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Effect of Soil Management on Soil Erosion – With Focus on Tillage System

LWS 548 – FINAL PROJECT

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Executive Summary

Population expansion and life quality improvements rapidly increase the global food demand. However, many arable lands are converted for industrial and residential use. The requirement to maximize food supply on limited arable land promotes the implementation of modern agriculture.

Modern agriculture can effectively increase food supply through monoculture, genetic manipulation, intensive tillage, and chemicals usage. However, the effects of modern agriculture on soil, including biodiversity reduction, nutrient deficiency, and soil structure destruction promote land degradation. It decreases the long-term ability of soil to provide food and environmental services.

Erosion is the primary reason for land degradation, and intensive tillage is the main practice to cause erosion. Intensive tillage breaks soil aggregates and reduces macroporosity, which decreases the water storage and water drainage ability of soil. The decreased soil organisms and aggregates resulting from frequent tillage decrease biodiversity and slow the soil nutrient cycling. Unlike chemical and biological effects, which have well-documented assessment methods, the interaction of soil and external factors makes physical effects hard to assess.

With the case study in the Anding District, this paper comprehensive literature reviews and the Universal Soil Loss Equation (USLE) to assess the physical effects of different tillage methods in the case study based on the loess plateau soil. Through the effect on bulk density, porosity, aggregates, and field capacity of the conventional tillage and three no-till methods, the result shows that no-till with stubble cover produces less soil disturbance and has the highest erosion resistance.

To promote the transformation of conventional tillage to no-till with stubble cover, this paper recommends the local government implement farmers' education, provide subsidies, and strengthen the collaboration between enterprises and farmers. These strategies can increase the willingness and ability of local farmers to change tillage methods, which support the erosion control program of the government.

Table of Contents

Introduction

Challenges on Global Food Supply

The growing food demand with the shrinking agricultural land base puts unprecedented pressure on the soil. Two reasons drive the rapid growth of the food requirement: population expansion and life quality improvements (Kopittke et al., 2019).

The United Nations Population Fund (UNFPA) expects the global population to reach 7.95 billion in 2022, which increases the population by 1 billion since 2011 (UNFPA, 2022). The rapid population growth exacerbates the food insecurity problem. By the 2022 estimation, about 768 million people will be in hunger, which is 161 million more than in 2019. The higher population of hunger indicates actions needed to increase the quantity of the food supply (FAO et al., 2021). In addition, the increasing global affluence on average improves the quality requirement for food. People nowadays pursue a healthy diet in which they consume nutrients from a more diverse food supply (FAO et al., 2021). The higher quantity and quality requirements of food signifies the need to increase healthy and nitrous food production.

More than 98% of the daily food production comes from the soil, a limited natural resource. The increase in food production can be reached by an expansion of agricultural land area or an improvement of the productivity per soil unit (Kopittke et al., 2019).

Before the mid-20th century, the increase in food production was achieved by agricultural land expansion, mainly through deforestation. The results included a reduction in biodiversity, soil fertility, and soil structure and deterioration of soil quality, which leads to overall land degradation. In the mid-20th century, the urban expansion increased the conversion of agricultural land for residential and industrial use (Kopittke et al., 2019). The shrinkage of agricultural land triggered the transformation from land expansion to modern agriculture.

Functions of Modern Agriculture

Modern agriculture is an evolving agricultural system. It aims to maximize crop production per unit area. The four practices within the modern agricultural system are intensive tillage, monoculture, genetic manipulation, and application of inorganic fertilizer, herbicide, and pesticide (Lanz et al., 2018). Each practice has its individual contribution to increasing crop yield, but when they work together in a system, they depend on and reinforce the effect of each other on crop production and often with unknown results (Lanz et al., 2018).

A major management activity in modern agriculture is soil tillage, as most crops are annual and require soil preparation for the yearly crop. Tillage prepares the soil for the desired seedbed conditions through soil manipulation. It turns over soil to increase the macropore size, which improves the soil water storage capacity and provides more space for root development. The increase in water-holding capacity and macropore size results in a more rapid infiltration rate and higher water acceptance ability, which reduces the surface runoff. The higher water infiltration rate also improves the soil aeration, which increases the microorganism activities. In addition, it facilitates the organic matter decomposition and mineralization rate to release more plant-available nutrients for crop growth (Al-Kaisi et al., 2018). To increase the crop yield, the tillage frequency and equipment selection should depend on the soil condition. In modern agriculture, tillage is usually done multiple times in multiple soil depths with different equipment in a field. Types of equipment include moldboard, disk, chisel, and plow. The intense tillage in modern agriculture may result in several negative effects that will be discussed later in the paper (Rust & Williams, n.d.).

Besides intensive tillage, monoculture is common in the modern agriculture. Monoculture aims to increase crop production by planting a single type of crop once a time in a particular field (Chen et al., 2009). The dominant crop types in modern agriculture are staple foods, which support the consumption of about 90% of the global population. These crops include wheat, rice, maize, and potato. They provide energy for over 5 billion people. The mass demand for these staple foods requires high-yield and high disease resistance characteristics of crops. Therefore, cultivated species commonly selected are high-yielding varieties which suit the local environment (Rutledge et al., 2022). From farmers' perspective, the monoculture field is relatively easy to manage since the planting schedule and the equipment needed are similar each year. The low financial and time input and high yielding result in considerable revenue (Earth Observing System, 2020).

The application of chemicals maintains and increases crop yields. Since plants can directly absorb the soluble inorganic fertilizer, inorganic fertilizer is the usual form of fertilizer in the modern agriculture system. For each pack of synthetic fertilizer, the ratio of nutrient composition is labelled on the package, which allows for calculating the required applied amount (Kopittke et al., 2019). Since pest attacks and weed competition reduce crop production, pesticides and herbicides are used to eliminate these threats (Kopittke et al., 2019).

The combination of these practices in the modern agriculture system efficiently improves crop production. However, the environmental outcome of agricultural intensification might threaten the long-term capability of the soil to provide food and services (Kopittke et al., 2019).

Environmental Outcomes of Modern Agriculture

The environmental effects of modern agriculture result from the interaction of multiple agricultural practices. The effects can be described as including biological, chemical, and physical aspects.

Monoculture increases ecological homogeneity, which results in low ecosystem resilience. Cultivating selected high-yielding variants reduces the genetic diversity of the crops, which decreases their adaptivity to climate change (Bourke et al., 2021). Monoculture also reduces biodiversity resulting in a relatively simple food web, which makes the ecosystem susceptible to environmental stresses. The low diversity and low abundance of soil microorganisms reduce the organic matter decomposition rate, which slows the nutrient cycling (Bourke et al., 2021). Intensive tillage aggravates the nutrient deficiency through ploughing, as it mixes the organic matter with the mineral particles to mineralize the organic matter. Then reduction of organic matter content decreases the cation exchange capacity, which is the ability of soil to accept and retain nutrients. In the long term, the low soil nutrient holding capacity triggers nutrient exhaustion leading to a reduction in the crop yield (Nunes & Moorman, 2020).

Besides aiding in nutrient cycling, soil organisms also create continuous bio pores by their movement activities. These continuous bio pores increase the macroporosity. Even though tillage can also increase the numbers of macropores, it destroys the bio pores in the plough layer (Zheng et al., 2018). Compared with isolated macropores created by tillage, the continuous bio pores created by activities of organisms can significantly increase the water infiltration and aeration.

Also, earthworms and ants can form casts. Casts are a mixture of organic components, mineral particles, and mucus which improve the soil aggregate stability (Li & Shao, 2021). The stable aggregates improve the soil structure to enhance water-holding capacity and water drainage. It makes soil becomes more resistant to erosion (Li & Shao, 2021). However, intensive tillage destroys the soil structure through the frequent ploughing. The low water-holding capacity and water drainage capability of the unstable soil structure might cause high surface runoff to increase the risk of soil erosion. The movement of tillage machines can cause soil compaction, which reduces the abundance of soil organisms due to the low survival space (Kopittke et al., 2019).

Since the interaction between intensive tillage and monoculture reduces the soil stability, exhausts the soil nutrient, deceases the organisms' diversity, and increases the pest attack and weed competition, a high amount of chemicals is needed to improve and maintain crop production. This practice results in chemical accumulation in soil and crops, which threatens food safety. The application of pesticides and herbicides in the long term can cause chemical resistance of pests and weeds, resulting in the need for a higher amount of chemical application (Woźniak, 2019;2020). Inorganic fertilizer directly adds soluble nutrients into the soil but does not improve the soil organic matter content. The overuse of inorganic fertilizer might result in soil acidification and soil crust formation that increases soil degradation (Kopittke et al., 2019).

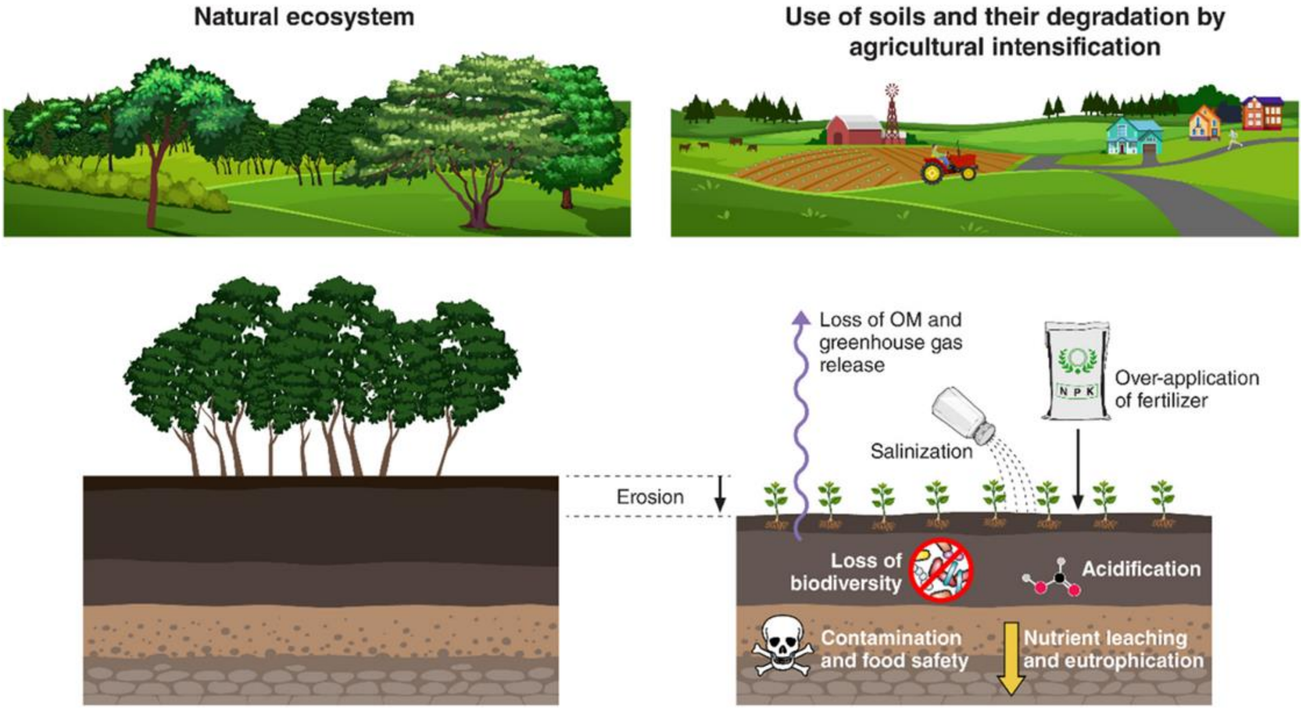

Figure 1: Effects of modern agriculture on soil degradation (Kopittke et al., 2019).

Approximately 52% of global agricultural land is moderately or severely degraded due to modern agricultural practices. The situation of land degradation will keep getting more severe over the next 25 years, which can potentially reduce 12% of crop production (Kopittke et al., 2019). The decrease of crop supply conflicts with the increase in food demand, which might increase food price by about 30%. The limited food supply and the high food price might result in more people in the world in hunger (Kopittke et al., 2019).

Soil degradation is the primary reason for the decrease in crop production, and soil erosion is the main factor causing soil degradation. Worldwide, there are about 20 to 30 Gt of soil lost at an erosion rate of 10 to 100 times higher than soil formation rate (Kopittke et al., 2019).-Therefore, erosion control is the key to solving the hunger problem.

Effect of Soil Erosion

Soil erosion is the detachment, movement, and deposition of soil by the interaction of soil with climate, topography, vegetation, and land-use practices. Eroded particles are mainly from the top layer, which is the nutrient-rich organic layer. The removal of topsoil reduces the organic matter content, which reduces the cation exchange capacity to accept and retain nutrients (Rejman, 2011). It results in the loss of approximately 42 Mt of nitrogen and 26 Mt of phosphorus on average per year worldwide. In addition to nutrient loss, soil erosion reduces the soil structure stability (Kopittke et al., 2019). The translocated fine particles increase soil density through compaction. It decreases the water drainage and water-holding capacity of the soil, which makes soil be more vulnerable to erosion (Rejman, 2011). Therefore, long-term erosion would result in irreversible damages to the soil.

Challenges On Assessing Erosion

There are three types of erosion: water erosion, wind erosion, and tillage erosion. Water erosion is the translocation of eroded material by water for a relatively long distance. It is caused by precipitation, especially the rainfall with long duration and high intensity. Therefore, the impact of water erosion can cause severe soil loss (Rejman, 2011). Wind erosion is the detachment and transportation of soil particles by wind. It occurs mainly in semi-arid and arid area where the soil is dry and loose. Similar to water erosion, wind erosion can result in large volume of soil loss, especially in strong wind events (Gromke & Burri, 2011).

Unlike water erosion and wind erosion, the primary cause of tillage erosion is not the occasional extreme events. Therefore, the impact of tillage erosion is not as noticeable as water and wind erosion. Tillage erosion redistributes soil by the action of the kind of tillage and gravity. It is a long-term event which usually interacts with wind or water erosion (Zhang, 2011). Two types of tillage erosion are topography-based erosion and field boundaries erosion. Opposite to the water erosion pattern, the most severe topography-based tillage erosion occurs on the convexities of the hillslope, and the deposition happens on the concavities (Figure 2a). The field boundaries tillage erosion occurs mainly at the terrace field, where the soil relocation is maximum at the upslope and downslope boundaries (Figure 2b) (van Oost et al., 2006).

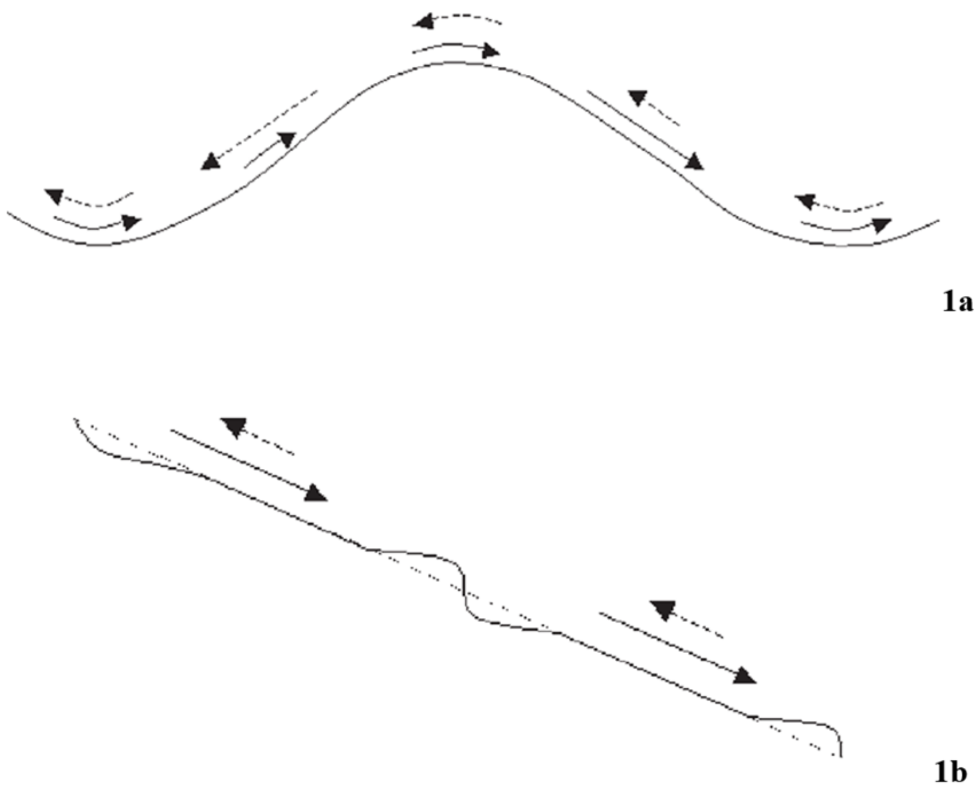

Figure 2: The pattern of two tillage erosion types: topography-based tillage erosion (1a) and field boundaries tillage erosion (1b) (van Oost et al., 2006).

Due to the pattern difference, the assessment method used for water erosion might not be suitable for tillage erosion. Through searching the UBC library, there are 187,672 studies related to water erosion, but only 11,975 studies on tillage erosion. Compared with water erosion which most studies focus on, tillage erosion is understudied.

The widespread use of intensive tillage in modern agriculture enhances the negative effect of tillage on soil properties. The 2008 Glossary of Soil Science terms indicates intensive tillage is known as conventional tillage, which causes full-width soil disturbance through multiple times of mechanical manipulation in different soil depths (Soil Science Society of America & Wiley Online Library, 2008). After the primary and secondary tillage, less than 30% of the crop residue remains on the soil surface. The bare soil resulting from residue removal is vulnerable to erosion (Ritter, 2018).

Tillage has been recognized as an important factor in soil erosion. Since three types of soil erosion usually interacts together in a landscape, it is necessary to assess their combined effects. (Zhang, 2011). Soil erosion impacts can be explained from physical, chemical, and biological aspects. Compared with the physical effects, there are well-documented techniques to evaluate the chemical and biological impact. For example, measurement of several indicators, such as pH and carbon content can quantify the chemical effects. The biological effects can be evaluated by the abundance of microorganisms, using the Polymerase Chain Reaction (PCR) method. However, the physical impact is relatively complex due to the interaction of soil with external factors (Ferreras et al., 2006). Therefore, it is hard to assess by simply measuring a few relatively static indicators. The variation of each factor depends on local conditions, so it is hard to make a general conclusion. To illustrate the negative effects of excessive tillage, the Loess Plateau in China (Han et al., 2016) will be documented as a typical erodible landscape is provided as a particular example in this paper.

As a vital arable land in China, the Loess Plateau has long cultivation history which can be traced back to 221 B.C. Loess plateau used to be forest and grassland. The reclamation for arable land was achieved through burning and harvesting reduced the vegetation coverage. Due to the long-term cultivation, the loess plateau was partially desertified in 618 B.C. which increased soil erosion (Li et al., 1989). Tillage was done by animal powers and iron farm implements traditionally. It required high energy and time input, which was inefficient. Due to modern industrial development, tillage equipment transformed toward machines to increase efficiency (Wang et al., 2017). Tillage practice in the Loess Plateau is dominated by conventional tillage in the summer fallow period. All residues are removed after harvesting. The primary tillage is between late May to June before the wet season. The bare loose soil after tillage is highly vulnerable to erosion in the wet season. After precipitation, another tillage is done to break soil crusts and loosen the soil. The same tillage practices repeat every year resulting in an unstable soil structure, low water drainage and water storage, which can increase soil erosion (Wang et al., 2017). The average eroded soil in the loess plateau is estimated as 5,000 to 10,000 t/km2, and the maximum can reach 30,000 t/km2, which makes the Loess Plateau one of the most erodible landscapes in the world (Han et al., 2016).

In 1999, the Chinese government processed the “Grains for Green Project” to control soil erosion in the loess plateau through terrace development and land conversion. The terrace development on sloping land has reduced eroded soil amount. The conversion of arable land into forest and grassland has increased 25% of vegetation coverage in the loess plateau (Yang & Huang, 2021). However, the Grains for Green Project does not mention any strategies to improve tillage practices.

Objectives

This paper assesses the impact of modern agriculture on soil properties, with a focus on the effect of tillage on soil erosion. A case study in the loess plateau is used as an example of the global concerns. This is accomplished by

- an analysis of the impact of intensive tillage on soil physical properties
- an assessment of the effect of intensive tillage on erosion
- a consideration of practical soil conservation strategies

Methods

Data Collection

The dataset is collected from published journal articles and books. Two databases UBC Library and Google Scholar were used to search keywords including "erosion", "intensive tillage", and "modern agriculture". The selected articles are classified based on

- definition and the pros and cons of modern agriculture
- definition and impact of soil erosion, and
- effects of intensive tillage on soil erosion

As stated earlier, biological, and chemical soil factors have accepted methods for making assessments of the soil erodibility . This is not the situation for the physical soil properties. However, the Universal Soil Loss Equation does provide a relative measure.

Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) predicts the long-term annual soil loss rate through the analysis of the related factors (Ministry of Agriculture, Food and Rural Affairs, 2012). The equation is

$$A = R.K.LS.C.P$$

A is the predicted soil loss rate (t/(hm2.a)). R represents the rainfall factors (MJ. mm/ (hm2.h.a)) that positively correlate with the soil loss rate. The rainfall with high duration or high intensity increases the erosion potential. Raindrops with high energy break the soil aggregate and translocate eroded particles such as silt and clay (Ministry of Agriculture, Food and Rural Affairs, 2012). When the rainfall rate is higher than the soil water infiltration rate, infiltration-excess runoff occurs. Saturation-excess runoff occurs when the rainfall amount is greater than the soil water holding capacity. Both types of runoffs move soil particles away from the original location, which causes erosion. A high amount of runoff mainly occurs during the snowmelt and raining seasons (Rejman, 2011).

K (t·hm2·h/(hm2·MJ·mm)) stands for the soil erodibility factor, which depends on the soil texture and soil structure (Ministry of Agriculture, Food and Rural Affairs, 2012). Compared with sand and clay particles, silt has the highest erodibility because its particle size is smaller than sand, and its aggregate formation ability is weaker than clay. Soil with a stable structure is more resistant to compaction and soil crust, which less erodible than poor structure soil (Dumbrovský et al., 2019).

LS is the length and steepness of the slope. They positively relate to the soil erodibility since the long and steep slope accumulates a large runoff amount which moves at high velocity. The high sediment carrying capacity of the runoff water can move particles in bigger sizes and larger amounts (Ministry of Agriculture, Food and Rural Affairs, 2012).

C represents the crop coverage. The high crop coverage can intercept the runoff and raindrops to reduce the kinetic energy to translocate soil particles. Crop roots absorb water and create macropores to reduce runoff amount and facilitate water infiltration to reduce soil erodibility (Ministry of Agriculture, Food and Rural Affairs, 2012).

P is the support practice factor which is highly affected by land-use management to reduce soil erosion. This paper focuses on the impact of excessive tillage on soil erosion (Ministry of Agriculture, Food and Rural Affairs, 2012).

The Universal Soil Loss Equation was initially used to predict the soil erosion rate in the agricultural land in the USA. The value of each factor in the equation can be determined by formulas. Many countries have developed alternatives based on USLE and local experimental data (Kinnell, 2010). The annual soil loss in China is predicted with the Geographic Information System (GIS) and Revised Universal Soil Loss Equation (RUSLE) model. GIS integrates geographic databases including maps, features, and numerical data to analyze the spatial conditions. With the database, the RUSLE can assess the annual soil loss in the local area (Gao et al., 2022).

Study Area

Location

The study area is located in the Anding District (104◦12’E- 105◦1’E, 35◦17’N- 36◦02’N) of the Eastern Gansu Province in China, on the western marginal area of the Loess Plateau. The total area is

363,919.93 hm^2 with about 149,904.11 hm^2 agricultural land. The average elevation of the study area is 1898.7 m (Li, 2019). Since the topography is dominated by loess hills and ravines in the north, and highlands in the south, the elevation decreases from southwest at 2570 m to northeast at 1662 m (Figure 3). The agricultural land is located mainly on 2036.9 m elevation (Li, 2019).

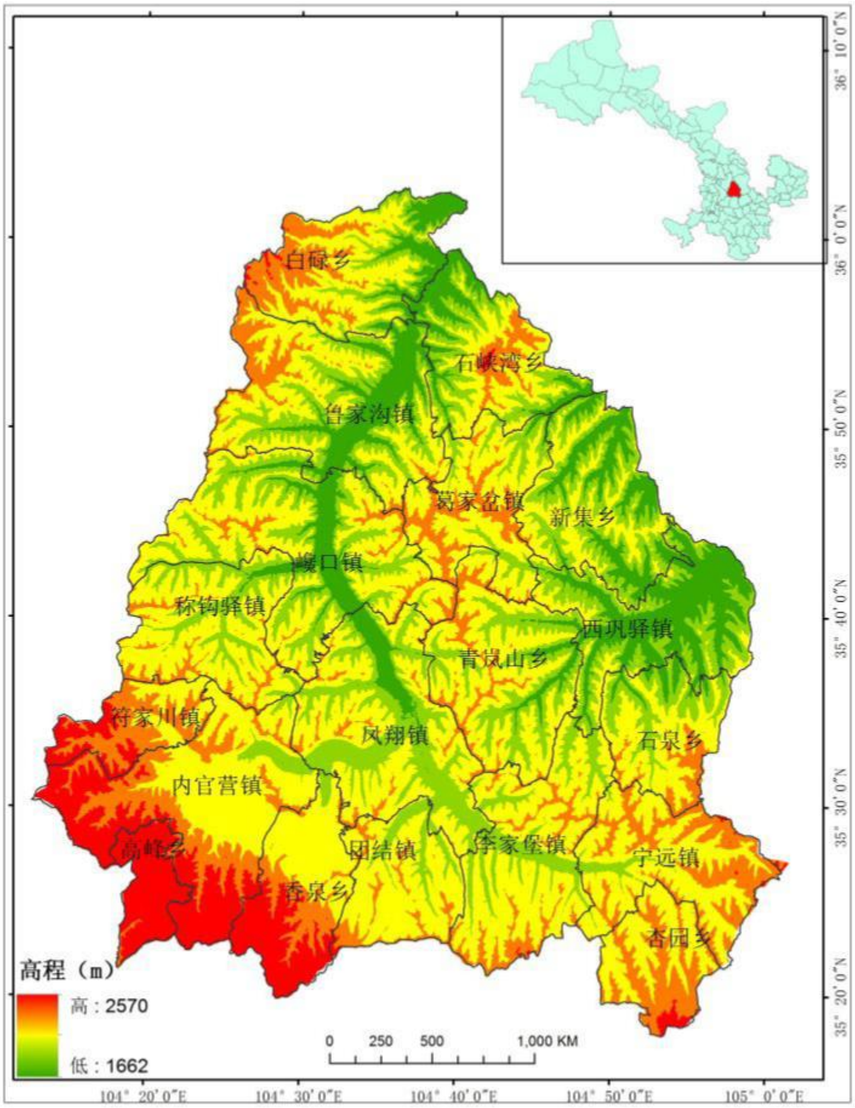

Figure 3: Geographic location and topography of Anding District. The red color indicates the area with relatively high elevation (2,570 m), and the green color indicators the area with relatively low elevation (1,662 m) (Li, 2019).

Climate

The study area belongs to the continental semi-arid climate. The average annual temperature is 6.3 ◦C, and the average sunshine duration is 2,599 hours (Li, 2019). The precipitation amount varies temporally and spatially. The annual rainfall is concentrated between June and September, mainly as storm and hail events. The rest of the year receives only 20% of the annual rainfall (Li, 2019). Spatially, rainfall increases from north to south in the range of 420 mm to 370 mm. The average annual evaporation is about 1,500 mm, which is much higher than the rainfall amount. The low rainfall and high evaporation lead to water deficit. In addition, strong wind frequently occurs from late winter to early spring, which blow away loosen soil particles (Nolan et al., 2008).

Hydrological Condition

The three main rivers in the Anding district are the Guanchuan, East, and West Rivers. The East River is located in the southeast region with about 788 km2 watershed area. It is the irrigation source of the east and middle agriculture area (Li, 2019).

West River is located in the southwest region, the watershed area is 636.9 km2. The high water quality makes the West River become the source of industrial and domestic water (Li, 2019).

The East and West Rivers converge in the Guanchuan River. The water rechanges for rivers highly depend on rainfall, so the streamflow is uneven temporally. In drought periods, the streamflow is 17.7 million m3, but in high-flow periods, the streamflow can reach 79 million m3. Besides surface water, the low annual rainfall and high evaporation also result in a shortage of groundwater. The water available per person is less than 200 m3, and the water available per acre is less than 7 m3 (Li, 2019).

Soil

The dominated soil types are the Huangmian and Heilu (Figure 4). Huangmian soil in the area experiences frequent erosion, especially if the soil that has a history of long-term cultivation (Niu et al., 2016). During the formation of Huangmian soil, soil erosion has removed the genetic horizons of Heilu soil to expose parent loess on the surface. Therefore, the organic matter content of Huangmian soil is low. The entire soil profile is calcareous in reaction (Niu et al., 2016). In layers with high gypsum content, the dense carbonate accumulation restricts water drainage and root development. Huangmian soil has a medium-loam texture (Niu et al., 2016). The water holding capacity is about 250 mm. However, the gypsum layer restricts the water drainage below 1 m soil depth (Niu et al., 2016). The evaporation also removes a high amount of water from the soil surface. The low rainfall is not enough to supplement the water storage, so the moisture content is below the field capacity for most of the year (Niu et al., 2016).

There is also the Heilu soil scattered through the Huangmian soil area (Niu et al., 2016). Similar to the Huangmian soil, the soil profile of Heilu soil is calcareous in reaction. Heilu soil has a relatively thick organic layer which is about 60 to 100 m . The high organic matter content provides the soil with relatively high cation exchange capacity in 16 meq./100 g soil (Niu et al., 2016). Therefore, Heilu soil can accept and retain more nutrients than Huangmian soil.

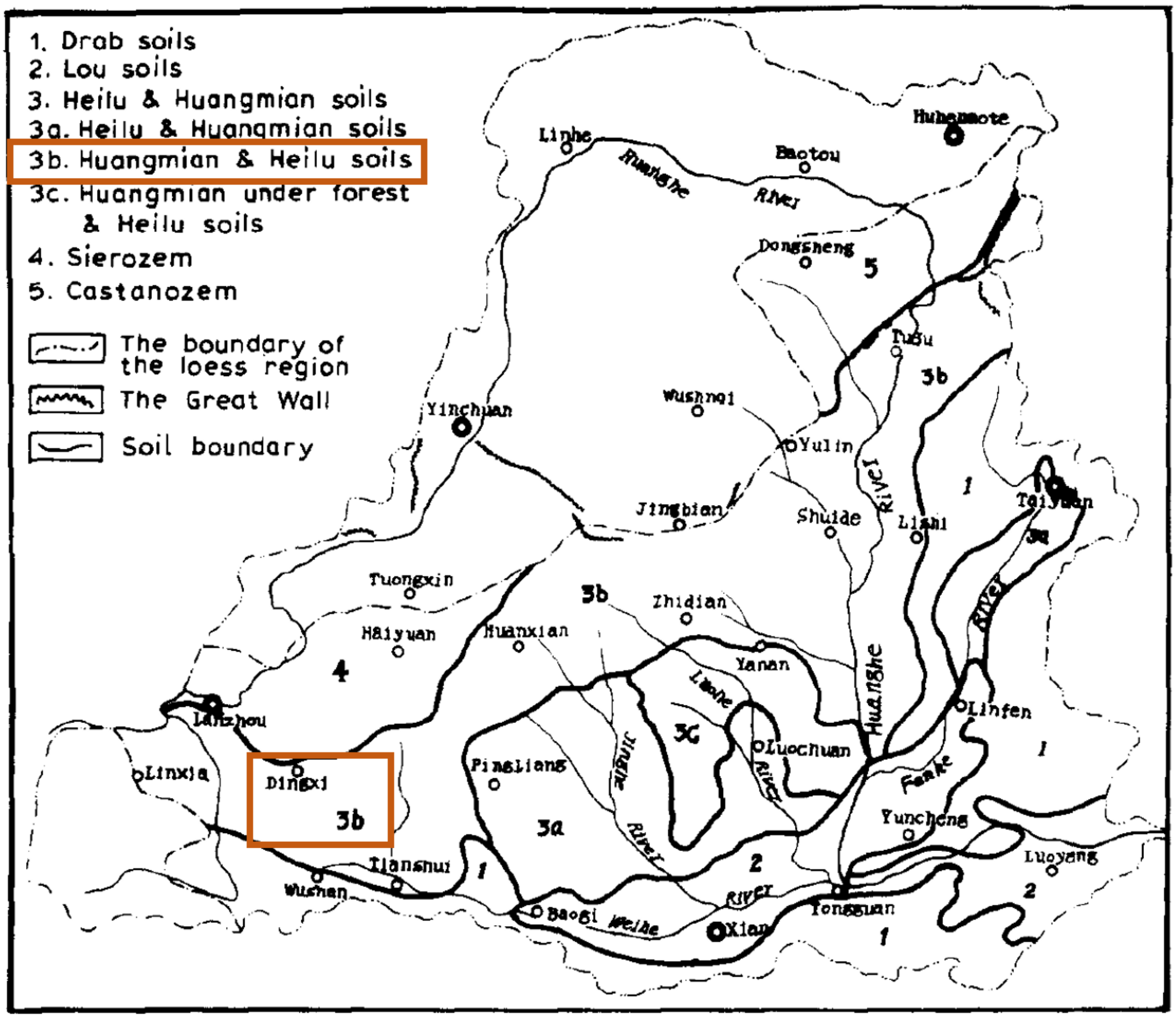

Figure 4: Map of soil distribution of Gansu province. The study area is in Anding district which belongs to Dingxi City. The location and the matched soil types are circled in red on the map (Niu et al., 2016).

Land Use

The total of the Anding district is 363,919.95 hm2, of which 77.8% of the area is agricultural land

(282,983.34 hm2) (Li, 2019). The agricultural land is dominated by spring wheat monoculture. Spring wheat strip cropping is done once per year due to a water deficit. Since the rainfall amount is highly variable, wheat production is low and unstable with a yield on average of 3000 kg/hm2 (Zhu, 2019). The terraced fields developed by the “Grains for Green Project” on the slopping area provide conditions for mechanical agriculture. The primary agricultural model is subsistence agriculture by smallholders. Some smallholders also sign purchase and sale contracts with local companies to cultivate desired crops (Nolan, 20018).

Tillage Practices

Conventional tillage with residue removal has been practiced in Anding district for a long history. The tillage is divided into primary tillage and secondary tillage (Chen et al., 2009).

In primary tillage, the harvesting is in early August. After harvesting, all residues are removed from the field as firewood and forage. Then, moldboard ploughing process occurs three times in August and September. The first ploughing happens just after harvesting to a 20 cm soil depth. The second ploughing is in late August to a 10 cm soil depth, and the last one happens in early September to a 5 cm soil depth. Ploughing loosens and turns over the soil. It also buries weed and crop residue (Chen et al., 2009).

After ploughing, use of a disc harrow breaks soil lumps and smooths the soil surface. The disc harrow can go through to 8 to 10 cm soil depth. The first harrowing processes occurs immediately after the ploughing in September, and the second times happen in October before the soil becomes frozen (Chen et al., 2009).

The process of secondary tillage depends on the soil conditions. In strip cropping of wheat, it is common to use land rollers to compact soil, which aims to reduce soil loss by wind erosion (Chen et al., 2009).

The multiple tillage practices modified the soil structure, that exacerbates soil erosion.

Results and Discussion

Analysis of Soil Erodibility

The soil erodibility was evaluated using the Universal Soil Loss Equation (A= R. K. LS. C. P) and the site conditions discussed above.

The average annual rainfall of the Anding district is 395 mm, which is much lower than the evaporation of 1,500 mm, which leads to severe drought (Li, 2019). Under the impact of climate change, the rainfall tends to be reduced by 1,7% every ten years, which might increase the frequency and intensity of drought events (Li et al., 2019). During drought period, strong wind occurs from late winter to early spring, which leads to dry and loose soil, highly vulnerable to wind erosion (Nolan et al., 2008).

The unevenly distributed rainfall concentrated between June and September of short-duration and high-intensity storm and hail events which results in severe pluvial flooding. Besides, the rainfall raises the water level of the three main rivers, which are East River, West River, and Guanchuan River resulting in fluvial flooding. Flooding creates a high amount of surface runoff which washes away soil particles and deposits in the valley (Li, 2019). Based on the calculation by Gao, et al., (2022), the average R value of the Anding district is 1,096.86 MJ. mm/ (hm2.h.a). Since the R value strongly relates to the rainfall, the R value decrease from south to north following the rainfall pattern. Temporally, the R value fluctuates due to the variation of the rainfall amount (Gao, et al., 2022).

Table 1: The K value of different soil classes in Gansu province. The soil class and the matched K value of the Anding district is circled in red (Gao, et al., 2022).

Classes	Max	Min	Average	Standard deviation	Range	CV (%)
Early breeding soil	0.397	0.067	0.329	0.103	0.330	31.268
Semi-leaching soil	0.392	0.235	0.307	0.040	0.156	13.137
Calcareous soil	0.417	0.281	0.339	0.039	0.136	11.560
Arid soil	0.380	0.257	0.335	0.039	0.123	11.782
Leaching soil	0.399	0.191	0.317	0.060	0.207	18.723
Desert soil	0.393	0.272	0.349	0.042	0.122	12.141
Artificial soil	0.413	0.304	0.351	0.027	0.108	7.781
Total	0.417	0.067	0.331	0.057	0.349	17.379

When the topsoil of the Huangmian soil is removed by erosion, the organic matter content decrease to about 0.65% of the soil volume. The low organic matter content reduces the soil aggregates ability to resist erosion. The Huangmian soil has a medium loam texture, with the soil composition is about 36% of sand, 43% of silt, and 21% of clay (Niu et al., 2016). Sand has large particle size, and clay can form aggregates, both of them has relatively high erosion resistance. Compared with sand and clay, the erodibility of silt is the highest (Dumbrovský et al., 2019). The high ratio of silt particles in the Huangmian soil potentially increases the K value. The Huangmian soil belongs to the calcareous soil class, so the average K value is 0.339 t·hm2·h/(hm2·MJ·mm) (Gao, et al., 2022). Figure 5 divides soil erodibility into five levels. The K value of the Huangmian soil in Anding district has the highest K value compared with other soil types in different areas (Ye et al., 2019).

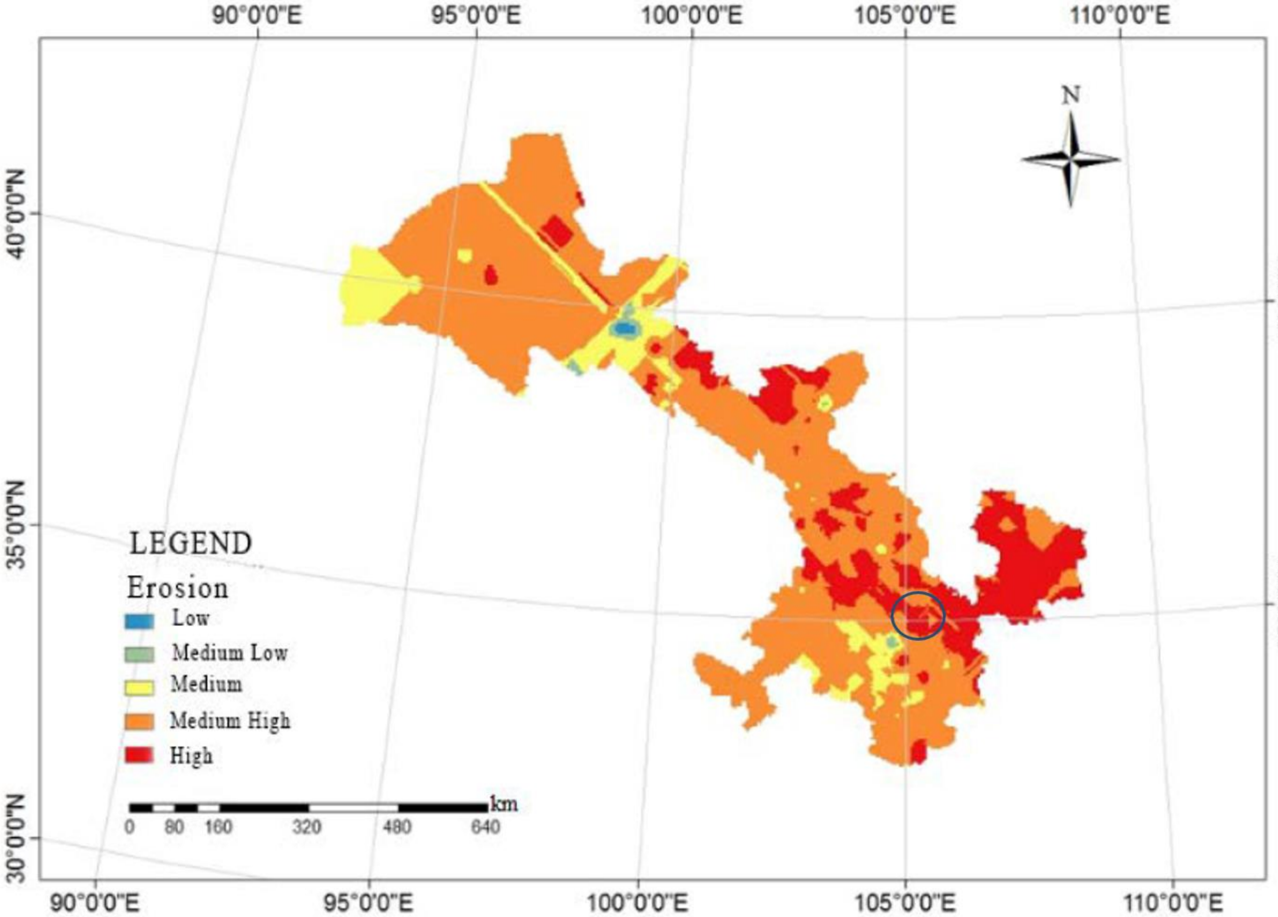

Figure 5: Levels of K values of different soil classes in Gansu province. Red color stands for high erodibility (K>0.35), orange color is medium high level (0.30<K<0.35), yellow represents medium level (0.25<K<0.30), Green color is medium low level (0.15<K<0.25), and the blue color is low level (K<0.15). Approximate location of Anding district is circled on the map (Ye et al., 2019).

The length and steepness of the slope are positively correlated with the erosion rate because energy and velocity of the runoff water increase with the slope length and steepness. The calculation of Gao et al., (2022) shows that the maximum slop length is 59.7 and the average slope length is 3.51. The slope steepness of the northern area is high since this region is dominated by loess hills and ravines. Therefore, the LS value decreases from north to south (Li, 2019). The slope gradient of the Anding district is between 15◦ to 25◦. The agricultural land of the Anding district is located mainly in an area with a 2,066.7 m elevation and 12◦ slope gradient (Gao, et al., 2022).

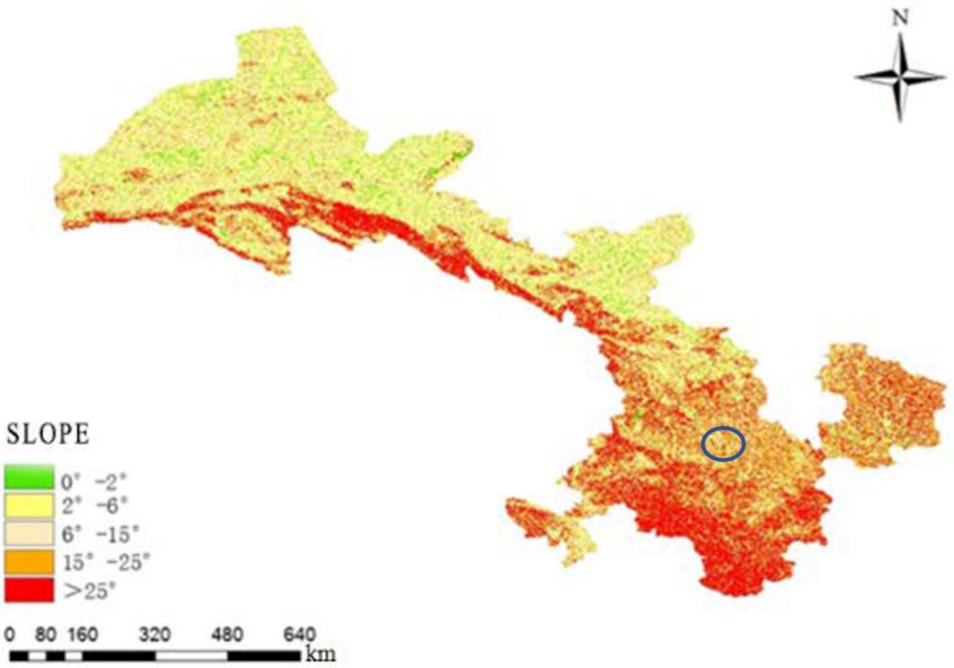

Figure 6: The spatial distribution of slope gradient in Gansu province. The approximate location of Anding district is circled in blue (Ye et al., 2019).

The vegetation cover is negatively correlated with soil erosion. Due to the “Grains for Green Project” which converts agricultural land into forest and grassland, the increase in vegetation coverage reduced the C value from 0.76 in 1980 to 0.41 in 2019 (Gao et al., 2022). However, in the remaining agricultural land, the practice of conventional tillage with residue removal results in bare soil from September to March of the next year. Due to the frequent occurrence of strong wind events, the soil in agricultural lands is highly vulnerable to wind erosion during drought season (Nolan et al., 2008).

Table 2: Estimation of P value of agricultural land through slope gradient

坡度 Slopes	<5°	5°～10°	10°～15°	15°～20°	20°～25°	⩾25°
P	0. 1	0. 221	0. 305	0. 575	0. 705	0. 800

The P value is the support practice factor, which aims to reduce soil erosion. The P value is positively correlated with the slope gradient. Since the slope gradient of agricultural land is 12◦, the P value is 0.305 (Table 2). The dominant land use in the Anding district is spring wheat strip cropping on terrace fields, and the tillage method is conventional tillage with residue removal (Gao et al., 2022). The estimated P value is 0.37 based on the factors table provided by the Ontario government. Therefore, the range of P value is between 0.305 to 0.37 (Ministry of Agriculture, Food and Rural Affairs, 2012).

With the analysis of each factor, the potential annual soil loss in the Anding district is approximately 604.22 t/hm2/a. Compared with the historical data, the overall soil erosion is reduced due to the agricultural land conversion into grassland and forest (Gao et al., 2022). However, the soil erosion of the southwest region shows an increasing trend. It might relate to the steep slope, high elevation, and agricultural land use. As discussed above, the elevation of the southwest region is about 2,570 m, and the slope gradient is higher than 15◦. The rainfall can reach 420 mm in the southwest region. Besides, the multiple tillage practices reduce the soil structure stability (Gao et al., 2022). The interaction of these factors might lead to soil erosion which moves soil particles from the top of the slope to the flat bottom.

Compared with rainfall, soil texture and topography factors which are difficult to alter, land-use activities are more practical to manage for erosion control. Land use management includes crop coverage, crop types, and tillage methods (Ministry of Agriculture, Food and Rural Affairs, 2012). Gansu is one of the primary domestic wheat production areas. Spring wheat is also the dominant food crop in the Gansu province, which occupies 42.81% of the total cultivation area. If to change spring wheat to other crop types, the reduction of spring wheat supply cannot satisfy the local and domestic demand, which might increase the wheat price to increase the hunger problem (Yang et al., 2005). Instead of modifying crops, altering the tillage methods might be more effective in reducing soil erosion while maintaining the crop production.

Comparison Between Conventional Tillage and No-till

The transformation of conventional tillage to no-till is a possible strategy to reduce soil erosion. The no-till method has proved to effectively reduce soil erosion by a six-year field experiment in Dingxi city. The experiment compared the effects of six tillage methods on soil properties (Table 3).

Table 3: Tillage methods used in the long-term experiment in Dingxi (Niu et al., 2016).

Tillage Methods	Abbreviation
Conventional tillage with stubble removed	T
No-till with stubble removed	NT
Conventional tillage with stubble incorporated	TS
No-till with stubble cover	NTS
Conventional tillage with plastic film mulch	TP
No-till with plastic film mulch	NTP

Conventional tillage with stubble removed (T) as the typical tillage method in the Anding district is compared with three no-till methods (NT, NTS, NTP) to assess which is the most effective method to reduce soil erosion (Niu et al., 2016). No-till means no tillage is done on the field. No-till belongs to the conservation tillage method in which the soil disturbance is usually less than ¼ of the row width (Niu et al., 2016). NTS is the method which does not till soil and remains more than 50% of the residue on the ground. NTP is the method which does not till soil and use plastic film mulch to cover soil surface. In NTP method, stubble is removed to layout plastic film mulch on the soil surface (Niu et al., 2016). The analysis is based on the data provided in Niu et al., (2016.) and the data is presented in Table 4.

Table 4: Comparison of effects of different tillage methods on soil physical properties (Niu et al., 2016)

Variable	Soil depth (cm)	Original	T	NT	NTS	NTP
Bulk density	0-5	1.29	1.23	1.17	1.14	1.17
(Mg/m3)	5-10	1.23	1.25	1.19	1.19	1.18
	10-30	1.32	1.30	1.23	1.27	1.23
Total porosity	0-5	-	53.4	55.7	57.2	56.0
(%)	5-10	-	52.7	55.1	55.1	55.3
	10-30	-	50.8	53.6	51.9	53.5
Non-capillary porosity	0-5	-	5.45	6.39	8.70	5.83
(%)	5-10	-	7.45	5.62	6.87	5.68
	10-30	-	4.62	4.86	5.13	4.50
Aggregates	0-5	-	13.40	15.10	18.20	14.60
(%)	5-10	-	8.36	9.12	13.20	8.67
	10-30	-	8.72	8.63	11.70	9.84
Field capacity	0-5	-	26.8	26.9	27.8	26.9
(%)	5-10	-	26.2	26.5	26.0	25.7
	10-30	-	24.0	25.6	25.4	25.2

Bulk density is an indicator of soil compaction. The high bulk density of soil relates to a low water infiltration rate, which can potentially increase the surface runoff during heavy rainfall (Al-Kaisi et al., 2004). The T treatment slightly decreases the bulk density in 0-5 cm and 10-30 cm soil depth and slightly increase the bulk density in 5-10 cm soil depth. Compared with T, all the no-till methods significantly reduce the bulk density in all soil depths. The differences in bulk density between each no-till method are not significant (Niu et al., 2016).

The total porosity and capillary porosity are indicators of the soil hydraulic conductivity. Hydraulic conductivity is the ability of water to flow through the soil solid phase under a specific hydraulic gradient (Ren et al., 2016). Total porosity is the percent of void spaces of the total soil volume. It influences multiple soil properties such as water retention and water drainage (Ren et al., 2016). Besides porosity, the hydraulic conductivity also depends on pore size distribution. Capillary pores have a relatively high adhesion force between soil particles and water, so they can tightly hold water within the pores. Therefore, if the ratio of non-capillary porosity and total porosity is high, the soil hydraulic conductivity is high (Ren et al., 2016).

The total porosity of the T treatment is the lowest in all soil depths. The total porosity of the NTS on 0-5 cm soil depth is the highest. The total porosity in 5 to 30 cm soil depth has no significant difference between no-till methods. The total porosity is highly affected by the surface tillage since the T treatment involves multiple times of tillage with different equipment (Niu et al., 2016). Excessive tillage reduces the abundance and diversity of microorganisms through habitat disturbance. Therefore, fewer bio pores are formed to increase the porosity (Bourke et al., 2021). The NTS treatment has the highest non-capillary porosity in 0-5 cm and 10-30 cm soil depth. In 5-10 cm soil depth, the T treatment has the highest non-capillary porosity, which might be due to the multiple ploughing in 5-10 cm soil depth to loosen the soil (Niu et al., 2016).

Soil aggregate stability is closely related to the organic matter content and microorganisms' abundance. The stubble left on the soil surface can be shredded and degraded by soil fauna and fungi. The degraded organic compounds mix with fungi exudates to form aggregates (Rust, n.d.). Aggregate formation also can be processed by soil fauna, such as earthworms, ants, and termites. These organisms mix organic matter with water mucus through digestion, the release aggregates are water stable in soil (Chenu et al., 2001). Water-stable aggregates are important to maintain soil structure and resist soil erosion. The aggregate content of the NTS treatment is the highest in 0-30 cm soil depth, which indicates stable soil structure in this treatment (Niu et al., 2006).

Field capacity is the water content held by micropores under a specific gravitational potential. It influences the amount of water available for crops (Ma et al., 2016). The filed capacity in 0-5 cm soil depth is the highest by NTS treatment. In 5-30 cm soil depth, NT treatment results in the highest field capacity. There is no significant difference of the field capacity between each treatment because field capacity is mainly dependent on soil clay content, it is not sensitive to tillage disturbance (Niu et al., 2006).

Through the comparison of different tillage methods, the no-till with stubble cover (NTS) treatment results in the most stable soil structure with high water drainage capability to resist soil erosion. Therefore, Transformation from conventional tillage with stubble removed method to no-till with stubble cover is recommended for reducing soil erosion. This tillage method has been demonstrated during the fallow period in the Anding district (Food and Agriculture Organization of the United Nations, 2022). In agricultural land with spring wheat cultivation, after harvesting, the stubble is cut into 5 to 10 cm long to cover the soil surface. The coverage stubble is controlled between 6,000 kg/hm2 to 7,000 kg/hm2 to prevent excessive pressure on seedlings (Zang et al., 2003). In March of the following year, a small seeder is used to directly sow crops in the stubbles (Niu et al., 2016). However, there are potential challenges on promoting the no-till with stubble cover.

Challenges on the promotion of no-till with stubble cover method

The Anding district has been identified as a severe poverty area since 1994. The low education level of the farmers, the fragile environment, and poverty forms a vicious circle to prevent development (China National Bureau of Statistics, 2004).

In the Anding district, 81.2% of population rely on farming to earn an income. However, the fragile environment, which is highly vulnerable to drought and soil erosion, limits agricultural development. The conversion of agricultural land into grassland, and the poor soil conditions reduce the yield of spring wheat., which results in low income for the farmers (Cao et al., 2010).

Table 5: Cost of each factor of spring wheat cultivation in 2018 (Zhu, 2019).

	Seeds (￥/hm^2)	Fertilizer (￥/hm^2)	Insecticide (￥/hm^2)	Labor (￥/hm^2)	Equipment (￥/hm^2)	Total
Spring wheat	492	615	101.1	4397.1	297.9	5903.1

In 2018, the average production of the spring wheat was about 3375 kg/hm3, which creates a gross income of ￥7425/ hm3. To subtract the gross cost ￥5903.1/ hm3 from the total income, the net income is ￥1521.9/ hm3. Financial limitation might be one of the reasons that farmers refuse to change tillage methods (Zhu, 2019). However, transformation to the no-till with stubble cover might reduce the cost of tillage.

Through analyzing of the cost of spring wheat cultivation, labor, fertilizer costs the most money. Conventional tillage in Anding district involves multiple times of ploughing and hallowing, which requires high labor force. The no-till methods would remove all the tillage practice after harvesting, that can save the cost of labor (Zhu, 2019; Niu et al., 2016).

In addition, excessive tillage destroys the soil structure to reduce the water infiltration rate, which accelerates the runoff production. High surface runoff removes the topsoil with high organic matter content. It leads to decease of soil fertility. The stubble removal of the conventional tillage makes the soil particles to be easily dislodged and removed by water. The small particles clog the soil pores to prevent water drainage, that requires more frequent and intense tillage to loosen soil. It creates a vicious circle to exacerbate soil erosion and fertility loss, which requires high amount of fertilizer to compensate the fertility loss (Kopittke et al., 2019). However, the degraded soil with high soil density and low macroporosity has low ability to recover the loss of crop yield. It finally leads to profit loss (Kopittke et al., 2019). Compared with conventional tillage, no-till with stubble cover largely reduce the tillage disturbance and remain stubble to decrease the soil loss and fertility loss. Therefore, the financial cost of this no-till method is less than conventional tillage (Zhu, 2019).

Besides poverty, the low education level of the local farmers might make it difficult for them to accept and practice new farming techniques and the low income to purchase equipment. Poverty has triggered most male youths to work away from home. Therefore, the primary labor force of local agricultural activities are women, elders, and children (Cao et al., 2010).

Table 6: Census of illiterate population in Dingxi in 2020 (China National Bureau of Statistics, 2004).

	Population with age ≥ 15	Illiterate population	% of illiterate population
Male	1,015,353	49,860	4.91
Female	1,003,720	1,32,088	13.16
Total	2,019,073	181,948	9.01

The Anding district belongs to the Dingxi City. According to the 7th domestic census, the total illiterate population in Dingxi city is 181,948, which is 9.01% of the total population. The illiterate female population is 82,228 more than the illiterate male population . The illiterate rate of females is much higher than males (China National Bureau of Statistics, 2004). Since women are the primary labour force in farming, the low educational level makes it difficult to learn a new tillage method. Although the no-till method is proven to increase crop yield and income, their willingness to change is very low (Niu et al., 2016). There are several potential strategies to increase the application of the no-till with stubble cover method.

Potential strategies to promote no-till with stubble cover method

One of the main challenges on soil erosion recovery is that local farmers have no awareness of land conservation. It results in a situation that restored land cannot be protected for the long term because it will be destroyed by inappropriate land use by the local farmers. Therefore, the first solution is to improve the education of farmers.

The first part of the education content is to explain the local environmental conditions and the effect of soil erosion to farmers. This would allow farmers to understand the environment they live on and explain how soil erosion works. Then, introduce and list the negative impact of soil erosion on social, economic, and environmental aspects, so that they realize the importance of controlling soil erosion. Finally, to illustrate the influence of different tillage methods on soil erosion to promote the no-till with stubble cover method, which is the most effective method for erosion reduction (Cao et al., 2010).

Since the illiterate rate of the farmers is relatively high, the information may be better to be communicated by pictures and videos. The media could be by newspapers, radios, televisions, and posters (Cao et al., 2010).

In addition, local government can open workshops or school programs to provide technical support, including equipment usage, chemical application, and stubble treatment (Cao et al., 2010). Besides technical support, the government also can provide financial support through subsidies and awards. The composition of the subsidies structure in China includes three parts which are direct subsidy, product price support, and general services support. Within the general service support, there is a subsidy for the implementation of key techniques, and there are subsidies for machinery purchase (Luo, 2017). These subsidies can provide finance to help smoothly transform toward the no-till method.

Figure 7: Structure of Chinese agricultural subsidies (Luo, 2017)

In addition to education and financial and technical support, the local government should strengthen the collaboration between enterprises and farmers to expand the local crop market. The entrance to a larger market increases the agricultural profitability, which might attract more youth who have a higher ability to learn and practice the no-till method in the Anding district (Dang, 2014).

Conclusion

Under the pressure of the increasing food demand, modern agriculture is evolving to sustain the global food supply. However, the intense agricultural practices put unprecedented pressure on limited soil resources that promotes soil degradation. In regions already facing erosion problems, such as the Loess Plateau, excessive agricultural practices, especially excessive tillage might facilitate the soil erosion rate. The case study in the Anding district proves that decreasing the frequency and intensity of tillage can effectively control soil erosion. The scientific research on erosion control needs to be applied at the landscape level, which is highly related to the local social and economic conditions. To smoothly transform the conventional tillage to no-till, requires the collaboration between government and farmers, which use scientific knowledge to manage the soil erosion based on the socio-economic needs.

Appendix

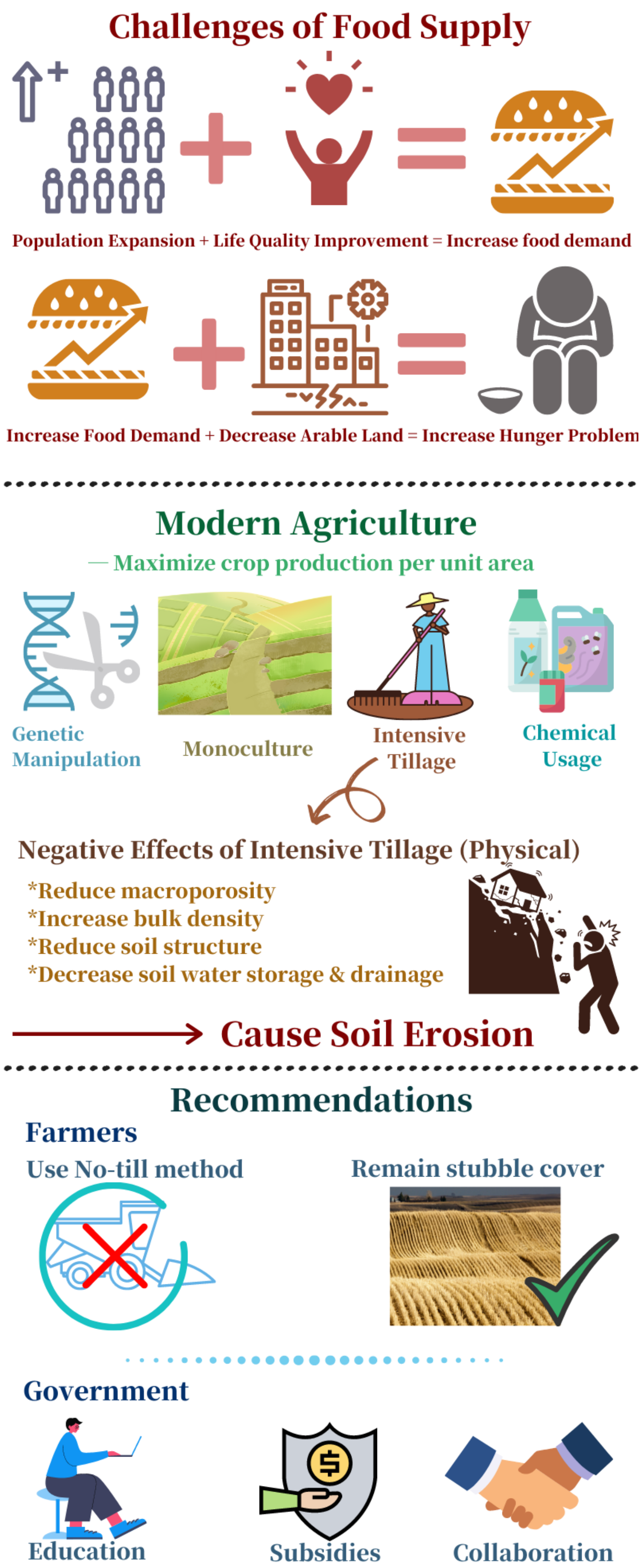

Figure 8: Communication feature for targeted local government

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