

Study on the practice and effect of alleviating apple orchard soil compaction in the Weibei plateau

Binmeng Wei^{1,2,3}, Zhonghui Li⁴, Yiquan Wang^{1,2,3}

¹Institute of Land Engineering Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an, China

²Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an, China

³Key Laboratory of Degraded and Unused Land Consolidation Engineering the Ministry of Land and Resources, Xi'an, China;

⁴College of Resources and Environment, Northwest A&F University, Yangling, China.

Abstract. Long-term planting and the application of chemical fertilizer merely have led to soil compaction in the Weibei plateau, which was not conducive to soil water infiltration and air exchange. The aim of this study was to develop knowledge of drilling and backfill materials effect on soil water content and CO₂ emissions. Five treatments consisted of control (no drilling) and drilling with vermiculite, slag, lime and backfill soil buried respectively. During the experiment, soil water content and CO₂ emissions were determined for each treatment. The results showed that drilling improved the water permeability of the soil without damaging the root system of fruit trees, and promoted the release of soil CO₂. The addition of vermiculite and slag had the best effect on soil water content improvement in the apple orchards. Additionally, soil CO₂ emission was closely related to soil water content. Both too high and too low soil water content can limit soil CO₂ release. The addition of lime can not only absorb the CO₂ in soil inside, but also increase soil calcium storage capacity. Therefore, drilling with lime backfilled may be the optimal practice to alleviate soil compaction in apple orchards in the Weibei plateau.

1. Introduction

Soil compaction is one of the main factors resulting in the reduction of crop yield [1]. Currently, the thinning soil tillage layer and soil compaction have become the common recessive degradation forms in farmland soil of China. Shi et al. [2] found that the compaction of the topsoil was still suitable for cultivation, but the ground floor of the plot was very tight and had formed an obvious barrier for planting in Shaanxi province. In recent years, with the increase of fruit planting years, the internal compaction of the orchard soil in Weise plateau has occurred gradually. Li et al. [3] found that soil compaction in Weise plateau orchard increased sharply with the increase of soil depth in 0 ~ 30 cm soil layer. Sun et al. [4] reported that the long-term planting apple trees could protect and improve soil structure of the surface layer of the orchard, but caused the compaction and harden in the deep soil layer.

The internal condensation and compaction of soil in Weise orchard are the main obstacles to soil water infiltration, gas exchange between upper and lower soil layers, and root extension of fruit trees.



In view of the deep depth (20-40 cm) and the relatively stable soil water condition, the compacted soil layer is difficult to be noticed and destroyed by the alternation of dry and wet process. Therefore, soil compaction in Weise orchard can maintain the tight state for a long time and have a continuous adverse effect on the growth of apple trees [5, 6]. If this soil physical degradation is not eliminated in time, it will inevitably hinder the growth of and development of fruit trees.

It is difficult to break the internal compacted soil layer by deep turning over and loosen soil, because this practice will be affected by the canopy of fruit trees and the huge root system. Additionally, the large area of deep tillage will inevitably hurt the roots of fruit trees and bring some other secondary damage to the fruit tree. According to the actual situation of orchard soil, drilling around apple trees was used to improve soil structure resulting from increasing water use efficiency, softening subsurface soils, and reducing soil compaction hazards. Furthermore, drilling can promote the exchange of soil gas in orchards, eliminating the problems caused by poor gas exchange in the compacted soil layers, such as the accumulation of reductive gases in the root system, which will threaten the root health.

With the age of the orchard in Weise plateau increasing, the degradation of calcium in soil is also becoming more and more serious [7, 8]. Given the convenience of artificial orchard management and the effect of drilling on compacted soil improvement, we hope to fill different materials in the drilled holes to improve or alleviate soil calcium degradation. Vermiculite is a layered ferric magnesium aluminosilicate mineral with complex chemical composition. Because of the unique spatial structure and obvious water absorbability and expansibility, vermiculite is often used as a kind of loose material to improve compacted soil [9]. The addition of vermiculite can improve soil structure, increase soil fertility, and enhance soil water retention and air permeability. Slag is discharged from industrial and civil boilers and other coal-burning equipment. It belongs to a kind of porous material, and plays a critical role in increasing soil water content, loosening soil particles, and protecting environment [10]. Lime is a good disinfectant, which can inhibit and sterilize the pathogenic microorganisms in the deep soil. Furthermore, liming can neutralize the acidity of the soil, increase soil buffer capacity, improve soil physical properties, stimulate soil beneficial microbial activity, and promote the absorption of nutrient elements in the soil by fruit trees [11]. The backfill soil, which is turned out of the orchard soil, is insolate and sterilized by the sun. It has both effects of the loose soil layer and sterilization. In this study, we explored the effect of drilling and padding different materials including vermiculite, slag, lime and backfill soil on soil water content and CO₂ emission. We want to find the optimal model and the best filling material to improve soil internal compaction in the orchard soil in Weise plateau. It also will provide scientific basis for obtaining soil management measures of orchard with sustainable development characteristics.

2. Materials and methods

2.1. Experimental design

In this study, three apple orchards more than 20 years old with serious soil degradation were selected as research subjects. In the germination stage of fruit trees, three Red Fuji apple (Mauls domestic Bork.) trees growing on *M. sieversii* rootstock since 1991 with similar growth vigour were selected for each treatment. Two holes with 30 cm deep and 10 cm diameter were drilled at the distance of 2/3 from the tree trunk in the canopy projection range by soil auger. Vermiculite, slag, lime (the mixture of lime and soil with V/V = 1:1), and backfill soil (insolate for 1 day) were buried in the holes respectively, with two replicates each.

In order to study the effect of drilling on soil permeability and its range of influence, soil CO₂ emissions were determined by a CO₂ gas measuring device (Figure 1). The test devices were set up at 0 cm and 15 cm in the holes, and at 0 cm, 15 cm and 30 cm soil layers from the holes 10 cm with three replicates each. At the same time, three sets of experimental devices were buried around another three apple trees which had no drilling as controls. During the period from June 4 to June 7, from July 14 to July 17, and from September 24 to September 27, the CO₂ trapped by the Noah was determined every

24 hours (from 8:00 ~ 9:00 in the morning until 8:00 ~ 9:00 in the next morning). Concurrently, soil samples from 10 cm intervals over a depth of 0 ~ 40 cm at each CO₂ sampling point were collected for soil water content determination.

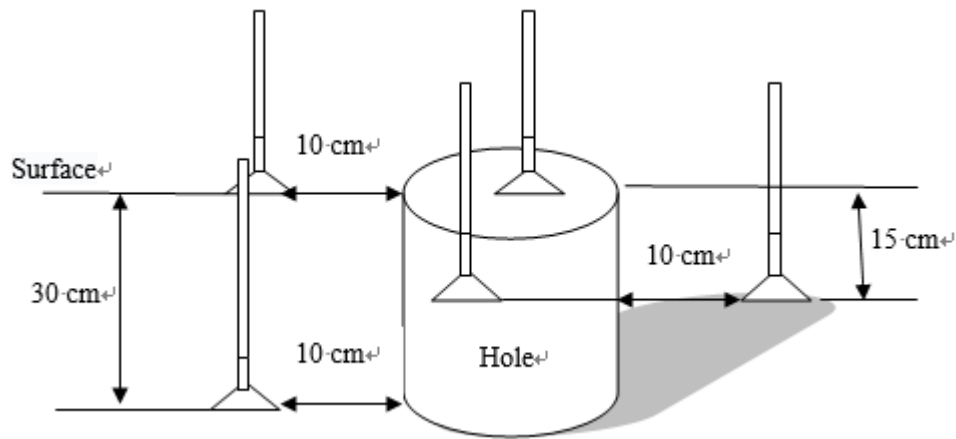


Figure 1. The funnel laying position

2.2. Analytical methods

The amount of CO₂ (mg kg⁻¹) trapped in the NaOH solutions were measured by neutralizing the remaining NaOH with 0.2 mol L⁻¹ HCl [12].

Soil gravimetric water content (w %) was determined from soil cores after oven-drying at 105° C [13].

2.3. Data statistics and analysis

A one-way analysis of variance (ANOVA) was performed to test for differences between treatments. Significant differences were evaluated at the 95% confidence level. When significant differences were observed ($P < 0.05$), a post hoc least significant difference (LSD) test was used to perform multiple comparisons. All statistical analyses were conducted using SPSS 19.0 software.

3. Results and analysis

3.1. Effects of drilling and backfill materials on soil water content

Soil water content is an important physical factor involving in many life activities of plants and microbes. It plays a crucial role in soil microbial community, soil nutrient migration and activity, and soil respiration. Especially in arid and semi-arid areas, soil water content is the main factor controlling soil respiration [14]. In this study, there were significant differences in soil water content between drilling treatments and the control treatment (Figure 2, 3 and 4).

In early June, soil water content at the depth of 0~40 cm ranged 16.1%~20.3% in the drilling treatments, but that only ranged from 10.7%~16.0% in the control treatment. It indicated that drilling can significantly enhance soil water permeability and soil water retention ability, especially in 20~40 cm soil layer. Compared with backfill soil, the addition of vermiculite and slag had no effect soil water content, but liming significantly decrease soil water content in the 10~40 cm soil layer.

During the period from early June to mid-July, soil water contents at the depth of 0~40 cm in the control was only 7.5%~9.5% due to prolonged absence of effective rainfall, which was almost consistent with wilting coefficient. However, soil water content in the drilling treatments was 11.0%~15.2%, in which the addition of vermiculite and slag had higher water content than lime and backfill soil addition. It indicated that drilling significantly contributed to the preservation of soil water in the apple orchards.

In September, soil water content was 19.7%~26.6% in the apple orchards due to the continuous precipitation in the rainy season. There was no significant difference between drilling and control treatment. Compared with CK, the addition of slag increased soil water content, but liming decreased soil water content.

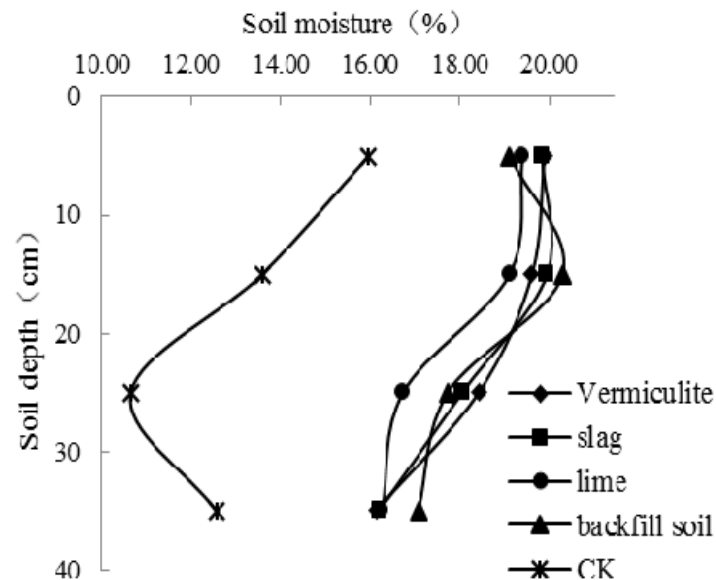


Figure 2. Changes of soil water content under different treatments from Jun. 4 to Jun. 7

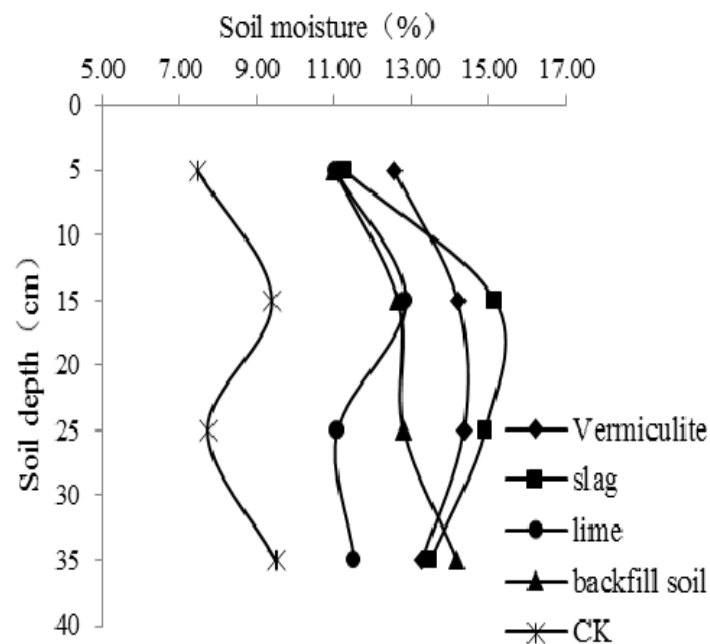


Figure 3. Changes of soil water content under different treatments from Jul. 14 to Jul. 17

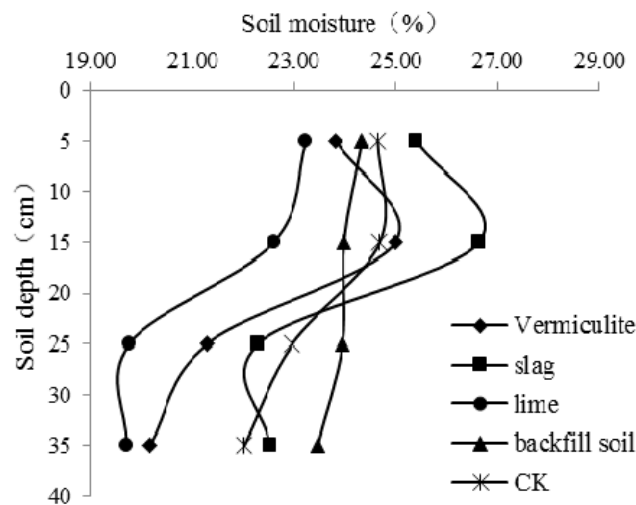


Figure 4. Changes of soil water content under different treatments from Sep. 24 to Sep. 27

3.2. Effects of drilling and backfill materials on soil CO₂ emission

Soil respiration including plant root respiration and soil microbial respiration can usually produce large amounts of CO₂ and discharge into the air [15]. In June, there were some differences in CO₂ emission at different soil depth with vermiculite, slag, and lime and backfill soil application. The CO₂ flux in surface soil treated with vermiculite, slag, and backfill was higher than that at 15 cm, but the lime treatment showed an opposite result. This was because lime could react with CO₂, for example $\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 \downarrow + \text{H}_2\text{O}$. Compared with the control, drillings increased soil CO₂ flux in the top soil, but they had lower CO₂ flux at the depth of 15 cm. It indicated that drilling played a role of a chimney that could drain CO₂ deposited inside the soil into the air. Furthermore, the effect of drilling on soil CO₂ emission can be extended to around 10 cm. Similarly, drilling increased CO₂ flux in the surface soil relative to the control, but decreased CO₂ flux at 15 cm.

In mid-July, soil was drier than June due to long-term no rainfall. Soil CO₂ release decreased significantly (Figure 6). This can be explained by the low soil water content limited the respiration of plant roots and soil microbes. Interestingly, in September, although soil water content increased significantly, soil CO₂ release flux was also lower than June (Figure 7). This was because that the high soil water content blocked soil pores, resulting in a reduction in soil CO₂ release. Accordingly, both too high and too low soil water content can limit soil CO₂ emissions. Additionally, the effects of drilling treatments on the CO₂ flux at different soil depths in inside and around the holes were consistent with June, except for backfill soil which showed the same effect as lime, in July and September. The reason may be that the backfill soil was re-compacted, thus the role of the “chimney” disappeared.

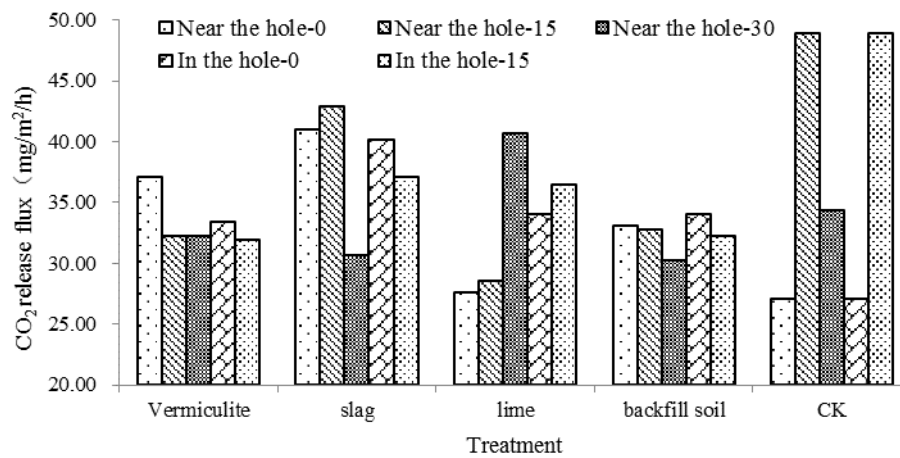


Figure 5. The changes of CO₂ release flux near and in the hole under different treatments from Jun. 4 to Jun. 7

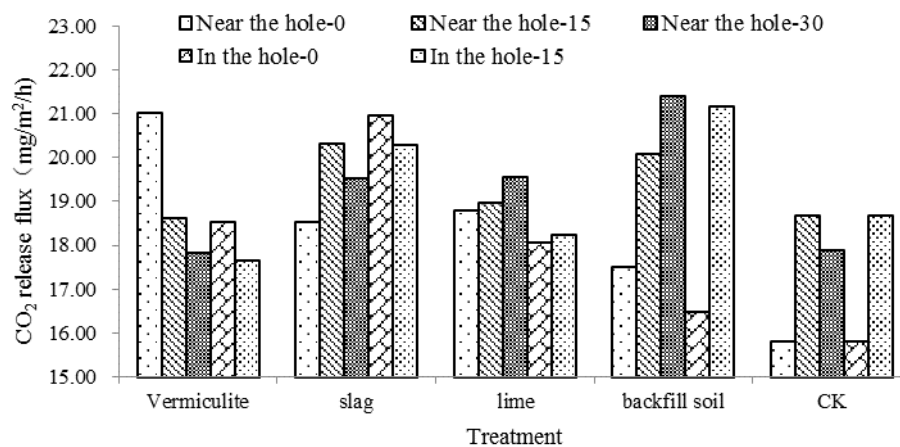


Figure 6. The variation of CO₂ release flux near and in the hole under different treatments from Jul. 14 to Jul. 17

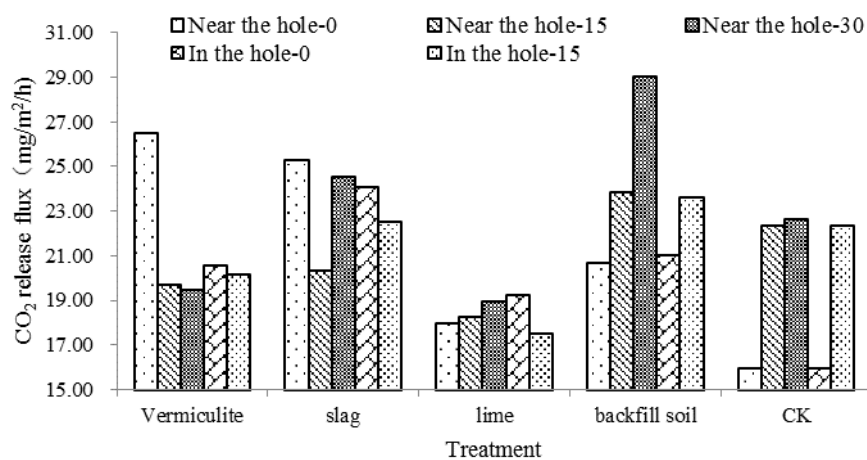


Figure 7. The variation of CO₂ release flux near and in the hole under different treatments from Sep. 24th to Sep. 27th

4. Conclusions and discussions

In the same ecological region, the soil water content is dependent on both soil water holding capacity and soil water infiltration rate. Soil compaction in the Weise apple orchards has limited the infiltration and movement of soil water to the deep soil layer. Therefore, the precipitation is stranded on the surface of the soil and lost through runoff and evaporation. This not only reduces the utilization of water, but also increases the risk of the disease and pests in fruit trees due to the increased air humidity in the canopy of the fruit trees, thus affecting the development of Weise fruit industry. Additionally, the inadequate water infiltration also cannot achieve the effect of improving deep soil water condition in the orchard and softening the internal compacted soil layer. Accordingly, drilling and backfilling with different materials play an important role in improving the water infiltration capacity and the performance of soil water conservation in the orchard soil, achieving the purpose of increasing soil moisture and drought resistance.

Soil compaction in the subsurface soil and its subsoil can hinder the exchange of soil air. The compacted soil, dense soil, and pores sealed by water all resulted in a decrease in soil aeration performance. Thus, CO₂ produced by the aerobic respiration of plant roots and soil microbes was not easily diffused and transmitted. The increased CO₂ in turn inhibited the aerobic respiration of plant roots and soil microbes, but increased the anaerobic respiration, resulting in an accumulation of alcohol, lactic acid and CO₂ [16]. Furthermore, high CO₂ concentration in the soil can break the balance between plant photosynthesis and respiration, and the increased plant respiration is not conducive to plant growth. Additionally, there is a close positive correlation between soil CO₂ and HCO₃⁻ concentration of in soil solution [17]. Zhang et al.[18] found that the high HCO₃⁻ content in soil solution could induce iron deficiency yellowing of plants. Moreover, the increase of CO₂ can react with calcium carbonate and form soluble and mobile calcium bicarbonate (CaHCO₃) in the soil. This accelerated soil calcium degradation and decreased the supply of calcium for plants, resulting in calcium deficiency in apple fruit trees. Meanwhile, soil decalcification also destroyed the soil aggregates due to leaching and deposition of activated clay, which further enhanced soil internal compactness. It concluded that the accumulation of soil CO₂ was the reason for soil degradation [19].

Drilling a localized amendment practice can partly promote soil CO₂ emission in the closed soil; partly improve soil water permeability without harming the root system of the apple trees. This increased soil water content and alleviated the soil drought stress in the apple orchards. There were significant differences in soil water content and CO₂ emission between different treatments. The addition of vermiculite and slag had the best effect on improving soil water condition, but liming can not only absorb the CO₂ in soil inside, but also increase soil calcium storage capacity. Furthermore, soil CO₂ emission was closely related to soil water content. Either too high or too low soil water content was not beneficial to the release of CO₂. Lime can be used as the optimal backfill material to improve soil quality in apple orchards on Weise plateau.

References

- [1] Wangou Liu, Lun Shan, Xiping Deng. Responses of plant to soil compaction[J]. Plant Physiology Communications, 2001, (3): 254-260.
- [2] Lei Shi, Juanling Wang, Mingxiang Xu, et al. Spatial variability and influence factors of cropland soil compaction in Shaanxi Province[J]. Acta Agriculturae boreali-occidentalis sinica, 2016, 25(05): 770-778.
- [3] Li Peng. Effects of Orchard Ages, Fertilizing Methods and Planting Patterns on Soil Compaction in Apple Orchards—A Case Study of Weibei Apple Orchard[J]. Journal of Anhui agricultural science, 2016, 44(21): 98-99.
- [4] Lei Sun, Yiquan Wang, Yulin Zhang, et al. Dual effect of fruit tree cultivation on soil physical characteristics[J]. Chinese Journal of Eco-Agriculture, 2011, 19(01): 19-23.
- [5] Weiqing Zhang, Jiangli Pang, Caiyun Zhang. Soil properties and soil micromorphological characteristics of the apple orchard in the Weibei Dry Highland, Shaanxi Province[J]. Arid Land Geography, 2010, 33(04): 564-571.

- [6] Binmeng Wei, Yiquan Wang. Physical degradation characteristics and mechanism of orchard soil in Weibei Region[J]. Journal of Plant Nutrition and Fertilizer, 2015, 21(03): 694-701.
- [7] Jun Chen. Analysis of the relationship between the fruit tree growth and soil conditions[J]. Modern Agricultural Sciences and Technology, 2010, (9): 155-156.
- [8] Binmeng Wei, Yiquan Wang, Zonglin Shi, et al. Calcium Degradation Status of Orchard Soil in Weibei Region, Shaanxi Province, China[J]. Scientia Agricultura Sinica, 2015, 48(11): 2199-2207.
- [9] Xinsheng Zhang, Jinguo Wang, Reziwanguli, et al. Analysis on the mechanism of increasing agricultural yield of vermiculite and vermiculite compound fertilizer[J]. Xinjiang agricultural science and technology, 2010, (4): 53.
- [10] Yonggong Zhai. Application of industrial slag in agricultural production[J]. World agriculture, 1994, (09): 34-35.
- [11] The effect of Lime and its rational Application[J]. Rural PepsiCo, 1994, (11):34.
- [12] Fasheng Xia, Yiquan Wang, Jun Liu, et al. Dynamic characteristics of CO₂ release flux in Lou soft[J]. Agricultural Research in the Arid Areas, 2010, 28(1): 118-120.
- [13] Shidan Bao. Soil Agrochemical Analysis. 3rd ed. Beijing: China Agriculture Press, 2000.
- [14] Shengguo Che, Shengli Guo, Huiyi Gao. Influence of orchard planting-life and returned to cultivated land on soil moisture content in typical gully region of the Loess Plateau [J]. Agricultural Research in the Arid areas, 2009, 27(04): 71-75+89.
- [15] Fuyuan Liang, Linhua Song, Jing Wang. Diurnal variation of soil CO₂ concentration and its relationship with soil CO₂ flux[J]. Progress in geography, 2003(02): 170-176.
- [16] Yan Sun, Yiquan Wang, Weijun Xu, et al. Effect of soil compaction on soil respiration intensity, plants growth and fruit quality of cucumber[J]. Acta pedologica sinica, 2008, 45(6): 1128-1134.
- [17] K. B. Marcum. Salinity tolerance mechanisms of grasses in the subfamily chloridoideae[J]. Crop Science, 1999, 39(4): 1153-1160.
- [18] Lingyun Zhang, Xianfa Zhang, Heng Zhai. Effects of soil factors on plant chlorosis due to iron deficit[J]. Chinese Journal of Soil Science, 2002, 33(1): 74-77.
- [19] L. G. Anderson, T. Tanhua, G. Bjork, et al. Arctic ocean shelf-basin interaction: An active continental shelf CO₂ pump and its impact on the degree of calcium carbonate solubility[J]. Deep-Sea Research Part I-Ocean ographic Research Papers, 2010, 57(7): 869-879.