Effects of Shallow-deep Drainage Ditch on Soil Chemical Properties and Soil Enzyme Activities in Sanhu Farm

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Abstract. Waterlogging has become a serious agricultural problem in Jianghan Plain. To lower groundwater level and mitigate the damage of waterlogging to crop growth, shallow-deep drainage ditch has been applied in agricultural production. The objectives of this study were to discover the effects of shallow-deep drainage ditch on soil chemical property and enzyme activity, and their correlations with each other. Winter wheat experiment was conducted from October to May in Sanhu Farm. Soil samples (0-20 cm depth) were collected from five plots that were 1 m, 3 m, 5 m, 7 m, 9 m away from deep drainage ditch, respectively. Soil water content (SWC), soil chemical properties and enzyme activities were measured in three growth stages of winter wheat. The results showed that SWC was increased with distance away from deep ditch. Soil chemical properties were lower at 1 m and 7 m away from deep ditch. Phosphatase and sucrase at 3 m away from deep ditch were 11.31% – 21.49% and 42.95% – 64.04% increase, and urease at 7 m was 6.24% – 44.29% increase compared to other sampling points, respectively. Soil nutrient contents and enzyme activities were positively correlated with each other except the relationship of total nitrogen and urease. Our studies demonstrated the improvement of soil chemical properties and soil enzyme activities in shallow-deep drainage ditch.

1. Introduction

Soil waterlogging created by seepage from irrigated uplands and canal water with inadequate water management practices[1], is estimated to affect adversely about 10 % of the global land area[2]. With the exception of rice, most crops are sensitive to waterlogging and show significant decline in yield when grown in flooded soils[3]. During waterlogging, gas exchange decreases between soil and air. In this condition, oxygen in soil is depleted rapidly, and the soil may become hypoxic (low oxygen) or anoxic (no oxygen) within a day[4], [5]. Lack of soil oxygen can limit plant yield directly by altering root metabolism or indirectly by changing plant nutrient availability[4], [6]. Also, high level of soil water content influence soil chemical and physical properties to decrease soil quality. Plant root growth and microbe activity are limited by oxygen deficit at high level of soil water content and nutrient cycling can be affected because of limited enzyme activities[5], [7]. So it is important to lower groundwater level for improving crop growth and soil quality[8].

In order to control groundwater level, drainage measures have been adopted in agricultural areas for many years. Drainage ditch, pipe drainage, drainage by pumping station and so on are typical waterlogged farmland drainage engineering measures[9], [10]. Drainage ditch is developed earliest and most widely used in these drainage measures[9], [11]. Drain depth and spacing are important...
factors in design of drainage ditch system. Hydraulic conductivity and drainable porosity are basic parameters required in design of field drain spacing, and these parameters obtained from laboratory analysis are to establish drainage equations to figure out drain spacing and drain depth[12]. But relationships between geophysical property and hydraulic conductivity are complex, non-unique and scale dependent[13]. A drain depth will be specified and the spacing will be calculated based on recharge schedule and midpoint water table depth. Subsequently, drain depth will be varied to calculate a range of depths and spacings for an economic analysis[14]. In contrast with ordinary drainage ditch, shallow-deep drainage ditch could achieve better drainage effects and be more cost-effective by combining deep and shallow ditches. To reduce soil moisture content, shallow-deep drainage ditch has been utilized to lower underground water level in Sanhu Farm where crop yield and quality can be decreased by waterlogging. Studies have demonstrated that shallow-deep drainage ditch is more efficiency than pipe drainage system, ranging from 6.5% to 16.3% increase in drainability[15]. As an important component of soil fertility, soil enzymes are mediators and catalysts in matter transformation and stabilized by colloids which are primarily from microbial origin[16]. After soil enzyme-mediated degradation processes, soil organic matter complex can be decomposed, then assimilated by microbe and plant[17]. Soil enzymes have been reported to be sensitive to changes and affected by many factors, including tillage treatment[18], crop species and climatic change[7], etc. Decades of research has revealed that mineral compound generally has significant effects on enzyme activity[19]. The relationships between soil enzyme activities and soil environmental factors contain the electrical conductivity of saturated soil extract, pH value, available nutrient, and organic carbon have been turned out to be significant correlative[20]. Therefore, soil chemical property and soil enzyme activity are indexes of soil activity and productivity to estimate soil fertility and health. Ditches play important roles in controlling the hydrologic, chemical, and biological processes[21]. However, the effects of shallow-deep drainage ditch on soil fertility and quality are scarcely known. The aim of this research was to assess the effect of shallow-deep drainage ditch on the soil chemical properties (pH, available phosphorus, available potassium, total nitrogen and soil organic matter) and soil enzyme (phosphatase, urease and sucrase) activities. And find the relationships among soil chemical properties and enzyme activities.

2. Materials and Methods
The experiment was carried out by planting winter wheat which grows from October to May in Sanhu Farm (latitude 30°10' N, longitude 112°29' E, elevation 27.3—31.1 m above sea level, slope 0.011°), located in Hubei Province, China. The experimental site belongs to north subtropical humid monsoon region with rainy spring and summer. The mean annual precipitation and air temperature are 1100 mm and 16.7°C, respectively. The soil is yellow brown paddy soil and its texture is loam. The topsoil (0-20 cm) particle size is summarized as 21.96% clay (0–2 µm), 75.00% silt (2–50 µm) and 3.04% sand (50–2000 µm), with following properties: pH 7.1 (1:2.5 soil : water ratio), available phosphorus (AP) 7.02 mg kg⁻¹, available potassium (AK) 152.10 mg , total nitrogen (TN) 0.8 g kg⁻¹, available nitrogen (AN) 118.42 mg kg⁻¹, soil organic matter content (SOC) 28.8 g kg⁻¹.

Soil was collected with a soil sampler from experimental site. Deep (1 m deep, 0.5 m wide, 20 m apart) and shallow (0.3 m deep, 0.3 m wide, 2 m apart) drainage ditch system was designed as Figure 1. Soil samples (0-20cm depth) were collected from five plots that were 1m, 3m, 5m, 7m, 9m away from deep drainage ditch, respectively, and air-dried before determination. To improve the accuracy, each soil sample was analyzed with three replicates.
Figure 1. Arrangement plan of shallow-deep drainage ditch and sampling positions.

Soil was sampled for three times respectively at the wheat growth stages of jointing (March), heading, and grain filling (May). Gravimetric soil water content (SWC) was determined by an oven at 105°C, soil organic matter content (SOC) was analyzed with wet combustion method by titration, and soil pH was measured by a pH meter (FG3-ELK, Mettler - Toledo international trading (Shanghai) Co., Ltd, China) in 1:2.5 soil-water extract. Soil total nitrogen content (TN) was determined by automatic kjeldahl apparatus (K9840, Hanon Instrument, Jinan, China), available phosphorus content (AP) was assayed spectrophotometrically (UV-5500PC Spectrophotometer, Shanghai Metash Instrument Co., Ltd. Instrument Co., Ltd., China) at 700 nm, available potassium content (AK) was determined on flamephotometer (FP640, Shanghai INESA Scientific Instrument Co., Ltd., China). Urease, phosphatase, and sucrase activities were determined according to Guan’s methods[22]. Urease activity was assayed using a 10% aqueous urea as substrate and incubated at 37°C for 24 h. The released NH$_4^+$ was determined by a spectrophotometer at 578 nm, and the urease activity was expressed as mg NH$_4^+$ g$^{-1}$ soil 24 h$^{-1}$. Alkaline phosphatase activity was measured using disodium phenyl phosphate substrate solution, and incubated for 24 h at 37 °C. The formation of phenol was determined spectrophotometrically at 600 nm, and enzyme activity was expressed as mg phenol g$^{-1}$ soil 24 h$^{-1}$. Sucrase activity was assayed using sucrose solution as the substrate. After incubating at 37 °C for 24 h, the filtrate was boiled in a water bath for 5 min with 3 mL 3, 5- dinitrosalicylic acid (DNS). Absorbance of the reducing sugars was measured at 508 nm, and sucrase activity was expressed as mg glucose g$^{-1}$ soil 24 h$^{-1}$. The determination procedures of all soil properties were according to standard methods and instrument instruction manuals[22], [23].

The significance of differences among treatment means was tested by one-way ANOVA, using SPSS 21.0 (SPSS Inc. Chicago, USA). When the $F$ value in the ANOVA was statistically significance, a least significant difference test (significance level of $P=0.05$) was used for seperation of the means.

Pearson correlation was applied to analyze the relationship of soil physical-chemical properties and enzyme activities, and the level of statistical significance was set at $P=0.05$.

3. Results and Discussion

3.1. Soil Chemical Properties

Changes of SWC and soil chemical properties influenced by different distances away from deep ditch were shown in Figure 2. SWC was higher in jointing stage and lower in filling stage, and increased with distance away from deep ditch in different growing stage owing to the drainage effects of deep ditches.

pH decreased with time and distance away from deep ditch. With the decrease of soil water content, soil pH decreased because of reduced groundwater evaporation and subsequently salt accumulation in surface soil [24]-[26].

Due to natural environment factors such as tempreture, illumination intensity, wind and so on, it was higher AP in jointing stage, higher AK and SOC in heading stage than other two growing stages[27]. AP, AK, TN and SOC increased, then decreased with distance away from deep ditch in all growing stages, owing to the effects of SWC on soil chemical properties[28]. High level of SWC altered the oxygen and nutrient availabilities to block respiration, and retarded the growth of plant root which is closely associated with nutrient transformation and absorption[4], [29]. Drainage is generally required to facilitate respiration of plant roots[30]. That's why AP, AK and TN contents were little lower at 9m compared to those at 5m away from deep ditch. However, soil nutrient may be decomposed and subsided quickly if groundwater level is lower than 5m, which would accelerate nutrient loss and further reduce plant productivity[31]. That may lead to decrease in soil nutrition contents near the deep ditch. Appropriate SWC could provide good soil porosity that promotes dynamic of N and C cycle which is positively correlated with root growth and soil enzymatic activity[32].
3.2. Soil Enzyme Activities

Variation of soil enzyme activities including phosphatase, urease and sucrase was shown in Figure 3. Similar to previous studies, phosphatase urease and sucrase activities were lower in heading stage and higher in filling stage [33]. Geisseler and Horwath have found similar reault that β-glucosidase activity and β-glucosaminidase activity are lower in April than those in May, due to environmental factors especially temperature[18], [34]. Temperature can influence enzyme activity by direct modification of enzyme kinetics and indirect influence on microbial proliferation[35]. Also, closely related to nutritional conditions, enzyme activity is regulated by soil chemical property in different growth periods[36]. For example, ammonium availability is much lower in spring due to active uptake of ammonium by microorganisms and plants[37].

Figure 2. Soil chemical properties at different distances from deep ditches. Error bar represent standard error of the mean. Letters above error bars donate significant differences at p < 0.05 levels.

Figure 3. Soil enzyme activities at different distances from deep ditches. Error bar represent standard error of the mean. Letters above error bars donate significant differences at p < 0.05 levels. Fluctuations of soil enzyme activities were similar that enzyme activity increased then decreased with distance away from deep ditch, except urease. Peaks of phosphatase and sucrase activities appeared at 5m, by 11.31% – 21.49% and 42.95% – 64.04% increase compared to other sampling points, respectively. Urease activity at 7m was 0.91 mg NH₄⁺ g⁻¹ soil 24 h⁻¹, by 6.24% – 44.29% increase compared with other sampling points. Minimums of phosphatase and sucrase activities were 1.19 mg phenol g⁻¹ soil 24 h⁻¹ and 0.42 mg glucose g⁻¹ soil 24 h⁻¹ at 1m by 6.71% – 37.92% and 26.80% – 79.50% decrease against rest sampling points, respectively. Urease activity was 0.50 NH₄⁺ g⁻¹ soil 24 h⁻¹.
h\(^{-1}\) at 9m, lower by 0.66% – 178.11% than other sampling points. Different distances away from deep ditch represented different levels of SWC. Nearer deep ditch, SWC was lower which limited soil enzyme activities by water stress[30]. Related to root activity closely, microbial and enzyme activities could be retarded due to the obstacles of soil anaerobic environment resulting from waterlogging or of water deficit by drought[7], [38], [39]. Furthermore, high groundwater level had significant effects on enzyme activity that decreased with increasing SWC[40]. Because waterlogging soil markedly affected the reaction rates of soil enzymes, impeded the decomposition, substrates cycling and enzymatic potential tied to substrate availability[41].

3.3. Pearson’s Correlation Analysis

Correlations among soil chemical properties and soil enzyme activities were shown in Table 1. SWC was positively correlated with pH, TN, SOC and phosphatase. pH had negative correlation with AP, AK, TN and sucrase. AP was positively correlated with TN, SOC and soil enzyme activities. AK was positively correlated with phosphatase (\(P < 0.05\)), urease (\(P < 0.05\)), sucrase (\(P < 0.01\)) significantly. TN was positively correlated with SOC, phosphatase and sucrase instead of urease. The correlations among these three soil enzymes turned out to be positive.

Mostly, soil enzyme activities were negatively correlated with SWC in result of waterlogging[40], [42]. Soil enzyme activities were positively correlated with SOC due to promoted soil enzyme activity by increasing soil microorganism[43]. [44] Phosphatase increased with soil chemical properties because of the positive effects of soil C, N, P and K on phosphatase[45]. Urease had positive correlations with soil chemical properties except TN due to higher microbial biomass and greater stabilization via humic substances as the same results of Zhang and Zhou[38]. Urease is offered an abundant substrate with nitrogen, and also can transfer organic N into mineralized N, then may produce more N\(_2\)O to cause TN loss[45]. Sucrease decreased with \(pH\) significantly may due to the suppression of \(pH\) [45]. [46]. Influenced by soil microbial biomass, sucrase which involves in C transformation was positively correlated with TN, AP, AK and SOC[47]. The way to enhance sucrase activity has been suggested to enhance microbial activity and substrate concentrations in soil[48].

**Table 1.** Pearson’s correlation coefficients between soil chemical properties and soil enzyme activities.

|          | AP   | AK    | TN   | SOC  | Phosphatase | Urease | Sucrease |
|----------|------|-------|------|------|-------------|--------|----------|
| SWC      | -0.228 | -0.514* | 0.614* | 0.203 | 0.081       | -0.42  | -0.179   |
| pH       | -0.253 | -0.033 | -0.182 | 0.150 | 0.055       | 0.145  | -0.485** |
| AP       | 1     | 0.325 | 0.467 | 0.555* | 0.368       | 0.496  | 0.511    |
| AK       | 1     | -0.289 | 0.238 | 0.556* | 0.586       | 0.767* | 0.767*   |
| TN       | 1     | 0.597* | 0.196 | -0.193 | 0.11        |        |          |
| SOC      | 1     | 0.529* | 0.174 | 0.493  |             |        |          |
| Phosphatase | 1     | 0.572* | 0.819* | 0.502  |             |        |          |
| Urease   | 1     | 0.529* | 0.174 | 0.493  |             |        |          |
| Sucrease | 1     |        |        |        |             |        |          |

* Correlation is significant at the 0.05 level (2-tailed).  
** Correlation is significant at the 0.01 level (2-tailed).

This study demonstrated that enzyme activities not only involved in mineralization of C, N, P and K, but correlated with each other [33]. Further studies found the significant linear correlations between phosphatase and protease activities, acid phosphatase and cellulase activities in rhizosphere soil due to the produce and release processes by physiological activities of root and microorganism in rhizosphere soil[49]. However, Zhang indicated that no significant differences in invertase and alkaline phosphatase activity were detected among different treatments[50]. The mechanism of the interaction among soil enzymes still need further research.

4. Conclusions

Soil chemical properties and enzyme activities were influenced by shallow-deep drainage ditch obviously in Sanhu farm. We found that SWC and pH decreased with time and distance away from deep ditch. It was higher for AP and TN in jointing stage, for AK in heading stage contrary to soil enzyme activities. The change of SOC by winter wheat growth stage was not significant. Soil
chemical properties as AP, AK, TN, SOC and soil enzyme activities were significantly lower near the deep ditch and the midpoint of two deep ditches compared to other sampling points. The result of pearson’s correlation analysis showed that soil chemical properties and enzyme activities were correlated with each other. TN, SOC and phosphatase were positively correlated with SWC. Phosphatase was negatively correlated with pH. Except the relationship of TN and urease, the correlations of soil nutrient contents and enzyme activities turned out to be positive. So did the correlations among enzyme activities. The results indicated that shallow-deep drainage ditch could improve soil quality and fertility by lower groundwater table. Our suggestions were based on the limited condition and more research on the mechanism should be conducted in the future.

5. References

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