



RESEARCH ARTICLE



Integrated nutrient management as a sustainable strategy to recover a decayed Pear (*Pyrus communis*) orchard

Hugo Poblete^{1,2} ; Rodrigo Ortega-Blu^{1,*} ; María Mercedes Martínez^{1,3} ; Paola Fincheira⁴ 

¹ Grupo de Investigación en Suelo, Planta, Agua y Ambiente (GISPA). Universidad Técnica Federico Santa María. Avenida Santa María #6400, Santiago. Chile.

² Sociedad Agrícola La Rosa Sofruco. Ruta H 66 G Km. 37, Peumo. Chile.

³ TROPEN - Tropical Crops, Institute of Crop Science and Resource Conservation INRES Bonn Universität, Bonn Germany Auf dem Hügel 6, 53121 Bonn, PC. 531113. Germany.

⁴ Centro de Excelencia en Investigación Biotecnológica Aplicada al Medio Ambiente (CIBAMA), Facultad de Ingeniería y Ciencias, Universidad de La Frontera, Av. Francisco Salazar 01145, Temuco, Chile.

* Corresponding author: rodrigo.ortega@usm.cl (R. Ortega-Blu).

Received: 25 January 2021. Accepted: 5 July 2021. Published: 19 July 2021.

Abstract

Integrated Nutrition Management (INM) is a concept developed during the last decade in fruit agroecosystems based on the application of organic matter, biostimulants, and adjusted chemical fertilization to improve soil quality, plant rhizogenesis, and nutrition. Nevertheless, there are few studies on the application of the INM concept on the recovery of decayed orchards. The present study was focused on the evaluation of the effects of INM on soil and plant quality changes as recovery indicators of a decayed pear orchard. Two treatments (T₁: conventional, T₂: INM) were evaluated under three tree vigor levels, during two growing seasons. Old pear trees were used in a factorial experiment of two treatments (control and INM) x three vigor levels, based on a previous aerial Normalized Difference Vegetation Index (NDVI) image. Soil properties, nutrient leaf contents, and NDVI were evaluated. Soil chemical and biological properties and their spatial variability were determined after two and five years of treatment application, respectively. The INM improved β-glucosidase activity, reduced bulk density, and increased soil porosity. Furthermore, nutrient indices (NDVI x N, K, Ca, Mg, Cu, Fe, and B) were significantly increased under INM. After two years, soil chemical properties and root density were improved by INM. A significantly higher yield, soil organic matter, soluble C, and dehydrogenase activity was observed with INM after five growing seasons. The results indicated that INM is a sustainable alternative for recovering decayed orchards, through the inclusion of good-quality organic matter within the management program.

Keywords: Pear; decayed orchards; tree vigor; integrated nutrition management; compost.

DOI: <https://dx.doi.org/10.17268/sci.agropecu.2021.035>

Cite this article:

Poblete, H., Ortega-Blu, R., Martínez, M. M., & Fincheira, P. (2021). Integrated nutrient management as a sustainable strategy to recover a decayed Pear (*Pyrus communis*) orchard. *Scientia Agropecuaria*, 12(3), 319-327.

1. Introduction

Pear (*Pyrus communis* L.) orchards in Chile occupy approximately 8,800 ha, where 2,200 ha (25%) are cultivated in the O'Higgins region (ODEPA, 2018). At the world level, the pear production reaches ~27 million tons, where the main producers are China, USA, Argentina, and Italy (FAOSTAT, 2018). During the 2018/2019 season, Chile exported near 25 million boxes of pears (ODEPA, 2020). The main pear variety is Packham's Triumph with approximately 3,000 ha. Despite its economic significance, 54% of Chilean orchards are more than 20-years old, with plant densities varying from 300 to 3,000 plants ha⁻¹. Pears

cultivated in Chile are mainly exported to North America (~12,000 t), Latin America (~60,000 t), and Europe (~72,000 t) (Universidad de Talca, 2018). In low-density pear orchards, when the decay process begins, the usual recommendation is to replace affected plants, because the low productivity in one plant would represent about 0.2% to 0.3% yield loss per hectare.

Orchard decay is a problem that seriously affects the production, growth, and duration of pear trees. It consists of the systematic loss of root mass, resulting in a severe reduction of the aerial part and yield reduction. In the case of pear trees, decay is a problem directly related to the

decrease of rhizogenesis, which is produced by many chemical and physical soil factors such as mechanical impedance by compaction (Brunetto et al., 2015; Morales-Olmedo et al., 2015). Furthermore, factors as pear root wooly aphid, nematodes, excess or deficit or quality of water irrigation, loss of soil structure, caused by the traffic of agriculture machinery, and the abnormal patterns in the water movement in the soil, are considered important factors causing decay in pear orchards (Brunetto et al., 2015; Ling-Fei et al., 2013; Poblete et al., 2013). Excessive water supply, high water table, and low porosity reduce the root growth (Jackson, 2003). On the other hand, soil moisture deficit affects primary root growth and its spatial distribution.

Soil temperature and nutrition are factors that also affect root growth. Pear roots begin growing at a temperature of 7-8 °C. Freeze damage could occur in superficial roots if air temperature reaches -9 °C. The nutrient demand of fruit species is dependent on the biomass produced by the different organs and mainly on fruit production; the total includes 3-4 kg N ton⁻¹, 0.5 kg P ton⁻¹ and 1.5 kg K ton⁻¹; corresponding to 30-70 kg N ha⁻¹, 20-30 kg P₂O₅ ha⁻¹ and 70-100 kg K₂O ha⁻¹, depending upon yield and soil type.

To handle these issues, the concept of Integrated Nutrition Management (INM) has emerged as a strategy used to improve soil properties and plant quality. It combines organic matter (OM) application (as a source of carbon, nutrients, microorganisms, and organic substances) with chemical fertilization to stimulate rhizogenesis for improving plant nutrition and soil quality (Roussos et al., 2019; Das et al., 2015; Ortega, 2015; Wu & Ma, 2015). The use of INM has resulted in significant increments in soluble C, root density, root dry weight, and plant biomass in pear, table grape, nuts, apple, and cherry trees (Martínez et al., 2018; Flores et al., 2015; Ortega, 2015). Besides, important soil effects as the increase in soluble P, available N, and β-glucosidase activity occur through an improved OM mineralization process (Roussos, 2019; Fincheira-Robles et al., 2018; Sorrenti et al., 2012; Burg et al., 2011). To evaluate the effects of the application of an INM program, different soil properties must be measured and correlated with agronomical indicators like vigor by normalized difference vegetation index (NDVI). Besides, bulk density, soil porosity, or soil enzymatic activities are important indicators of the influence of management systems on crops (Ouyang et al., 2018; Nimmo, 2013; Martínez et al., 2010). Many soil processes are influenced by soil biota, which releases enzymes (i.e β-glucosidase and phosphatases) that participate in mineralization processes and solubilization of nutrients (i.e organic P) (Merino et al., 2016; Kujur & Kumar Patel, 2014; Riches et al., 2013). Furthermore, plant tissue analysis must be performed to determine potential nutrient deficiencies or excess to perform follow up of the fertilization management (Shunfeng et al., 2018; Ikinici et al., 2014).

The objective of this research was to evaluate INM as an agronomic strategy to recover a low-density, decayed pear orchard. The focus of the study was to evaluate the effects of INM on: (1) soil quality, (2) plant vigor and nutritional status (3) spatial variability of soil properties, and (4) yield and SOM changes.

2. Materials and methods

2.1 Location

The experiment was performed in Peumo commune (Rapel Valley, Chile) located at the coordinates 34°19'34.92" South and 71°15'23.67" West. The study area corresponds to a semi-arid, Mediterranean region, with a temperate climate. The soil belongs to the order Mollisol, which presents a silt loam texture, neutral pH, low organic matter content (~2%), and medium fertility. Temperatures are in the range of 5.5 to 27.6 °C, while precipitation varies between 400 and 420 mm yr⁻¹.

2.2 Plant material and growth conditions

The pear orchard (*Pyrus communis* L), Packam's Triumph variety (on winter Nellis rootstock) was established in July 1976 in low density (333 plants ha⁻¹). The planting density was 6 x 4.6 m. No organic matter was applied at planting. Pruning material was chipped and left between rows, every season, for the last sixteen years. The orchard was drip-irrigated with a double drip line with 6 drippers per plant (0.8 mm ha⁻¹ hour⁻¹). The average yield of the orchard was 60 ton ha⁻¹, 75% exporting quality. The orchard presented a large spatial variability in terms of aboveground biomass due to decayed plants characterized by lower shoot growth, smaller size, and chlorotic leaves, compared to healthy plants.

2.3 Organic amendment and chemical fertilization

Mature compost type A, according to Chilean standard (NCh 2880/04-2016), was produced from grape pomace. The material had 20% of C, a NH₄-N /NO₃-N/ ratio of 0.81, and low content of trace elements (INN, 2016) (Table 1). The compost was applied in a band around each tree, during wintertime (July) of each evaluated season. The chemical fertilization contained N, P₂O₅, and K₂O and it was applied during the growing season from October to February.

Table 1

Chemical properties of compost and soil

Property	Units	Soil	Compost
pH		7.04	7.8
E.C. (suspension)	(dS/m)	0.07	0.86
Organic Matter	%	2.45	38.7
NaHCO ₃ -P	ppm	17	448
Moisture content	%	-	47.2
Total nitrogen	%	-	1.3
Total phosphorus	%	-	0.24
C/N ratio	-	-	16
NO ₃ -N	ppm	-	229.0
NH ₄ -N	ppm	-	185.0
Extractable nitrogen	ppm	10	414.0
NH ₄ -N/ NO ₃ -N	-	-	0.81
K	ppm	257	-
Cu	ppm	90.4	-
Fe	ppm	56.5	-
Mn	ppm	21.5	-
Zn	ppm	2.9	-
B	ppm	0.9	-
S	ppm	0.4	-
Ca	meq 100g ⁻¹	16.4	-
Mg	meq 100g ⁻¹	3.0	-
K	meq 100g ⁻¹	0.6	-
Na	meq 100g ⁻¹	0.2	1.4
NMP <i>Salmonella</i> sp.	NMP g ⁻¹	-	< DL
NMP <i>Escherichia coli</i>	NMP g ⁻¹	-	< DL

2.4 Experimental design

To evaluate the effects of INM two treatments were applied: T₁: control (conventional) and T₂: integrated nutrition management (INM). Treatments were assigned on 189 pear trees of different initial vigor (very low, low, medium, and normal). The initial vigor was determined by an existing aerial NDVI image. The experimental design was completely randomized, in a factorial arrangement of 2 treatments x 4 vigor levels, with four replicates. The INM treatment consisted of the application of 4 ton ha⁻¹ of carbon (C) as compost, together with an adjusted chemical fertilization of 70 kg N ha⁻¹, 20 kg P₂O₅ ha⁻¹, and 66 kg K₂O ha⁻¹ season⁻¹, respectively. The control included only the chemical fertilization at the same rates. The irrigation water applied was, on the average, 9,200 m³ ha⁻¹ season⁻¹, corresponding to 27.6 m³ plant⁻¹ season⁻¹. The management for recovery also included the absence of winter pruning in the first season, pruning in the second one, and removal of all fruit set in summer each season.

2.5 Evaluation of agronomic variables

For each pear tree, the total growth of branches \geq 20 cm was measured. Four branches (one at each cardinal point), at 1,5 m height, were selected for NDVI measurement. The NDVI was measured using the active sensor Crop Circle ASC-210 (Holland Scientific®); 20 leaf samples per tree were taken at different heights. Root density was determined using a known volume of soil which was washed through a 2-mm sieve for preventing the passage of the roots. Collected roots were carefully washed and dried in an oven with forced air at 65 °C. Root density was reported in kg root m⁻³ of soil. Pruning weight was determined from each tree in winter (g tree⁻¹).

2.6 Tissue analysis

The foliar analysis was performed in the summer, following the methodologies proposed by the National Laboratory Accreditation Commission (Sadzawka et al., 2007).

2.7 Soil analysis

Soil pH and electrical conductivity (EC) were measured according to Sadzawka (1990). Ammonium (NH₄-N) and nitrate (NO₃-N) contents were quantified by the colorimetric method described by Mulvaney (1996). Phosphorus availability was estimated by using the NaHCO₃ extractant and determined according to Sadzawka et al. (2006). Organic matter content was determined by the Walkley and Black method (Sadzawka et al., 2006). Yeast and phosphate solubilizing microorganisms were grown in potato dextrose agar and SMRS1 agar, respectively (Novo et al., 2015). Microbial colonies were counted as colony forming units per fresh gram of soil (CFU g⁻¹) (Novo et al., 2015). Furthermore, β -glucosidase was evaluated by measuring the *p*-nitrophenol released from *p*-nitrophenyl- β -D-glucopyranoside (pNPG), expressing the results in terms of β -glucosidase units (UBG = μ g *p*-nitrophenol glucopyranose released g⁻¹ h⁻¹ of the dry sample).

2.8 Soil quality and yield follow up after 5 growing seasons

After five growing seasons, a systematic soil sampling was performed at 30 cm depth to evaluate the changes produced with the application of INM. A total of 20

composited samples (5 probes point⁻¹) were collected in a systematic grid, 10 of them for the INM and the remaining 10 for the conventional one. Each sample was georeferenced using a Global Navigation Satellite System (GNSS) unit. The following variables were measured: soil pH, soil organic matter, soluble C, and dehydrogenase activity, using the methodologies described before. Along with that, the yields for the pear orchard were recorded for the whole field.

2.9 Statistical analyses

Data were evaluated by correlation and regression analyses, and independent sample t-test using the Stata® software. The stepwise procedure was developed to estimate a regression model to explain root density. Properties measured after five years, were mapped for the whole field, to evaluate their spatial variability. Maps were performed using the kriging interpolation algorithm in the software SMS (AgLeader Technology, Ames, Iowa, USA).

3. Results and discussion

Pear is one of the most important fruits worldwide (FAOSTAT, 2018). After some years of production, orchards show a decay process, which affects tree growth and production, caused by several physical, chemical, and biological changes in soil properties, as soil infiltration, water holding capacity, electrical conductivity among others (Aruani et al., 2012). Using the tools of integrated nutrient management (INM), through the application of organic matter and adjusted mineral fertilization it is possible to improve soil quality, nutritional status, and root development to increasing tree vigor, rhizogenesis and yield (Martínez et al., 2018). The changes in soil properties could be “tracked” using sensible indicators as biological activity or potential enzymatic activity, which are soil quality indicators due to its participation in organic matter degradation and mineralization (Huera-Lucero et al., 2020; Adetunji et al., 2017, Angulo et al., 2015). The degradation of compost and other cellulose-related compounds in soil is directly related to potential of endoglucanases, especially to β -glucosidase, which is a very practical and sensitive indicator (Partey et al., 2019; Martínez et al., 2018). Other studies evidenced that vermicompost, straw mulch, farmyard manure applied to a subtropical mango (*Mangifera indica* L.) orchard improves microbiological activity, soil nutrient availability and carbon stock, enhancing fruit yield (Kumari et al., 2020). In this study, potential β -glucosidase activity increased 66% under INM treatment at all evaluated vigor levels (478.0 μ g *p*-nitrophenol g⁻¹h⁻¹ versus 288.3 of control μ g *p*-nitrophenol g⁻¹h⁻¹) (Data not shown). The values of β -glucosidase are considerably higher compared to previous studies in table grape soils (~ 50 μ g *p*-nitrophenol g⁻¹h⁻¹), suggesting differences in soil quality, irrigation, and fertilization management (Morugán-Coronado et al., 2019; Martínez et al., 2018). Moreover, the data support that β -glucosidase activity increased under INM due to the presence of organic amendments, which improve the microorganism's activity (Günel et al., 2018). Our results were consistent with those obtained by Mariscal-Sancho et al. (2018), who concluded that β -glucosidase activity depends directly on the presence of

organic carbon and biological activity, constituting an indicator of soil quality. Furthermore, the increase in β -glucosidase activity indicates further degradation of cellulose converted into glucose, which is an energy source for soil microorganisms, thus increasing the activity of the microbial biomass (Partey et al., 2019; Martínez et al., 2010).

Regarding physical properties, INM reduced soil bulk density (BD) compared to the control treatment, regardless of the vigor level (0.8 vs 1.1 g cm⁻³) (Data not shown). BD impacted the porosity, which increased by 19% under INM (55.9 to 66.6% porosity). These results showed that BD decreased under INM, suggesting its positive influence on root development and nutrient uptake. Besides, BD determines the pore space, which is a key property for irrigation and soil aeration processes. On the contrary, a high BD generally indicates compaction problems, decreased porosity, poor aeration, reduction of water infiltration rate, and a mechanical impediment for root growth (Martínez et al., 2018). It is noted that organic matter included in INM treatment can play an important role to modulate BD (Chen et al., 2017; Liu et al., 2013).

Additionally, root density significantly increased with INM application, reaching around 20 kg cm⁻³ versus 2.5 kg cm⁻³ of the control treatment (Figure 1). It noteworthy that root density is a relevant indicator of rhizogenesis process. Root density was almost 1,000% larger under the INM treatment compared to conventional management. Similar results were obtained by Baldi et al. (2010ab) using annual compost applications, increasing root density by 435% and the SOC from 2.45 to 7.82%. Martínez et al. (2018) found an increased root density with the increase in C rate in a study performed in table grapes because of the effects of different organic matter fractions on BD and the improvement of porosity. Moreover, the presence of organic matter in the soil increases biological and microbiological activity, improving nutrient availability and releasing growth-promoting substances into the soil solution that improves root development (Morugán-Coronado, 2019; Sharma et al., 2017; Magdoff & Van Es, 2010). A larger root mass improves water and nutrient uptake, stimulating the rhizogenic process and microbial - plant beneficial associations. Besides, enhanced root growth also improves plant greenness and aboveground biomass (Roussos et al., 2019; Wasaya et al., 2018; Ortega & Fernandez, 2007). It has been shown that compost application produces larger shoot length and diameter compared with mineral fertilization in apple and pears (Safaei Khorram et al., 2018). In this study, a significant increase in growth parameters as shoot growth and pruning weight was found (Data not shown).

Few significant effects were observed on foliar nutrient levels. The INM increased Cu and Na concentrations in leaves compared to conventional treatment ($P < 0.05$). Besides, Zn concentration was 25% lower under the INM treatment, probably by Cu competition. Significant differences were observed in foliar P levels, with a significant orderly interaction treatment x vigor. On average, P levels were lower under INM compared to conventional management. Probably, the dilution effect could explain part of these results. Nevertheless, no statistically

significant differences were found in the leaf content of N, K, Ca, Mg, Mn, Fe, and B (data not shown). A nutritional index (NI) was built to estimate absolute amounts of nutrients within the tree biomass by multiplying nutrient concentration times NDVI. This index allows comparing the nutrient amounts present in the leaves eliminating the concentration/dilution effects. Specifically, NDVI corresponds to a non-linear combination of the visible (red) and near-infrared bands to enhance vegetation (Tan et al., 2020; Xue & Su, 2017). Table 2 shows nutrient amounts in leaves as estimated by NI. The INM had a significant effect on NI compared to the conventional treatment. The INM affected nutrient absorption by plants and stimulated plant development (Ortega & Fernandez, 2007). On average, NDVI measured in summer was almost 17% larger for INM compared to the conventional treatment. The INM treatment increased nutrient uptake as compared to the conventional treatment in terms of N (13.6%), K (17.6%), Ca (11.4%), Mg (11%), Cu (41%) and Fe (23%). On the other hand, NI for Zn was 13.2% lower under INM corroborating that the decrease was not due to the dilution effect. The results showed significant effects of INM on Cu leaf content since the field had a high copper content (>50 ppm DTPA-Cu, data not shown). Consequently, Zn content was 25% lower under INM, probably by Cu competition. The large increase in Cu could be explained due to its high content in the soil as explained above. Previous studies indicate that the INM, and particularly the applications of organic matter, generates changes in the absorption ratios of metals such as Cu or Zn (Salam et al., 2019). In the case of P, although there were significant statistical differences in foliar levels for INM respect to conventional management, there was significant interaction treatment x vigor. On average, P foliar levels were lower under INM compared to conventional management. However, the difference was larger as the plant vigor (biomass) increased. This is an expected result since under INM a dilution of P content with vigor was observed. In the case of N and K results differ from those obtained by Ortega & Fernandez (2007), who found statistical differences in the uptake of N, P and K in ryegrass.

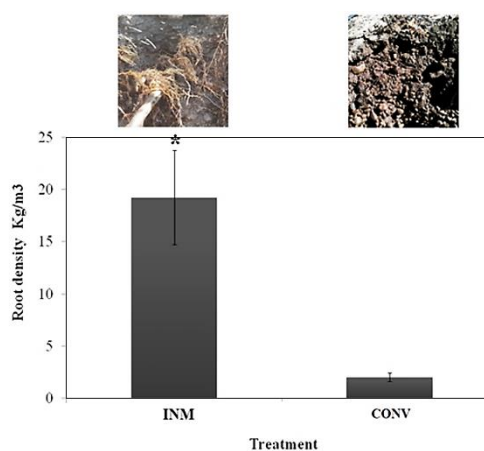


Figure 1. Effect of INM on root density in pear after 2 seasons. * = Indicates statistically significant differences. Abbreviations: INM= Integrated Nutrition Management, CONV= Conventional.

Table 2

Treatment and vigor effects on Nutritional Indices (NI). Abbreviations: CONV =Conventional, INM= Integrated Nutrition Management, AV= Average

Vigor	Nutritional Index (NI)											
	N			P			K			Ca		
	CONV	INM	AV	CONV	INM	AV	CONV	INM	AV	CONV	INM	AV
	Unitless											
Very low	0.798	0.952	0.88	0.072	0.089	0.08	0.426	0.586	0.51	0.874	0.914	0.89
Low	0.931	0.997	0.96	0.078	0.085	0.08	0.570	0.609	0.59	0.850	0.962	0.91
Medium	0.918	1.063	0.99	0.083	0.084	0.08	0.528	0.605	0.57	0.886	1.015	0.95
Normal	0.883	1.006	0.94	0.083	0.078	0.08	0.516	0.599	0.56	0.852	0.978	0.92
Average	0.88	1.000		0.08	0.08	0.08	0.510	0.600		0.870	0.970	
	<i>P</i> -value											
Treatment	0.032			0.028			0.052			0.007		
Vigor	0.238			0.835			0.418			0.293		
Treat. x vigor	0.961			0.005			0.542			0.199		

Vigor	Nutritional Index (NI)											
	Mg			Cu			Zn			Mn		
	CONV	INM	AV	TRAD	INM	AV	TRAD	INM	AV	TRAD	INM	AV
	Unitless											
Very low	0.095	0.101	0.10	3.04	3.82	3.43	14.44	10.53	12.49	58.90	49.05	53.98
Low	0.085	0.121	0.10	2.61	3.79	3.20	11.96	11.60	11.79	43.28	51.40	47.23
Medium	0.087	0.115	0.10	2.77	4.08	3.43	12.78	11.76	12.27	49.42	59.28	54.35
Normal	0.083	0.099	0.09	2.48	3.76	3.12	12.85	11.28	12.07	49.35	51.46	50.41
Average	0.090	0.11		2.73	3.86		13.01	11.29		50.24	52.80	
	<i>P</i> -value											
Treatment	0.036			0.001			0.001			0.007		
Vigor	0.507			0.271			0.271			0.293		
Treat. x vigor	0.732			0.227			0.227			0.199		

Vigor	Nutritional Index (NI)									
	Fe			Na			B			
	TRAD	INM	AV	TRAD	INM	AV	TRAD	INM	AV	
	Unitless									
Very low		150.86	176.37	163.62	10.26	15.07	12.67	153.90	145.50	149.70
Low		150.29	177.19	163.75	13.48	14.45	13.97	145.94	144.03	144.99
Medium		150.40	187.20	168.80	12.35	14.88	13.62	152.32	152.88	152.60
Normal		111.56	152.04	131.80	11.61	13.39	12.50	126.08	138.18	132.13
Average		140.78	173.20		11.93	14.45		144.56	145.15	
	<i>P</i> -value									
Treatment	0.039			0.928			0.040			
Vigor	0.132			0.172			0.834			
Treat. x vigor	0.598			0.172			0.374			

Additionally, we evaluated the INM to determine its impact in soil properties after two seasons. Soil samples corresponding to INM and conventional treatments were collected after two seasons from application to evaluate changes in chemical and biological properties (Table 3). The INM increased ($P < 0.05$) electric conductivity (0.28 versus 0.17 dS m⁻¹, respectively), organic matter (5.25 versus 2.39 %, respectively), and available nitrogen (57.7 versus 3.9 ppm, respectively) compared to the conventional treatment. Regarding biological activity, there were statistical differences in β- glucosidase activity with higher potential activity for the INM treatment (316.8 vs 132.5 μg p-nitrophenol g⁻¹h⁻¹). The soil analyses are in concordance with the results of other authors (Partey et al., 2019; Mariscal-Sancho et al., 2018; Adetunji et al., 2017; Van Schoor et al., 2012). For soil nutrient contents, INM showed significantly higher levels than the control in terms of available N, NO₃-N, and NaHCO₃-P, similarly, as described by Riches et al. (2013) and Roussos et al. (2019). To evaluate the more permanent effects of INM, soils were analyzed after 5 years from establishment (Figure 2). The results showed that after 5 years, there was no difference in soil pH of both evaluated treatments. It was possible to

observe a large increase in soluble C and dehydrogenase activity, both properties related to rhizogenesis and biological activity in the soil. Besides, the application of mature and stabilized organic matter as compost improved soil organic carbon, nutrient content, plant available water and microorganism's activity (Kranz et al., 2020; Sánchez-Monedero et al., 2019; Kallenbach et al., 2016; Angulo et al., 2014). Organic matter contents were higher in soil under INM compared to conventional management (SOM~ 8% versus ~ 5.5%). Besides, soluble C (35 mg Kg⁻¹ versus 15 mg Kg⁻¹) and dehydrogenase activity increased under INM (110 μg TFP g⁻¹ day⁻¹ versus 56 TFP g⁻¹ day). The importance of the application of enriched compost with an adjusted inorganic fertilizer has been evidenced in rice crops through enhancing Zn, Cu, Fe, Ni, and Mn in soil and mitigating the Al toxicity in acids soil after ten years of application (Patra et al., 2021). Furthermore, Triverdi et al. (2020) reported that 60 years of INM with adjusted inorganic fertilizers improved carbon sequestration in corn (*Zea mays L.*) and corn (*Triticum aestivum L.*) crops at different soil layers (15-60 cm of soil depth). On the other hand, it has been found that the application of organic and inorganic amendments

together with microbial inoculants improved P mobilization and solubilization at long- term cereal-vegetables-legume rotations (Ghosh et al., 2021). Figure 3 shows the spatial variability of soil pH, OM, soluble carbon, and dehydrogenase between treatments, which is reflected by color intensity.

According to the results obtained in this study, the recovery of decayed trees in a pear orchard must be performed from a holistic perspective. The orchard management recognizes a system where soil, plants and microorganisms coexist and interact with each other. An integrated nutrition management program allows the orchard recovery through the improvement of the

physical, chemical, and biological soil properties directly involved in root growth. This was demonstrated by the regression model obtained using the stepwise procedure to explain root density (equation 1).

$$\text{Root Density} = 198 + 0.029 \beta\text{Glu} - 30\text{BD} - 293\text{EC} - 23\text{pH} + 23 \text{OM} \quad [\text{eq. 1}]$$

$$R^2 = 0.90, n = 189$$

Where Root density: root density (kg/m³); β Glu: beta-glucosidase activity (μg p-nitrophenol g⁻¹h⁻¹); EC: electrical conductivity (dS/m); pH: soil pH (pH units); OM: organic matter (%).

Table 3

Treatment effects on soil properties determined in spring after two seasons. Abbreviations: INM= Integrated Nutrition Management, CONV= Conventional Management

Variable	Unit	CONV	INM	Average	P-value
pH	-	7.4	7.3	7.4	0.52
Electrical conductivity	dSm ⁻¹	0.1	0.2	0.2	< 0.01
Organic matter	%	2.3	5.2	3.8	< 0.01
Available nitrogen	ppm	3.9	57.7	30.8	< 0.01
NO ₃ -N	ppm	3.5	56.7	30.1	< 0.01
NH ₄ -N	ppm	0.3	0.9	0.6	0.239
P-Olsen	ppm	47.5	103.0	75.2	0.01
β-Glucosidase	μg p-nitrophenol g ⁻¹ h ⁻¹	132.5	316.7	224.6	< 0.01
Yeast count	UFC g ⁻¹	87.0	277.5	182.2	0.080
Phosphate solubilizers	UFC g ⁻¹	110.0	29.5	69.7	0.340

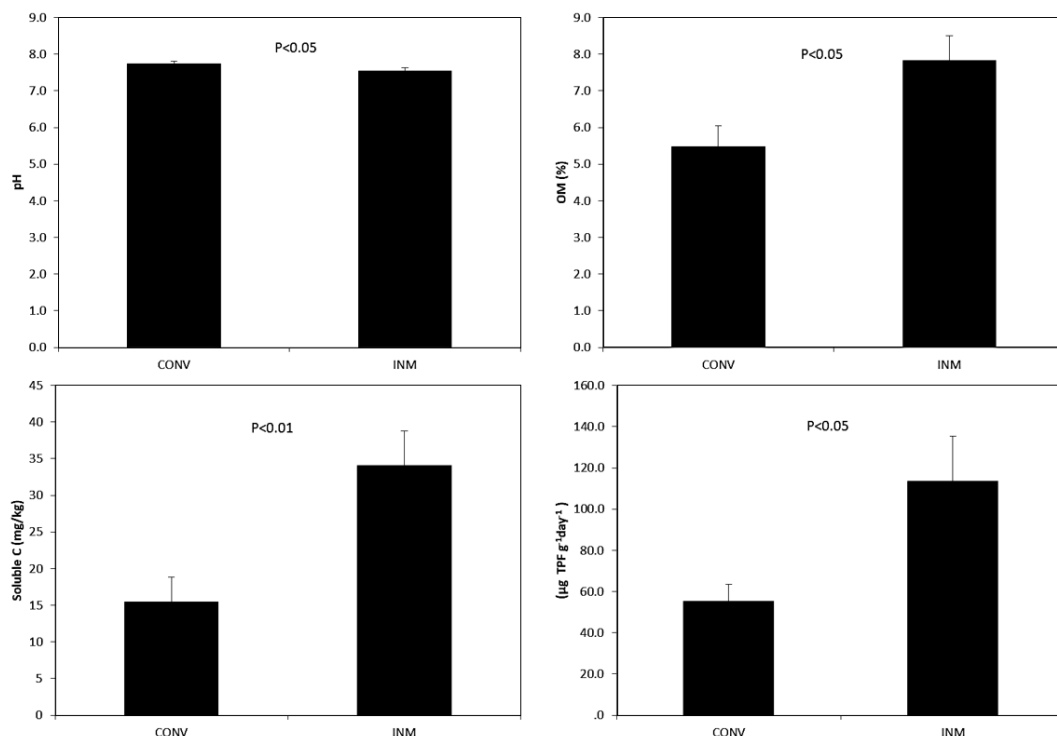


Figure 2. Comparison between conventional and integrated nutrition management in terms of soil pH (left above), organic matter (right above), soluble C (left below), and dehydrogenase activity (right below) after 5 years.

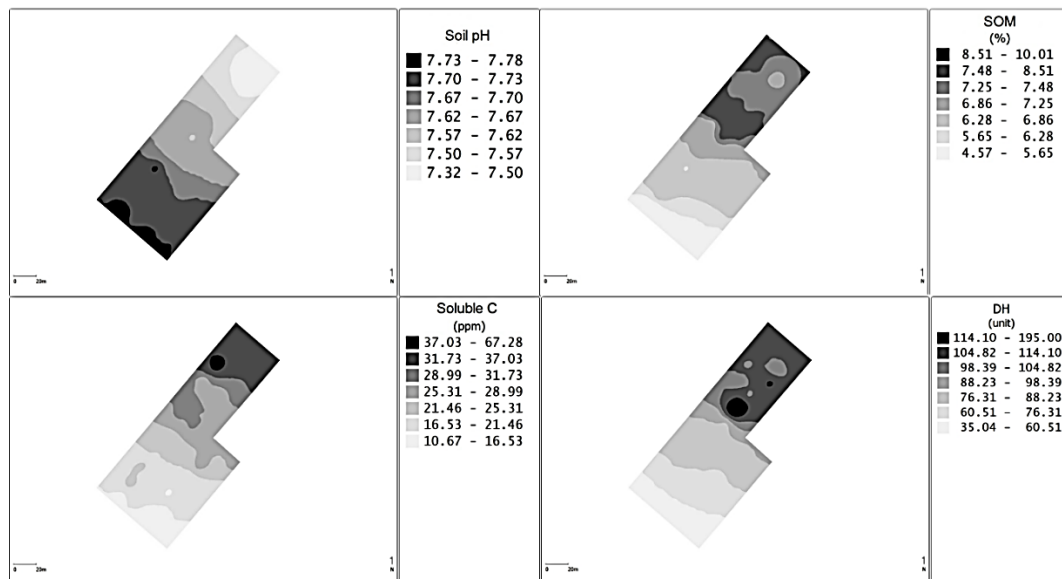


Figure 3. Spatial variability of soil pH (left above), organic matter (right above), soluble C (left below), and dehydrogenase activity (right below) after 5 years. In each map, the INM corresponds to the upper half of the field.

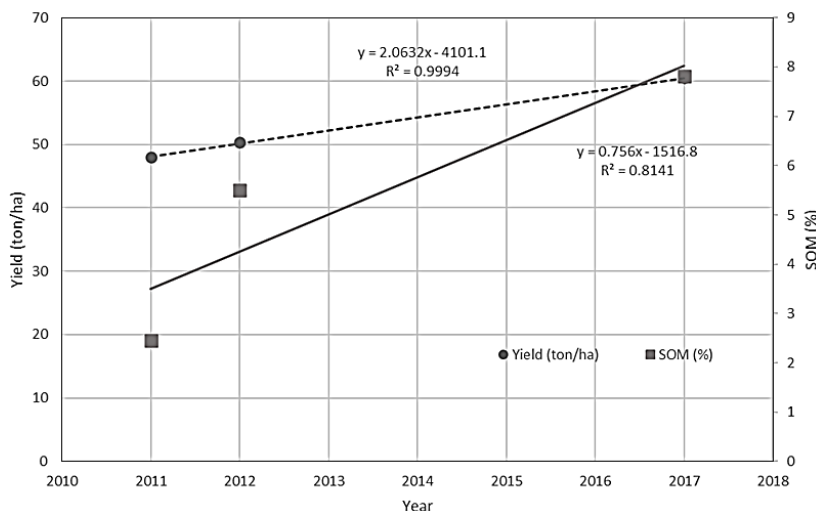


Figure 4. Yield and SOM for trends in the INM experiment after 5 years.

The model clearly describes the importance of soil organic matter and microbial activity on pear root density. Finally, Figure 4 shows the increase in pear yield in parallel to SOM increment. In terms of soil quality, several indicators significantly changed after 5 years of INM, which directly related to orchard productivity.

4. Conclusions

The main effects of Integrated Nutrition Management (INM) were an increase in soil organic matter and overall soil fertility, which increased microbial activity in the soil, decreased soil bulk density, and increased porosity, which in turn allowed for a better root development, which expressed in terms of improved vigor and a continuous increase in yield. Integrated nutrition management, along with proper canopy management, resulted in an effective practice to recover decayed pear orchards within an

appropriate time frame. Although the integrated management of soils and crops is an ancient concept, demonstrating its effects in time and space will allow for a better use of organic matter and mineral fertilization, in both organic and conventional fruit agroecosystems, according to their site-specific requirements and objectives.

Acknowledgements

The authors thank the Sociedad Agrícola La Rosa and its collaborators for the support received to carry out this project.

ORCID

- H. Poblete [ID https://orcid.org/0000-0002-2072-6074](https://orcid.org/0000-0002-2072-6074)
- M.M. Martínez-Salgado [ID https://orcid.org/0000-0001-9028-0752](https://orcid.org/0000-0001-9028-0752)
- R. Ortega-Blu [ID https://orcid.org/0000-0001-8294-1311](https://orcid.org/0000-0001-8294-1311)
- P. Fincheira [ID https://orcid.org/0000-0002-6234-4808](https://orcid.org/0000-0002-6234-4808)

References

- Adetunji, A. T., Lewu, F. B., Mulidzi, R., & Ncube, B. (2017). The biological activities of β -glucosidase, phosphatase and urease as soil quality indicators: a review. *Journal of Soil Science and Plant Nutrition*, 17(3), 794-807.
- Angulo, J., Ortega, R., Martínez, M., Molina, M., & Torres, A. (2014). Evaluation of solid and liquid soil organic amendments for agronomic use in Chile. *Acta Horticulturae*, 1018, 109-114.
- Aruani, M., Gili, P., Machuca, Y., & Spera, N. (2012). Evaluación de las características físico-químicas y biológicas en dos suelos superficiales cultivados con pera (*Pyrus communis* L.) cv. Williams bajo manejo convencional. *Revista de la Facultad de Ciencias Agrarias, Universidad Nacional de Cuyo*, 44(1), 77-84.
- Baldi, E., Tosselli, M., & Maragoni, B. (2010a). Nutrient partitioning in potted peach (*Prunus persica* L.) trees supplied with mineral and organic fertilizers. *Journal of Plant Nutrition*, 33, 2050-2061.
- Baldi, E., Tosselli, M., Esissenstat, D. M., & Maragoni, B. (2010b). Organic fertilization leads to increased peach root production and lifespan. *Tree physiology*, 30, 1373-1382.
- Brunetto, G., Bastos de Melo, G., Toselli, M., Quartieri, M., & Tagliavini, M. (2015). The role of mineral nutrition on yields and fruit quality in grapevine, pear and apple. *Revista Brasileira de Fruticultura*, 37(4), 1089-1104.
- Burg, P., Zemanek, P., & Michálek, M. (2011). Evaluating of selected parameters of composting process by composting of grape pomace. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 59(6), 75-80.
- Chen, Y., Huang, Y., & Sun, W. (2017). Using organic matter and pH to estimate the bulk density of afforested/reforested soils in Northwest and Northeast China. *Pedosphere*, 27(5), 890-900.
- Das, D., Dwivedi, D. S., & Meena, M. C. (2015). Integrated nutrient management for improving soil health and crop productivity. *Indian Journal of Fertilisers*, 11(4), 64-83.
- Fincheira-Robles, P., Martínez-Salgado, M.M., Ortega-Blu, R., Janssens, M., & Parada-Ibañez, M. (2018). Soil quality indicators in table grape (*Vitis vinifera* cv. Thompson seedless) crops under integral nutrition management. *Scientia Agropecuaria*, 9(1), 17-24.
- Flores, L., Martínez, M. M., & Ortega, R. (2015). Integrated nutrition program in cherry (*Prunus avium* L.). *Acta Horticulturae*, 1076, 187-192.
- Food and Agriculture Organization of the United Nations (FAOSTAT). 2018. Production quantities of pears by country. <http://www.fao.org/faostat/en/#data/QC/visualize>.
- Ghosh, D., Mandal, M., & Pattanayak, S.K. (2021). Long term effect of integrated nutrient management on dynamics of phosphorous in an acid *Inceptisols* of tropical India. *Communications in Soil Science and Plant Analysis*, in press.
- Günel, E., Erdem, H., & Demirbaş, A. (2018). Effects of three biochar types on activity of β -glucosidase enzyme in two agricultural soils of different textures. *Archives of Agronomy and Soil Science*, 64(18), 1963-1974.
- Huera-Lucero, T., Labrador-Moreno, J., Blanco-Salas, J., & Ruiz-Téllez, T. (2020). A framework to incorporate biological soil quality indicators into assessing the sustainability of territories in the Ecuadorian amazon. *Sustainability*, 12, 3007.
- Ikinci, A., Bolat, I., Ercisli, S., & Ossama, K. (2014). Influence of rootstocks on growth, yield, fruit quality and leaf mineral element contents of pear cv. 'Santa Maria' in semi-arid conditions. *Biological Research*, 47, 71.
- Instituto Nacional de Normalización-INN. (2016). *Compost- Quality requirements and classification 2880-2016*. 16 p.
- Jackson, J. E. (2003). *Biology of apples and pears*. Cambridge University Press, United Kingdom. 488 p.
- Kallenbach, C. M., Frey, S. D., & Grandy, A. S. (2016). Direct evidence for microbial-derived soil organic matter formation and its ecophysiological controls. *Nature Communications*, 7, 13630.
- Kranz, C. N., McLaughlin, R. A., Johnson, M.; Miller, G., & Heitman, J. L. (2020). The effects of compost incorporation on soil physical properties in urban soils – A concise review. *Journal of Environmental Management*, 267, 110209.
- Kujur, M., & Kumar Patel, A. (2014). Kinetics of soil enzyme activities under different ecosystems: An index of soil quality. *Chilean Journal of Agricultural Research*, 74(1), 96-104.
- Kumari, R., Kundu, M., Das, A., Rakshit, R., Sahay, S., et al. (2020). Long-term integrated nutrient management improves carbon stock and fruit yield in a subtropical mango (*Mangifera indica* L.) orchard. *Journal of Soil Science and Plant Nutrition*, 20, 725-737.
- Ling-Fei, X., Peng, Z., Qing-fang, H., Zhi-Hui, L., Bao-Ping, Y., & Jun-Feng, N. (2013). Spatial distribution of soil organic matter and nutrients in the pear orchard under clean and sod cultivation models. *Journal of Integrative Agriculture*, 12(2), 344-351.
- Liu, C.H., Liu, Y., Fan, C., & Kuang, Z. (2013). The effects of composted pineapple residue return on soil properties and the growth and yield of pineapple. *Journal of Soil Science and Plant Nutrition*, 13(2), 433-444.
- Magdoff, F., & Van Es, H. (2010). *Building soils for better crops*. Sustainable Agriculture Research and Education (SARE) program. 294 pp.
- Mariscal-Sancho, I., Ball, B., & McKenzie, B. (2018). Influence of tillage practices, organic manures and extrinsic factors on β -glucosidase activity: The final step of cellulose hydrolysis. *Soil Systems*, 2, 21.
- Martínez, M., Gutiérrez, V., & Novo, R. (2010). *Microbiología aplicada al manejo sustentable de suelos y cultivos*. Ed. Universidad Santa María, Chile. 235 p.
- Martínez, M., Ortega, R., Janssens, M., & Fincheira, P. (2018). Use of organic amendments in table grape: effect on plant root system and soil quality indicators. *Journal of Soil Science and Plant Nutrition*, 18(1), 100-112.
- Merino, C., Godoy, R., & Matus, F. (2016). Soil enzymes and biological activity at different levels of organic matter stability. *Journal of Soil Science and Plant Nutrition*, 16(1), 14-30.
- Morales-Olmedo, M., Ortiz, M., & Sellés, G. (2015). Effects of transient soil waterlogging and its importance for rootstock selection. *Chilean Journal of Agricultural Research*, 75, 45-56.
- Morugán-Coronado, A., García-Orenes, F., McMillan, M., & Pereg, L. (2019). The effect of moisture on soil microbial properties and nitrogen cyclers in Mediterranean sweet orange orchards under organic and inorganic fertilization. *Science of the Total Environment*, 655, 158-167.
- Mulvaney, R. (1996). *Methods of Soil Analysis: Chemical Methods*. Soil Science Society of America. Madison, United States.
- Nimmo, J. R. (2013). *Porosity and pore size distribution*. Reference Module in Earth Systems and Environmental Sciences. 10 p.
- Novo, R., Martínez, M. M., Ortega, R., Ospina, P., & Carrascal-Camacho, K. (2015). *Manual de prácticas clásicas en microbiología y bioquímica para el estudio de suelos, bioproductos y materiales orgánicos*. Editorial USM. Santiago, Chile. 137 pp.
- Oficina de Estudios y Políticas Agrarias - Centro de Información de Recursos Naturales (ODEPA-CIREN). (2017). *Catastro frutícola principales resultados Región Metropolitana / Julio 2017*. 52 pp.
- Oficina de Estudios y Políticas Agrarias (ODEPA). (2018). *Boletín de Fruta Fresca Octubre 2018*. Santiago, Chile.
- Oficina de Estudios y Políticas Agrarias (ODEPA). (2020). *Boletín de Fruta Febrero 2020*. Santiago, Chile.
- Ortega, R., & Fernandez, M. (2007). Agronomic evaluation of liquid humus derived from earthworm humic substances. *Journal of Plant Nutrition*, 30(12), 2091-2104.
- Ortega, R. (2015). Integrated nutrient management in conventional intensive horticulture production systems. *Acta Horticulturae*, 1076, 159-164.
- Ouyang, Y., Reeve, J. R., & Norton, J. M. (2018). Soil enzyme activities and abundance of microbial functional genes involved in nitrogen transformations in an organic farming system. *Biology and Fertility of Soils*, 54(4), 437-450.
- Partey, S., Zougmoren, R., Thevathasan, N., & Preziosi, R. F. (2019). Effects of plant residue decomposition on soil n availability, microbial biomass and β -glucosidase activity during soil fertility improvement in Ghana. *Pedosphere*, 29(5), 608-618.
- Patra, A., Sharma, V. K., Nath, D. J., Purakayastha, T. J., Barman, M., et al. (2021). Impact of long term integrated nutrient management (INM) practice on aluminum dynamics and nutritional quality of rice under acidic Inceptisol. *Archives of Agronomy and Soil Science*, In press.
- Poblete, H., Martínez, M., & Ortega, R. (2013). Integrated plant nutrition on the recovery of a pear (*Pyrus communis* 'Packam's Triumph') orchard. *Acta Horticulturae*, 1076, 179-186.
- Riches, D., Porter, I. J., Oliver, D. P., Bramley, R. G. V., Rawnsley, B., et al. (2013). Review: soil biological properties as indicators of soil quality in Australian viticulture. *Australian Journal of Grape and Wine Research*, 19, 311-323.
- Roussos, P., Flessoura, I., Petropoulos, F., Massas, I., et al. (2019). Soil physicochemical properties, tree nutrient status, physical, organoleptic and phytochemical characteristics and antioxidant capacity of clementine mandarin (*Citrus Clementine* cv. SRA63) juice under integrated and organic farming. *Scientia Horticulturae*, 250, 414-420.
- Sadzawka, A. (1990). *Métodos de análisis de suelos*. Serie La Platina N°16. Instituto de Investigaciones Agropecuarias- INIA. Santiago, Chile. 130 p.
- Sadzawka, A., Carrasco, M., Grez, R., Mora, M., Flores, H., & Neaman. (2006). *Métodos de análisis recomendados para los suelos de Chile Revisión 2006*. Serie actas INIA N° 34. Instituto de Investigaciones Agropecuarias- INIA. Santiago, Chile. 164 pp.
- Sadzawka, A., Carrasco, M., Demanet, R., Flores, H., Grez, R., et al. (2007). *Métodos de análisis de tejidos vegetales*. Serie actas INIA N°40. Instituto de Investigaciones Agropecuarias- INIA. Santiago. Chile. 120 pp.
- Safaei Khorram, M., Zhang, G., Fatemi, A., Kiefer, R., Maddah, K., et al. (2018). Impact of biochar and compost amendment on soil quality, growth and yield of a replanted apple orchard in a four-year field study. *Journal of the Science of Food and Agriculture*, 99(4), 1862-1869.
- Salam, A., Bashir, S., Khan, I., Hussain, Q., Gao, R., & Hu, H. (2019). Biochar induced Pb and Cu immobilization, phytoavailability attenuation in Chinese cabbage, and improved biochemical properties in naturally co-contaminated soil. *Journal of Soils and Sediments*, 19(5), 2381-2392.

- Sánchez-Monedero, M. A., Cayuela, M. L., Sánchez-García, M., Vandecasteele, B., D'Hose, T., et al. (2019). Agronomic evaluation of biochar, compost and biochar-blended compost across different cropping systems: Perspective from the european project FERTIPLUS. *Agronomy*, 9, 225.
- Sharma, A., Nath Saha, T., Arora, A., Shah, R., & Nain, L. (2017). Efficient microorganism compost benefits plant growth and improves soil health in calendula and marigold. *Horticultural Plant Journal*, 3(2), 67-72.
- Shunfeng, G. E., Zhanling, Z., Peng, L., Chen, Q., & Jiang, Y. (2018). Soil nutrient status and leaf nutrient diagnosis in the main apple producing regions in China. *Horticultural Plant Journal*, 4(3), 89-93.
- Sorrenti, G., Tosselli, M., & Marangoni, B. (2012). Use of compost to manage Fe nutrition of pears trees grown in calcareous soil. *Scientia Horticulturae*, 136, 87-94.
- Triverdi, A., Bhattacharyya, R., Biswas, D.R., Das, S., Das, T.K., et al. (2020). Long-term impacts of integrated nutrient management with equivalent nutrient doses to mineral fertilization on soil organic carbon sequestration in a sub-tropical Alfisol of India. *Carbon Management*, 11, 483-497.
- Universidad de Talca. (2018). *Boletín Técnico Pomáceas*. Boletín Técnico Universidad de Talca, 18(1). Recuperado de: <http://pomaceas.utalca.cl>.
- Tan, C. W., Zhang, P. P., Zhou, X. X., Wang, Z. X., Xu, Z. Q., et al. (2020). Quantitative monitoring of leaf area index in wheat of different plant types by integrating NDVI and Beer-Lambert law. *Scientific Reports*, 10, 929.
- Van Schoor, L., Stassen, P. J. C., & Botha, A. (2012). Effect of organic material and biological amendments on pear tree performance and soil microbial and chemical properties. *Acta Horticulturae*, 933, 205-214.
- Wasaya, A., Zhang, X., Fang, Q., & Yang, Z. (2018). Root phenotyping for drought tolerance: A review. *Agronomy*, 8, 241.
- Wu, W., & Ma, B. (2015). Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. *Science of the Total Environment*, 512, 415-427.
- Xue, J., & Su, B. (2017). Significant remote sensing vegetation indices: a review of developments and applications. *Journal of Sensors*, 2017, ID 1353691.