy Research Institute (IFPRI); 2013

[39] Druilhe Z, Barreiro-Hurlé J. Fertilizer Subsidies in Sub-Saharan Africa. ESA Working paper No. 12–04. Rome: FAO; 2012

[40] Minot N, Benson T. Fertilizer Subsidies in Africa: Are Vouchers the Answers? Washington, DC: International Food Policy Research Institute; 2009

[41] Hoekstra A. The hidden water resource use behind meat and dairy. Animal Frontiers. 2012;**2**:3-8

[42] Aune JB, Bationo A. Agricultural intensification in the Sahel–The ladder approach. Agricultural Systems. 2008;**98**(2):119-125

[43] Cooper PJM, Dimes J, Rao KPC, Shapiro B, Shiferaw B, Twomlow S. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? Agriculture, Ecosystems and Environment. 2008;**126**:24-35

[44] Tittonell P, Vanlauwe B, de Ridder N, Giller K. Nutrient use efficiencies and crop responses to N, P, and manure applications in Zimbabwean soils: Exploring management strategies across soil fertility gradients. Field Crop Research. 2007;**100**:348-368

[45] Pan L, Christiaensen L. Who is vouching for the input voucher? De-centralized targeting and elite capture in Tanzania. World Development. 2012;**40**(8):1619-1633

[46] Gregory DI, Bumb BL. Factors Affecting Supply of Fertilizer in Sub-Saharan Africa. Agriculture and Rural Development Discussion Paper 24. Washignton, DC: The World Bank; 2006

[47] Pauw K, Thurlow J. Agricultural growth, poverty, and nutrition in Tanzania. Food Policy. 2011;**36**(6):795-804

Edited by Roland Nuhu Issaka
and Mohammed Moro Buri

Soil Productivity Enhancement comprises five chapters written by scientists from various parts of the world. The book is divided into three sections. 1: Conversion of Environmentally Polluting Waste into Fertilizer. This section discusses the conversion of waste water and other by-products from factories into organic fertilizers. It further examines how these materials can be used to enhance crop production and improve soil productivity. 2: Practices for Improving Nutrient Availability. Good nutrient management and proper composting of organic materials are options that can be used to enhance the productivity of soil. These and other practices are examined in this section. 3: Policy on Fertilizer Use. The need for effective policies to control and promote the effective and efficient use of fertilizers is discussed in this section.

Published in London, UK

IntechOpen

ISBN 978-1-83881-772-5