# Soil Chemical and Enzyme Activity after Irrigation with Diluted Winery Wastewater in the Vineyard at Stellenbosch, Western Cape Province

Takalani Sikhau, Adewole Tomiwa Adetunji, Carolyn Howell, Reckson Mulidzi and Francis Bayo Lewu

***Abstract-*** This study assessed the effect of diluted WWW and raw water on soil chemical parameters including pH, potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na), and soil enzyme activities including β-glucosidase, phosphatase, and urease, where different summer catch crops were cultivated over one season. The experimental design was a complete randomized block design (CRBD) with 3 replications. After the application of diluted WWW and raw water over one season, there was a significant impact in soil pH in the 0-15 cm soil layer. In the 15-30 cm soil layer, the significant impact was on soil pH and K. Results showed that irrigation with either diluted WWW or raw water had no significant effect on the three soil enzymes throughout the study period. Thus, irrigation with diluted WWW may not adversely affect soil microbial population, ecosystem, and nutrient cycle.

***Keywords-*** soil chemicals, soil enzymes, summer catch crops, Winery wastewater,

## I. INTRODUCTION

The global climate change and continuous increase in world population are leading to water scarcity, growing demand for clean water, and a decline in agricultural productivity [1]. This shift has further resulted in an increase in the shortage and demand for irrigation water in the farming system. To reduce the pressure on the demand for clean water and meet the irrigation demand, the practice of supplementing available clean water with untreated, treated, and urban/industrial wastewater is becoming popular [2].

Winery wastewater (WWW) can provide a valuable irrigation source especially, in regions where water accessibility is problematic or sustainable disposal of waste is essential [3]. It is estimated that about 3 to 5 m3 of WWW with high organic load and variable salinity and nutrient levels is produced per tonne of grapes crushed [4]. The South African wine industry produces more than 980 000 m3 volumes of WWW annually [5]. However, WWW is badly handled and deposited into freshwater sources, contributing to significant contamination in the environment [6]. A potential solution to this issue is the reuse of this WWW for irrigation in agricultural soils.

Irrigation with WWW which is rich in nutrients including potassium (K) and sodium (Na) can be beneficial to the overall soil fertility as this can replace conventional fertilizers. However, the long-term application may alter soil physiochemical properties and increase the concentration of the salts associated with saline or sodic soils, which can be detrimental to the soil ecosystem and crop performance. Few studies have also shown that irrigation with WWW can affect soil quality properties such as microbial enzymes responsible for organic soil breakdown and mineralisation of nutrients [7]. Thus, it is imperative, that when WWW is used for irrigation, water conservation benefits are not compromised by a decline in soil health, plant productivity, and environmental quality [3]. However, there is less information on the effects of WWW on soil chemical and biological properties known to be reliable soil quality indicators. More information on this topic is crucial for broader understanding and proper management of WWW irrigation to minimise the negative impacts on the soil and environment and improve crop quality and yield. The objective of this study was to determine the effect of diluted WWW and raw water on soil chemicals such as pH, potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) and soil enzyme activities including β-glucosidase, phosphatase, and urease, where different summer catch crops were cultivated.

## II. MATERIALS AND METHODS

### *A. Experimental Description*

A field trial was conducted in a Shiraz/110 Richter vineyard established on sandy loamy soil in 2020 season at Agricultural Research Council (ARC) Nietvoorbij experimental farm (33° 55′ 02″, 18° 526′ 04″) in Stellenbosch, Western Cape Province, South Africa. Grapevines were spaced 1.2 m in the

Takalani Sikhau, Adewole Tomiwa Adetunji and Francis Bayo[1] Lewu, Department of Agriculture, Cape Peninsula University of Technology, Wellington 7655, Western Cape, South Africa.

Takalani Sikhau, Carolyn Howell and Reckson Mulidzi, Soil and Water Science Division, ARC Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch 7599, South Africa.

https://doi.org/10.17758/IICBE3.C0322254

row and 2.4 m between rows. The vineyard was divided into 104 $m^2$ plots, each containing 10 experimental vines, five in each of two adjacent rows. A randomized block design was used, and each treatment was replicated three times. Eight treatments (six irrigated with diluted WWW and two irrigated with raw water) were applied (Table I).

TABLE I: TREATMENTS APPLIED INSIDE THE VINEYARD

| Treatment no. | Summer catch crops | Irrigation |
|---|---|---|
| 1 | Pearl millet | Diluted winery wastewater |
| 2 | Pearl millet | Diluted winery wastewater |
| 3 | Dolichos beans | Diluted winery wastewater |
| 4 | Dolichos beans | Diluted winery wastewater |
| 5 | Chicory | Diluted winery wastewater |
| 6 | Chicory | Diluted winery wastewater |
| 7 | No cover crop | Raw water |
| 8 | No cover crop | Raw water |

### *B. Application of Diluted WWW*

Irrigation was applied by means of micro-sprinklers. Winey wastewater was collected from the Leeuwenkuil winery. The chemical oxygen demand (COD) and electrical conductivity (EC) of undiluted WWW was diluted to obtain COD and EC of less than 5 000 mg/L and 200 mS/m, respectively, to abide by the current laws specified by the General Authorization [8] on the quality of irrigation water. Irrigation of the vineyard commenced when there was available WWW. Due to the Level 5 lockdown in 2020, unfortunately, no WWW irrigations could be applied in April. The raw water treatments were irrigated with raw (clean) water from the local dam.

### *C. Soil Sampling and Chemical/Enzyme Analyses*

Soil samples were collected from 0-15 cm and 15-30 cm soil layers after irrigation with diluted WWW. Soil samples were passed through a 2 mm mesh. The soil chemical status of pH, K, Ca, Mg, and Na was determined using the method as described by [9]. The pH was expressed as KCL while K, Ca, Mg, and Na were expressed as cmol(+)/kg. The activities of β-glucosidase, phosphatase, and urease are known to play a critical role in the carbon, phosphorus, and nitrogen cycle, respectively, were determined from each sample using colorimetric methods [10-12]. The activities of β-glucosidase and phosphatase were expressed as μg p-nitrophenol g-1 soil h-1 while urease activity was expressed as μg ammonium g-1 soil 2 h-1.

### *D. Statistical Analysis*

The experimental design was a randomised complete block design with eight catch crop treatments and three block replicates. The data were subjected to analysis of variance (ANOVA) using General Linear Models Procedure (PROC GLM) of SAS software (Version 9.4; SAS Institute Inc, Cary, USA). Shapiro-Wilk test was performed to verify the normality of standardized residuals [13]. Fisher's least significant difference was calculated at the 5% level to compare treatment means [14]. A probability level of 5% was considered significant for all significance tests.

## III. RESULTS AND DISCUSSION

### *A. Effect of Diluted WWW and Raw Water on Soil pH*

Results of this study showed that after diluted WWW application in the vineyard, soil pH(KCl) was significantly higher in treatments irrigated with diluted WWW compared to treatments irrigated with raw water at both 0-15 cm and 15-30 cm soil layers (Table II). This is consistent with other studies where the application of WWW increased soil pH(KCl) from 4.6 to 5.0 in the top-soil and from 5.0 to 5.3 in the sub-soil [15], [16]. Reference [17] reported that soil pH(KCl) increased when irrigated with WWW, regardless of the soil types. Similarly, in two case studies where pastures and a vineyard were irrigated with WWW, soil pH(KCl) increased [18]. In contrast, [19] reported that after WWW application, there were no clear trends in soil pH(KCl) that could be related to the different levels of dilution of WWW compared to the river water. An increase in soil pH (acidic soils in particular) supports better nutrient balance for plant growth. Given that irrigation using WWW is likely to increase soil K and Na, soil pH will consequently increase via alkaline hydrolyses [19], [20].

### *B. Effect of Diluted WWW and Raw Water on Soil K*

At 0-15 cm soil layer, there was no significant effect between treatments irrigated with diluted WWW and treatments irrigated with raw water (Table II). However, at 15-30 cm soil layers, soil K was significantly higher in treatments irrigated with diluted WWW compared to treatments irrigated with raw water. This was to be expected given that WWW contains high levels of K. Several other studies have also reported increased K due to irrigation with WWW [21], [22], [16]. Reference [20] reported that irrigation with diluted WWW increased K substantially in the 0-10cm layer of four different soils over four simulated seasons in a pot study. Despite the cultivation of Kikuyu grass where a plot of land was irrigated with WWW, K levels increased in the 0-10 cm soil layer, and to some extent in the 10-20 cm soil layer, at the end of the harvest periods [21]. High soil K could lead to an increase in K uptake by grapevines, which could have negative effects such as grape musts with high pH, malate concentrations, and poor colour [23], [24].

### *C. Effect of Diluted WWW and Raw Water on Soil Ca, Mg and Na*

Results of this study showed that after irrigation with diluted WWW and raw water inside the vineyard, there was no significant impact in soil Ca across all the treatments from 0-30 cm soil layers (Table II). Similarly, reference [4] reported that irrigation with WWW diluted up to 3 000 mg COD/L had little or no effect on soil Ca due to low amounts present in the WWW. Reference [25] also reported that the application of WWW did not increase soil Ca over two and half years of the study period. In contrast, Ca concentrations were higher in the

WWW irrigated soils having 6.63 mg/kg at the 20-40 cm soil layer compared to 4.38 mg/kg for the control irrigated soil in the Napa Valley American region in Northern California [22]. Also, pastures irrigated with WWW for over 100 years increased soil Ca levels substantially compared to controls [26]. Results are inconsistent about the effects of WWW in soil Ca, therefore long-term research is required in this regard.

There was no significant impact in soil Mg between treatments irrigated with diluted WWW and those irrigated with raw water from 0-30 cm soil layers (Table II). Similarly, [4] reported that where diluted WWW (3 000 mg/L COD) was used for the irrigation of a vineyard in a sandy, alluvial soil, due to their low levels in the diluted WWW, soil Mg did not respond to levels of dilution of the WWW. However, pastures irrigated with undiluted WWW for over 100 years increased soil Mg [26]. Magnesium concentrations were higher in the WWW irrigated soils having 9.10 mg/kg at the 20-40 cm soil layer compared to 4.90 mg/kg soil for the control irrigated soil in Napa Valley American region in Northern California [22]. However, where Kikuyu grass was irrigated with WWW, Mg concentration in all layers showed only limited fluctuation [25]. Longer-term WWW irrigation may be required to observe a significant increase in soil Mg. An increase in soil Mg through WWW irrigation will aid vine chlorophyll and soil enzyme activation and results in soil having less water-stable aggregates and less pore integrity.

Treatments irrigated with diluted WWW and raw water had no significant effect in soi Na at both 0-15 cm and 15-30 cm soil layers (Table II). However, at 15-30 cm soil layer, treatments irrigated with diluted WWW were slightly higher than treatments irrigated with raw water. The previous study has, however, shown that irrigation with WWW increased the Na levels [16]. Where diluted WWW was used for the irrigation of a vineyard in sandy, alluvial soil, Na increased linearly as the level of WWW dilution decreased, particularly in the topsoil [4]. Also, WWW irrigated soils contained significantly higher concentrations of Na (from 48.7 to 72.6 mg/kg soil) than the control irrigated soils (from 7.52 to 16.1 mg/kg soil) across all depths in the Napa Valley American region [28]. A high concentration of Na in the soil due to WWW application can reduce soil aggregate stability, reduce water availability for plants and be toxic to some plants [27]. More studies found that the application of WWW increases soil Na.

### *D. Effect of diluted WWW and Raw Water on Soil Enzymes Activities*

Results from this study showed that irrigation with either diluted WWW or raw water had no significant impact on the activities of β-glucosidase, phosphatase, and urease at 0-15 cm and 15-30 cm soil layers (Table III). In contrast to results from the current study, the β-glucosidase and urease activities were substantially greater in the 0-10 cm compared to the 10-20 cm soil layers after irrigation with diluted WWW in a study by [28]. Furthermore, the application of WWW irrigation had a significant effect on β-glucosidase activity in a field study at Rawsonville [27] where activity was more pronounced in the topsoil than in the sub-soils and the β-glucosidase activity also increased as the chemical oxygen demand (COD) concentration in WWW increased. Soil β-glucosidase, phosphatase, and urease are involved in C, P, and N cycling and be reliable soil quality indicators in the in-soil management systems [29], [30]. A longer-term study may be required to observe considerable enzyme activities in this study.

TABLE II: THE CHEMICAL STATUS OF THE SOIL IN THE 0-15 CM AND 15-30 CM SOIL LAYERS AFTER IRRIGATION DILUTED WWW

| Treatment no. | $pH_{KCl}$ | Exchangeable cations ($cmol^{(+)}$/kg) | | | |
|---|---|---|---|---|---|
| | | K | Ca | Mg | Na |
| 0-15 cm | | | | | |
| 1 | 5.87 a | 0.50 a | 2.57 a | 0.75 a | 0.18 a |
| 2 | 5.93 a | 0.50 a | 2.60 a | 0.80 a | 0.17 a |
| 3 | 5.83 a | 0.51 a | 2.53 a | 0.78 a | 0.18 a |
| 4 | 5.77 a | 0.50 a | 2.67 a | 0.72 a | 0.20 a |
| 5 | 6.10 a | 0.42 a | 2.70 a | 0.76 a | 0.23 a |
| 6 | 6.10 a | 0.50 a | 2.70 a | 0.81 a | 0.18 a |
| 7 | 5.20 b | 0.25 a | 2.47 a | 0.69 a | 0.13 a |
| 8 | 5.10 b | 0.32 a | 3.03 a | 0.90 a | 0.18 a |
| 15-30 cm | | | | | |
| 1 | 5.77 ab | 0.53 a | 2.17 a | 0.64 a | 0.18 a |
| 2 | 5.73 abc | 0.41 bc | 1.77 a | 0.56 a | 0.18 a |
| 3 | 5.53 bc | 0.37 abc | 1.87 a | 0.62 a | 0.16 a |
| 4 | 5.73 abc | 0.46 a | 2.53 a | 0.73 a | 0.18 a |
| 5 | 5.97 a | 0.41 ab | 2.20 a | 0.68 a | 0.19 a |
| 6 | 5.83 ab | 0.36 abc | 2.30 a | 0.69 a | 0.20 a |
| 7 | 5.40 cd | 0.20 c | 2.30 a | 0.65 a | 0.13 a |
| 8 | 5.17 d | 0.25 bc | 2.47 a | 0.76 a | 0.13 a |

Refer to Table I for details of treatments.

Values designated by the same letters within a column do not differ significantly ($p \leq 0.05$)

TABLE III: Β-GLUCOSIDASE, PHOSPHATASE AND UREASE DETERMINED IN THE SOIL IN THE 0-15 CM AND 15-30 CM SOIL LAYERS AFTER IRRIGATION WITH DILUTED WWW AND RAW WATER

| Treatment no | B-glucosidase (μg *p*-nitrophenol $g^{-1}$ $h^{-1}$) | Phosphatase (μg PNP $g^{-1}$ soil $h^{-1}$) | Urease (μg $NH_4^+$ $g^{-1}$ soil 2 $h^{-1}$) |
|---|---|---|---|
| 0-15 cm | | | |
| 1 | 151.30 a | 327.32 a | 45.48 a |
| 2 | 145.02 a | 322.95 a | 49.03 a |
| 3 | 165.04 a | 341.48 a | 56.74 a |
| 4 | 112.87 a | 287.82 a | 35.86 a |
| 5 | 122.08 a | 291.11 a | 34.61 a |
| 6 | 127.53 a | 290.18 a | 44.09 a |
| 7 | 126.99 a | 284.60 a | 38.54 a |
| 8 | 156.82 a | 379.02 a | 40.80 a |
| 15-30 cm | | | |
| 1 | 37.41 a | 117.51 a | 15.84 a |
| 2 | 34.57 a | 116.89 a | 12.53 a |
| 3 | 30.94 a | 109.71 a | 15.34 a |
| 4 | 34.71 a | 126.60 a | 13.29 a |
| 5 | 45.76 a | 133.57 a | 13.42 a |
| 6 | 24.98 a | 92.42 a | 13.01 a |
| 7 | 36.23 a | 106.23 a | 12.02 a |
| 8 | 36.36 a | 121.66 a | 12.26 a |

Refer to Table I for details of treatments.

Values designated by the same letters within a column do not differ significantly ($p \leq 0.05$)

## IV. Conclusion

Large volumes of WWW of poor quality are generated by wineries, especially during harvesting of the wine grapes. Due to the scarcity of water resources, WWW is being considered as a potential alternative source of irrigation water for vineyards. The use of WWW as a source of irrigation water rather than raw water increased soil K and soil pH in the vineyard. Soil K and soil pH decrease as the soil depth increase. The use of WWW does not harm soil enzymes activities. Farmers with soils that are poor in soil pH and soil K can use WWW as a source of irrigation to improve nutrient availability and fertility in the soil.

## Acknowledgment

This conference paper forms part of Project K5/2561//4 funded by the Water Research Commission (WRC), Winetech and the Agricultural Research Council (ARC). I thank WRC for the bursary to study. ARC for infrastructure and resources. We also thank Isabella Van Huyssteen, Luvuyo Mabongo, Francois Baron and Trevor Harris (Soil Science Department, ARC- Infruitec/Nietvoorbij) for their technical support in the lab and field, respectively.

## Reference

[1] A.H. Faisal, "Effect of laundry greywater irrigation on soil properties." Journal of Environmental Research and Development. 2011;5(4):863-70.

[2] A.R. Mulidzi, C.E. Clarke, and P.A. Myburgh, "Effect of irrigation with diluted winery wastewater on phosphorus in four differently textured soils." South African Journal of Enology and Viticulture. 2016;37(1):79-84. https://doi.org/10.21548/37-1-761

[3] S. Laurenson, N.S. Bolan, E. Smith, and M. McCarthy, "Use of recycled wastewater for irrigating grapevines. Australian Journal of Grape and Wine Research." 2012 Feb;18(1):1-0. https://doi.org/10.1111/j.1755-0238.2011.00170.x

[4] C.L. Howell, P.A. Myburgh, E.L. Lategan, and J.E. Hoffman, "Effect of irrigation using diluted winery wastewater on the chemical status of a sandy alluvial soil, with particular reference to potassium and sodium." South African Journal of Enology and Viticulture 39, no. 2. 2018: 1-13. https://doi.org/10.21548/39-2-3171

[5] SAWIS (South African Wine Industry and Systems), 2020.Availablehttp://www.sawis.co.za/info/download/Book_2020_eng. pdf (accessed 2020).

[6] E.E.O. Odjadjare, and A.I. Okoh, "Physicochemical quality of an urban municipal wastewater effluent and its impact on the receiving environment." Environmental monitoring and assessment. 2010 Nov;170(1):383-94. https://doi.org/10.1007/s10661-009-1240-y

[7] R.D. Bardgett, W.D. Bowman, R. Kaufmann, and S.K. Schmidt, "A temporal approach to linking aboveground and belowground ecology." Trends in ecology & evolution. 2005 Nov 1;20(11):634-41 https://doi.org/10.1016/j.tree.2005.08.005

[8] Department of Water Affairs, 2013. Revision of general authorizations in terms of Section 38 of the National Water Act, 1998 (Act No. 36 of 1998), No. 665. Government Gazette No. 36820, 6 September 201. Deaprtments of Water Affairs, Pretoria, South Africa, 3-31. determination of ammonium. Biol.Fertil.Soils,6,68.72.http://dx.doi.org/10.1007/BF00257924.

[9] The Non-Affiliated Soil Analyses Work Committee, 1990. Handbook of standard soil testing methods for advisory purposes. Soil Sci. Soc. S.A., P.O. Box 30030, Sunnyside, Pretoria.

[10] E. Eivazi, and M.A. Tabatabai, 1988. Glucosidases and galactosidases in soils. SoilBiolBiochem20:601606.http://dx.doi.org/10.1016/0038-0717(88)90141-1. https://doi.org/10.1016/0038-0717(88)90141-1

[11] M.A. Tabatabai, and J.M. Bremner, "Use of p-nitrophenyl phosphate for assay of soil phosphatase activity." Soil biology and biochemistry. 1969 Nov 1;1(4):301-7. https://doi.org/10.1016/0038-0717(69)90012-1

[12] E. Kandeler, and H. Gerber, "Short-term assay of soil urease activity using colorimetric determination of ammonium." Biology and fertility of Soils. 1988 Mar;6(1):68-72. https://doi.org/10.1007/BF00257924

[13] S.S. Shapiro, and M.B. Wilk, "An analysis of variance test for normality (complete samples)." Biometrika. 1965 Dec 1;52(3/4):591-611. https://doi.org/10.1093/biomet/52.3-4.591

[14] R.L. Ott, and M. Longenecker, "An Introduction to Statistical Methods and Data analysis." Brooks/Cole, Cengage Learning. 6th Edition. Belmont, US. 2010 Pp 445-481 of 1179 pp.

[15] S. Shilpi, B. Seshadri, B. Sarkar, N. Bolan, D. Lamb, and R. Naidu, "Comparative values of various wastewater streams as a soil nutrient source." Chemosphere. 2018 Feb 1;192:272-81. https://doi.org/10.1016/j.chemosphere.2017.10.118

[16] A.R. Mulidzi, C.E. Clarke, and P.A. Myburgh, "Response of soil chemical properties to irrigation with winery wastewater on a well-drained sandy soil." South African Journal of Enology and Viticulture. 2019;40(2):1-. https://doi.org/10.21548/40-2-3403

[17] A.R. Mulidzi, C.E. Clarke, and P.A. Myburgh, "Effect of irrigation with diluted winery wastewater on cations and pH in four differently textured soils." South African Journal of Enology and Viticulture. 2015;36(3):402-12. https://doi.org/10.21548/36-3-973

[18] A. Kumar, P. Rengasamy, L. Smith, H. Doan, D. Gonzago, A. Gregg, S. Lath, D. Oats, and R. Correl, "Sustainable recycled winery water irrigation based on treatment fit for purpose approach." Report CSL1002. 2014 Grape and Wine Research Development Corporation/CSIRO Land and Water Science, Adelaide, Australia.

[19] C.L. Howell, "Using diluted winery effluent for irrigation of Vitis Vinifera. Cv. Cabernet Saugvignon and the impact thereof on soil properties with special reference to selected grapevine responses." PhD diss., Stellenbosch: Stellenbosch University, 2016.

[20] B. Mpelasoka, D.P. Schachtman, M.T. Treeby, and M.R. Thomas, "A review of potassium nutrition in grapevines with special emphasis on berry accumulation." Australian Journal of grape and wine research. 2003 Oct;9(3):154-68. https://doi.org/10.1111/j.1755-0238.2003.tb00265.x

[21] D.R. Hirzel, K. Steenwerth, S.J. Parikh, and A. Oberholster, "Impact of winery wastewater irrigation on soil, grape and wine composition." Agricultural Water Management. 2017 Jan 31;180:178-89. https://doi.org/10.1016/j.agwat.2016.10.019

[22] A.R. Mulidzi, C.E. Clarke, and P.A. Myburgh, "Annual dynamics of winery wastewater volumes and quality and the impact of disposal on poorly drained duplex soils." South African Journal of Enology and Viticulture. 2018 Sep 20;39(2):305-14. https://doi.org/10.21548/39-2-3208

[23] S. Kodur, "Effects of juice pH and potassium on juice and wine quality, and regulation of potassium in grapevines through rootstocks (Vitis): a short review." VITIS Journal of Grapevine Research. 2011;50(1):1-6.

[24] W.C. Quale, N. Jayawardane, and M. Arienzo, "Impacts of winery wastewater irrigation on soil and groundwater at a winery land application site." In Proceedings of the 19th World Congress of Soil Science, Soil solutions for a changing world 2010 Aug 1 (pp. 1-6).

[25] K.P.M. Mosse, A.F. Patti, R.J. Smernik, E.W. Christen, and T.R. Cavagnaro, "Physicochemical and microbiological effects of long- and short-term winery wastewater application to soils." 2012 J Hazard Mater 201- 202:219-228. 180, 178-189. https://doi.org/10.1016/j.jhazmat.2011.11.071/

[26] A.R. Mulidzi, and J. Wooldridge, "Effect of irrigation with diluted winery wastewater on enzyme activity in four western cape soils." Sust Environ 2016 1:141. https://doi.org/10.22158/se.v1n2p141

[27] Laurenson, S. & Houlbrooke, D., 2012 Review of guidelines for the management of winery wastewater and grape marc. Report prepared for the Marlborough District Council, New Zealand.
[28] A.H. Meyer, 2014. Chapter 6: Effect of irrigation with augmented winery wastewater on soil microbial status. In: Myburgh, P.A. and Howell, C.L. (eds). The impact of wastewater irrigation by wineries on soils, crop growth and product quality. WRC Report No. 1881/14, Water Research Commission, Private Bag X03, 0031 Gezina, South Africa.
[29] A.T. Adetunji, B. Ncube, R. Mulidzi and F.B. Lewu, “Potential use of soil enzymes as soil quality indicators in agriculture. Front. Soil Environ. Microbiol,” 2020 pp.57-64. https://doi.org/10.1201/9780429485794-6
[30] A.T. Adetunji, F.B. Lewu, R. Mulidzi, and B. Ncube, "The biological activities of β-glucosidase, phosphatase and urease as soil quality indicators: a review." Journal of soil science and plant nutrition 17, no. 3 (2017): 794-807. https://doi.org/10.4067/S0718-95162017000300018

T. Sikhau obtained her B-Tech in Agriculture (Crop Production) at the Cape Peninsula University of Technology (CPUT), Cape Town, South Africa in 2019. Currently, she is a M-Tech Fellow in the Department of Agriculture, Cape Peninsula University of Technology, with a focus on the soil chemical and microbiological response to irrigation with diluted winery wastewater inside the vineyard.