Terrace agriculture in the Yellow River delta, China, needs timely revolution

Dongxiao He [1], **Zhiqiang Fang** [1], **Hongxiao Yang** [Corresp. 1]

[1] Qingdao Agricultural University, Qingdao, China

Corresponding Author: Hongxiao Yang
Email address: hongxiaoyang@126.com

Background: Crude flats in delta areas are often saline–alkaline and unsuitable for agricultural use. In the 1990s, people residing in the Yellow River delta constructed terraces on the flats for agricultural development. Herein, we investigated environmental changes resulting from this agricultural development and evaluated whether the current land use is effective and sustainable. **Methods:** We sampled soil and weeds from croplands, terrace slopes, and crude flats within the delta terrace landscape. The measured soil properties included soil salinity, pH, total N, total P, and organic matter in different lands and soil layers: 0–10, 10–20, and 20–30 cm. The surveyed weed characteristics were the biomass of roots and rhizomes, species composition, life form, cover and height. These indices were statistically verified by considering different land types and soil layers. **Results:** Soil salinity in the terrace croplands was found to have successfully reduced to <4 g $\cdot$kg^{-1}, whereas in the crude flats, it remained >6 g $\cdot$kg^{-1}. Soil pH in the terrace croplands was surprisingly increased to >9; meanwhile, organic matter content decreased drastically, which is considerably different from that observed in the case of terrace slopes and crude flats. Total N and P content in the terrace croplands were seemingly unchanged but considerably reduced at depths >20 cm; moreover, the N and P content were observed to be much lower than those at the same depths in other lands. Weeds grew well on the terrace slopes to protect the terraces but were insufficient to compensate for the decomposition of soil organic matter in the cropland. Overall, terrace construction is effective for developing saline delta flats for agricultural use; however, the current land use regime has caused profound soil degradation and needs timely renovation.

Terrace agriculture in the Yellow River delta, China, needs timely revolution

Dongxiao He, Zhiqiang Fang, Hongxiao Yang *

Qingdao Agricultural University, Chengyang, Qingdao, Shandong Province 266109, China

* Corresponding author. E-mail address: hongxiaoyang@126.com (H.X. Yang)

Running title: delta saline land development

Abstract

Background: Crude flats in delta areas are often saline–alkaline and unsuitable for agricultural use. In the 1990s, people residing in the Yellow River delta constructed terraces on the flats for agricultural development. Herein, we investigated environmental changes resulting from this agricultural development and evaluated whether the current land use is effective and sustainable.

Methods: We sampled soil and weeds from croplands, terrace slopes, and crude flats within the delta terrace landscape. The measured soil properties included soil salinity, pH, total N, total P, and organic matter in different lands and soil layers: 0–10, 10–20, and 20–30 cm. The surveyed weed characteristics were the biomass of roots and rhizomes, species composition, life form, cover and height. These indices were statistically verified by considering different land types and soil layers.

Results: Soil salinity in the terrace croplands was found to have successfully reduced to <4 g·kg^{-1}, whereas in the crude flats, it remained >6 g·kg^{-1}. Soil pH in the terrace croplands was surprisingly increased to >9; meanwhile, organic matter content decreased drastically, which is considerably different from that observed in the case of terrace slopes and crude flats. Total N and P content in the terrace croplands were seemingly unchanged but considerably reduced at depths >20 cm; moreover, the N and P content were observed to be much lower than those at the same depths in other lands. Weeds grew well on the terrace slopes to protect the terraces but were insufficient to compensate for the decomposition of soil organic matter in the cropland. Overall, terrace construction is effective for developing saline delta flats for agricultural use; however, the current land use regime has caused profound soil degradation and needs timely renovation.

Keywords: delta; land degradation; land use; saline land; soil fertility; sustainable agriculture

1. Introduction

River deltas are newly formed terrestrial lands that feed more than 500 million people worldwide with a population density of more than seven times of the global mean (Rahman et al., 2019). Initially, the deltas comprise various marshes that can be used for aquaculture (Alam et al., 2017). With sediment depositing, they can be gradually lifted, and subsequently transform into saline-alkaline lands, as observed in the Yellow River delta, China (Yang, 2012; Goodbred et al., 2014; Liu et al., 2014). The Yellow River delta is the largest river delta in Northern China, and its size is still growing (Fan et al., 2012; Mao et al., 2016). The formerly developed areas of this delta have experienced radical changes in environmental conditions, making the aquaculture or fishery no longer viable industries. Thus, locals have to seek for alternative uses for these saline-alkaline lands.

In the formerly developed areas, the water table always appears to be underground; however, soil capillaries transport soluble minerals upward for deposition (Sun et al., 2017; Moreno et al., 2018). In the 1990s, the locals were encouraged and subsided via policies to build terraces with the deposited soils (Fang et al., 2005; Luan, 2007; Ning et al., 2018). Clay was excavated from crude or original flats and was stacked as a series of raised terraces. These terraces were leveled off at heights of 2–3 m, and the remaining pits were reformed as connected ponds and ditches for collecting and draining rainfall. Concept behind this engineering is that upon raining, the rainfall can wash off the salt from terraces, thereby reducing the soil salinity of the terrace lands to facilitate crop growth (Yang et al., 2019).

Currently, all the terraces have been used for growing crops, such as cotton, wheat and maize for nearly 20 years, and soil conditions must have changed (Wang et al., 2004). Soil directly provides crops with nutrients and other necessities; thus soil fertility is a key indicator for evaluating environmental changes occurring in this region (Liu et al., 2015; Wang et al., 2017; Chi et al., 2018). Soil fertility is often dependent on properties such as salinity, pH, organic matter, nitrogen (N), phosphorous (P) and weeds (Cierjacks et al., 2016; Storkey & Neve, 2018; Zhang et al., 2019). Among these, organic matter is a key component that not only decomposes to supply crops with nutrients but also serve as an adhesive to maintain soil structure and function (Tiessen et al., 1994; Subedi et al., 2019; Fu et al., 2020). However, organic matter is a variant of weeds and crop residuals (Stenchly et al., 2017; Ebabu et al., 2020; Jensen et al., 2020). Moreover, weed can prevent the erosion of terrace soils during storms (Lenka et al., 2017).

Herein, we evaluated the sustainability of land use in the early Yellow River delta by monitoring variations in soils and weeds within the delta terrace landscape, and considered the approaches toward using lands in a sustainable manner. Overall, we test the hypothesis that terrace constructing may be useful in developing saline deltas; however, they cannot be enough in this regard unless soil fertility of these lands can be conserved through renewed land-use regime. This study provides an example from the Yellow River delta that can be informative for people in deltas challenged by saline-land development.

2. Methods

2.1. Sampling and measuring

In September 2017 and 2018, we conducted field surveys near a typical rural village (Maotou village, 118.49°E, 37.82°N) in the early Yellow River delta (Figure 1). It is approximately 80 km away from the new formed mouth of the Yellow River. The annual average temperature is approximately 12 ℃; the annual precipitation is approximately 580 mm and primarily occurs from June to August. The lands were made of sediments that were deposited by the old Yellow River between 1855 and 1976 (Yang, 2012). In the 1990s, locals started constructing terraces in this area. Currently, these terraces have been used for growing crops such as cotton and maize. These croplands are irrigated only once a year in spring for sowing, and the fresh water is drawn from the Yellow River rather than using underground water. A few areas of crude flats are still reserved for folk sacrifice ceremonies.

We selected three land types within the terrace landscape: crude flats that remained in their natural state; terrace slopes (30-50°), which skirt the terraces; and terrace croplands, which are leveled tops of the terraces and have been subject to tillage, cropping and fertilization for approximate 20 years. For each land type, we surveyed weeds in 40 random quadrats (1 × 1 m), measuring the cover and height of each weed species. Subsequently, we selected four random points from each land type for soil sampling. At each of these points, we sampled soil at three layers: 0-10, 10-20, and 20-30 cm deep. Furthermore, we sampled a soil cube (10×10×10 cm) from each of these layers. These samples were taken to laboratory for further analysis. The cube samples were washed so that live roots and rhizomes, namely, underground organs (UO), remained. These UOs were then oven-dried at 85℃ for two days and weighed using an electronic scale (precision = 0.01g).

Other soil samples were air-dried, fully ground, and sieved with a 20-mesh wire screen. We measured the pH, salinity, organic matter, total N, and total P of the sieved soil samples. We took 10 g from each sample and mixed the subsamples with pure water at the mass ratio of 1:5 (soil:water). We measured the pH of steady clear solution of the subsamples using an electronic meter (ST2100), and measured the salinity of the solution after fully drying and H_2O_2 solving. Organic matter (OM) in the soil was measured using the potassium bichromate titrimetric method; total N (TN) was measured using the Micro-Kjeldahl method; total P (TP) was measured using the Mo-Sb colorimetric method (Bao, 2008).

2.2. Data analysis

We examined variations in the soil salinity, pH, OM, TN, TP, and dry UO among the three land types using covariance analysis, where the soil layers were included as a covariate (James et al., 2013). This method requires the examined data to follow a normal distribution. As a supplement, we additionally conducted another analysis using the nonparametric Kruskal-Wallis test, which does not require normally distributed data (Hollander & Wolfe, 1973). The Kruskal-Wallis test is similar to the method of one-way ANOVA, while takes advantage of the relative ranks of the data. All these analyses were completed using the software R4.0.3 (R Core Team, 2020).

For evaluating the weed prevalence, we used a composite index, the product of coverage and height (PCH) of weed species in a quadrat, thus quantifying the standard cover thickness of a weed species. Then, we classified all weeds by their life forms as follows: single (grows as a standing singleton), clump (grows as a clump of numerous tillers), vine (grows as an aboveground vine) and rhizome (grows underground with rhizomes to generate new ramets). In addition, we classified these weeds by their longevity (annual vs. perennial). Finally, we summed the PCHs of each weed type in a quadrat and averaged the PCH sums of a certain weed type among the 40 quadrats of the same land type.

3. Results

Soil salinity differed among the land type (Covariance analysis, $F_{2, 32}$=52.87, $p < 0.001$; Kruskal-Wallis, $x_2^2 =$ 23.49, $p < 0.001$), but did not differ as significantly among the soil layer (Covariance analysis, $F_{1, 32}$=4.31, p = 0.046; Kruskal-Wallis, $x_2^2 =$ 1.81, p =0.41). Soil salinity was lower in the terrace croplands (< 4 $g \cdot kg^{-1}$) than in the crude flatlands and terrace slopes (> 6 $g \cdot kg^{-1}$) (Figure 2). Soil pH varied depending on the land type (Covariance analysis, $F_{2, 32}$= 95.13, $p < 0.001$; Kruskal-Wallis, $x_2^2 =$ 24.78, $p < 0.001$) but did not vary as significantly with differing soil layers (Covariance analysis, $F_{1, 32}$=6.01, $p < 0.020$; Kruskal-Wallis, $x_2^2 =$ 3.48, p = 0.175). Soil pH was higher in the terrace croplands (> 9) than in the crude flats and terrace slopes (<9) (Figure 2).

The total N content in the soil did not vary with the land type (Covariance analysis, $F_{2, 32}$= 1.30, p = 0.285; Kruskal-Wallis, $x_2^2 =$ 0.95, p = 0.623), but varied with the soil layer (Covariance analysis, $F_{1, 32}$= 28.43, $p < 0.001$; Kruskal-Wallis, $x_2^2 =$ 17.68, $p <0.001$), with the highest variation in topsoil being <10 cm (Figure 3). The N content at 20-30 cm deep was 0.23 ± 0.10 $g \cdot kg^{-1}$ in the terrace croplands, 0.34 ± 0.03 $g \cdot kg^{-1}$ in the crude flatlands, and 0.34 ± 0.10 $g \cdot kg^{-1}$ in the terrace slopes. Similarly, the total P content of the soil did not vary with the land type (Covariance analysis, $F_{2, 32}$=3.09, p=0.059; Kruskal-Wallis, $x_2^2 =$ 0.77, p = 0.681), but varied among different soil layers (Covariance analysis, $F_{1, 32}$=16.08, p<0.001; Kruskal-Wallis, $x_2^2 =$ 8.46, p = 0.015) (Figure 3). The P content in the soil at a depth of 20 - 30 cm layer was 1.006 ± 0.032 $g \cdot kg^{-1}$ in the terrace croplands, 1.038 ± 0.117 $g \cdot kg^{-1}$ in the crude flats, and 1.087 ± 0.097 $g \cdot kg^{-1}$ in the terrace slopes.

Soil OM was basically different among the land types (Covariance analysis, $F_{2, 32}$=3.28, p = 0.051; Kruskal-Wallis, $x_2^2 =$ 4.95, p = 0.084), and among different soil layers (Covariance analysis, $F_{1, 32}$=17.91, p < 0.001; Kruskal-Wallis, $x_2^2 =$ 12.08, p = 0.002). The lowest OM value was observed for the soil at a depth >10 cm in the terrace croplands (Figure 4). The biomass of plant UOs varied significantly with the land type (Covariance analysis, $F_{2, 32}$= 6.87, p = 0.003; Kruskal-Wallis, $x_2^2 =$ 12.84, p = 0.002) and varied nearly to a significant level with the soil layer (Covariance analysis, $F_{1, 32}$=11.79, p = 0.002; Kruskal-Wallis, $x_2^2 =$ 5.52, p = 0.063). Furthermore, the biomass of plant UOs was extremely low in the terrace croplands (Figure 4).

The weed types mainly comprised perennials and rhizomes (Figure 5). The relative cover thickness of weeds was the greatest on the terrace slopes (>600 cm), and the lowest in the terrace croplands (<50 cm). However, weeds did not grow well (<100 cm) in the crude flats; they were only slightly better than in the terrace croplands. The richness of weed species showed a similar pattern, with 23 species found on the slopes, 16 species found in the terrace croplands, and only 10 species found in the crude flats.

4. Discussion

4.1. Positive changes with the terracing and cropping

Comparison of the different lands revealed some positive changes, which are discussed below. Soil salinity in the terrace croplands was significantly lower than in the crude flats. Soil salinity in the flats remained high at >6 $g \cdot kg^{-1}$. After terraces were built using the deposited soils, rainfall likely accelerated the desalination process. Some years later, salinity was no longer a hindrance to growing certain varieties of cotton and maize; thus, the locals began growing them on the terraces. Harvesting the crops also contributed to reducing salinity in the lands (Zhao et al., 2013). Presently, soil salinity in the terrace croplands has successfully reduced to < 4 $g \cdot kg^{-1}$, whereas in the crude flats, it remains >6 $g \cdot kg^{-1}$, which suggests the efficiency of terrace construction in reducing soil salinity and favoring agricultural use.

Weeds on the terrace slopes grew considerably thicker than in the flats or croplands, and the richness of weed species was also the highest on the terrace slopes. This is partly attributed to farmers intentionally permitting weed growth because weeds (particularly perennials) can protect the terraces from eroding and collapsing during storms (Liu et al., 2013; Asimeh et al., 2020). In the croplands, weeds were scarce because of farmers' tillage and weeding activities; in the crude flats, they grew only slightly better than in the croplands owing to high soil salinity and compaction (Bennett et al., 2009; Xia et al., 2009). This indicates that terrace slopes can be refuges for conserving a considerable number of plant species, which would consequently protect the croplands against erosion and collapses.

4.2. Negative changes with the farming

Unfortunately, negative changes were also observed. As previously mentioned, soil pH in the terrace croplands was higher (>9) than in the crude flats (<9). Soil OM content, particularly at depths > 10 cm, was lower in the croplands than in the flats. These changes certainly reduced soil fertility in the croplands (Chapagain & Raizada, 2017; Zhang et al., 2020). They are considered to be a chronic response to the current farming regime, rather than to the terracing practice, because these changes were not as evident in the terrace slopes.

Subsequent to the commencement of agricultural practices in the terrace lands, fertilizers and herbicides were repeatedly added to eradicate weeds and to replenish N and P contents in the soils. However, these chemicals could also cause cumulative changes in the soils (Zalidis et al., 2002; Kaur et al., 2018). Some of the commonly used chemical fertilizers, such as diammonium phosphate and urea, can slightly increase the soil pH (Zhou et al., 2004; Jin et al., 2008). This increase may be small initially; however, it could accumulate year after year, thereby causing a significant change, as it currently seen. Aboveground and underground amounts of weeds (plants) were observed to be extremely low in the croplands, thus they cannot compensate for the yearly decomposition of soil OM (Hobley et al., 2018; Storkey & Neve, 2018).

4.3. Obscure changes of soil total N and P

The total N and P contents in the soils seemed to be equivalent among the three land types. As the most-required elements by crops, soil N and P must be repeatedly taken away from the soils with annual crop harvest. To compensate for the loss of N and P contents, locals added chemical fertilizers, such as diammonium phosphate and urea. The N and P contents in the soil seemed to be maintained and were not significantly lower than in the crude flats and terrace slopes. However, this is only a judgment based on averages.

The N and P contents in the soil were dependent on the soil depths. For soil layers at the depth of 20-30 cm, N and P were observed to be much lower in the croplands than in other lands. This indicates that the added chemical fertilizers could not supplement the N and P loss in the subsoil appropriately. If the loss cannot be timely reversed, soil degradation could become more severe, and may ultimately make the terrace lands unsuitable for agriculture development (Dai et al., 2017; Jensen et al., 2020). Considering this, we propose that it is time to convert the current land use regime into a new one that can restore the fertility of terrace soils (Ordóñez-Fernández et al., 2018; Fu et al., 2020).

5. Conclusion

After the delta saline soil was stacked as raised terraces, soil salinity decreased gradually, and with terracing, abundant weeds grew on the new habitats of slopes for protecting the terraces from erosion. However, subsequent agricultural practices have caused profound degradation of the terrace lands, including increased soil pH, and soil organic matter loss, and loss of total N and P in subsoil at the depth of >20 cm. The current land use is believed to be unsustainable, and it is time to renovate it to restore fertility of the terrace soil.

Acknowledgements: We gratefully acknowledge Liwen Bianji (www.liwenbianji.cn/) for editing the article.
Funding: This study is funded by Qingdao Agricultural University.
Competing Interest: The author declares no conflict of interest.
Authors' Contributions
Dongxiao He, conducted the survey and measurement, wrote the manuscript.
Zhiqiang Fang, conducted the survey and measurement.
Hongxiao Yang, directed the study and revised the manuscript.
Data Availability: The data presented in this study are available on request from the author.

REFERENCE

Alam MS, Sasaki N, Datta A. **2017**. Waterlogging, crop damage and adaptation interventions in the coastal region of Bangladesh: A perception analysis of local people. *Environmental Development* **23**:22-32 DOI https://doi.org/10.1016/j.envdev.2017.02.009

Asimeh M, Nooripoor M, Azadi H, Van Eetvelde V, Sklenička P, Witlox F. **2020**. Agricultural land use sustainability in Southwest Iran: Improving land leveling using consolidation plans. *Land Use Policy* **94**:104555 DOI https://doi.org/10.1016/j.landusepol.2020.104555

Bao SD. **2008**. *Soil and Agricultural Chemistry Analysis*. Beijing, China: China Agriculture Press.

Bennett SJ, Barrett-Lennard EG, Colmer TD. **2009**. Salinity and water logging as constraints to saltland pasture production: A review. *Agriculture, Ecosystems & Environment* **129**:349-360 DOI https://doi.org/10.1016/j.agee.2008.10.013

Chapagain T, Raizada MN. **2017**. Agronomic challenges and opportunities for smallholder terrace agriculture in developing countries. *Frontiers in Plant Science* **8**:331 DOI https://doi.org/10.3389/fpls.2017.00331

Chi Y, Shi H, Zheng W, Sun J, Fu Z. **2018**. Spatiotemporal characteristics and ecological effects of the human interference index of the Yellow River Delta in the last 30 years. *Ecological Indicators* **89**:880-892 DOI https://doi.org/10.1016/j.ecolind.2017.12.025

Cierjacks A, Pommeranz M, Schulz K, Almeida-Cortez J. **2016**. Is crop yield related to weed species diversity and biomass in coconut and banana fields of northeastern Brazil? *Agriculture Ecosystems & Environment* **220**:175-183 DOI https://doi.org/10.1016/j.agee.2016.01.006

Dai S, Wang J, Cheng Y, Zhang J, Cai Z. **2017**. Effects of long-term fertilization on soil gross N transformation rates and their implications. *Journal of Integrative Agriculture* **16**:2863-2870 DOI https://doi.org/10.1016/S2095-3119(17)61673-3

Ebabu K, Tsunekawa A, Haregeweyn N, Adgo E, Meshesha DT, Aklog D, Masunaga T, Tsubo M, Sultan D, Fenta AA, Yibeltal M. **2020**. Exploring the variability of soil properties as influenced by land use and management practices: A case study in the Upper Blue Nile basin, Ethiopia. *Soil and Tillage Research* **200**:104614 DOI https://doi.org/10.1016/j.still.2020.104614

Fan X, Pedroli B, Liu G, Liu Q, Liu H, Shu L. **2012**. Soil salinity development in the Yellow River Delta in relation to groundwater dynamics. *Land Degradation & Development* **23**:175-189 DOI

Fang H, Liu G, Kearney M. **2005**. Georelational analysis of soil type, soil salt content, landform, and land use in the Yellow River Delta, China. *Environmental Management* **35**:72-83 DOI 10.1007/s00267-004-3066-2

Fu D, Wu X, Duan C, Zhao L, Li B. **2020**. Different life-form plants exert different rhizosphere effects on phosphorus biogeochemistry in subtropical mountainous soils with low and high phosphorus content. *Soil and Tillage Research* **199**:104516 DOI https://doi.org/10.1016/j.still.2019.104516

Goodbred SL, Paolo PM, Ullah MS, Pate RD, Khan SR, Kuehl SA, Singh SK, Rahaman W. **2014**.

Piecing together the Ganges-Brahmaputra-Meghna River delta: Use of sediment provenance to reconstruct the history and interaction of multiple fluvial systems during Holocene delta evolution. *Geological Society of America Bulletin* **126**:1495-1510 DOI https://doi.org/10.1130/B30965.1

Hobley EU, Honermeier B, Don A, Gocke MI, Amelung W, Kögel-Knabner I. **2018**. Decoupling of subsoil carbon and nitrogen dynamics after long-term crop rotation and fertilization. *Agriculture, Ecosystems & Environment* **265**:363-373 DOI https://doi.org/10.1016/j.agee.2018.06.021

Hollander M, Wolfe D. **1973**. *Nonparametric Statistical Methods*. New York: John Wiley & Sons.

James G, Witten D, Hastie T, Tibshirani R. **2013**. *An Introduction to Statistical Learning: With Applications in R*: Springer.

Jensen JL, Schjønning P, Watts CW, Christensen BT, Obour PB, Munkholm LJ. **2020**. Soil degradation and recovery - Changes in organic matter fractions and structural stability. *Geoderma* **364**:114181 DOI https://doi.org/10.1016/j.geoderma.2020.114181

Jin L, Zhou J, Wang H, Chen X, Du C. **2008**. Vertical diffusion and transformation of diammonium phosphate in acidic soil. *Journal of Ecology and Rural Environment* **24**:45-50 DOI 10.1287/opre.51.4.645.16103

Kaur S, Kaur R, Chauhan BS. **2018**. Understanding crop-weed-fertilizer-water interactions and their implications for weed management in agricultural systems. *Crop Protection* **103**:65-72 DOI https://doi.org/10.1016/j.cropro.2017.09.011

Lenka NK, Satapathy KK, Lal R, Singh RK, Singh NAK, Agrawal PK, Choudhury P, Rathore A. **2017**. Weed strip management for minimizing soil erosion and enhancing productivity in the sloping lands of north-eastern India. *Soil and Tillage Research* **170**:104-113 DOI https://doi.org/10.1016/j.still.2017.03.012

Liu SL, Dong YH, Li D, Liu Q, Wang J, Zhang XL. **2013**. Effects of different terrace protection measures in a sloping land consolidation project targeting soil erosion at the slope scale. *Ecological Engineering* **53**:46-53 DOI 10.1016/j.ecoleng.2012.12.001

Liu Y, Chengliang LI, Gao M, Zhang M, Zhao G. **2015**. Effect of different land-use patterns on physical characteristics of the soil in the Yellow River delta region. *Acta Ecologica Sinica* **35**:5183-5190 DOI 10.5846/stxb201312253030

Liu Y, Gao S, Wang YP, Yang Y, Long J, Zhang Y, Wu X. **2014**. Distal mud deposits associated with the Pearl River over the northwestern continental shelf of the South China Sea. *Marine Geology* **347**:43-57 DOI https://doi.org/10.1016/j.margeo.2013.10.012

Luan B. **2007**. Research on the landscape of terrace land: discussion on its form, function and value. *Urban Space Design* **6**:26-30 DOI http://en.cnki.com.cn/Article_en/CJFDTOTAL-CSHJ200706008.htm

Mao W, Kang S, Wan Y, Sun Y, Li X, Wang Y. **2016**. Yellow River sediment as a soil amendment for amelioration of saline land in the Yellow River Delta. *Land Degradation & Development* **27**:1595-1602 DOI 10.1002/ldr.2323

Moreno J, Terrones A, Juan A, Alonso MÁ. **2018**. Halophytic plant community patterns in Mediterranean saltmarshes: shedding light on the connection between abiotic factors and the distribution of halophytes. *Plant and Soil* **430**:185-204 DOI 10.1007/s11104-018-3671-0

Ning J, Gao Z, Meng R, Xu F, Gao M. **2018**. Analysis of relationships between land surface temperature and land use changes in the Yellow River Delta. *Frontiers of Earth Science* **12**:1-13 DOI 10.1007/s11707-017-0657-9

Ordóñez-Fernández R, Repullo-Ruibérriz De Torres MA, Márquez-García J, Moreno-García M, Carbonell-Bojollo RM. **2018**. Legumes used as cover crops to reduce fertilisation problems improving soil nitrate in an organic orchard. *European Journal of Agronomy* **95**:1-13 DOI https://doi.org/10.1016/j.eja.2018.02.001

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rahman MM, Penny G, Mondal MS, Zaman MH, Kryston A, Salehin M, Nahar Q, Islam MS, Bolster D, Tank JL, Müller MF. **2019**. Salinization in large river deltas: Drivers, impacts and socio-hydrological feedbacks. *Water Security* **6**:100024 DOI https://doi.org/10.1016/j.wasec.2019.100024

Stenchly K, Lippmann S, Waongo A, Nyarko G, Buerkert A. **2017**. Weed species structural and functional composition of okra fields and field periphery under different management intensities along the rural-urban gradient of two West African cities. *Agriculture, Ecosystems & Environment* **237**:213-223 DOI https://doi.org/10.1016/j.agee.2016.12.028

Storkey J, Neve P. **2018**. What good is weed diversity? *Weed Research* **58**:239-243 DOI 10.1111/wre.12310

Subedi P, Jokela EJ, Vogel JG. **2019**. Soil respiration and organic matter decomposition dynamics respond to legacy fertilizer and weed control treatments in loblolly pine stands. *Soil Biology and Biochemistry* **137**:107548 DOI https://doi.org/10.1016/j.soilbio.2019.107548

Sun W, Sun Z, Tian L, Hu X. **2017**. Variation and prediction of different marsh landscapes in intertidal zone of the Yellow River Delta. *Acta Ecologica Sinica* **37**:215-225 DOI 10.5846/stxb201607261524

Tiessen H, Cuevas E, Chacon P. **1994**. The role of soil organic matter in sustaining soil fertility. *Nature* **371**:783-785 DOI 10.1038/371783a0

Wang H, Gong P, Liu GH. **2004**. The review and prospect on land use and land cover change research in Yellow River Delta. *Journal of Natural Resources* **19**:110-118 DOI http://en.cnki.com.cn/Article_en/CJFDTOTAL-ZRZX200401013.htm

Wang Z, Zhao G, Gao M, Chang C. **2017**. Spatial variability of soil salinity in coastal saline soil at different scales in the Yellow River Delta, China. *Environmental Monitoring & Assessment* **189**:80 DOI 10.1007/s10661-017-5777-x

Xia JB, Lu ZH, Gao P, Xu JW, Li CR. **2009**. Soil water storage ability of different vegetation types in lowlands of the Yellow River Delta. *Journal of Soil and Water Conservation* **23**:72-75 DOI 10.1007/978-1-4020-9623-5_5

Yang T, Šimůnek J, Mo M, Mccullough-Sanden B, Shahrokhnia H, Cherchian S, Wu L. **2019**. Assessing salinity leaching efficiency in three soils by the HYDRUS-1D and -2D simulations. *Soil and Tillage Research* **194**:104342 DOI https://doi.org/10.1016/j.still.2019.104342

Yang W. **2012**. Shifting of coastline and evolution of tidal flat in modern yellow river delta. *Marine Geology Frontiers* **28**:17-23 DOI http://en.cnki.com.cn/Article_en/CJFDTOTAL-HYDT201207004.htm

Zalidis G, Stamatiadis S, Takavakoglou V, Eskridge K, Misopolinos N. **2002**. Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology. *Agriculture, Ecosystems & Environment* **88**:137-146 DOI https://doi.org/10.1016/S0167-8809(01)00249-3

Zhang H, Niu L, Hu K, Hao J, Li F, Gao Z, Wang X, Influence Of Tillage SAMF. **2020**. Influence of tillage, straw-returning and mineral fertilization on the stability and associated organic content of soil aggregates in the North China Plain. *Agronomy* **10**:951 DOI 10.3390/agronomy10070951

Zhang W, Wang C, Xue R, Wang L. **2019**. Effects of salinity on the soil microbial community and soil fertility. *Journal of Integrative Agriculture* **18**:1360-1368 DOI https://doi.org/10.1016/S2095-3119(18)62077-5

Zhao ZY, Zhang K, Wang L, Wang P, Tian CY. **2013**. Desalination effect of halophytes in heavily salinized soil of Karamay,Xinjiang,China. *Journal of Desert Research* **33**:1420-1425 DOI http://qikan.cqvip.com/Qikan/Article/Detail?id=47314316

Zhou X, Zeng Q, Jiang Z, Tang C. **2004**. Effects of urea on soil pH and the accumulation of NH_3 and NO_2 in a simulative greenhouse. *Chinese Journal of Soil Science* **35**:374-376 DOI 10.3321/j.issn:0564-3945.2004.03.031

Figure Legends

Figure 1. Typical terrace landscape in the early Yellow River delta. The right panel is a satellite image around Maotou village, and the left panel denotes the three land types, namely, terrace cropland, terrace slope, and crude flat.

Figure 2. Soil salinity and pH in different lands of the terrace system

Figure 3. Soil total N and P contents in different lands of the terrace system

Figure 4. Soil organic matter contents and mass of dry underground organs in different lands of the terrace system

Figure 5. Cumulative PCH of weeds in different lands of the terrace system. PCH, the product of coverage and height of weed species

Figure 1

Figure 1. Typical terrace landscape in the early Yellow River delta. The right panel is a satellite image around Maotou village, and the left panel denotes the three land types, namely, terrace cropland, terrace slope, and crude flat.

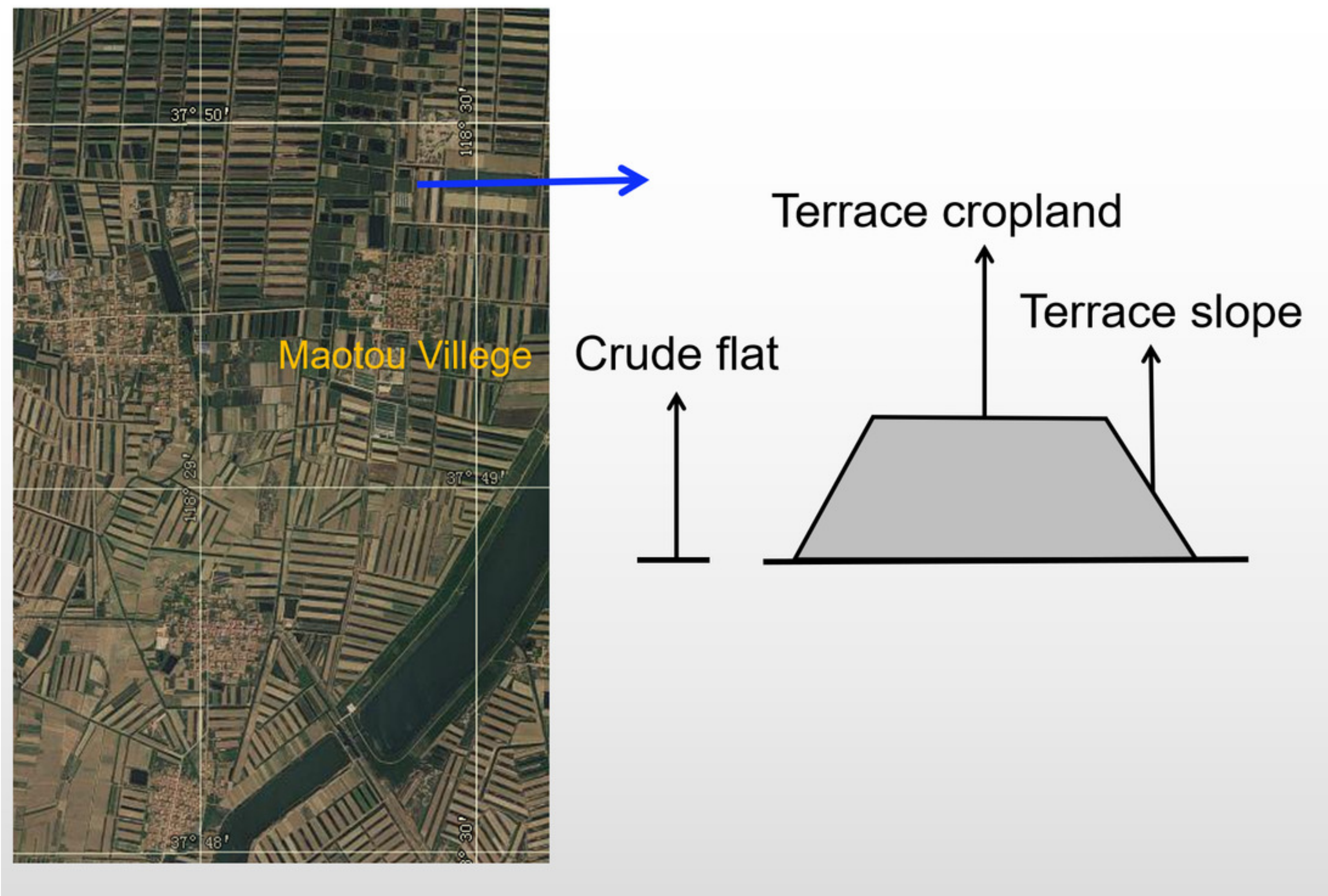


Figure 2

Figure 2. Soil salinity and pH in different lands of the terrace system

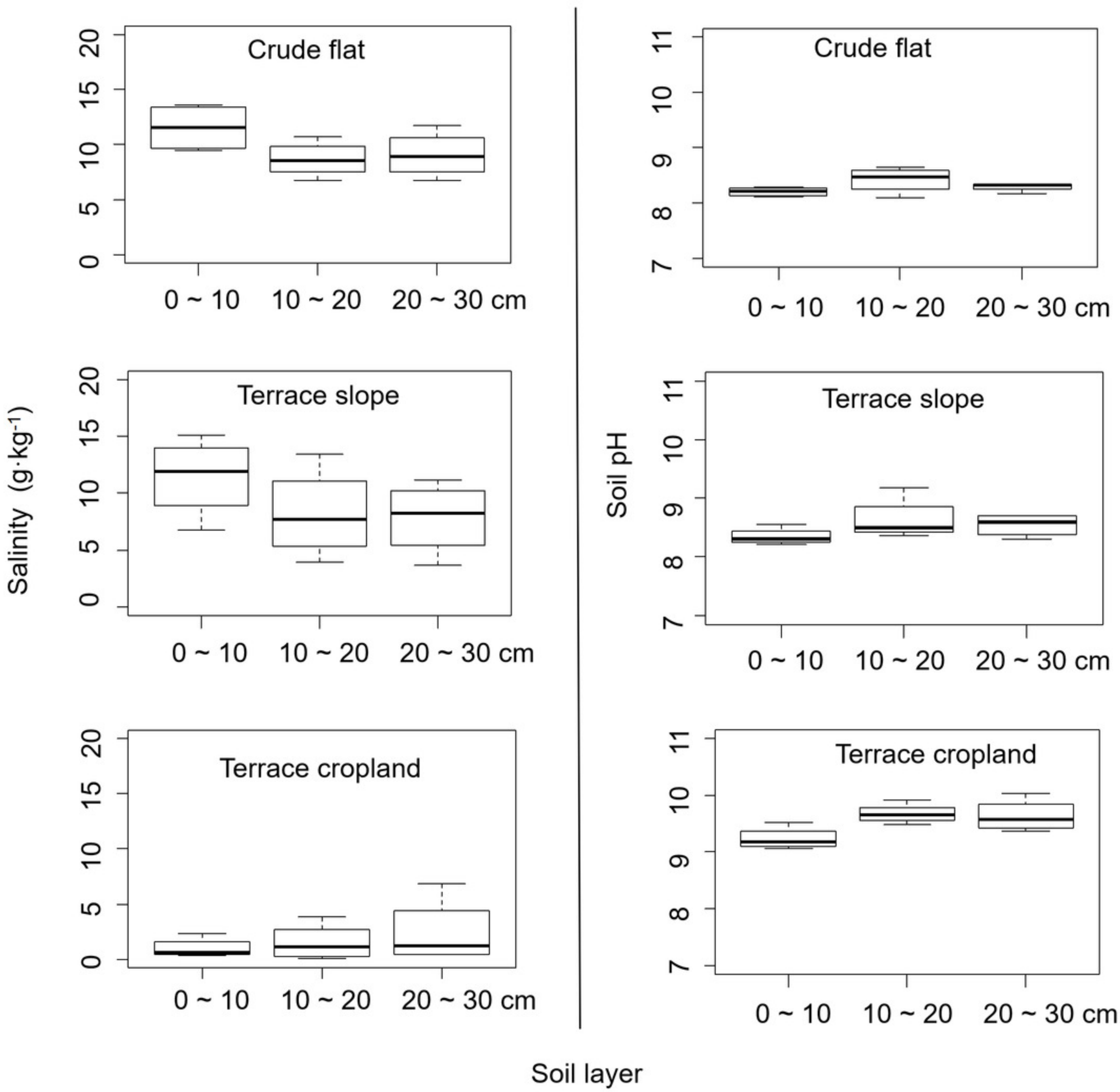


Figure 3

Figure 3. Soil total N and P contents in different lands of the terrace system

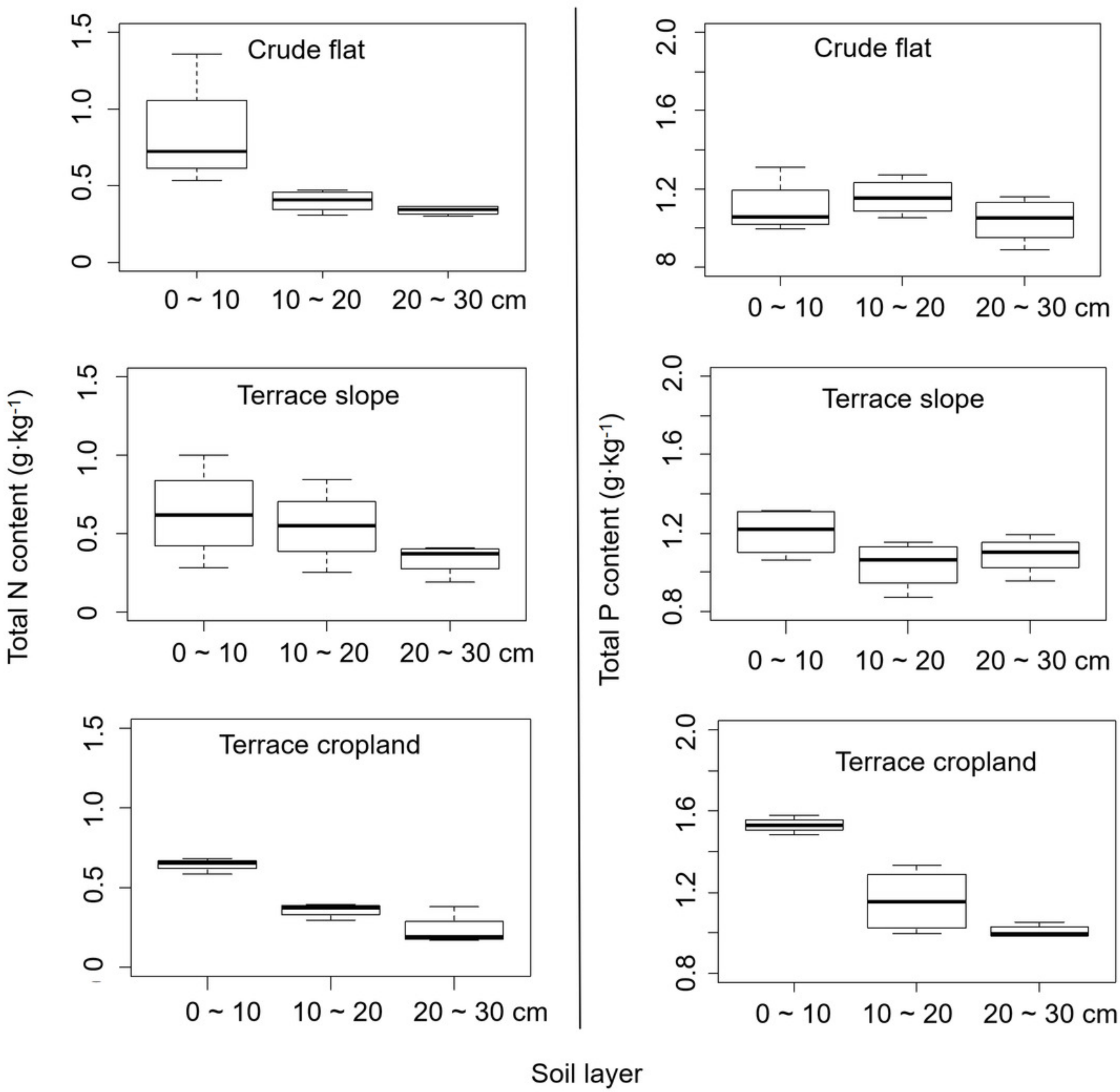


Figure 4

Figure 4. Soil organic matter contents and mass of dry underground organs in different lands of the terrace system

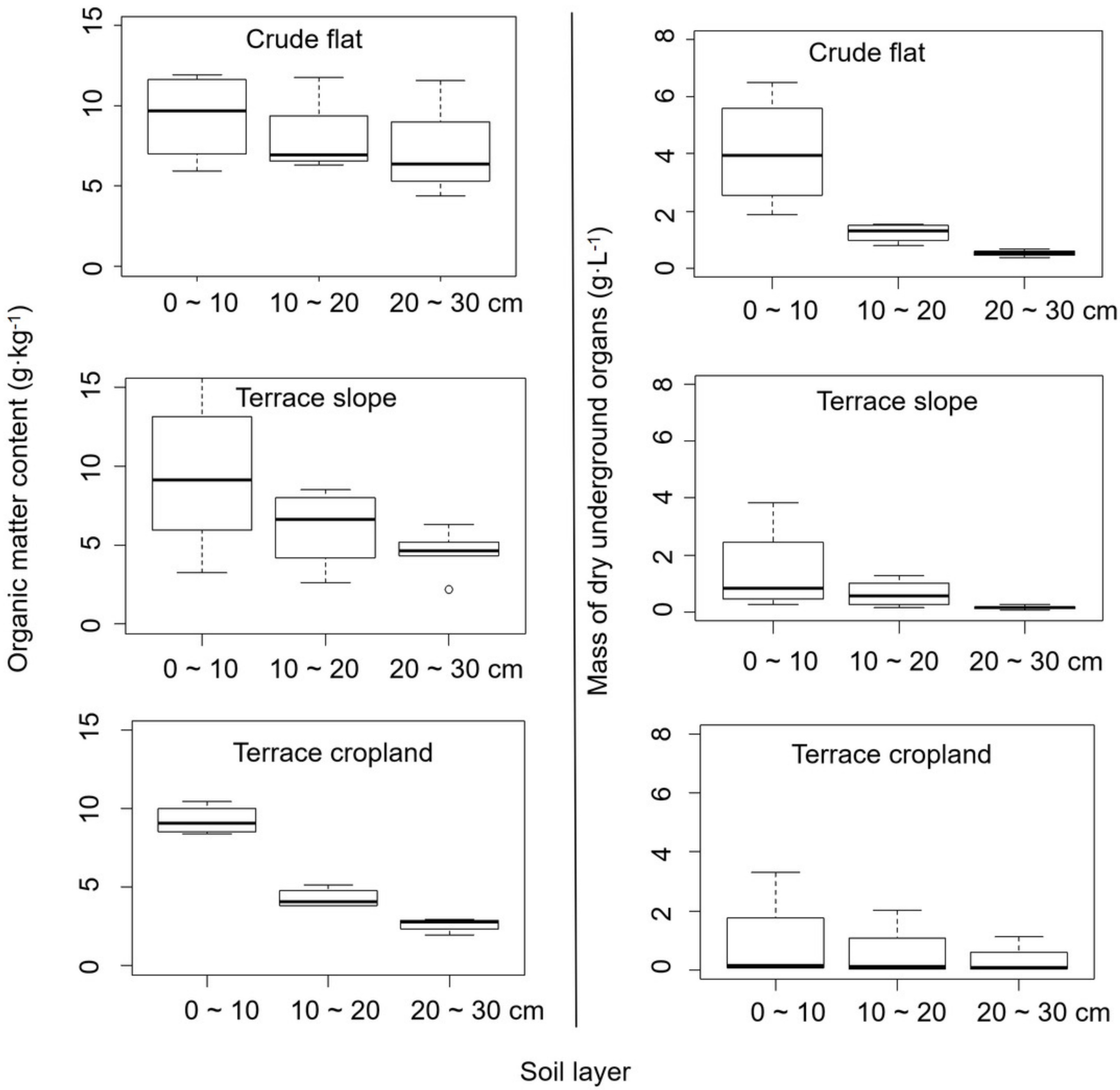
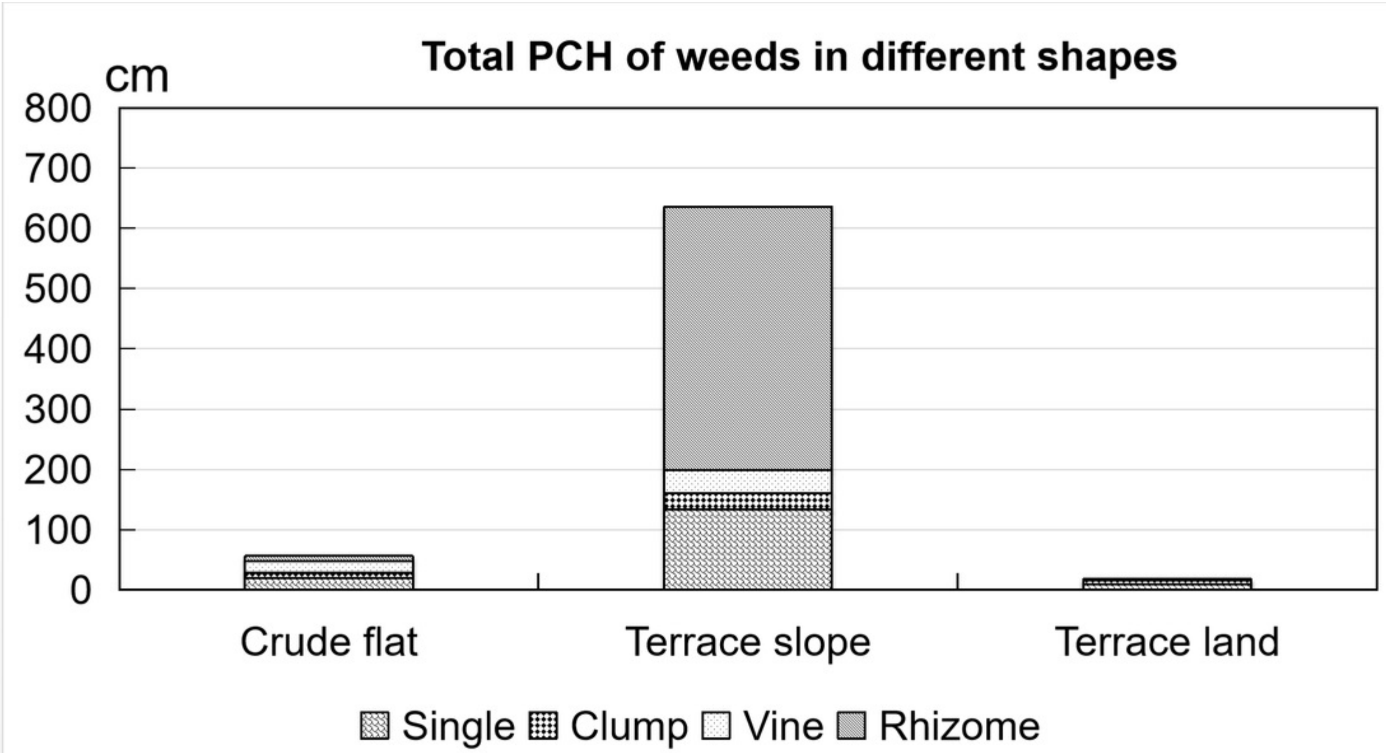
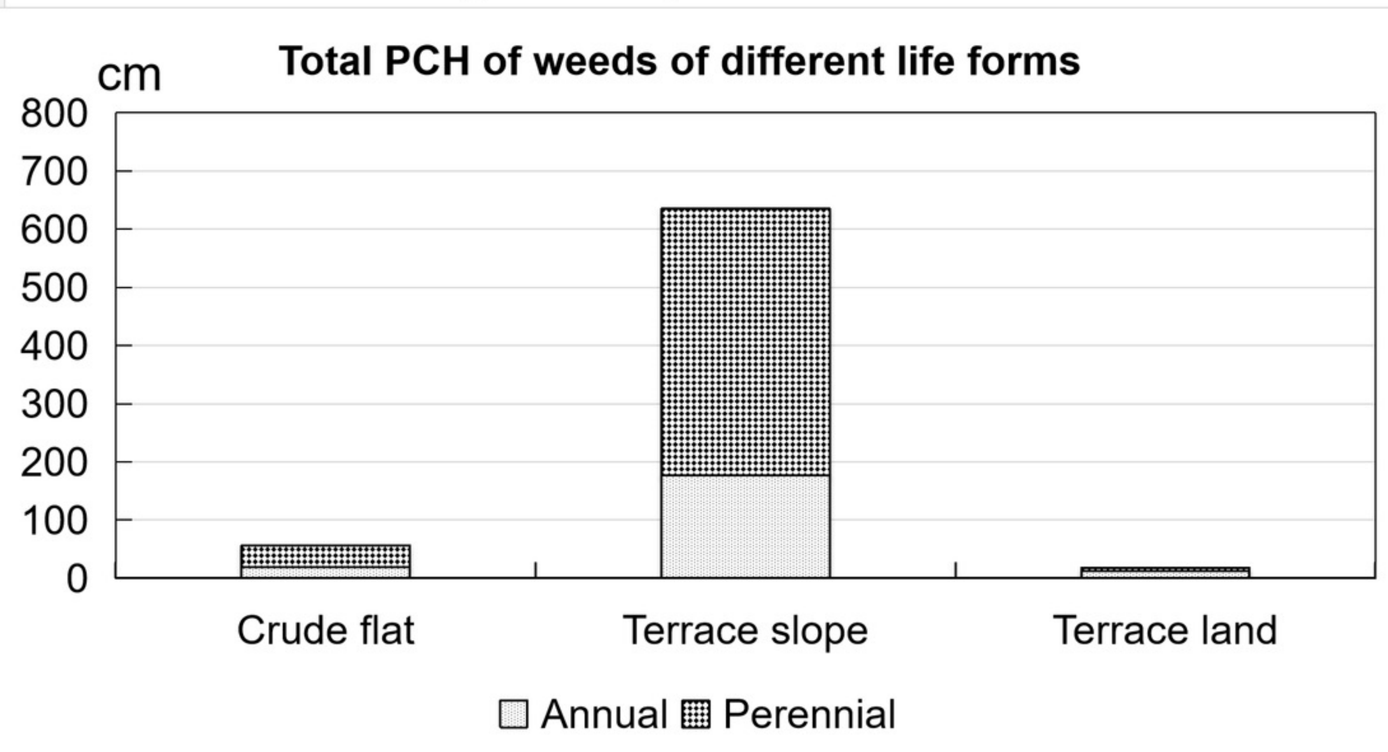


Figure 5

Figure 5. Cumulative PCH of weeds in different lands of the terrace system. PCH, the product of coverage and height of weed species


Total PCH of weeds in different shapes
cm
800
700
600
500
400
300
200
100
0
Crude flat
Terrace slope
Terrace land
Single
Clump
Vine
Rhizome


Total PCH of weeds of different life forms
cm
800
700
600
500
400
300
200
100
0
Crude flat
Terrace slope
Terrace land
Annual
Perennial