Land Degradation Assessment and Soil Conservation Strategy for Mixteca Region, Mexico

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Summary

1. Background and objectives

Land resources are indispensable for agriculture. High intensity rainfall events or drought happen more frequently due to progressing global warming. In addition, farming systems depending on agricultural chemicals threaten land resources, especially soil environment. Although there are many reports and studies dealing with land degradation, soil environment is still affected. El Jicaral Village in Mexico is also one of the areas where land degradation has been progressing.

Soil degradation processes are divided into three: physical, chemical and biological ones. Dominate factors that influence soil degradation processes are soil properties, climate, topography and vegetation. Soil properties are the parent materials and all those inherent properties of the soil, such as physical, chemical and biological properties. Concerning the climate, components that influence soil degradation are precipitation, temperature, evapotranspiration and seasons. Topographic components include slope, water systems and landscape position. Vegetation components are related with biomass, biodiversity and succession.

There are several causes that produce soil degradation. Bio-physical causes are those related with land use, deforestation, farming systems, and crop and soil management. Also, socio-economic causes, such as ownership of the land, institutional strength, markets, poverty and health, influence soil degradation. In addition, there are political causes, which are political stability and policies. Soil degradation is part of a descending spiral, where degraded soils are only capable to carry out subsistence agriculture, leading to poverty, including poor health and malnutrition, conducting to political instability, putting more pressure on natural resources.

Accordingly, this study dealt with the assessment methods for evaluating land degradation and the development of a soil conservation strategy that are applicable even in remote areas in developing countries.

2. Natural and agricultural conditions in research site

The research site for the investigation is located in Mixteca Region, which is one of the poorest regions in Mexico with land degradation and water scarcity situation. The Ministry of Environment and Natural Resources estimated around 500,000 hectares in the region presented high levels of land degradation in 1998. Mixteca Region is located in Oaxaca State in the southern part of Mexico with a surface of 15,600 km^2 and around 450, 000 habitants.

The weather in Mixteca Region according to Koppen and Geiger is classified as Csb, which is for those areas with cool, dry summer and frost danger in winter. According to the National Meteorological Service, the average annual precipitation is of 1988.3 mm and the annual mean temperature is 15.0 ºC.

The objective of this chapter is to assess the local farming situation of the research site. For this reason, El Jicaral Village, Coicoyan de las Flores municipality, Mixteca Region, Oaxaca state, which is the second poorest municipality in Mexico with high levels of soil degradation, was selected for this study. Main crops are rain-fed corn, chili and beans. Due to the uneven topography of the region, the upland fields being mostly situated in hillsides are prone to land degradation process. In this village, questionnaire survey was carried out to local farmers.

3. Land degradation assessment in research site

Soil erosion represents the most extensive areas of degraded land worldwide, as more than 83% of the areas have been affected. In the classification of the land degradation, the processes of soil erosion dominated for rating the degree and extent of the land degradation. Placed on this statement, land degradation assessment was conducted in El Jicaral Village based on the analysis of several variables observed on topographical maps and satellite images. The results of this assessment showed that more than 35% of the study area was under severe land degradation. To confirm the reliability and accuracy of the remote assessment, land degradation assessment was conducted by means of the field assessment. Accordingly, the objectives of this chapter are to evaluate the viability of the land degradation assessment based on the remote assessment compared with the field assessment and to analyze the level of soil degradation in El Jicaral, Mixteca Region, Mexico.

Both remote and field assessments were done in the study area, on a mesh of 50 meters by 50 meters, covering an area of around 0.5 km^2. The results of land degradation assessment through the field assessment were compared with that through the remote assessment.

In the field assessment, a global navigation satellite system (GNSS) was employed for clarifying the location in every cell. Then observation was conducted based on *'Morgan Coding System'* with rating a value from 0 to 5 at the assigned cell. After obtaining a value based on '*Morgan Coding System*' for each mesh, a comparison was done between the field assessment and the remote assessment. For the comparison, statistical method using a correlation analysis was employed.

The results of statistical analysis indicated that there was a correlation between both assessments at 99% significant level. It means that the remote assessment based on several variables, such as steepness, slope, vegetation density and land use may be enough for assessing the land degradation in a small scale. This technique is useful when the land degradation assessment is necessary in small areas and it is not possible to conduct an on-site assessment.

According to the remote assessment as well as the field assessment through the survey in the research area, it may be concluded that El Jicaral Village is facing a serious land degradation process due to land use conditions in the village, such as crop cultivation under steep slope conditions, deforestation and cattle overgrazing. Furthermore, no soil conservation practices are conducted and chemical products are being used without understanding of their negative impacts. Due to these conditions, land degradation is a continuing process in El Jicaral Village.

4. Developing soil conservation strategy for Mixteca Region

The application of animal waste is beneficial for soil conservation, especially in lands degraded or being susceptible to erosion. Oaxaca State where Mixteca Region is located, is the main state by number of goats (around 952,000 goats) in Mexico, which represents 10.9% of the national production. In this study, animal waste was used as a natural resource for protecting soils against erosion. The objective of this chapter is to develop a soil conservation strategy with animal waste slurry for mitigating soil loss in leptosol from Mixteca Region.

For this purpose, a raindrop model and a slope model were used. Raindrop model consisted in stainless steel cores of 1.0 cm long with inside diameter at 1.1 cm. Soil was placed inside at a dry density of 1.0 ± 0.1 g/cm^3. Fifty drops of artificial rain were dripped on the soil inside the core and soil loss was measured. On the other hand, slope model consisted of a plot of 91 cm x 3.15 cm x 1.4 cm, with a triangular cross section. Soil was filled in with the same dry density of raindrop model and 1.2 cm^3/s of deionized water was supplied during one hour on a 12 degree slope. Discharge was collected every ten minutes and soil loss was measured.

As a treatment for both models, horse waste slurry was used. It was collected in the Horsemanship Club of Tokyo University of Agriculture and passed through a sieve at 212 μm in order to obtain slurry. Two treatments were set up; animal waste slurry incorporated with soil, and crust formed with animal waste slurry. The oven dried mass ratio of soil to slurry was 66:1. Soil losses were compared among these 2 treatments. The results of raindrop experiment showed that the addition of animal waste slurry decreased significantly soil loss rate from 6.4% to 1.3% for slurry incorporated cores and to 0.2% for formed bio-crust cores. The same tendency was observed in the slope model experiment, where the application of animal waste slurry reduced significantly the soil losses from 558.6 g/m^2 to around 60 g/m^2 for both plots where slurry was added. Concerning the loss of nitrogen component, the results showed that there was a higher release of nitrogen in the control plot than in the other plots where animal waste slurry was applied.

Therefore, it was concluded that the application of animal waste slurry was effective to reduce significantly soil losses by protecting the soil against kinetic energy of raindrops, and it might be effective as well against shearing forces of surface runoff on at 12 degree slope in leptosol soil of Mixteca Region.

5. Treatment of animal waste for elimination of *E coli*

Although the application of animal waste slurry was effective for mitigating splash and sheet erosion, there is a risk of pollution for efflux of *E. coli* when applying animal waste slurry. For this reason, treatment for killing *E. coli* of animal waste was carried out. Air drying was conducted for animal waste slurry. After four weeks, the amount of *E. coli*, coliform bacteria and general bacteria was measured. On the fourth week, water content of slurry was 695%. There was neither *E. coli* survival, nor coliform bacteria in the slurry after four weeks of air drying. But the amounts of general bacteria 7 x 10^4 cfu/g survived. The experiment was done in summer, the maximum temperature was 36 ºC during the experiment. However, usually harvest in El Jicaral Village is done around

September, where the average temperature is around 16 ºC. For this reason, it is recommended to apply an increasing pH treatment, with the purpose of increasing pH to 9.0 and on doing so to kill *E. coli* and coliform bacteria. In Mexico, and particularly in local indigenous areas, where corn is the main product, there is a process called Nixtamalization that is boiling the corn in an alkaline solution, usually limewater. So, it is recommended to use the residues of this process in the preparation of slurry.

6. Conclusions

This study dealt with land degradation assessment and soil conservation strategy that are applicable in Mixteca Region, Mexico. According to the land degradation assessment, it was confirmed that degradation is advancing in most of research site, with a hilly topography, shallow vegetation cover and main land use as an upland farming. So, it is necessary to conduct soil conservation practices to ensure the future productivity of the farmlands. For this purpose, the application of animal waste slurry was proposed as a soil conservation strategy in the research site, especially for mitigating the occurrence of soil erosion with kinetic energy of raindrops and shearing force of surface runoff. The results showed that the application of animal waste slurry reduced soil loss from 6.4% in control cores to 1.3% in slurry incorporated and to 0.2% in bio-crust formed. The same tendency was observed in the slope model experiments, where the application of animal waste slurry reduced significantly soil losses from 558.6 g/m^2 to around 60 g/m^2 in both plots where slurry was added.

However, it was considered that there is a potential risk of pollution of water bodies due to the efflux of *E. coli* when applying animal waste slurry. So, air drying of slurry was conducted as a treatment to kill *E. coli*. It was found out that this treatment was effective with 0% of *E. coli* and coliform bacteria survival in the study case. For these reasons, it can be concluded that the air dried slurry application is an effective soil conservation strategy for mitigating land degradation in El Jicaral Village, Mixteca Region, Mexico.

和文要約

第 1 章　第五研究の背景と目的

土壌は、農業を営む上で不可欠な土地資源である。地球温暖化に伴って高強度の降雨や干害の発生頻度が高まっている。加えて、化学肥料や農薬に依存した営農形態は土地資源、特に土壌環境を脅かしている。土地劣化を扱ったレポートや研究は多数あるものの、土壌環境の劣化は未だに止まっていない。メキシコ国のエルヒカラル村も土地劣化の進行している地域の一つである。

土壌劣化のプロセスは、物理的、生物的、化学的プロセスの三つに大別される。土壌劣化に影響を与える主因子には、土壌、気候、地形、植生が挙げられ、土壌については母材や物理的、化学的、生物的な土壌特性が挙げられ、気候については降水、温度、蒸発散、そして季節の有無が影響している。また地形には傾斜、水文環境、景観構成要素があり、植生に関して言えば、バイオマス、生物多様性と生物遷移が挙げられる。

土壌劣化を生じさせるのに、いくつかの原因がある。生物物理学的な原因としては土地利用、森林伐採、営農体系、土壌や作物の管理法が関係している。社会経済的な原因もまた土壌劣化に影響を及ぼしている。例えば、土地保有権、制度上の課題、市場、貧困、そして健康である。最後は政治的な原因であり、これには政情安定と政策が挙げられる。土壌劣化は、負のスパイラルの一つで、土壌劣化が進行すると、自給自足しか行えなくなり、貧困をもたらし、健康被害や栄養失調等の問題を引き起こす。それによって政治的不安定とともに、自然資源の枯渇化が進行してしまう危険がある。

第 2 章　研究対象地における自然および農業の現状

研究対象地はメキシコ国の中でも最貧困地域で土地劣化と水資源が枯渇しているミクステカ地域である。1998 年のメキシコ国環境自然資源省に発表によると、ミクステカ地域の約 500,000 ha が高い土地劣化状態にあると見積もられている。このミクステカ地域はメキシコ南部のオハカ州に位置し、面積はおける 15, 600 km^2 で人口は 450, 000 人である。

コッペンとガイガーによると、ミシュテカ地域の気候は Csb に分類され、夏は乾燥して涼しく、冬は高湿で寒冷を呈する。国立気象サービスによると、年平均降水量は 1988.3 mm で年平均気温は 15.0 ℃である。

この章では研究対象地における営農状況に関する調査を扱った。研究対象地には深刻な土壌劣化が発生しているとともに、メキシコで二番目に貧しい村であるエルヒカラル村が選定された。主な穀物は、天水とうもろこし、唐辛子や豆類である。複雑な地形のために、土地劣化の進行しやすい山腹斜面にまでも畑地が広がっている。そのエルヒカラル村において、現地農家を対象にアンケート調査を実施した。

第 3 章　研究対象地における土地劣化の評価

世界規模でみて土壌侵食は土地劣化の進行しているほとんどの地域で見られ、約 83%以上で発生していると推定されている。土地劣化の分類によると、土地劣化の主な要因は土壌侵食であると報告されている。これに基づき、エルヒカラル村における土地劣化の評価を行った。この評価にあたっては、地形図やサテライトイメージから取得できるいくつかの変数の分析に基づいた。分析の結果として、研究対象地の約 35%以上の地域が深刻な土地劣化であることが明らかと

なった。このリモート評価の正確性と信頼性を調べるために、現地調査によるフィールド評価を実施した。このように、この章では現地調査と比較したリモート評価に基づいた土壌劣化評価の適応性の評価を扱った。

研究対象地の約 0.5 km^2 を対象に 50 m×50 m のメッシュを作成して、リモート評価と現地調査によるフィールド評価を進め、各々の結果を比較した。現地調査において各セルの位置の確認には GPS を使用した。現地調査では Morgan Coding System に基づいて、各セルにおける土地劣化の程度を 0 から 5 までの範囲内で評価し、リモート評価の結果と比較した。

リモート評価と現地調査によるフィールド評価を比較した統計分析の結果、両方の評価間に 99%のレベルで相関関係があることが明らかとなった。そのことは、起伏、傾斜、植生密度や土地利用に基づいたリモート評価によって、土地劣化の評価を行えることを意味している。現場でのフィールド評価を実行できない場合でも、適用できる土地劣化の評価方法として位置づけられる。

またこれらのリモート評価と現地調査によるフィールド評価の結果から、急傾斜地での営農や森林伐採等が行われているエルヒカラル村では、深刻な土地劣化の状況にあると判断できた。さらに、エルヒカラル村では土壌保全対策は実施されておらず、化学肥料や農薬の施用方法も理解しないまま適用されている現状から、土地劣化は今後も進行するものと考えられた。

第 4 章　ミクステカ地域に適用できる土壌保全対策

有機資源である動物の排出物の適用は土壌保全に有効で、特に劣化した土地や侵食を受けやすい土壌においては顕著である。メキシコ国オハカ州ではヤギの飼育が盛んであり、その頭数は約 952,000 頭で国内生産の 10.9%を占めている。

この研究では、動物排出物を土壌侵食防止のための自然資源資材として適用したものである。具体的にはミクステカ地域のラプトソル土壌からの侵食流出を軽減するために、動物排出物スラリーを土壌保全対策として適用した。

実験には雨滴モデルと斜面モデルが使用された。雨滴モデルでは、直径 1.1 cm、長さ 1.0 cm のステンレスコアが使用され、コア中に乾燥密度 1.0±0.1 g/cm3 で土壌を充填した。このコアに詰まった土壌に人工降雨 50 滴を落下させて、土壌飛散量を測定した。他方、斜面モデルでは、長さ 91 cm×幅 3.15 cm×深さ 1.4 cm の三角断面を有している斜面モデルを傾斜 12°に設置して供試した。斜面モデルに充填した土壌についても雨滴モデルと同じ乾燥密度に調整した。この斜面モデルに脱イオン水を供給して、流量 1.2 cm3/s の表面流を 1 時間発生させて 10 分毎に土壌流亡量を測定した。

　両モデルにおいて動物排出物のスラリーを適用した。馬糞は東京農業大学農友会馬術部より採取し、212 μm のふるいを通過させてスラリーを作成した。このスラリーの土壌への適用には 2 つ方法が採られ、一つは動物排出物スラリーを土壌に混合する方法で、もう一つは動物排出物スラリーを土壌表面に散布してクラストを形成する方法である。土壌に対するスラリーの炉乾燥質量比は 66 : 1 とした。雨滴モデルによる実験の結果、スラリー混合およびスラリーでクラスト形成した場合、土壌飛散量は無処理の 6.4%から 1.3%および 0.2%にまで減少することが明らかとなった。斜面モデル実験でも同じ傾向を観察でき、スラリー混合およびスラリーでクラスト形成した場合、558.6 g/m^2 を記録した無処理の土壌流亡量が、両モデルともおよそ 60 g/m^2 にまで減少する結果となった。窒素成分に関しても、スラリー混合およびスラリーでクラスト形成した場合、有意で無

処理を下回る結果となった。

従って、動物排出物スラリーの土壌保全対策としての適用は、雨滴による運動エネルギーに対しても、傾斜 12°で発生した表面流によるせん断力に対しても、ミクステカ地域で採取されたラプトソル土壌の侵食量を軽減するために有効であると考察された。

第 5 章　動物排出物からの大腸菌の処理

動物排出物スラリーの土壌保全対策としての適用は、雨滴侵食に対しても、面状侵食に対しても有効であったが、動物排出物スラリーの適用によって E. coli 汚染が拡散する恐れがある。そこで、動物排出物スラリー中の E. coli 殺菌の処置について研究を進めた。ここでは乾燥処理について扱った。スラリーの作成から 4 週間乾燥処理を進めたところ、スラリーの含水比は 695%にまで低減した。併せて、E. coli と大腸菌群、一般細菌を測定した結果、E. coli および大腸菌群は検出されず、一方、一般細菌は 7×106 cfu/g であった。

実験は夏期に実施しており、最高温度は 36 ℃を記録した。しかし、通常エルヒカラル村の収穫期は 9 月頃であり、その月の平均温度はおよそ 15.6 ℃である。その温度では動物排出物スラリー中の E. coli の殺菌は期待できず、エルヒカラル村では pH 9.0 まで上昇させる pH 処置が適正であると考察できた。エルヒカラル村では石灰水などのアルカリ性溶液でコーンを茹でる食品加工プロセスがあり、動物排出物スラリー中の E. coli の殺菌にはこの石灰水の残液が使用できると判断した。

第 6 章　結論

この研究は、メキシコ国ミクステカ地方における土地劣化の評価と現地で適

用できる土壌保全対策を扱ったものである。土壌劣化の評価では、大部分の研究対象地において傾斜地形、低い植生密度、畑作の実施などにより土地劣化が進行していることを確認できた。農地における将来の生産性を確保するためにも、土壌保全対策を実施することが必要であると判断した。

そこで研究対象地における土壌保全対策として、動物排出物スラリーの適用を提案した。雨滴モデルによる実験の結果、スラリー混合およびスラリーでクラスト形成した場合、土壌飛散量は無処理の 6.4%から 1.3%および 0.2%にまで減少することが明らかとなった。斜面モデル実験でも同じ傾向を観察でき、スラリー混合およびスラリーでクラスト形成した場合、558.6 g/m^2 を記録した無処理の土壌流亡量が、両モデルともおよそ 60 g/m^2 にまで減少することが明らかとなった。

しかし、動物排出物スラリーの適用によって *E. coli* 汚染が拡散する恐れがある。そこで、動物排出物スラリー中の *E. coli* 殺菌の処置について研究を行った。ここでは乾燥処理を進めたところ、*E. coli* と大腸菌群は検出されない結果となった。これらの結果から、メキシコ国ミクステカ地方エルヒカラル村の土地劣化の軽減を目指した風乾処理済みの動物排出物スラリーの適用は有効な土壌保全対策であると判断できた。

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Chapter 1

Background and objectives

1.1 Background

1.1.1 Overview of Mexico

Mexico is a federal republic located in the north of America continent (Fig. 1-1). It shares the north border with the United States, the southeast border with Guatemala and Belize. On the west and south is faces the Pacific Ocean, and on the east the Gulf of Mexico. The total area is almost 2 million square kilometers (1,920,550 km^2), and 2.5% of its territory is covered by water. It is located between latitudes 14º and 33ºN and longitudes 86º and 119ºW. Mexico is crossed by two mountain ranges, from north to south, called Sierra Madre Oriental and Sierra Madre Occidental. For this reason, most of Mexico's area is located in high altitudes.

Fig. 1-1 Map of Mexico

1.1.2 Population in Mexico

The population is estimated of being over 120 million (INEGI, 2010), placing the country as the eleventh most populous in the world, and the first by number of native Spanish speakers (Fig 1-2).

According to Conapo, 2006, the increasing in population will continue until 2042, where for the first time since 1921 the population will start to decrease. There are several factors, including the reduction in fecundity. In 1970 a woman had in average 6.7 children, and in 2005 this decreased to 2.2. Other factors include increase of mortality rate, from 5.0% in 2005 to 6.8% in 2050.

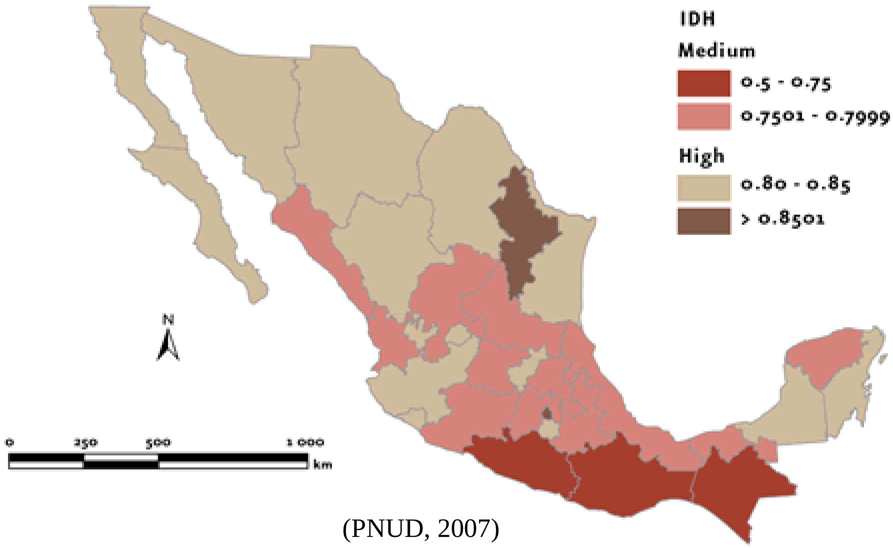
Fig. 1-2 Population and growth rate in Mexico, 1900 – 2050 (Conapo, 2005)

With the increase in the population, urbanization is a current phenomenon in Mexico. When people move to the cities, there is a high pressure in local ecosystems. On 1900, around 75% of the population lived in rural areas throughout the country, but in 2005, only 23.5% lived in those areas (Anzaldo-Gomez, C., 2006). The excessive concentration of people in urban zones usually has negative consequences for the environment, due to the demand of natural and economical resources.

Rural areas are often the most vulnerable, where subsistence agriculture is conducted and where basic services, such as health care, education, clean water, energy supply are not available.

1.1.3 Socioeconomic situation in Mexico

Socioeconomic situation in a country can be known through the level of poverty of its population. For measuring the poverty, several indicators have been established. One of these indicators is the Human Development Index (HDI), formulated by the United Nations Development Program (UNDP, 2006) to classify countries based on three parameters, namely: health, education and income. The results are shown through a coefficient between 0 and 1. According to the report of UNDP 2006, the human development index for Mexico was calculated at 0.8031. This value is slightly above the HDI level that separates the countries with a high human development (Fig 1-3).



(PNUD, 2007)

Fig. 1-3 Human development index (HDI) by state, 2004

Nevertheless, at municipality level inside Mexico it can be found that the Human Development Index is very low. For example, in Coicoyan de las Flores, Mixteca Region, this value is about 0.4768. Coicoyan is a rural municipality, with an indigenous population of around 98%. The main economic activity in this municipality is subsistence agriculture.

1.1.4 Environment

There are several ways to measure the impact of population on the environment. One of the most representative is the ecological footprint, which refers to the total area of the earth used by an individual, country or the entire world for providing the resources that will satisfy the demand of the population (WWF, 2008). In Mexico, a study was conducted using the footprint indicator to calculate the current environment situation (Semarnat, 2006).

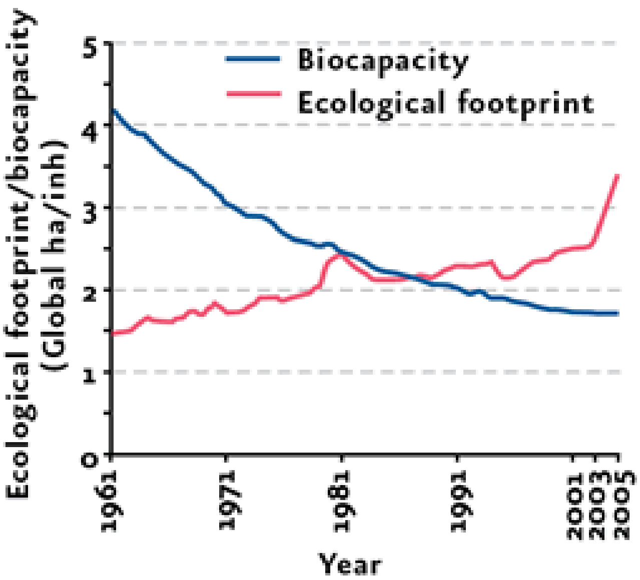


Fig. 1-4 Ecological footprint and biocapacity in Mexico, 1961-2005

As can be observed in the above figure (Fig. 1-4), Mexico, as several countries in the world has overpassed the biocapacity level, which means that the current development is not sustainable and that the negative impact for the environment is bigger and bigger.

1.1.5 Soil degradation

Soil degradation is the term used to describe processes by which soil loses the quality to provide support for humans (Lal, 2001). This could be understood as the weakening of soil productivity, its capacity to moderate environment and the reduction of biodiversity (Fig. 1-5).

Fig. 1-5 Soil degradation

The soil degradation problem has been affecting the earth surface since the very start of agriculture (Lowdermilk, 1953). Problems related with degradation of soil, such as erosion, overgrazing and deforestation have made empires fall apart and big civilizations to disappear. Nowadays, due to the fast increase in population, pressure on natural resources is higher, accentuating soil degradation risks drastically (Richards, 1991).

For these reasons, it is important to understand soil degradation, causes that produce it and factors that are involved in this process.

Soil degradation processes are divided into three types: physical, chemical and biological (Lal, 1998). Physical degradation can be observed as erosion, compaction, crusting and structural decline in general. Chemical degradation can be described as acidification, salinization, leaching, nutrient imbalance, volatilization and decrease in

CEC. Biological degradation can be summarized as the reduction in soil biodiversity and the decrease of soil organic carbon.

Factors that influence soil degradation processes are soil properties, climate, topography and vegetation.

Among soil properties are the parental material and all those inherent properties of the soil, such as horizons, physical, chemical and biological properties. Concerning the climate, factors that influence soil degradation are precipitation, temperature, evapotranspiration and seasons. Topographic factors include slope, drainage density and landscape position. Vegetation factor has to do with biomass, biodiversity and succession.

There are several causes that produce soil degradation. Bio-physical causes are those related with land use, deforestation, cropping systems, soil and crop management (tillage and drainage). Also, socio-economic causes influence in soil degradation, such as tenure of the land, institutional strength, markets, poverty and health. Last but not least, the political causes, namely, political stability and policies.

Soil degradation is part of a descending spiral, where degraded soils are only capable to carry out subsistence agriculture, leading to poverty, which leads to poor health and malnutrition, conducting to political instability, putting more pressure in resources such as soil, and so on.

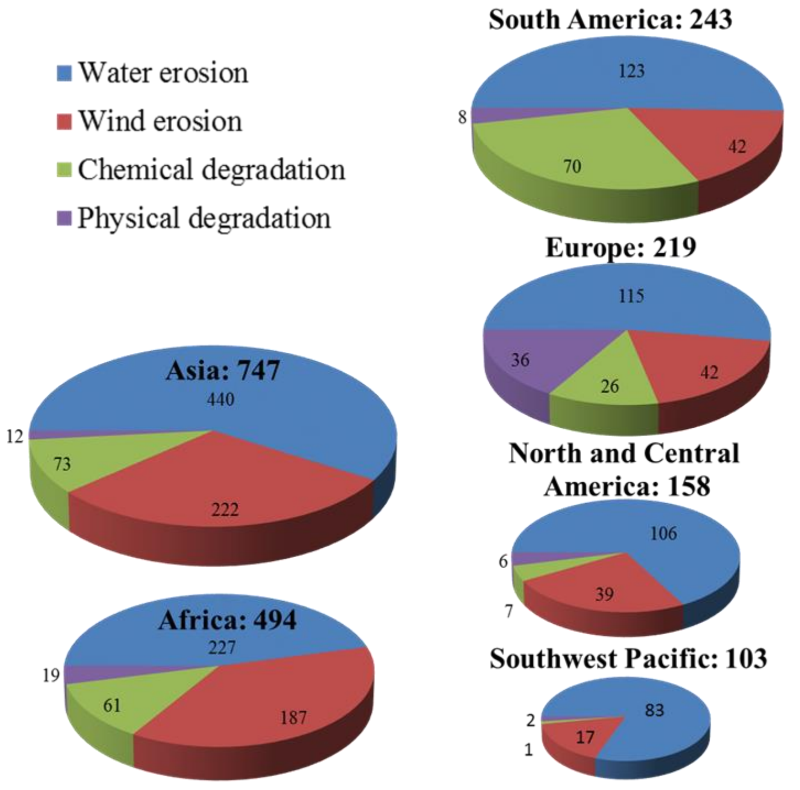
1.1.6 Soil degradation categories

According to Oldeman, 1998, soil degradation can be divided in two categories, based on the agents that produce it. The first category is about external agents that produce soil degradation by displacement of soil material, namely water erosion and wind erosion. Water erosion can be observed on site as loss of topsoil and terrain deformation. Off-site can be presented as reservoir sedimentation, flooding and destruction of sea beds (Oldeman, 1988). Regarding the effect of wind erosion, it can be observed on site as loss of topsoil and terrain deformation, and off-site as overblowing, affecting roads, buildings and vegetation cover.

The second category is by internal soil deterioration, including those processes that affect soil properties and structure. These processes are physical deterioration, chemical deterioration and biological deterioration. Physical deterioration involves sealing and crusting of topsoil, compaction, deterioration of soil structure, waterlogging, acidification and subsidence of organic soils. Chemical deterioration includes loss of nutrients, pollution and acidification, salinization, discontinuation of flood induced fertility, among other chemical problems. Biological deterioration is the loss of balance of microbiological activity in the top soil (Oldeman, 1988).

1.1.7 Soil degradation by type and area in the world

Soil degradation was classified by FAO 1995. According to this classification, Asia presented the wider area affected by soil degradation, with 747 million hectares, followed by Africa, 494 million hectares and South America, 243 million hectares. As can be observed, water erosion accounted for the main factor causing soil degradation (Fig. 1-6).



(FAO, 1995)

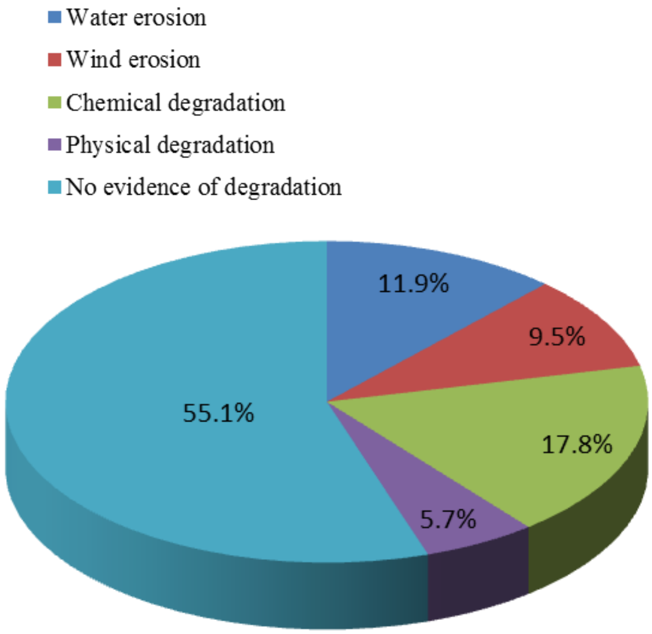
Fig. 1-6 Soil degradation in the world
(Million hectares)

1.1.8 Soil degradation in Mexico

In Mexico several studies about soil degradation have been conducted. The most recent being the assessment of soil degradation caused by man in Mexico (Semarnat-CP, 2003), with a scale of 1:250,000.

For this study, four degradation processes were considered: water erosion, wind erosion, chemical degradation and physical degradation. As can be observed in Fig. 1-7, more than 50% of the soils did not present evidence of degradation. However, chemical degradation accounted for the main process of soil degradation, affecting almost 18% of the country's surface area. Water erosion was the next process with

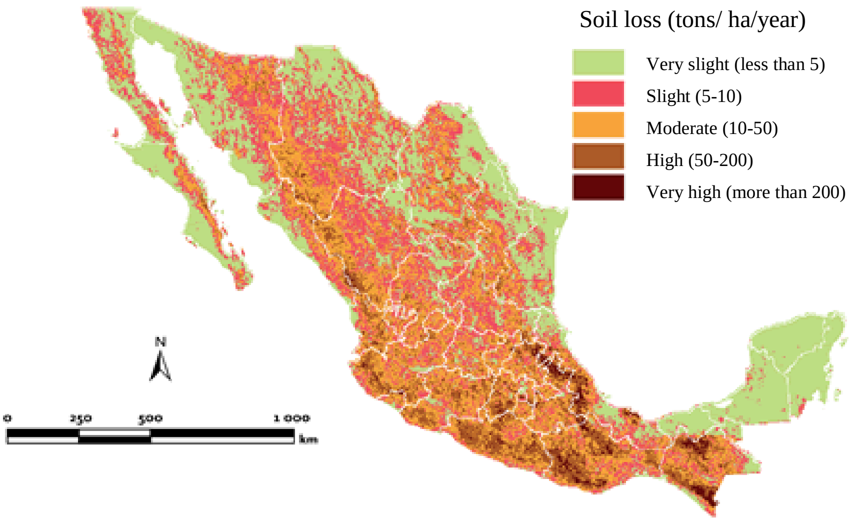
11.9%, wind erosion with 9.5% and physical degradation with 5.7%



(Semarnat-CP, 2003)

Fig. 1-7 Soil degradation in Mexico

Through this assessment it was calculated the soil erosion by level in Mexico (Fig. 1-8). The most affected areas were the mountainous regions of Sierra Madre, as well as wide areas in several states in the south (Chiapas, Guerrero and Oaxaca).



(Semarnat-CP. 2003)

Fig. 1-8 Soil erosion in Mexico

1.1.9 Soil conservation strategies

The main purpose of soil conservation strategies is to get the highest level of sustained production from a certain cultivated area and at the same time to maintain soil loss under a level where soil can recover naturally (Morgan, 1996).

For achieving this, soil must be protected from the detachment and transport of soil particles due to the effect of rain drops splash. It is also effective to improve the soil properties to increase the infiltration and reduce runoff.

According to Morgan, 1996, conservation strategies can be divided in three big categories: agronomic measures, soil management and mechanical methods. Agronomic measures rely on the coverage by vegetation to protect the soil. Soil management consist in the preparation of soil to increase its resistance to erosion improving its structure. The last one, mechanical methods, involve engineering structures to change the relief. Often this last practice is very expensive, and can be avoided if good soil management is carried out.

1.2 Objectives

1.2.1 Overall objectives of this dissertation

For the present dissertation entitled 'Soil Degradation Assessment and Soil Conservation Strategy for Mixteca Region, Mexico' the overall objective is to discuss the most convenient, effective and adaptable erosion control system for the research site. In achieving the goal of this dissertation, objectives were implemented as follows:

(1) To evaluate soil degradation condition in the research site

(2) To analyze the effectiveness of a proposed soil conservation strategy

(3) To evaluate the application of the proposed conservation strategy

1.2.2 Objectives of each chapter

In order to achieve the overall objectives and for giving a general overview of this dissertation, the research structure was formulated as shown in Fig. 1-9. In the present chapter it was stated that soil degradation is a serious environmental problem that affects deeply the capacity of human beings' surviving, and that it is present in every continent. In Mexico it is also a problem that needs to be addressed to the immediate future. One of the main reasons of soil degradation is the level of poverty that is present in several municipalities inside the country.

For this reason, the land degradation process was calculated in a study case in El Jicaral Village, and then the use of local resources was tested in order to propose a conservation strategy easy to adopt and replicate in several regions of the country.

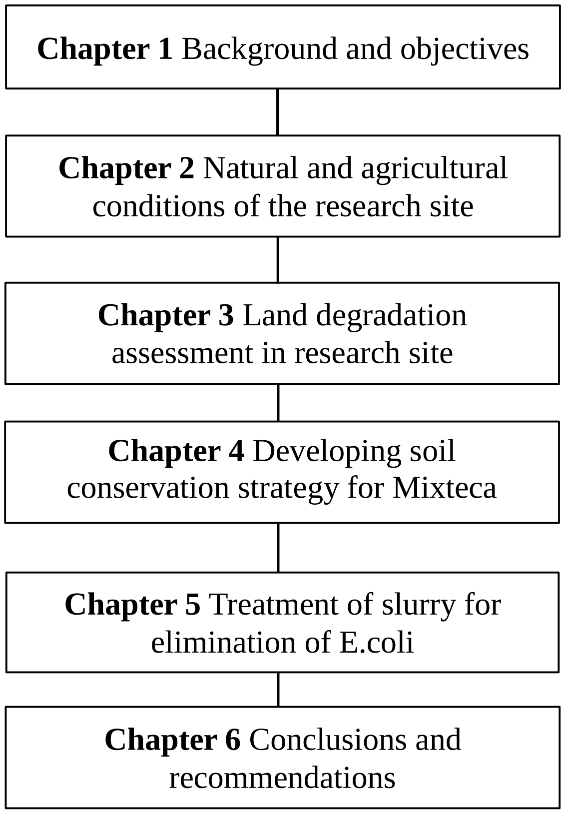


Fig. 1-9 Research structure of this dissertation

Regarding to this, **Chapter 2** deals with the definition of the research site, which is located in Mixteca Region, classified as one of the poorest areas in Mexico, with almost one third of its territory under the effects of high levels of land degradation. The objective of this chapter is to assess the local farming situation by means of a questionnaire survey.

Chapter 3 focuses on land degradation, taking soil erosion processes as indicators of its extent and severity. Land degradation assessment was conducted in El Jicaral Village, Mixteca Region, based on the analysis of several variables observed on topographical maps and satellite images (remote assessment). To confirm its reliability, land degradation assessment was conducted by means of a field assessment. Therefore the objectives of this chapter are to analyse the level of land degradation in the study site and to evaluate the viability of the land degradation assessment based on the remote method compare to the field method.

The results showed that there was correlation between both assessment methods at a significant level of 99%. For this reason, this technique might be useful when land degradation assessment is necessary in small areas and it is not possible to conduct an on-site assessment.

Since more than one third of the area was identified as under land degradation, it is necessary to develop a conservation strategy which could help to mitigate this tendency. In order to do this, in **Chapter 4** it is discussed the convenience of using animal waste as a conservation strategy, since the application of animal waste is beneficial to soil, especially in land degraded areas. For this study, it was used animal waste, since it is an available resource in the study site. The objective of this study is to develop a soil conservation strategy using animal waste slurry in order to mitigate soil loss in Mixteca Region. Results of soil loss experiments showed that there is a significant reduction of soil loss when using animal waste slurry compared to the control plot.

Even though the application of animal waste slurry was effective for mitigating soil loss, in **Chapter 5** it is intended to eliminate E.coli inside animal waste, in order to ensure that the addition of animal waste will improve soil conditions without harming the environment. For this reason air drying treatment was conducted. It was found that this treatment reduce significantly the amount of E.coli and coliform bacteria, and did not affect significantly the amount of general bacteria inside the animal waste.

Chapter 6 summarizes the outcome of each chapter of this dissertation and states the overall conclusion of the present study entitled: “Land Degradation Assessment and Soil Conservation Strategy in Mixteca Region, Mexico”.

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Chapter 2

Natural and agricultural conditions in research site

2.1 Introduction of this chapter

2.1.1 Background

One of the main problems when conducting investigation in the traditional way, including that carried out in rural communities in Mexico, as well as in any other part of the world, is that the final outcome, being methodologies or technologies, hardly is applied to resolve the problems they were designed for.

For this reason, emphasis is done in the use of participatory investigation (Velásquez, 2002), which main purpose is that the knowledge obtained through the investigation is available for all the persons involved.

In order to achieve the active participation of the studied communities, is vital the involvement of the researcher in the productive activities of these communities, even though it is a tough work, and uncommon, is the most efficient way to apply the scientific knowledge generated during the research. This approach is essential in the short term in developing countries (Baraza, 2008).

Nevertheless, in order to analyze deeply the bio productive and socioeconomic environment, in addition to the direct interaction with the community, it is necessary to measure quantitatively these aspect by means of a questionnaire survey applied to the family production units (Hérnandez Hernández, 2004).

2.1.2 Objectives

The objective of this chapter is to assess the local farming situation in El Jicaral Village, Mixteca Region.

2.2 Description of study site

2.2.1 Mixteca Region

Mixteca Region is located at the convergence of three states: Puebla, Guerrero and Oaxaca, in the southern of Mexico. The Oaxacan Mixteca Region (Fig. 2-1) has surface of 15, 600 km^2 (INEGI, 2005) and around 450, 000 habitants (INEGI, 2010). Out of the habitants of these region, 68% live in rural areas and 35% belong to an indigenous groups, which could be Mixtecos (majority), the Triqui, the Chochomixtecos, the Amuzgos, and the Tacuates (SAGAR, 1999).

Fig. 2-1 Mixteca Region, Mexico

2.2.2 Climate, precipitation and topography

According to Velásquez (2002), the predominant climates present in Mixteca Region are semitropical (Acw), semitropical temperate (C(w)) and temperate semiarid (Bs1k) . The average annual rainfall for this region ranges from 300 to 750 mm, distributed between June and October (INEGI, 1996).

The climatological values observed in Coicoyan de las Flores, Mixteca Region (latitude: 17°15’00” N, longitude: 098°17’59” W, Elevation: 2003 masl) are shown in Fig. 2-2 . The average annual rainfall is 1988.3 mm and average mean temperature is 15 Celsius degrees (SMN, 2010).

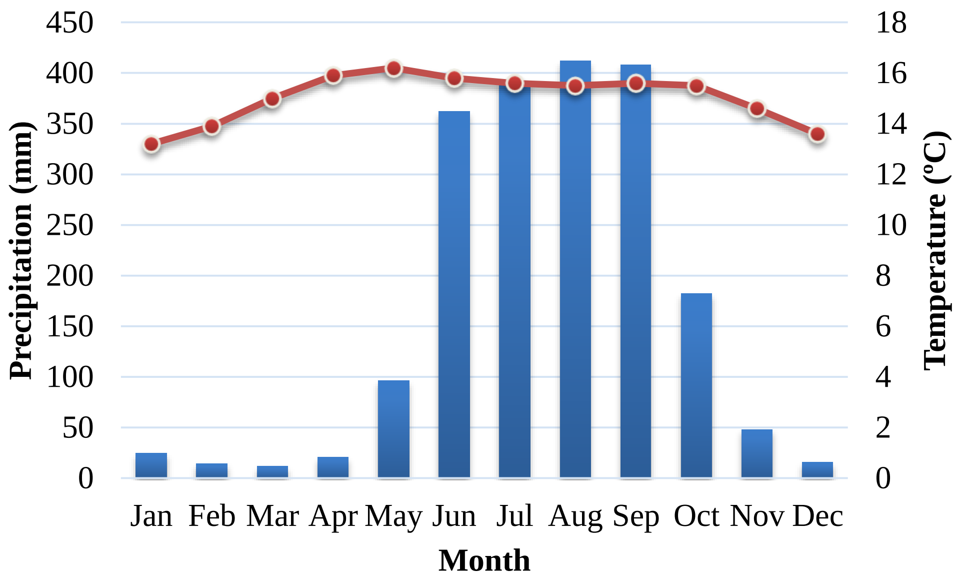

Fig. 2-2 Climatological normal values for Mixteca Region, 1951-2010

About the topography, the terrain is mountainous, and usually the farming practices are conducted on hillsides or at the edge of gullies, mainly for self-consumption. Altitude ranges from 1000 to 3000 masl.

Soils in Mixteca Region are generally lacking organic matter and deficient in nitrogen as well as several important micro nutrients. pH of soil are 6.8 to 8.7, and are often of medium texture. Most farming fields have pronounced slopes of 9 to 20% (SAGAR, 1999).

Local economy in this region is based on agriculture, mainly producing crops such as corn, beans and wheat, and grazing of livestock, such as goats, cows and sheep. Other main source of income is the money sent back by relatives working outside the region, inside Mexico or in the United States.

2.2.3 Land degradation in Mixteca Region

This region is characterized as being one of the poorest regions in Mexico, with high levels of land degradation, deforestation and water shortages. The Ministry of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales, SEMARNAT) estimated around 500,000 hectares in the region (Fig. 2-3) presented high levels of land degradation in 1998 (Semarnat-CP, 2003).

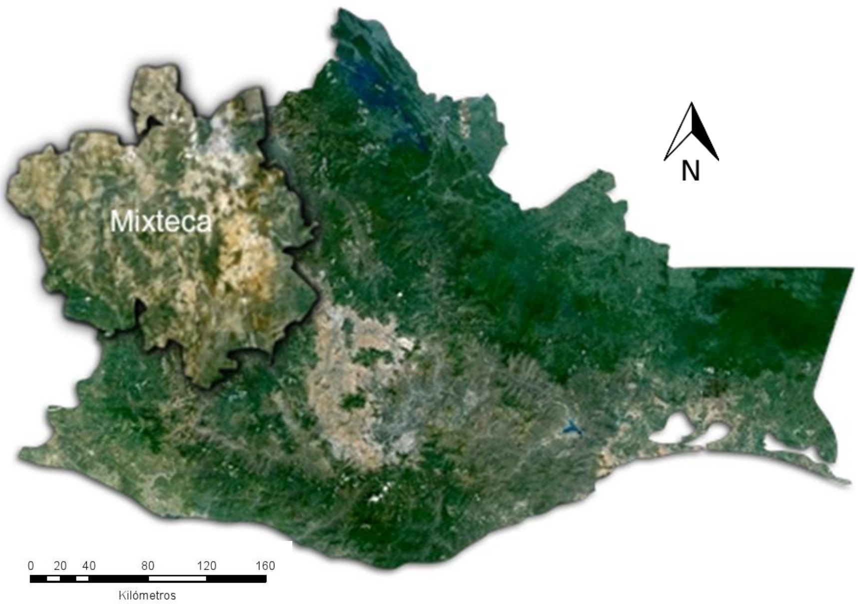

Fig. 2-3 Land degradation in Oaxaca State

Based on the study on soil erosion of Mexico conducted by Semarnat-CP (2003), it was calculated the surface of Oaxaca state affected by soil degradation processes, namely: physical degradation, chemical degradation, water erosion and wind erosion (Oldeman, 1998).

For Oaxaca state, chemical degradation (17.9%) and water erosion were the main processes of soil degradation (Table 2-1).

Table 2-1 Soil degradation in Oaxaca state

Physical degradation	Chemical degradation	Water erosion	Wind erosion
4,833 km^2	16,786 km^2	16,684 km^2	438 km^2
5.2 %	17.9 %	17.8 %	0.5 %

As a result of historical processes of deforestation, overgrazing and the change of land use to agricultural fields after the Spanish colonization, erosion has reached high levels of disaster (Fig. 2-4), and for this reason Mixteca Region is considered as an ecological disaster area (Martínez and Altieri, 2006).

Fig. 2-4 Disaster levels of soil degradation

For the analysis of geographical data obtained from INEGI (2014), the software ArcGIS 10.2 was used. The analysis consists of three variables: type of erosion, form of erosion and degree of affectation.

About the variable of type of erosion, this was classified in four categories: hydric (H), eolic (E), anthropogenic (A), and no evident erosion (SE).For form of erosion, variables are: gully (C), furrow (S), laminar (L), mound (M) dune (D) and other (O).

In case of degree of affectation, variables were: slight (1), moderate (2), strong (3) and extreme (4).

Soil erosion units are compounded of three elements: the first letter is the type of erosion, the second is the form and the third one is the degree (Fig. 2-5).

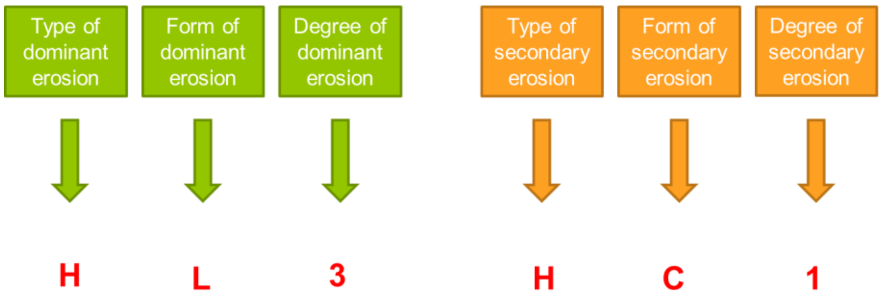

Fig. 2-5 Soil erosion units

A map was processed using the above mention classification for soil erosion in Mixteca Region, Mexico (Fig.2-6).

According to the values of the map, it could be observed that the bigger area is for not evident soil erosion (SE), with more that 25%. The next one, with more that 12% corresponds to HL1 unit, that means that hydric erosion (H), in the form of laminar runoff (L) in a slight degree is the most significant in the region.

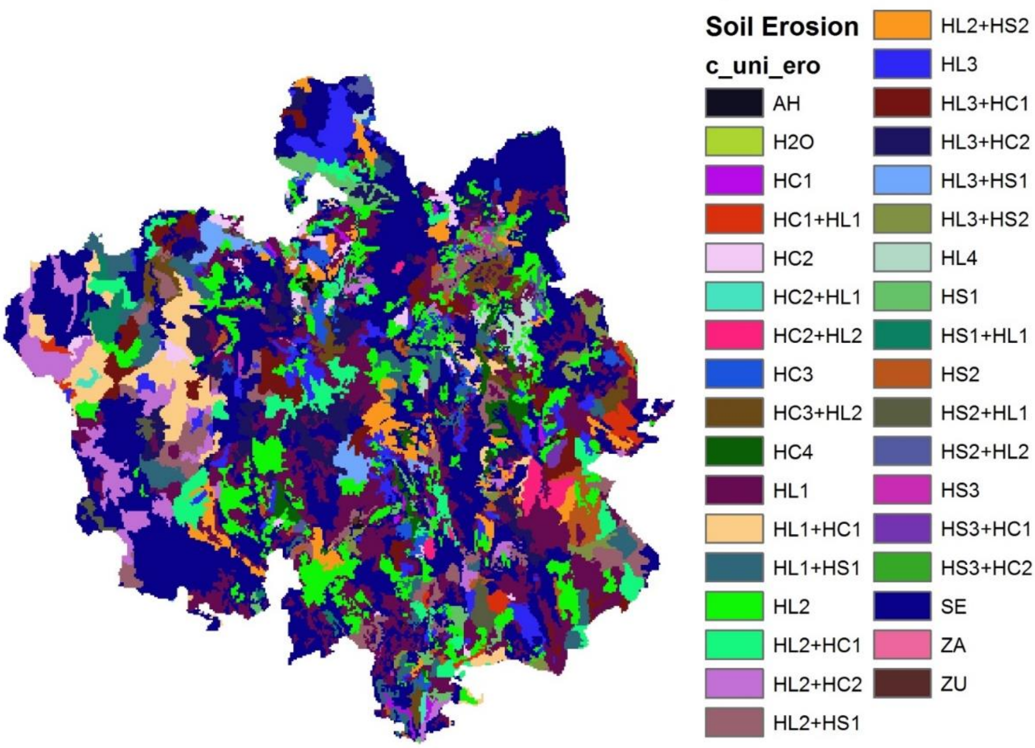

Fig. 2-6 Types of erosion in Mixteca Region

The erosion in Mixteca Region is a consequence of low productivity farming activities that put pressure on the environment, such as deforestation, overgrazing and slash and burn agricultural activities (UNEP, 2010).

2.3 Local farming survey in the study site

2.3.1 Study site

For this research El Jicaral Village, Coicoyán de las Flores Municipality, Mixteca Region was chosen because the degree of poverty is high, also it locates in the most land degraded region of the country (PNUD, 2008). El Jicaral Village is an indigenous community with around 1,000 inhabitants, in which people speak in Mixtec, ancient language in the area. The main crops in the village are corn, chili and beans. It locates in the coordinates 17º 07' 34.6" latitude North and 98º 11' 48.9" longitude West (Fig. 2-7).

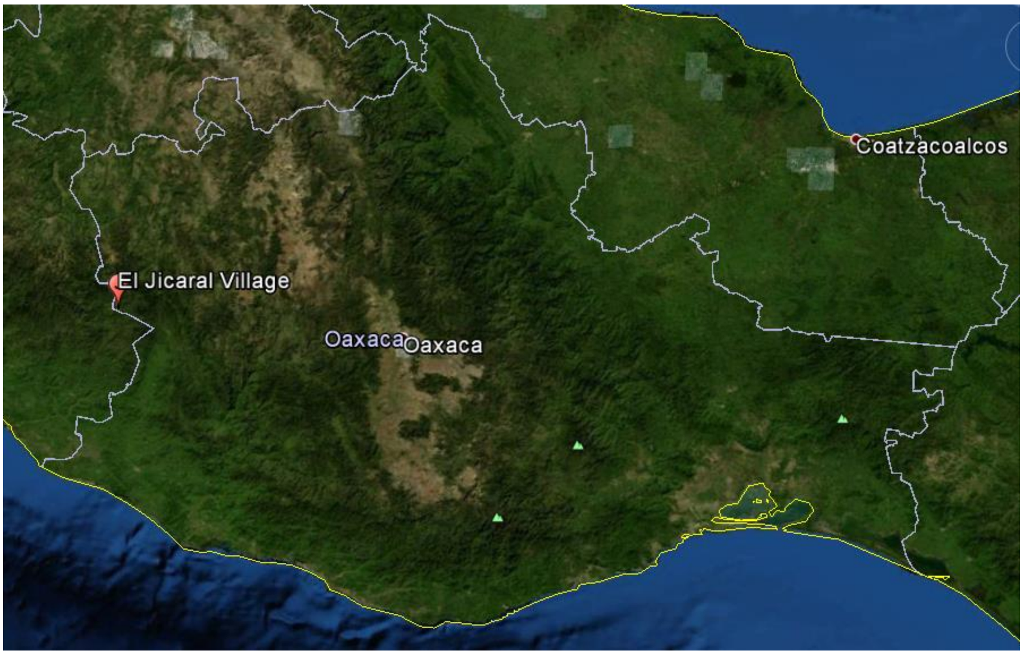

Fig. 2-7 El Jicaral Village, Mixteca Region

2.3.2 Rainfall measurement

In order to get a better understanding about the rain patterns in El Jicaral, a data logging rain gauge, model RG3 of Onset Company was installed and data was collected during all the year 2014.

Fig. 2-8 Rain Gauge installed in El Jicaral Village

The annual precipitation in El Jicaral Village for 2014 was 2,553.6 mm. The rainy season was comprehend between the months of May to October (Table 2-2)

Table 2-2 Rainfall data in El Jicaral Village (2014)

	Total Monthly Rainfall (mm)	Maximum Daily Rainfall (mm)	Highest Rainfall Intensity (mm/hr)
Jan	8.4	3.8	2.8
Feb	0	0	0
Mar	0	0	0
Apr	20.4	20.4	19.4
May	375.4	80.8	49.6
Jun	495.0	49.2	25.6
Jul	273.0	71.2	53.6
Aug	428.8	81.0	32.6
Sep	438.0	54.4	38.0
Oct	422.8	175.8	22.0
Nov	72.6	61.2	33.8
Dec	19.2	8.4	5.2

June was the month with the highest amount of rainfall, with 495 mm (Fig. 2-9)

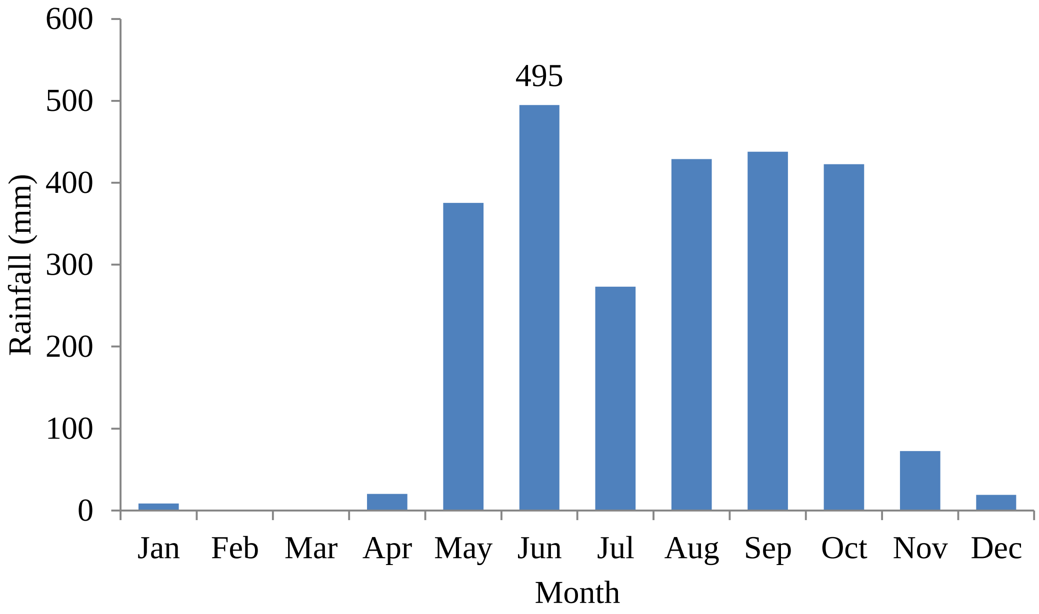

Fig. 2-9 Monthly rainfall in 2014 in El Jicaral Village

Through the collected data, an analysis was carried out to calculate the rainfall intensity (millimeter of rain per hour) in a given day. It was found that the maximum intensity occurred on July 20, with 53.6 mm/hr, followed by and event of May 27, with a rainfall intensity of 49.6 mm/hr (Fig. 2-10).

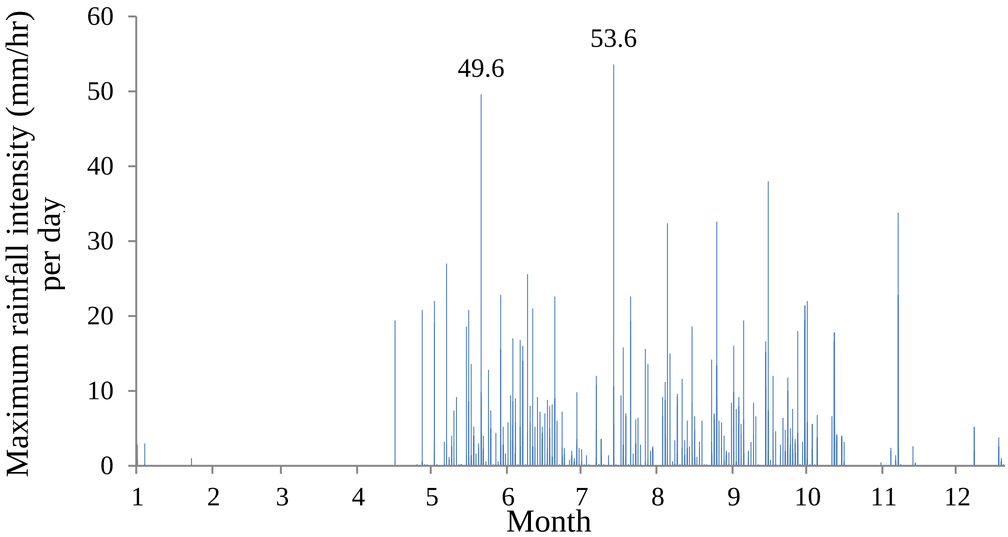

Fig. 2-10 Rainfall intensity in El Jicaral Village

2.3.3 Questionnaire survey

In order to assess the farming situation in El Jicaral Village, a questionnaire survey was conducted. 24 questions, divided into three sections such as 'Basic information of local farmers', 'Application of agricultural chemicals' and 'Current problems in farming systems' are shown in Table 2-3.

Table 2-3 Questionnaire survey for land degradation assessment

Basic information of local farmers	Application of agricultural chemicals	Current problems in farming system
Name, Age, Gender	Application of chemical fertilizers, formula, quantity	Main problems in the farming system
Number of family members working in agricultural sector	Amount of money expend for chemical fertilizers	Soil erosion awareness
Crops, area cultivated, destination of production	Application of pesticides and herbicides	Attendance to soil conservation workshops
Water source, breeding of animals	Application frequency	Concrete information about crops

The survey was conducted in July, 2013 in the village with the assistance of a Spanish-Mixtec translator at the workshop on ‘Soil conservation for sustainable agriculture’ (Fig. 2-11). The targets were local farmers, being older than 18 years old, who have been conducting agriculture in the village. From one household, only one representative was invited to attend the workshop. There were 69 household interviewees in the workshop and it counted 35% of all 200 households in the village. Due to their local customs, the survey must be divided into several times for each group with around 10 persons.

Fig. 2-11 Questionnaire survey application

Table 2-4 Contents of the questionnaire survey

Soil Conservation Questionnaire Survey

(Local Farming Situational Approach – A Preliminary Survey)
El Jicaral, Mixteca Region, Mexico

1. **Name:** ……………………………………………… 2. **Age:**……………. 3. ☐ **Male** ☐ **Female**
4. **Address:** ……………………………………………………………………………………………………
5. **Total numbers of family member:** ……….. person/people
6. **Number of family members working in agricultural sector:** ………….. person/people
7. **Total area of agricultural land owned:** …………..m^2, **cultivated:** …………..m^2
9. **What kind of crops are you cultivating in your field?**
   Name of crop: …………Maize……. Total: ………. m^2. Month of cultivation: …………………………
   Name of crop: ………Beans……..… Total: ………. m^2. Month of cultivation: …………………………
   Name of crop: ……Pumpkin………. Total: ………. m^2. Month of cultivation: …………………………
10. **What did you do on the products?**
   ☐ For family consumption ☐ Put into the market. Amount: ………………Pesos/year
11. **Which sources of water are you using for irrigation?** (Check any of the items below)
   ☐ Rain water ☐ Ground water ☐ Tap water ☐ Pond ☐ River ☐ Others………………..…
12. **What problems are there in your farmland?** (Check any of the items below)
   ☐ Hard to cultivate ☐Low fertility ☐Lot of stones ☐Slope ☐Erosion ☐ Others……………..……
13. **Are you conducting slash-and-burn farming?**
   ☐ Yes (Which month? ……………………………………)
   ☐ No
14. **Do you breed any animals?**
   ☐ Yes (Kind of animals:……………………………………...Total numbers.…..……)
   ☐ No
15. **Do you carry on any sustainable farming practice?**...
16. **Do you know about soil erosion and its effect?** ☐ Yes ☐ No (If yes, please check in the box below)
   ☐ Nutrient loss ☐ Degradation of soil ☐ Water pollution ☐ Increase in land productivity
   ☐ Decrease in land productivity ☐Others………………
17. **Do you apply chemical fertilizers in your farmland?**
   ☐ Yes. Formula of chemical fertilizers ……:……:......., Applied for (name of crop)……………………
   Amount: …………. (sack/ ha). Price per sack ....(Pesos)
   Formula of chemical fertilizers ……:..…..:......., Applied for (name of crop)……………………
   Amount: …………. (sack/ha). Price per sack ....(Pesos)
   ☐ No
18. **How much is your expenditure for chemical fertilizers per year?** ………………… (Pesos)
19. **Do you want to decrease the expenses for chemical fertilizers?** ☐ Yes ☐ No
20. **Do you apply pesticides or herbicides in your farmland ?**
   ☐ Yes (Name of the pesticide/herbicide……………………. Frequency of application………..)
   ☐ No
21. **Are you a member of any agro related associations or cooperatives in your village**?
   ☐ Yes (Name of the group…………………… When was it established? .... Number of members………..)
   ☐ No
22. **Have you ever been attending workshops about soil conservation?**
   ☐ Yes (Organized by………………………………………………)
   ☐ No
23. **If there is any opportunity, are you interested in joining workshops about soil conservation for sustainable agriculture?** ☐Yes ☐ No
24. **What kind of knowledge or support do you want to acquire for farming?**
   ……
   ……

2.4 Results and discussion

The results of the questionnaire survey in the village are summarized in the following charts.

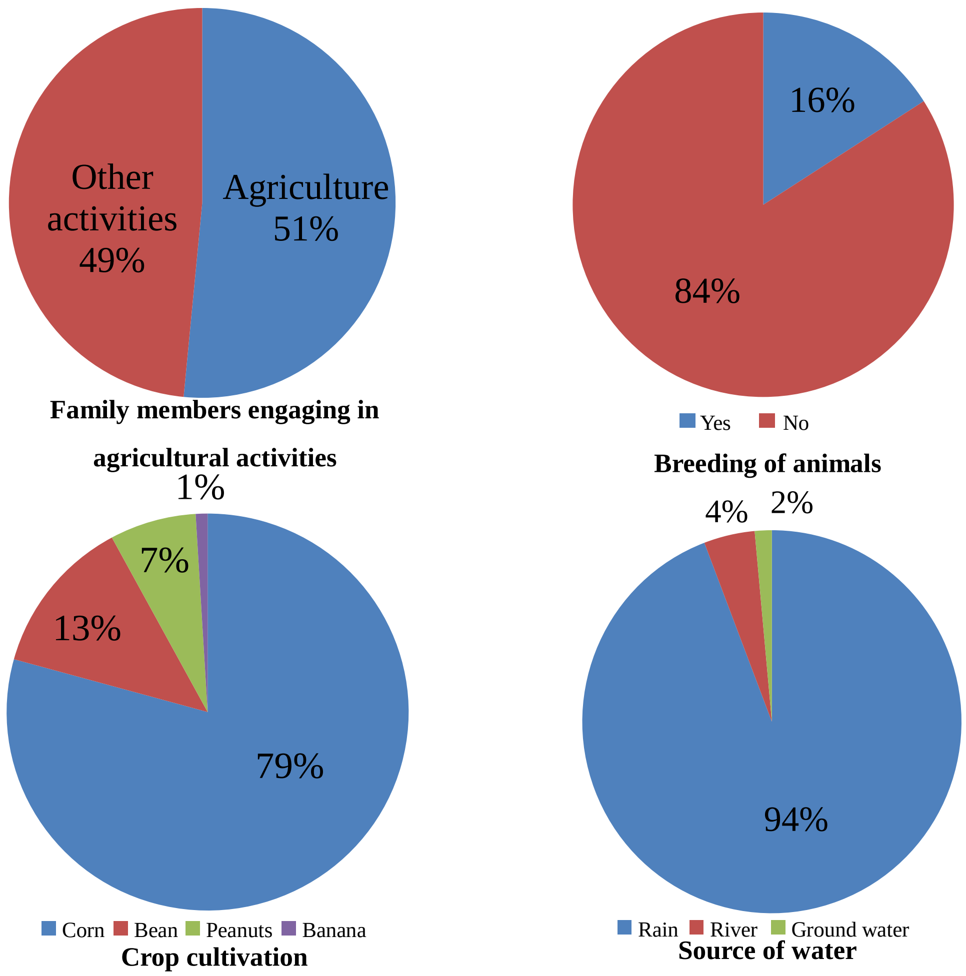

Fig. 2-12 Basic information of local farmers

It was observed that 35% of the interviewed households dedicated to agricultural activities were between 31 to 40 years old and that 65% was female, this is due to the strong social phenomenon of migration for male. Also, around half of all members at interviewed households were engaged in agricultural activities. 84% of interviewed households did not breed animals, and the main crop was corn. It counted at 79% of all cultivated areas hold by interviewed households, followed by beans at 13%. In addition, the main water source for the crop cultivation was rain water at 94%, and followed by river and ground water.

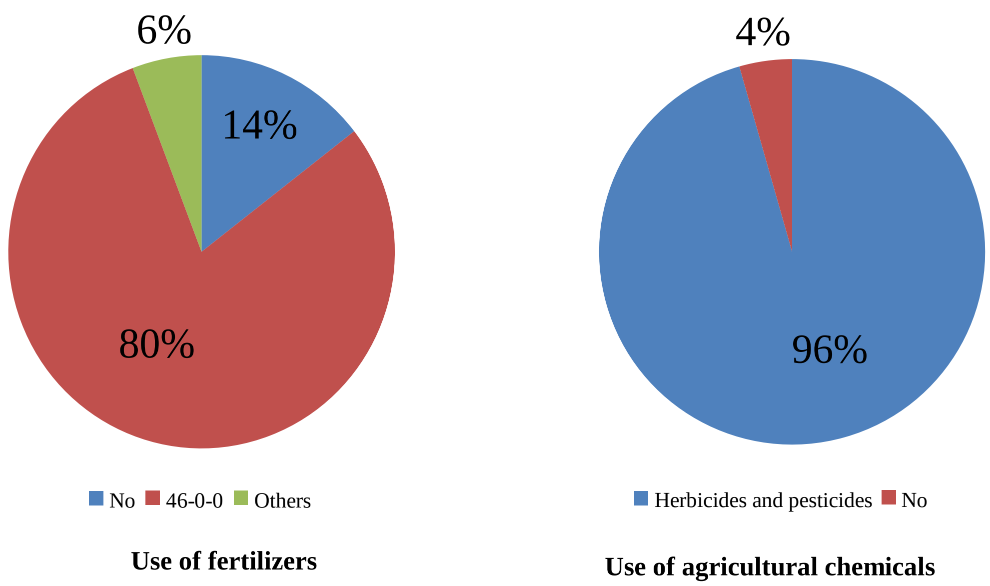

Fig. 2-13 Application of agricultural chemicals

Concerning the usage of agricultural chemicals, 80% of the interviewed households applied chemical fertilizers and 96% applied herbicides and pesticides to their farmlands as shown in Fig. 2-13. Some parts of these products are promoted in the Mexican governmental programs.

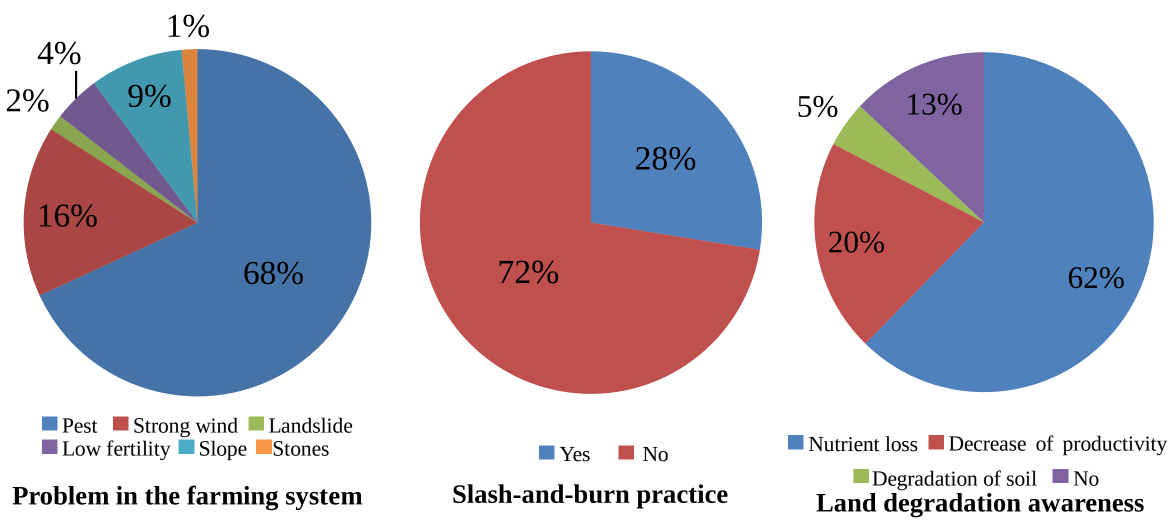

Fig. 2-14 Current problems in farming systems

Among the problems that farmers face in the village, the main one is pest problem that 68% of the interviewees responded. Especially, the damage by worms like 'gusano cogollero' (Spodoptera frugiperda) is severe in the village. The main insecticide applied for the worm is chlorpyrifos. Also, for controlling weeds, the herbicide entitled Paraquat is the most common in the village. However in the village, slash-and-burn farming is not common, as only 28% of the interviewees have been conducting.

Also, the results of questionnaire survey for land degradation assessment indicated that the interviewees had certain awareness on land degradation as well as nutrient loss associated with soil erosion. They also know that the processes of land degradation cause low in land productivity (Fig. 2-14).

The results of questionnaire survey also indicated that farmers have a perception on land degradation accelerating in the village. Nevertheless, under the current conditions of poverty and less knowledge on sustainable agriculture or land conservation, the farmers have no other alternatives of farming systems. They just continue the same farming even in sloping upland fields for obtaining short-term benefits to survive.

All the interviewed farmers are willing to join land conservation program for sustainable agriculture if there are any opportunities.

2.5 Conclusions of this chapter

In the present chapter a questionnaire survey was applied in order to know better the current local farming situation of El Jicaral Village, Mixteca Region, Mexico, since the quantitative measurement of these aspects helped to applied more precisely technologies to improve the land degradation.

Through the interview of 69 households, it could be understand that currently the farming systems are based mainly in subsistence agriculture conducted in hillsides, depending on rainfall as a source of water. Through the results of the rain gauge installation it was also understood that there is a high amount of precipitation, with around 2,500 mm in 2014, and that during the productive cycle of maiz, strong rainfall intensity was also presented in the months of May and July, wiith around 50 mm/hr. For this reason is important to protect the soil surface prone to erosion.

It was also understood that conservation practices are not conducted and that the use of chemical pesticides and herbicides is a common practice, even though the negative effects of applying it, to the health as well as to the land resource.

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Chapter 3

Land degradation assessment

in research site

3.1 Introduction of this chapter

3.1.1 Background

Land degradation is a natural and socioeconomic cause-effect phenomenon (Hammad, 2012). Demand on the land for economic development from an increasing population is driving unsuitable land use changes; hence land degradation through soil erosion, nutrient depletion, salinity, water scarcity, soil pollution, disruption of biological cycles and loss of biodiversity. The causes are multiple and complex, such as the expansion of cattle raising, the over-exploitation of forest resources, deforestation through slash and burn for agricultural practices and for energy needs (UNEP, 2010). Severity of land degradation has been increasing in many parts of the world, where more than 30% of forests, 20% of all cultivated areas and 10% of grasslands are undergoing degradation (Bai et al., 2008).

According to Kapalanga (2008), soil erosion represents the most extensive areas of degraded land worldwide, as more than 83% of the areas have been affected. In the classification of the land degradation, the processes of soil erosion dominated for rating the degree and extent of the land degradation.

3.1.2 Objective

The objectives of this chapter are to evaluate the degree of land degradation in research site by remote assessment and to confirm the reliability and accuracy of remote assessment by means of a land degradation assessment by field observation.

3.2 Research methods

3.2.1 Research site

El Jicaral (Fig. 3-1) is an indigenous community with around 1,000 inhabitants, whose spoken language is Mixteco. The main crops are corn, chili and beans. Due to the uneven topography of the region, the upland fields are mostly situated in hillsides, being prone to land degradation processes.

Fig. 3-1 Land degradation in El Jicaral

3.2.2 Land degradation assessment

There have been several attempts to define land degradation since the first international meeting on desertification in 1977 (UNCOD, 1978), in order to identify the current and future extend of this problem and to propose solutions in a global scale.

For carrying out land degradation assessments, several scientific techniques have been employed, such as ecological assessment, satellite remote sensing, measurement of soil properties, economic analyses, among other methods. (Stringer, 2006).

In this study, remote assessment was carried out by satellite image and by evaluation of soil erosion in the research site.

3.2.3 Direct assessment

Through the use of digital maps obtained from Google Earth software, a mesh was constructed above the community of El Jicaral, which is located in the coordinates 17º07'34.56"N Latitude, and 98º11'48.9"W Longitude. Cells dimensions were 50 meters by 50 meters, covering an area of around 0.5 km^2.The digital photography used for this research was taken in November 19th, 2010 (Fig. 3-2).

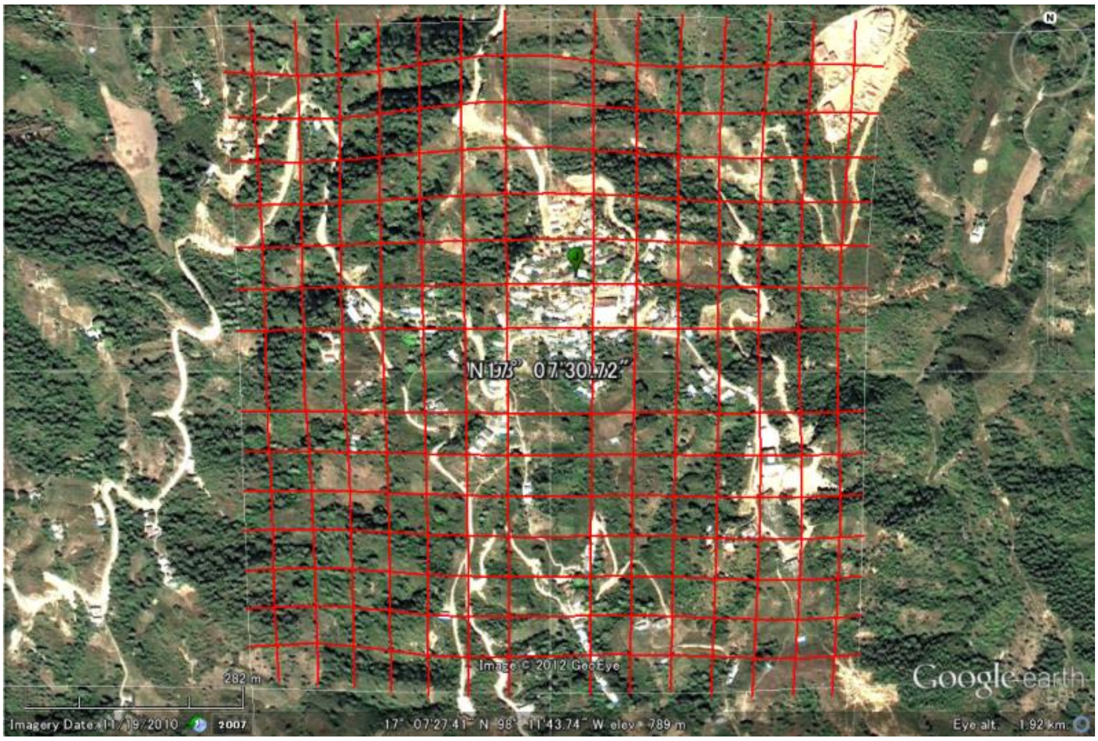

Fig. 3-2 Mesh projected in El Jicaral community

The Haversine formula of spherical trigonometry was used to calculate the distance between two points in the mesh using coordinates. This formula estimates the shortest distance over the earth's surface, ignoring any hills, Eq. (1).

$$harvesin\left(\frac{d}{r}\right) = haversin(\emptyset_2 - \emptyset_1) + \cos(\emptyset_1)\cos(\emptyset_2)\, harvesin(\lambda_2 - \lambda_1) \qquad (1)$$

In Eq. (1) harvesin is the Harvesine function, Eq. (2).

$$harvesin(\theta) = sin^2\left(\frac{\theta}{2}\right) = \frac{1-\cos(\theta)}{2} \qquad (2)$$

In Eq. (2) d is the distance between the two points along the sphere; r is the radius of the sphere, Φ_1 and Φ_2 are the latitude of point 1 and point 2 respectively, and λ_1 and λ_2 are longitude of point 1 and point 2, respectively.

After the mesh was projected in the study field, the elevation value of every intersection was obtained. Knowing the distance between intersections, the steepness and slope in every cell was calculated. Furthermore, with the mesh defined, vegetation density as well as land use values were assigned to every cell (Fig. 3-3).

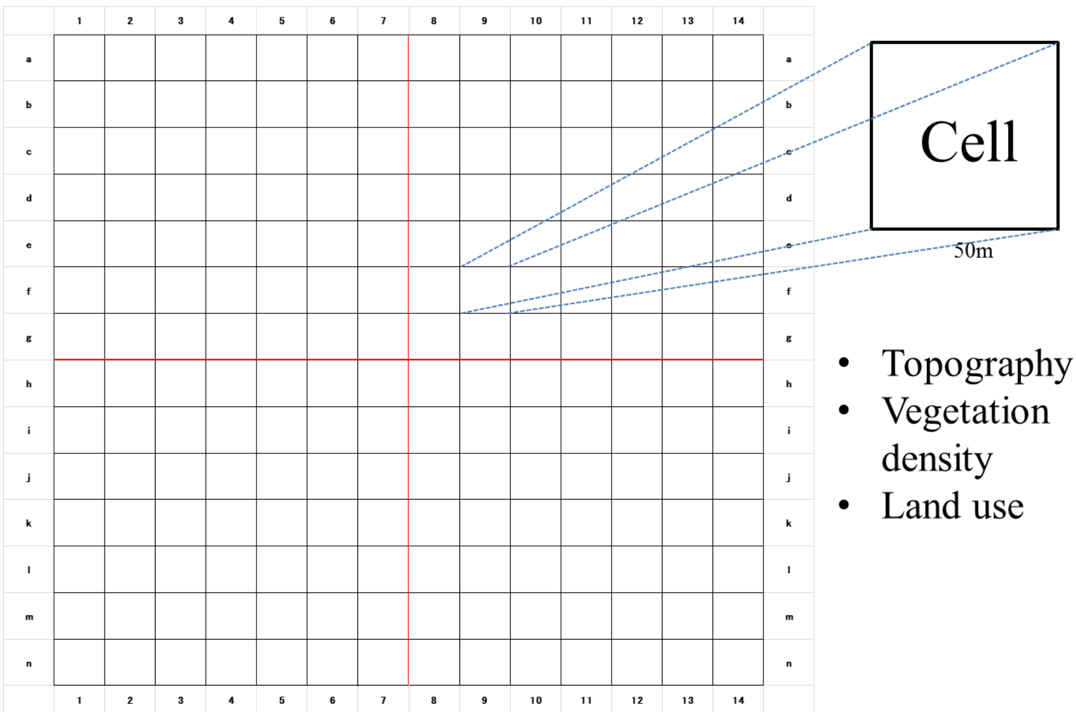

Fig. 3-3 Projected mesh in the research site

Steepness (ΔL) is the difference of elevations between two points. In every cell there are four intersections, so the steepness was calculated choosing the highest value and the lowest value among these four intersection points and then making the subtraction of these two values. Then with the values of steepness, and already knowing the distance between the two points chosen (Δd) the value of slope was calculated (fig. 3-4).

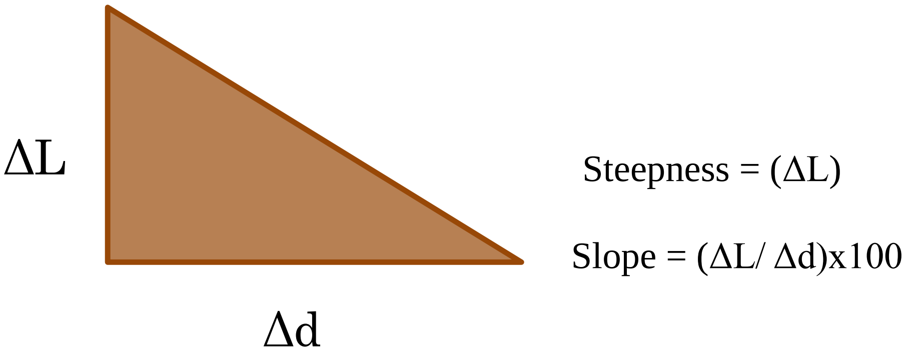

Fig. 3-4 Steepness and slope

Using the mesh projected in the research area, for every cell of 50 meters by 50 meters, a value was assigned, according to the vegetation observed. The values were from 1 to 5, being 1 the highest vegetation density value and 5 the lowest (Fig. 3-5). This was done in order to represent higher risk of land degradation when the vegetation is lower in a given cell.

1	Very Dense	Forest is predominant and dense
2	Dense	Farmlands and few trees in the area
3	Moderate	Farmlands and shrubs
4	Low	There is few vegetation, but mainly it consist of deforested areas or crops in the first stage of growing
5	Very Low	There is almost not vegetation visible in the area Instead there is human settlements or roads

Fig. 3-5 Vegetation density values

For land use assessment, values were assigned also from 1 to 5 (Fig. 3-6) in order to observe if there is a relation between land degradation and the land use. Water was considered since there were some water bodies in the study site.

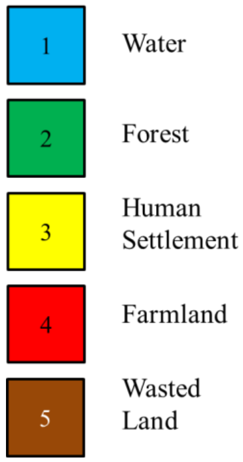

Fig. 3-6 Land use values

3.2.4 Indirect assessment

In order to compare the reliability of land degradation assessment done by the remote method, land degradation assessment was conducted in El Jicaral Village through the field observation in the study area divided into a mesh of 50 meters by 50 meters, the same mesh used in the remote assessment, covering an area of around 0.5 km^2 (Fig. 3-2). The results of land degradation assessment through this field observation were compared with that through the remote assessment carried out, described in the previous section.

In the field assessment, GPS was employed for clarifying the location in every cell. Then detailed observation was conducted based on Morgan Coding System (Morgan, 1995) with rating a value from 0 to 5 at the assigned cell. The Morgan Coding System constituted with several parameters developed for integrated soil erosion appraisal in the field as shown in Table 3-1. After obtaining a value based on Morgan Coding System for each mesh, a comparison was done between the field assessment and the remote assessment done in the previous study. For the comparison, statistical method using a correlation analysis was employed.

Table 3-1 Coding system for soil erosion appraisal in the field

Code	Indicators
0	No exposure of tree roots; no surface crusting; no splash pedestals; over 70% plant cover (ground and canopy)
1	Exposure of tree roots, formation of splash pedestals, soil mounds protected by vegetation, all to depths of 1-10 mm; slight surface crusting; 30-70% plant cover
2	Tree root exposure, splash pedestals and soil mounds to depths of 1-5 cm; crusting of the surface; 30-70% plant cover
3	Tree root exposure, splash pedestals and soil mounds to depths of 5-10 cm; 2-5 mm thickness of surface crust; grass muddied by wash and turned downslope; splays of coarse material due to wash and wind; less than 30% plant cover
4	Tree root exposure, splash pedestals and soil mounds to depths of 5-10 cm; splays of coarse materials; rills up to 1-8 cm deep; bare soil
5	Gullies; rills over 8 cm deep, blow-outs and dunes; bare soil

Detailed observation was carried out in every cell through the use of the above mentioned coding system. It was taken into account the plant cover, exposure of roots in the farmlands as well as the formation of splash pedestals and presence of rills and gullies, due to water or wind erosion.

3.3 Results and discussion

3.3.1 Direct assessment results

As mention above, three variables were taken into account for assessing the land degradation through remote method. The first one is topography, which includes steepness and slope values. Steepness (ΔL) is the difference of elevations between two points. Steepness was calculated choosing the highest value and the lowest value in a given cell, as shown in Fig. 3-7.

16	10	17	25	22	13	4	22	14	17	14	19	22	18
13	12	18	24	23	15	8	20	16	21	9	11	17	14
10	15	19	17	25	19	15	13	15	21	13	12	14	12
11	16	18	18	22	20	18	22	30	34	21	12	11	11
14	17	18	17	21	18	18	17	15	19	11	11	11	9
16	16	16	15	19	18	18	11	11	22	23	16	10	9
18	16	15	14	16	16	18	13	18	14	14	11	16	14
18	19	20	19	18	17	14	13	14	10	9	5	13	17
18	25	26	25	18	14	12	13	13	12	12	2	10	21
12	19	22	23	17	13	9	11	9	7	17	7	5	16
12	16	21	22	15	11	8	10	8	8	18	8	3	16
13	16	21	21	14	10	9	11	8	9	20	14	9	18
16	16	21	21	10	6	7	9	8	10	18	16	12	19
17	18	22	22	9	4	8	9	8	10	17	16	14	19

1-7 8-14 15-21 22-28 29-35

Meters

Fig. 3-7 Steepness values

Then with the values of steepness, and already knowing the distance between the two points chosen (Δd) the value of slope was calculated, as shown in Fig. 3-8. As can be observed, the darker the cell, the higher is the value of steepness and slope.

22.70	14.18	24.11	35.46	31.21	18.44	8.00	31.21	19.86	24.11	28.00	26.95	31.21	25.53
18.44	17.02	25.53	34.04	32.62	21.28	11.35	28.37	22.70	29.79	12.77	22.00	24.11	19.86
20.00	21.28	26.95	24.11	35.46	26.95	21.28	26.00	21.28	29.79	26.00	17.02	19.86	17.02
15.60	22.70	25.53	25.53	31.21	28.37	25.53	31.21	42.55	48.23	29.79	17.02	22.00	15.60
19.86	24.11	25.53	24.11	29.79	25.53	25.53	24.11	21.28	26.95	15.60	15.60	15.60	12.77
22.70	22.70	22.70	21.28	26.95	25.53	25.53	15.60	22.00	31.21	32.62	22.70	20.00	18.00
25.53	22.70	21.28	19.86	22.70	22.70	25.53	18.44	25.53	19.86	19.86	22.00	22.70	19.86
25.53	26.95	28.37	26.95	25.53	24.11	19.86	18.44	19.86	14.18	18.00	10.00	18.44	24.11
36.00	35.46	36.88	35.46	25.53	19.86	17.02	18.44	18.44	24.00	17.02	4.00	14.18	29.79
17.02	26.95	31.21	32.62	24.11	18.44	12.77	15.60	12.77	9.93	24.11	9.93	10.00	22.70
17.02	22.70	29.79	31.21	21.28	15.60	11.35	14.18	11.35	11.35	25.53	11.35	4.26	22.70
18.44	22.70	29.79	29.79	19.86	14.18	18.00	15.60	16.00	12.77	28.37	19.86	12.77	25.53
22.70	22.70	29.79	29.79	14.18	8.51	9.93	12.77	16.00	14.18	25.53	22.70	17.02	26.95
24.11	25.53	31.21	31.21	12.77	5.67	11.35	12.77	11.35	14.18	24.11	22.70	19.86	26.95

1-10 11-20 21-30 31-40 41-50

Percentage (%)

Fig. 3-8 Slope values

The average slope value for the mesh was 21.9%. The maximum value was 48.3% and the minimum was 4%.

Using the mesh projected in the research area, for every cell of 50 meters by 50 meters, a value was assigned, according to the density of vegetation observed. The values were from 1 to 5, being 1 the highest vegetation density value and 5 the lowest (Fig. 3-9).

5	3	4	3	2	5	4	4	3	5	3	4	2	5
4	3	2	1	3	5	5	5	4	4	5	5	3	4
4	2	3	3	4	4	3	4	3	1	2	4	3	3
4	3	3	1	4	4	3	5	4	3	2	3	2	2
4	2	5	5	5	2	4	5	5	4	5	5	3	4
2	1	5	5	5	4	5	5	5	4	3	5	4	2
1	4	5	5	4	5	5	5	4	5	4	3	4	2
2	5	4	4	4	5	5	4	5	3	4	4	4	1
4	3	4	5	5	4	5	3	5	4	4	3	4	3
2	5	5	5	5	5	3	3	4	5	4	3	5	5
4	4	3	3	3	4	4	5	4	3	2	4	5	3
2	2	3	3	3	5	4	5	5	4	3	4	5	3
3	2	3	3	4	4	4	4	3	4	4	4	5	5
3	4	4	4	4	4	3	3	3	5	5	4	5	5

Very dense	Dense	Moderate	Low	Very low
1	2	3	4	5

Fig. 3-9 Vegetation density values

In the community of El Jicaral it was observed that most of the research area presented Very low and Low vegetation density.

The classification of land use was also carried out in the research area (Fig. 3-10). As in vegetation density, values for land use were assigned to every cell according to direct observation of the digital map.

4	2	4	2	2	4	4	4	2	4	4	4	2	3
2	4	2	2	2	5	5	4	4	4	5	5	2	3
2	2	2	2	4	4	5	5	2	2	2	5	2	4
2	2	4	2	4	4	4	3	3	2	2	5	2	4
4	2	3	4	4	4	3	3	3	3	4	5	4	4
2	2	3	3	3	4	3	3	3	3	4	4	4	4
2	2	4	4	4	3	4	2	4	4	4	4	2	2
2	4	4	4	4	3	4	4	4	4	3	4	4	2
4	2	4	4	4	3	4	4	4	4	4	4	5	4
2	4	4	4	4	4	3	4	4	4	4	5	5	5
4	4	4	4	4	4	4	4	4	4	2	3	3	2
4	4	4	4	2	4	4	4	4	2	4	4	4	4
4	4	4	4	2	4	4	3	2	4	4	4	4	4
4	4	4	4	4	4	4	3	4	4	4	4	4	4

Water	Forest	Human set	Farmland	Wasted land
1	2	3	4	5

Fig. 3-10 Land use values

Most of the area land use corresponds to farming activities, despite the steepness of the relief.

Through the average of values from vegetation density mesh, land use mesh and the slope mesh, was conducted, for determining the level of land degradation in the study site (Fig. 3-11).

$$\text{Land degradation} = \frac{\text{Topography} + \text{Vegetation} + \text{Land use}}{3}$$

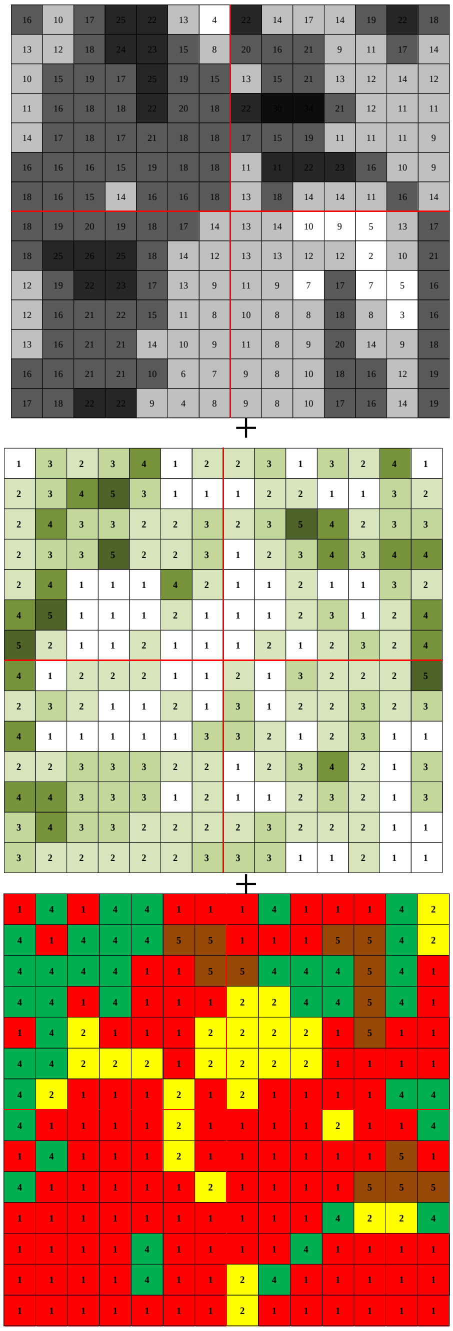

Fig. 3-11 Land degradation calculation

The map of land degradation in El Jicaral Village, Mixteca Region, was obtained through the average of three observed variables by remote assessment (Fig. 3-12).

4	2	4	3	3	4	3	4	2	4	3	4	3	4
3	3	2	2	3	4	4	4	4	4	4	4	3	3
3	2	3	3	4	4	4	4	3	2	2	4	2	3
3	3	3	2	4	4	3	4	4	3	2	3	2	3
3	2	4	4	4	3	3	4	4	3	4	4	3	3
2	2	4	4	4	4	4	3	4	3	4	4	3	3
2	3	4	4	4	4	4	3	4	4	3	3	3	2
2	4	4	4	4	4	4	3	4	3	3	3	3	2
4	3	4	4	4	3	4	3	4	4	3	3	4	3
2	4	4	4	4	4	3	3	3	3	4	3	4	4
3	4	3	4	3	3	3	4	3	3	2	3	3	3
3	3	3	3	2	4	3	4	4	3	3	3	4	3
3	3	3	3	3	3	3	3	2	3	4	4	4	4
3	4	4	4	3	3	3	3	3	4	4	4	4	4

Very low	Low	Moderate	High	Very high
1	2	3	4	5

Fig. 3-12 Land degradation by remote assessment

Through the land degradation assessment, it was found that almost 90% of the cells (176) presented moderate and high land degradation.

3.3.2 Indirect assessment results

Field observation, based on the coding system for erosion appraisal, was conducted in the study site. The observation was supported by the use of GPS, in order to make the evaluation inside every cell (Fig. 3-13).

Fig. 3-13 Land degradation assessment in the field

The results of the field observation were summarized in the map called “field assessment” (Fig. 3-14).

2	2		4	4	2	1	4	4	5	3	5	4	5
2	2	3	4	4	5	2	4	4	5	2	5	3	2
2	3	3	3	5	5	3	4	4	3	3	2	2	2
2	3	3	3	5	5	3	5	5		3	4	4	4
2	3	5	5	3	3	3	5	5	5	2	4	4	4
3	3	5	5	3	3	3	2	5	5	4	4	4	4
3	3	3	5	3	3	3	2	5	2	2	4	4	4
3	3	3	5	5	5	2	2	2	5	2	2	4	4
3	4	3	5	5	4	4	4	4	5	2	1	2	3
2	3	3	3	3	4	4	4	4	1	5	1	2	5
2	3	3	4	3	4	4	4	4	2	3	2	1	3
2	3	3	3	2	3	4	4	3	2	3	2	2	3
3	3	3	3	2	1	4	4	2	2	5	5	2	5
3	5	5	5	2	1	4	4	2	2	5	5	5	5

Very low	**Low**	**Moderate**	**High**	**Very high**
1	2	3	4	5

Fig. 3-14 Land degradation by field assessment

In every cell it has been assigned a value based on the coding system for soil erosion appraisal, being 1 to the cells where observed land degradation was very low, and 5 to the cells where land degradation was very high. Through the land degradation assessment by field observation, it was found that 75% of the cells (150) presented moderate and high land degradation.

After obtaining the land degradation maps with both methods (“field assessment” and “remote assessment”), a correlation analysis by simple regression analysis with a confidence interval at 99% significant level was carried out for evaluating the correlation between both assessments (Fig. 3-15).

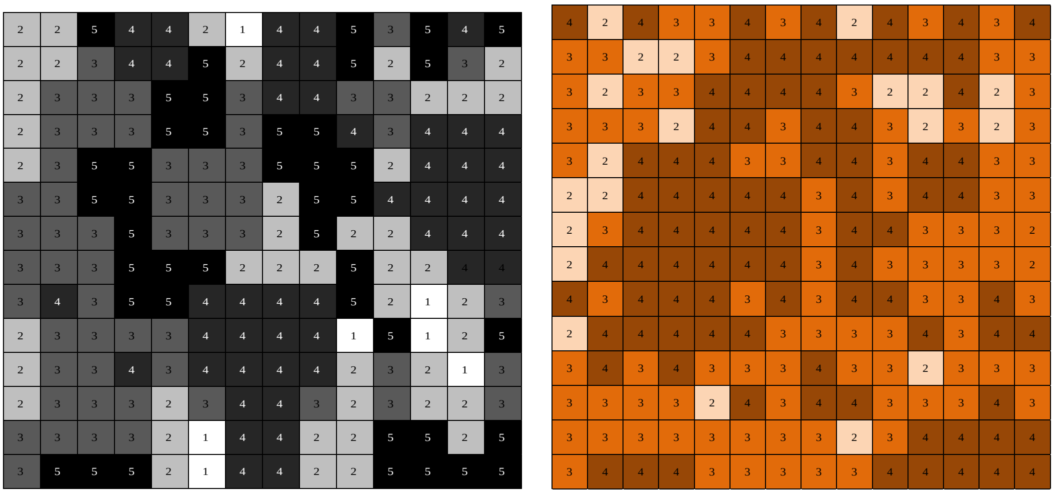

Fig. 3-15 Comparison between land degradation assessments (remote and field methods)

To carry out the correlation analysis, “x” axis was assigned to field assessment values and “y” axis was assigned to remote assessment values. Every cell on field assessment corresponded to the same cell position on remote assessment

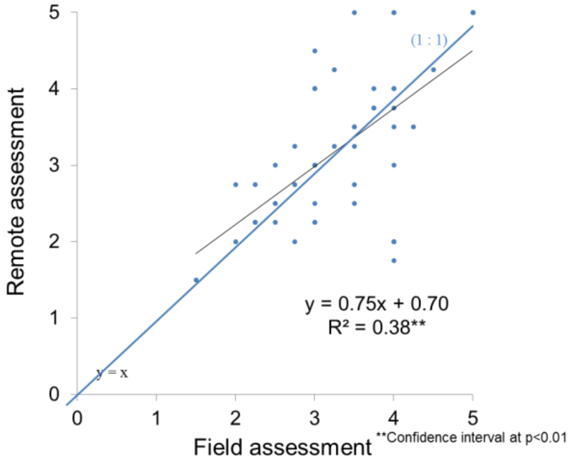

Fig. 3-16 Correlation between land degradation assessments by simple regression analysis

The results of statistical analysis indicated that there was the correlation between both assessments at 99% significant level (Fig. 3-16). It means that the remote assessment based on several variables, such as steepness, slope, vegetation density and land use may be enough for assessing the land degradation in a small scale. This technique is useful when the land degradation assessment is necessary in small areas where it is not possible to conduct an on-site assessment.

A multiregression analysis was also conducted to observe the possible relation of every variable of remote assessment (slope, vegetation and land use) in land degradation done by field assessment (Table 3-2).

Table 3-2 Correlation between three variables observed (Slope, vegetation and land use) and on field assessment results

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	,032	,436		,074	,941	-,827	,892
X_1	Slope_perc	,860	,094	,559	9,181	,000	,675	1,045
X_2	Vegetation_density	,164	,072	,152	2,262	,025	,021	,306
X_3	Land_use	,129	,087	,101	1,487	,139	-,042	,300

Y a. Dependent Variable: On_Field_assess

$R^2=0.305$

3.4 Conclusions of this chapter

In order to have a better understanding of the research site, land degradation assessments done by remote method (through the factors of topography, vegetation cover and land use) and field method was conducted. Through the results of both methods, it was clear that land degradation is a current problem in El Jicaral Village, Mixteca Region, since in the remote assessment, almost 90% of the cells (50m x 50m) presented moderate to high land degradation levels, and in the field assessment, 75% of the cell presented the same condition.

Furthermore, through a simple regression analysis, it was found that both methods are correlated. For this reason, land degradation assessment method done by remote method may be useful when land degradation assessment is necessary in small areas and it is not possible to conduct it through field method.

So, it is necessary to implement conservation strategies since it is known that El Jicaral Village, Mixteca Region is under land degradation process, taking into account that precipitation quantity is elevated and that farming practices are mainly conducted on hillslides, causing high levels of soil erosion.

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Chapter 4

Developing soil conservation strategy for Mixteca Region

4.1 Introduction of this chapter

4.1.1 Background

Several studies point that the application of animal wastes could be beneficial for soil conservation, especially in degraded soils and soils being susceptible to erosion (Pinamonti and Zorzi, 1996). The use of compost or mulch blankets as a soil cover could help control soil erosion and provide sustainable alternatives to disposal for many biomass resources (Faucette et al. (2009)).

Oaxaca State where Mixteca Region located in, is the main state by number of goats (around 952,000 goats), which represents 10.9% of the national production (SAGARPA, 2008). Moreover, according to García Hernández (1996), the majority of units of production are extensive, where goat waste is left in the croplands (Fig. 4-1). For this reason, animal waste was used as a resource for protecting soils against soil erosion in the present research.

Fig. 4-1 Goat overgrazing in Mixteca Region

4.1.2 Objectives

The objective of this study is to measure the effectiveness of animal waste application for mitigation of soil loss by raindrop and surface runoff and to discuss effective conservation measures with animal waste slurry application based on the amounts of soil and nitrogen component losses.

4.2 Research methods

4.2.1 Soil samples

For this experiment soil samples from Mixteca Region were used (Fig.4-2). Physical and chemical properties are summarized in Table 4-1.

Fig. 4-2 Soil samples from Mixteca Region

For this experiment, horse waste (from now on referred as animal waste) was used as animal waste, obtained from the horsemanship club of Tokyo University of Agriculture. Analysis of total nitrogen, total phosphorus and coliform bacteria was conducted (Table 4-1).

Table 4-1 Physical and chemical properties of soil

Soil	Specific gravity	Particle size distribution, %					Soil texture	pH	EC (μ S/cm)	IL (%)
		Gravel	Coarse sand	Fine sand	Silt	Clay				
Leptosol	2.59	5.4	25.6	29.9	19.5	19.6	SCL	5.81	15.5	25.76

Table 4-2 Properties of soil and animal waste

Sample	T-N (mg/kg)	T-P (mg/kg)	Coliform bacteria (cfu/g)
Soil	920.20	124.28	0
Slurry	6744.19	13466.06	3.2×10^7

The preparation of horse waste slurry was carried out through the sieving of the horse waste through a sieve of 212 μm to eliminate straw residues. Deionized water was used for this process. Since the horse waste slurry had a high water content after this process, and for reducing the amount of coliform bacteria (Saito and Mihara, 2010), slurry was dried up during four weeks (Fig. 4-3).

Fig. 4-3 Animal waste slurry

For measuring the effectiveness of animal waste slurry, two experiments were carried out. The first experiment was splash erosion conducted with the purpose to measure the ability of animal waste slurry added soil to decrease erosion by kinetic energy of raindrops. The second experiment was surface runoff with the purpose to measure the ability of animal waste slurry added soil to decrease surface erosion. For both experiments, two treatments were applied.

4.2.2 Splash erosion experiment

For this experiment stainless steel cores were used, which are averagely 1.0 cm long with an internal diameter of 1.1 cm. They were filled with soil under a dry density of 1.0 ±0.1 g/cm3 to keep a similar compaction between samples. Constant water pressure was controlled by means of a Mariotte's bottle (Fig. 4-4).

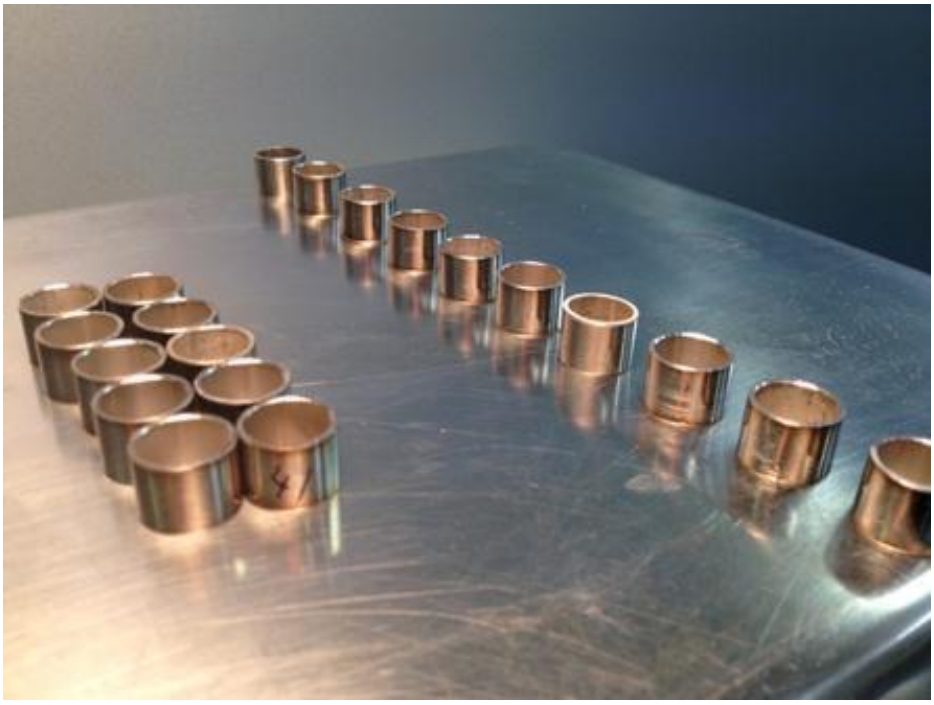


Fig. 4-4 Stainless cores for raindrop experiment

A needle from the DIK-6000 rainfall simulator equipment was used for this experiment. The kinetic energy of raindrops was 2.36 x 10-5J, calculated based on the equation Ek= ½ m v^2 (Fig. 4-5).

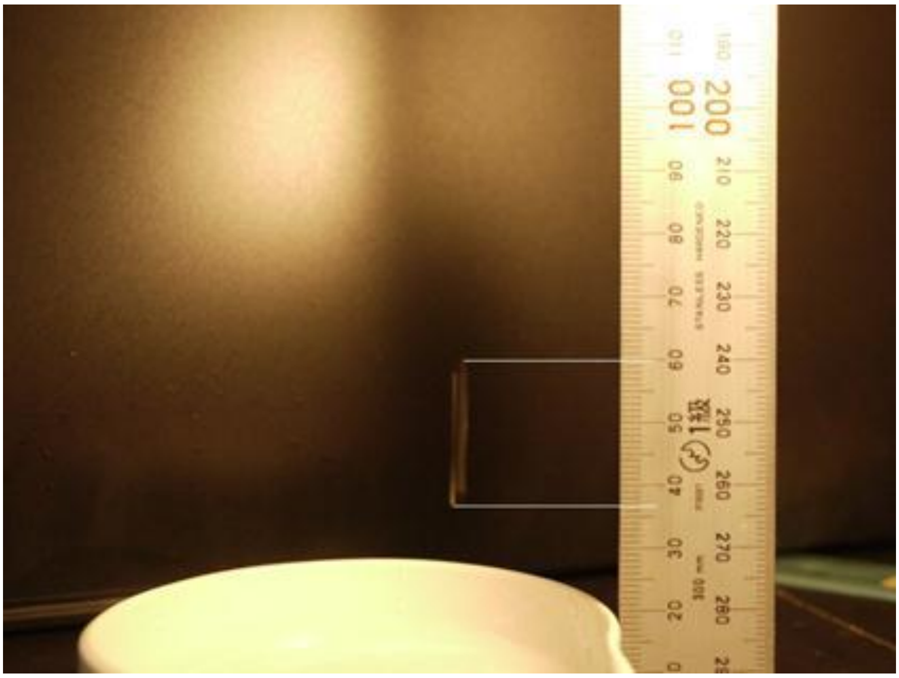


Fig. 4-5 Raindrop velocity for calculating kinetic energy

For both experiments, two treatments were defined. In these two treatments, the same dried mass ratio of soil : slurry was kept at 66 : 1. The first treatment consisted of incorporating the slurry into the soil by mixing both materials and placing the mixture into the stainless cores. This treatment was called “incorporated with soil”. The second treatment consisted of placing the soil into the stainless core, compacted under the above-mentioned dry density, and then covering completely its surface with animal waste slurry. This treatment was called “Formed bio-crust” (Fig. 4-6).

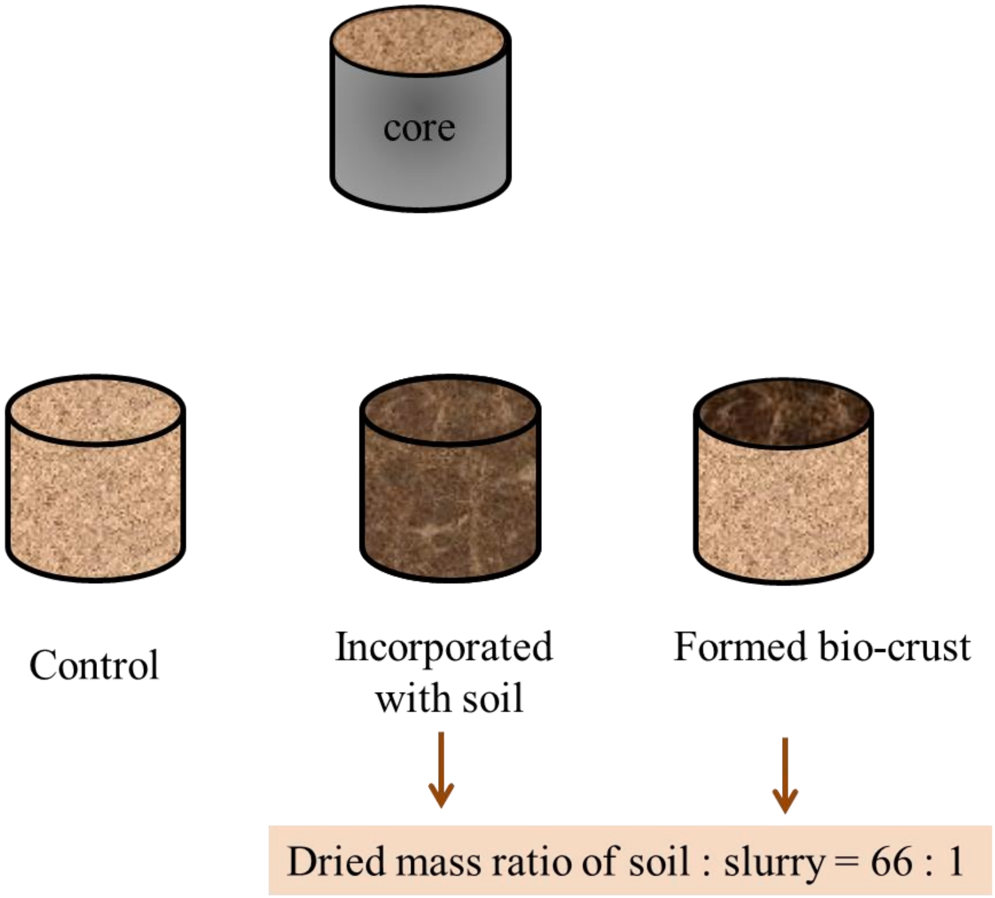


Fig. 4-6 Treatments for splash erosion experiment

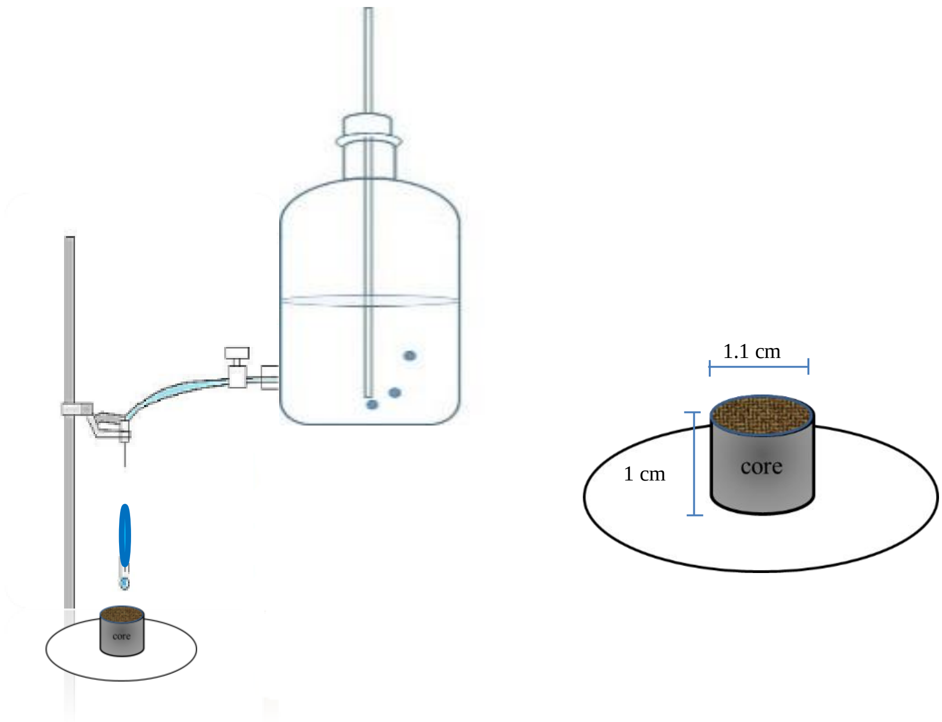


Fig. 4-7 Splash erosion model

For each treatment, 10 cores were used. 50 drops of artificial rain were dripped into every stainless core (Fig 4-7). Then, the remaining mass of soil inside the core was calculated (Eq. 1).

$$\left(1 - \frac{Remained\ soil\ mass\ in\ the\ metal\ core}{Initial\ soil\ mass\ in\ the\ metal\ core}\right) \times 100 \quad (1)$$

4.2.3 Surface runoff experiment

In this experiment, a triangular-section plot was used. The length was 91.0 cm and the triangular section had a height of 1.4 cm and a base of 3.1 cm (Fig. 4-8). Similar to the previous experiment, the compaction was kept under a dry density of 1.0 ±0.1 g/cm^3. And for this experiment the constant supply of deionized water (1.2 to 1.3 cm3/s) was done by the use of a Mariotte's bottle during 60 minutes. The slope of this plot was determined as 12 degrees for all the samples.

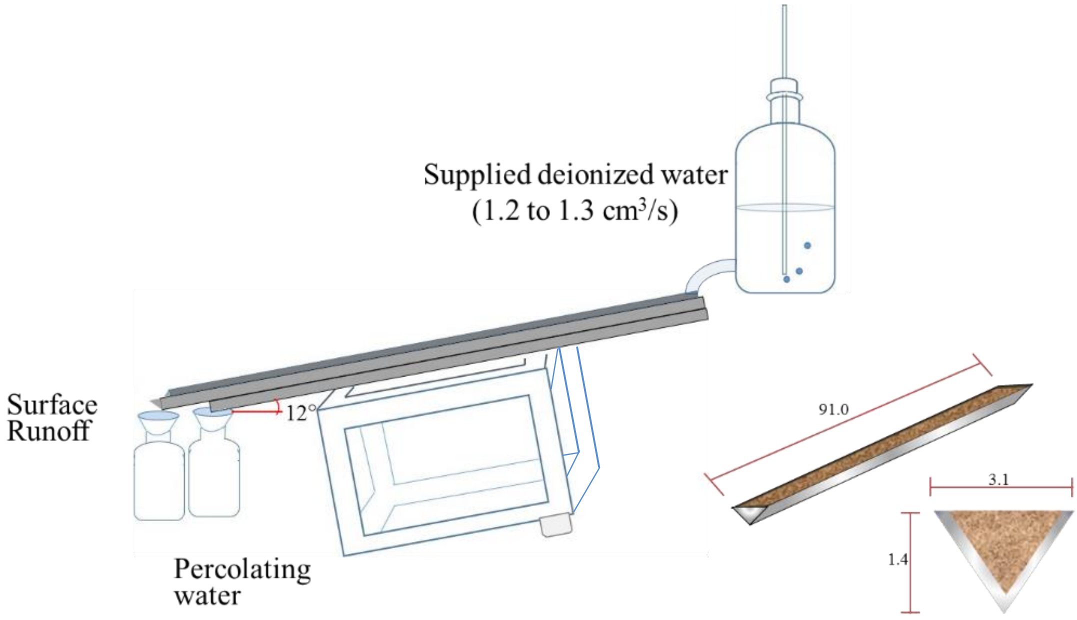


Fig. 4-8 Surface runoff plot model

The percolation water and runoff water was collected every 10 minutes for analyzing the amount of soil loss and the contents of total nitrogen.

Similar to the previous experiment, two treatments were defined for the surface runoff experiment (Fig 4-9). The first treatment consisted of incorporating the slurry into the soil by mixing both materials and placing the mixture into the plots (Incorporated with soil). The second treatment consisted of placing the soil into the plot and then covering completely its surface with animal waste slurry (Formed bio-crust). In both treatments, dried mass ratio of soil : slurry was kept at 66 : 1.

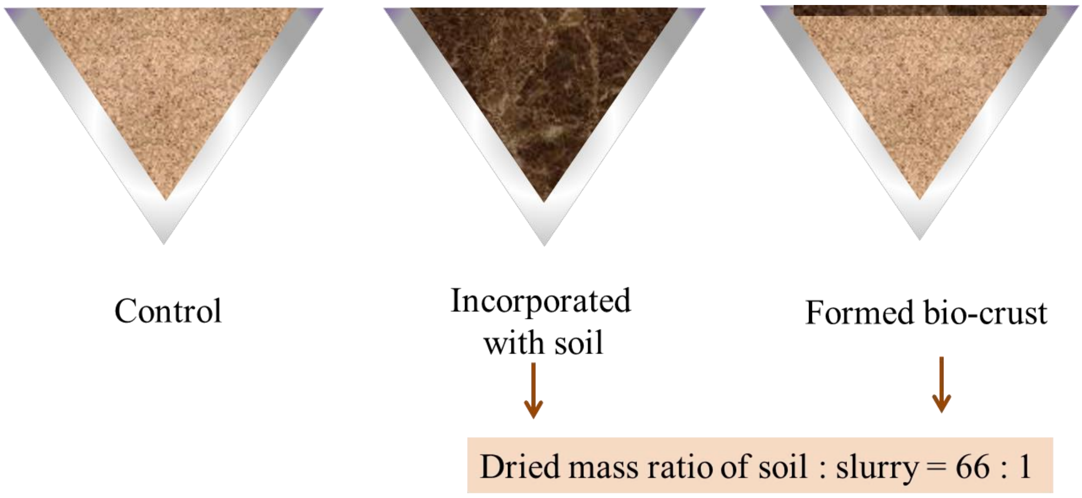


Fig. 4-9 Treatments for surface runoff experiment

4.3 Results and discussion

4.3.1 Splash erosion experiment

For every treatment ten stainless cores were used. After the 50 drops were applied, the samples were dried and then the weight inside every can was measured. Figure 4-10 shows the cores after the experiment. As can be observed, the cores in control showed a higher dispersion of soil particles.

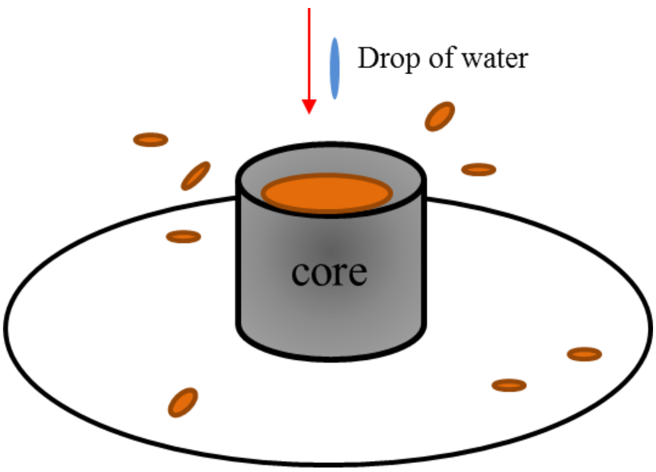
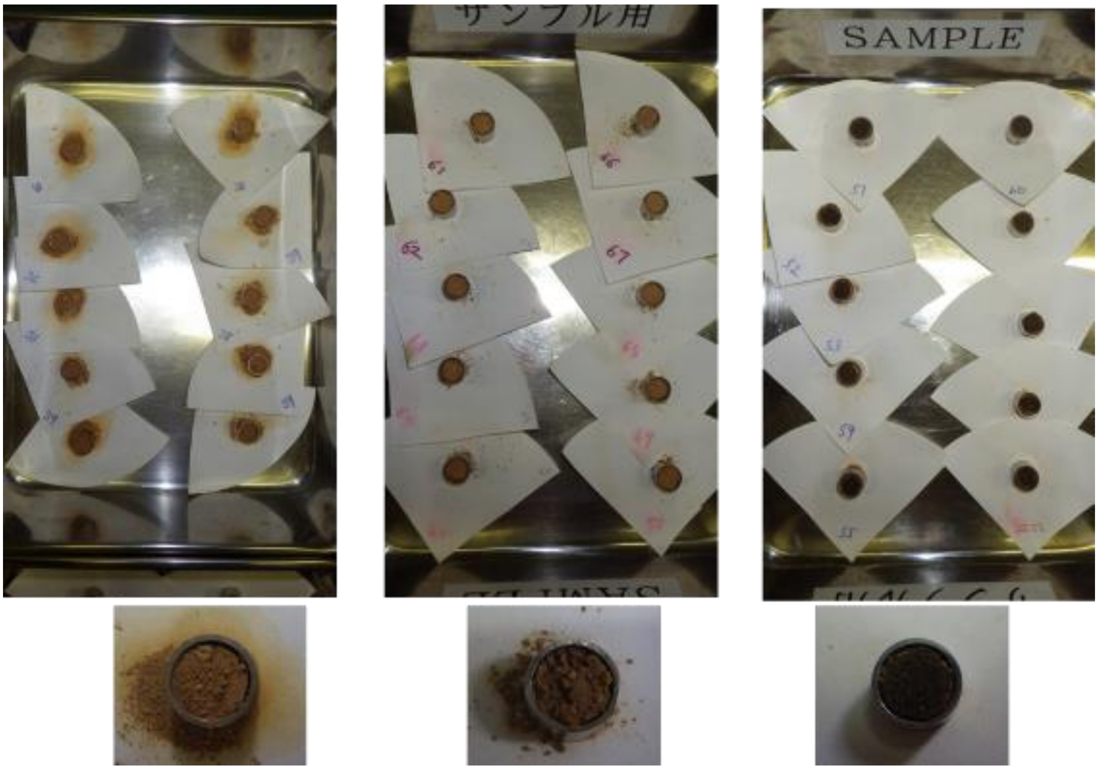


Fig. 4-10 Raindrop impact on soil samples



Control Incorporated with soil Formed bio-crust

Fig. 4-11 Raindrop experiment results

After the 50 drops were applied into the stainless cores, the soil loss rate was calculated. As can be observed in Fig. 4-11, control samples showed a higher dispersion of soil particles caused by the impact of raindrops compared to the treatments where animal waste slurry was added into the soil.

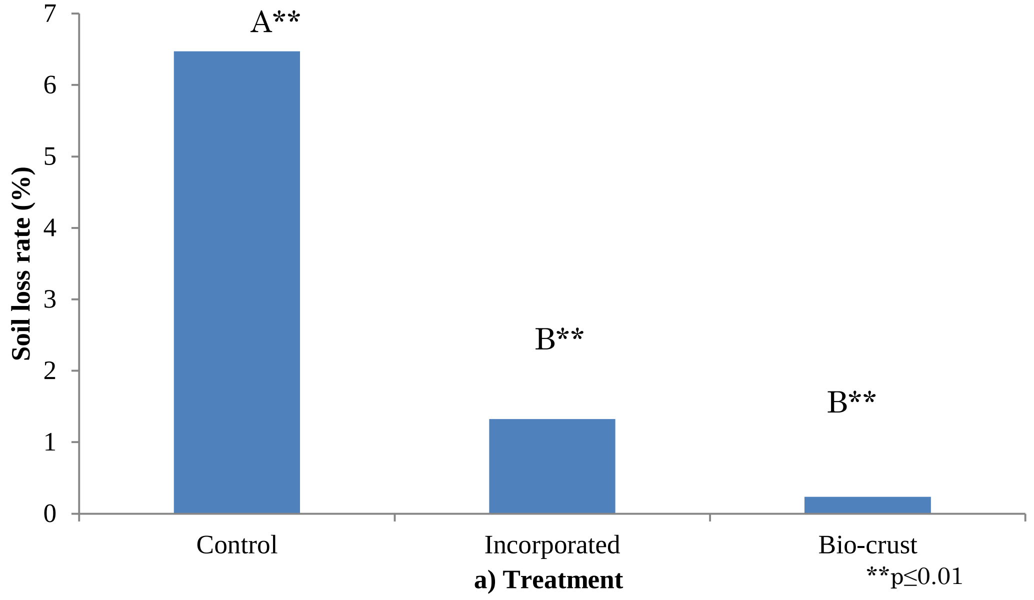
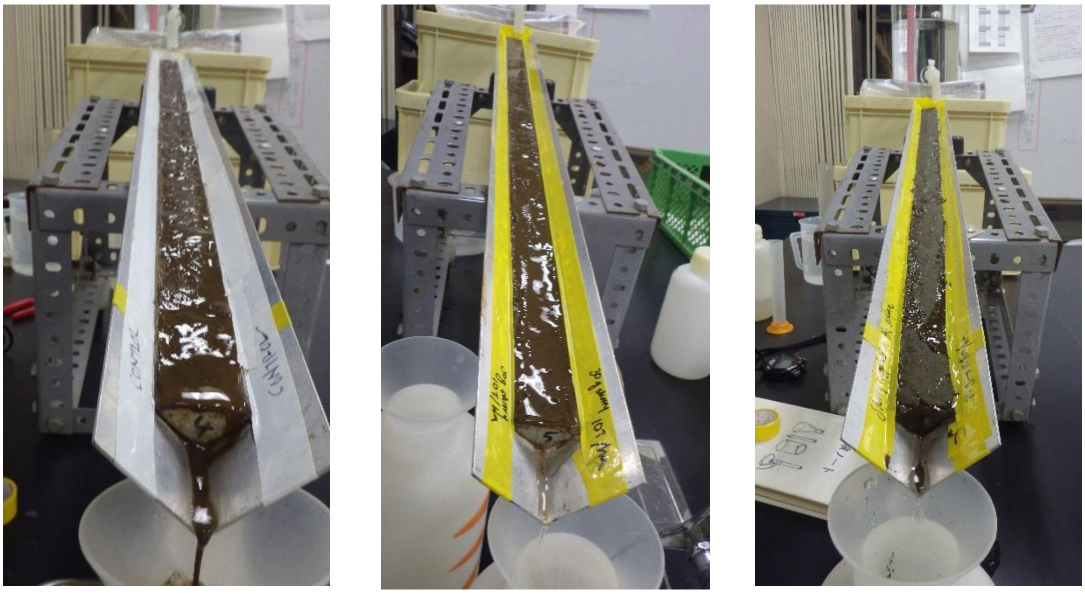


Fig. 4-12 Soil loss rate between treatments

The average soil loss in control was 6.4%. The incorporation of animal waste slurry into the soil reduced the soil loss to 1.3%, and the application of slurry into the surface reduced the soil loss until a 0.2% (Fig 4-12). It was found that there was a significant difference between the control samples and the treatment with animal waste slurry. However, there was no significant difference between treatments. This can suggest that either way of applying animal waste slurry, being incorporated into the soil as a mixture or just applied on the surface, is effective for reducing soil loss caused by the raindrop energy.

4.3.2 Surface runoff experiment

The collection of runoff samples was carried out every ten minutes during one hour in the surface runoff experiment as shown in Fig. 4-13.



Control Incorporated with soil Formed bio-crust

Fig. 4-13 Runoff experiment plots

Figure 4-14 shows the results of the discharge collect in the three plots. As can be observed, there is no significant difference between treatments.

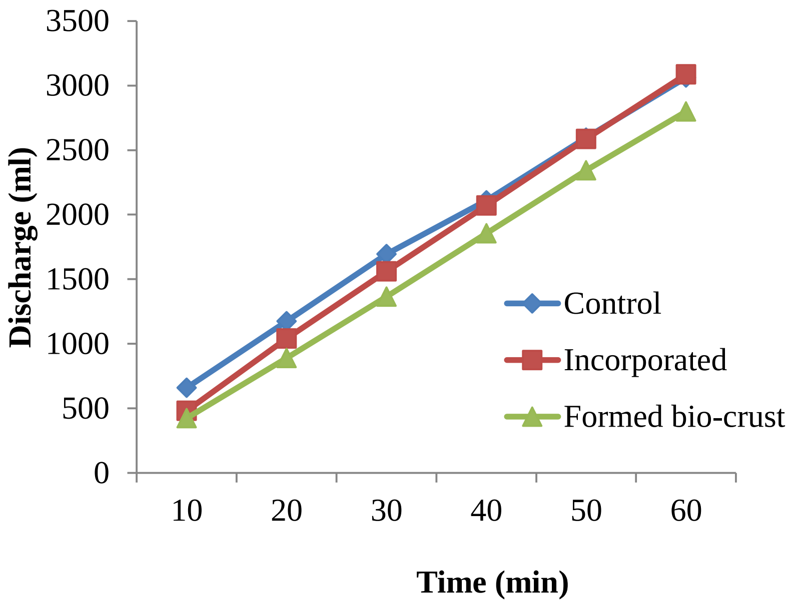
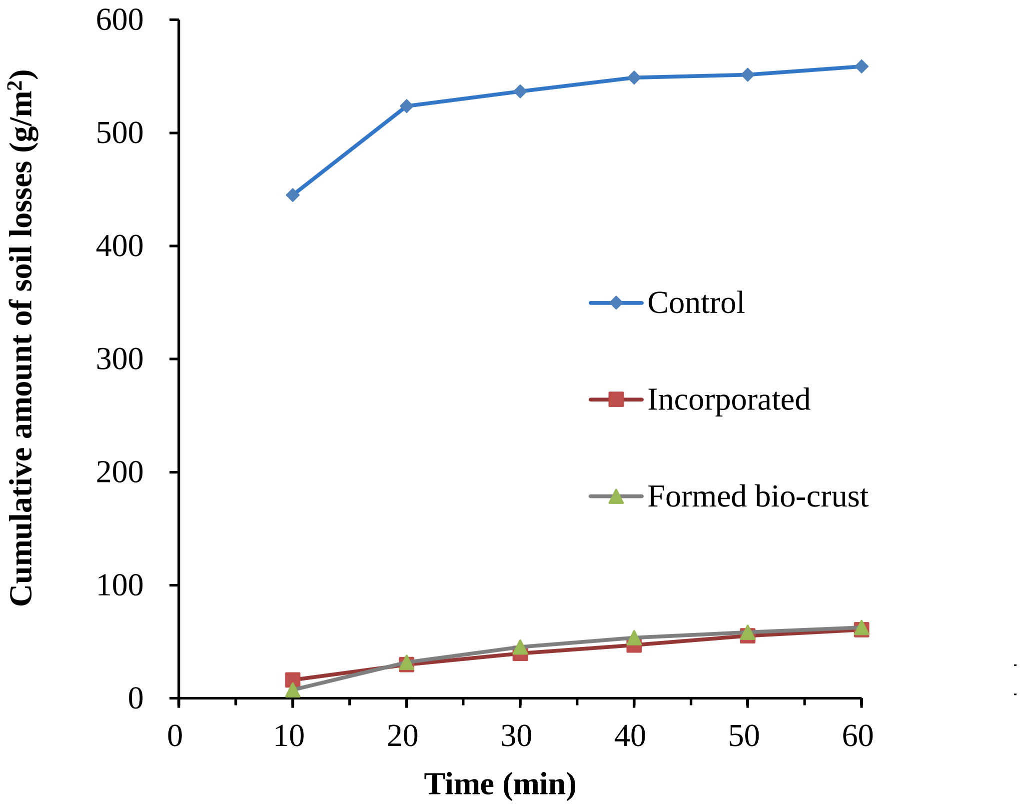


Fig. 4-14 Surface discharge

It is considered that the addition of animal waste slurry did not change drastically the infiltration properties of the soil, since the discharge amount was similar.

After collecting the suspended water samples, the amount of soil losses was measured by the oven drying method. Data was analyzed through a Fischer's T-statistical analysis. The results showed that the plots where animal waste slurry was applied had lower amounts of soil losses than that of control plot, as shown in Fig. 4-15. It was indicated that the addition of animal waste slurry mitigates soil losses (p<0.01).



Significant difference at $p \leq 0.01$

Fig. 4-15 Cumulative amount of soil losses

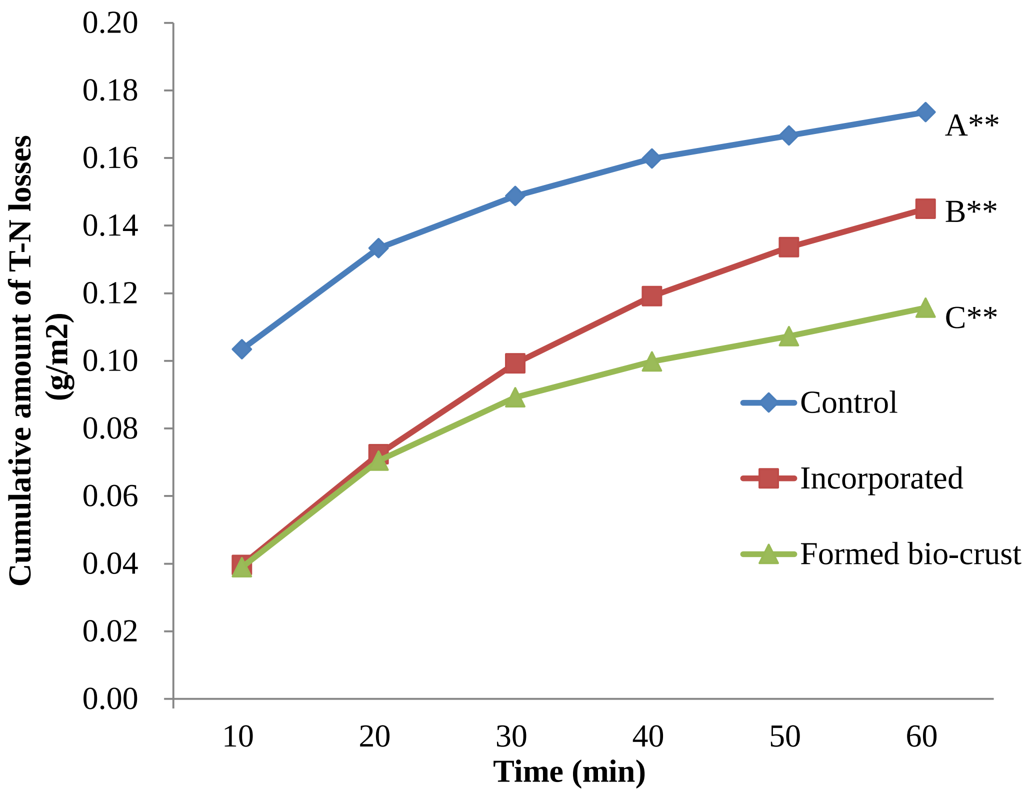


Fig. 4-16 Total nitrogen losses

Concerning the amount of nitrogen, suspended water samples collected from surface discharge were analyzed for total nitrogen (T-N). Figure 4-16 shows that control plot released a higher amount of nitrogen, compared to treatments where animal waste slurry has been added. So even if animal waste slurry contains nitrogen, when added to the soil, there was a fewer release of nitrogen into the runoff water samples than that of control sample where animal waste slurry was not added.

It is considered that between the treatments, the addition of animal waste slurry incorporated to the soil as well as applied into the surface to form a bio-crust significantly reduced the amount of soil losses compared to the control plot, in both the raindrop experiment and the runoff model. This could be due to the cohesion force produced by adding organic materials of animal waste slurry into the soil particles being beyond the kinetic energy of raindrops or shearing force of surface runoff.

4.4 Conclusions of this chapter

Adding animal waste slurry into the soil, incorporated or applied on the surface, reduced splash erosion rate significantly in leptosol of Mixteca Region, as well as soil and nitrogen loss in the surface runoff. This is because the addition of organic matter into the soil in the form of slurry improved the cohesion between soil particles, making it stronger against the kinetic energy of raindrops or the shearing forces of surface runoff.

Nevertheless, future research has to be conducted in order to ensure that the addition of slurry is not harmful for the environment. Furthermore, from a view point of nitrogen loss in the runoff experiment, formed bio-crust may be recommendable to apply as a conservation strategy above the incorporation of slurry into the soil.

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Chapter 5

Treatment of slurry for elimination of *E.coli*

5.1 Introduction of this chapter

5.1.1 Background

The application of residues in farmland is important for soil conservation as well as for management of residues disposal, because it is a valuable source of nutrients that can enhance soil fertility and in some cases to improve soil properties, when increasing the amount of organic matter in the soil (Navas, 1998).

However, there is the risk of pollution of certain residues increase the concern regarding environmental problems (Breuer, 1996)

One of these pollutants is *E.coli*, which is a bacterium of the Escherichia genus, gram-negative, and some strains can cause food poisoning (Vogt, 2005). In immature compost, as well as in manure, there is survival of this bacteria (Abu-Ashour, 2000).

For this reason it is advisable to implement a treatment of residues when necessary, such as air drying process that is an effective method for sterilizing *E.coli* in manure (Saito et. al, 2010)

5.1.2 Objectives

To compare three types of animal waste and to evaluate the effectiveness of air drying for sterilizing animal waste

5.2 Research methods

5.2.1 Samples

Horse dung collected from the Horsemanship club of Tokyo University of Agriculture was used for measuring the amount of *E.coli* and coliform bacteria as well as the slurry used in the experiments of Chapter 4

Since the main source in the study site is goat dung, three different kind of goat samples were analyzed for total nitrogen and total phosphorus (Fig.). Goat dung samples were provided by the Department of Bioproduction of Tokyo University of Agriculture, and are as follows:

(1) Dried fecal sample of female Tokara goat fed with Italian ryegrass straw, collected during 23rd-30th of June, 2015; (2) Dried fecal sample of male Tokara goat fed with Italian ryegrass straw. Sampling period was 23rd to 30th of june, 2015 and (3) Fresh female goat's feces, Dec. 15, 2015. For the last sample *E.coli* and coliform bacteria analysis was also conducted.

5.2.2 Total phosphorus and total nitrogen

For analyzing the amount of total nitrogen (T-N) and total phosphorus (T-P), the spectrometric method described in chapter 4 was applied.

5.2.3 Measurement of microorganisms

The amount of microorganisms (*E.coli*, coliform bacteria and general bacteria) was measure using the XM-G agar as a cultivation medium. 10 g of animal waste sample were added into a 90 ml solution, then stirred during 10 minutes. Inside the clean bench, from this solution 1 ml was taken and poured into a test tube previously filled with 9 ml of NaCl solution, it was stirred and again 1 ml was taken and poured into the next test tube, and so on several times (Fig. 5-1).

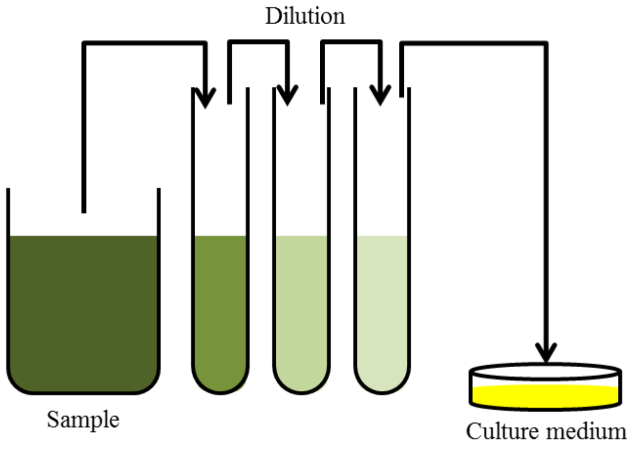

Fig. 5-1 Dilution of sample for counting microorganisms

After dilution was carried out, from every test tube 0.1 ml of solution was taken an spread throughout the cultivation medium with the help of a glass bacteria spreader (Fig. 5-2). For cultivation, the petri boxes containing the diluted samples were kept in an incubator at 37ºC during 24 hours, and then the amount of Colony formed units (CFU) was counted.

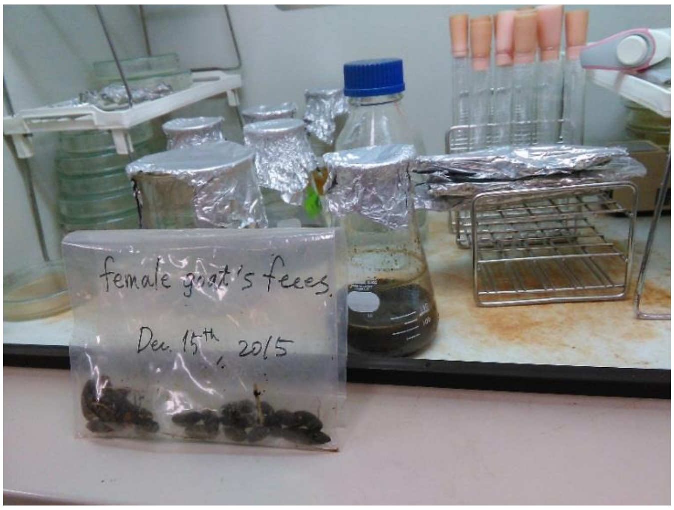

Fig. 5-2 Dilution method for counting microorganisms

5.2.4 Air drying method

Previous studies has shown that air drying method is effective for sterilizing cow dung (Ishikawa, 2013). Air drying experiment was conducted in the artificial rainfall experimental field during 28 days, in July 2015. Stirring was conducted for supplying oxygen to the animal waste slurry prepared from horse dung.

5.3 Results and discussion

5.3.1 Total nitrogen and phosphorus in animal waste samples

Analysis of three different types of goat dung was conducted (Fig. 5-3), and compared with the results of horse dung and cow dung.

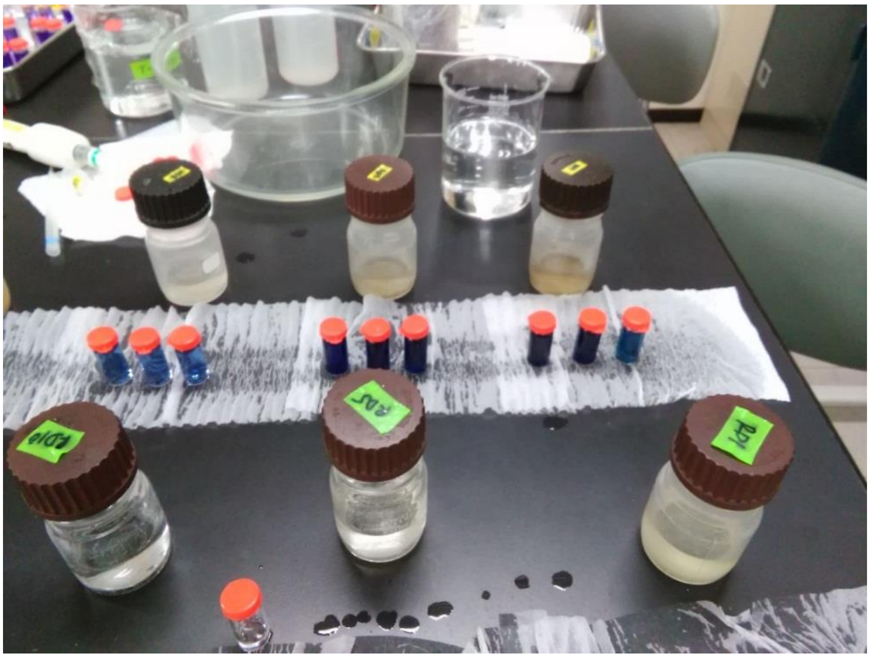

Fig. 5-3 Total nitrogen and total phosphorus analyses

As shown in Table 5-1, there was found that in all three goat dung samples nitrogen and phosphorus was found. In fresh dung sample, total nitrogen was 5,130 mg/kg and total phosphorus was 5,740 mg/kg. It is possible that in dried samples the amount of nitrogen was higher due to contamination with urine when collecting the samples. However, the amount of total phosphorus did not vary considerably in three samples.

Table 5-1 Amount of total nitrogen and total phosphorus for goat dung samples

Sample	T-N (mg/kg)	T-P (mg/kg)
Dried dung (female)	8320.00	4240.00
Dried dung (male)	9990.00	5440.00
Fresh dung (female)	5130.00	5740.00

On the other hand, including the fresh goat dung sample, horse dung and goat dung were also analysed for total nitrogen and total phosphorus (Table 5-2). It can be observe that horse dung, with 6,744 mg/kg of total nitrogen and 13, 466 mg/kg presented higher amount of these elements, compare to the other samples. In chapter number 4, according to the results of runoff experiment, even of the high concentration of horse dung, there was higher amount of total nitrogen from control plot, where no animal waste was applied.

Table 5-2 Amount of total nitrogen and total phosphorus for several animal waste samples

	T-N (mg/kg)	T-P (mg/kg)
Cow dung	4345	4745
Horse dung	6744	13466
Goat dung	5130	5740

5.3.2 Counting microorganisms in animal waste samples

After incubation during 24 hours of animal waste samples, counting of *E.coli*, coliform bacteria (Fig. 5-4) and general bacteria CFU was carried out (Fig. 5-5)

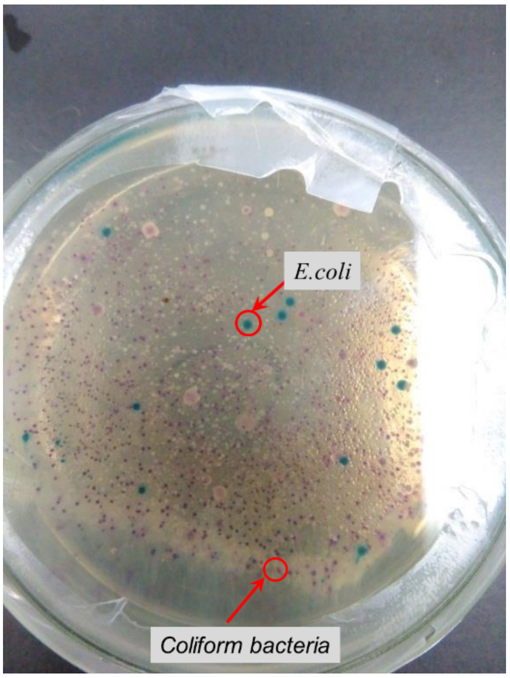

Fig. 5-4 Counting of *E.coli* and conliform bacteria

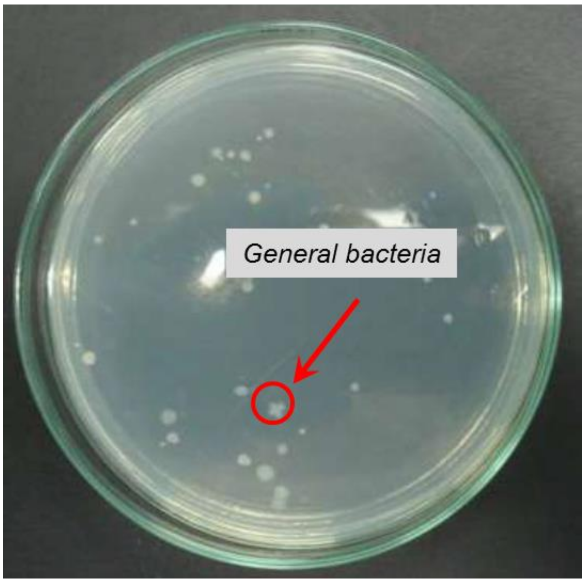

Fig. 5-5 Counting of general bacteria

Results are summarized in Table 5-3. As can be observed, *E.coli* and coliform bacteria was present in all animal waste samples. Among the three samples, horse dung presented the highest number of *E.coli* and coliform bacteria, with 3.6 X 10^6 cfu/g of *E.coli* and 3.2 X 10^7 cfu/g. For this reason, it is important to conduct a treatment for reducing the number of microorganisms that may harm the environment.

Table 5-3 Microorganisms present in animal waste samples

	E.Coli **(cfu/g)**	**Coliform bacteria (cfu/g)**	**General bacteria (cfu/g)**
Cow dung	13 X 10^6	4 X 10^6	84 X 10^7
Horse dung	3.6 X 10^6	3.2 X 10^7	4 X 10^7
Goat dung	5.28x10^4	7.5x10^5	54x10^4

5.3.3 Air drying process

Horse dung used in Chapter 4 was used effectively for mitigating soil erosion. However, for minimizing the negative effects of its application, an air drying treatment was carried out (Fig. 5-6).

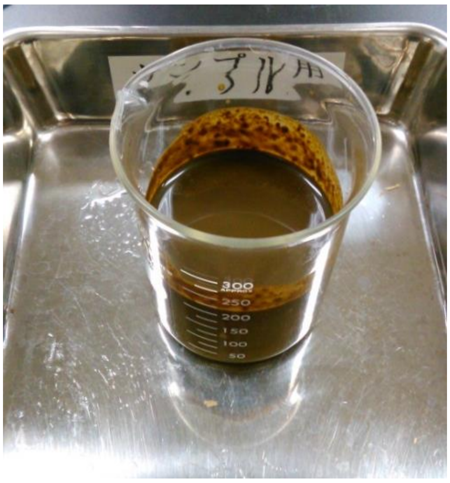

Fig. 5-6 Air drying process

In Table 5-4 it is shown how after 4 weeks of air drying treatment, the amount of *E.coli* and coliform bacteria were sterilized from the horse dung samples.

Table 5-4 Air drying process

	E. coli **(cfu/g)**	**Coliform bacteria (cfu/g)**	**General bacteria (cfu/g)**
Horse dung	3.6×10^6	3.2×10^7	4×10^7

(4 weeks of air drying)

	E. coli **(cfu/g)**	**Coliform bacteria (cfu/g)**	**General bacteria (cfu/g)**
Horse dung	0	0	7×10^6

The air drying process was conducted during the month of July, 2015, where high temperatures are present in Japan. However, in the research site, where the average temperature is 15 ºC, it might not be possible to get the same results. For this reason the alcalinization of samples might be an alternative way to sterilized animal waste before applying it into the farmland.

5.5 Conclusions of this chapter

In the present chapter, it was observed that among the three samples of animal waste, horse dung presented the highest values. According to the soil loss results of chapter 4, when applying horse dung as animal waste slurry, the release of total nitrogen was significantly less than the control plot.

Further research is necessary to confirm that the application of slurry of goat or cow dung will behave as the application of horse dung slurry.

On the other hand, *E.coli* and coliform bacteria was found in all the samples. Horse dung presented the highest values between the three samples. For this reason, air drying treatment was applied for horse dung slurry.

It was found that the number of *E.coli* and coliform bacteria decreased with air-drying process in all samples. However, decrease was also observed in general bacteria, which is necessary for decomposition process. For further research it is necessary to test other sterilization methods, for example through the increase of pH through addition of lime water.

References of this chapter

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Chapter 6

Conclusions

This dissertation dealt with the land degradation assessment in Mixteca Region, and the utilization of animal waste as a conservation strategy, focus mainly to the mitigation of soil erosion by the application of animal waste slurry, since land resources are indispensable for agriculture, and hence the importance to preserve this resource. Furthermore, it is necessary to have a proper management of the farming systems, since the application of agricultural chemicals threaten the soil environment.

Even though there are several studies dealing with land degradation in Mexico, soil environment is still affected. El Jicaral Village, Mexico, is also one of the areas where land degradation is progressing.

In order to understand better the situation in the study site, as well as to develop the proper technology, it was necessary to apply a questionnaire survey to have a quantitative measurement of several aspects. 69 households were interviewed. It could be understand that currently the farming systems are based mainly in subsistence agriculture conducted in hillsides, depending on rainfall as a source of water. Through the results of the rain gauge installation it was also acknowledged that there is a high amount of precipitation, with around 2,500 mm in 2014, and that, strong rainfall intensity was also presented in the months of May and July, when the soil is under cultivation, wiith around 50 mm/hr. For this reason is important to protect the soil surface prone to erosion.

Conservation practices in the study site are not conducted and the use of chemical pesticides and herbicides is a common practice, even though the negative effects of applying it, to the health as well as to the land resource.

In order to have a better understanding of the research site, in addition to the questionnaire survey, land degradation assessments done by remote method (through the factors of topography, vegetation cover and land use) and field method was conducted. Through the results of both methods, it was clear that land degradation is a current problem in El Jicaral Village, Mixteca Region, since in the remote assessment, almost 90% of the cells (50m x 50m) presented moderate to high land degradation levels, and in the field assessment, 75% of the cell presented the same condition.

Furthermore, through a simple regression analysis, it was found that both methods are correlated. For this reason, land degradation assessment method done by remote method may be useful when land degradation assessment is necessary in small areas and it is not possible to conduct it through field method.

So, it is necessary to implement conservation strategies since it is known that most of the area in El Jicaral Village, Mixteca Region is under land degradation process, and also taking into account that precipitation quantity and that farming practices are mainly conducted on hillsides, causing high levels of soil erosion.

On this respect, animal waste application was proposed since this is an available resource in the study site. Adding animal waste slurry into the soil, incorporated or applied on the surface, reduced splash erosion rate significantly in leptosol of Mixteca Region, as well as soil and nitrogen loss in the surface runoff. This is because the addition of organic matter into the soil in the form of slurry improved the cohesion between soil particles, making it stronger against the kinetic energy of raindrops or the shearing forces of surface runoff.

Nevertheless, future research has to be conducted in order to ensure that the addition of slurry is not harmful for the environment. Furthermore, from a view point of nitrogen loss in the runoff experiment, formed bio-crust may be recommendable to apply as a conservation strategy above the incorporation of slurry into the soil.

There is the risk of pollution due to release of nutrients as well as microorganism when applying organic matter into the soil. For this reason animal waste samples were analyzed. It was observed that among the three samples of animal waste, horse dung presented the highest values. According to the soil loss results of chapter 4, when applying horse dung as animal waste slurry, the release of total nitrogen was significantly less than the control plot.

On the other hand, *E.coli* and coliform bacteria was found in all the samples. Horse dung presented the highest values between the three samples. For this reason, air drying treatment was applied to horse dung slurry.

It was found that the number of *E.coli* and coliform bacteria decreased with air-drying process in all samples. However, decrease was also observed in general bacteria, which is necessary for decomposition process. For further research it is necessary to test other sterilization methods, for example through the increase of pH through addition of lime water.

For these reasons, it can be concluded that the air-dried slurry application is an effective soil conservation strategy for mitigating land degradation in El Jicaral Village, Mixteca Region, Mexico.

Appendices

List of appendices

Appendix 1 Rainfall data obtained at research site in El Jicaral Village, Mixteca Region, Mexico

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Appendix 4 Amount of soil loss during the raindrop experiment

Appendix 5 Amount of soil, total nitrogen and total phosphorus losses during the surface runoff experiment

Appendix 6 Amount of water content on animal waste samples

Appendix 1 Rainfall data obtained at research site in El Jicaral Village, Mixteca Region, Mexico

El Jicaral Village, January, 2014

Unit: mm · hr^{-1}

Time (h) / Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																								
2																								
3																								
4																								
5																								
6																								
7	0.8	2.8	0.2																					
8																								
9																								
10			3					0.2																
11																								
12																								
13																								
14																								
15																								
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24																								
25																								
26																								
27																								
28																								
29																		0.2	1	0.2				
30																								
31																								

El Jicaral Village, February, 2014

Unit: mm · hr^{-1}

Time (h) / Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																								
2																								
3																								
4																								
5																								
6																								
7																								
8																								
9																								
10																								
11																								
12																								
13																								
14																								
15																								
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24																								
25																								
26																								
27																								
28																								

El Jicaral Village, March, 2014

Unit: mm · hr^{-1}

Time (h) / Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																								
2																								
3																								
4																								
5																								
6																								
7																								
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23																								
24																								
25																								
26																								
27																								
28																								
29																								
30																								
31																								

El Jicaral Village, April, 2014

Unit: mm · hr^{-1}

Day \ Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																								
2																								
3																								
4																								
5																								
6																								
7																								
8																								
9																								
10																								
11																								
12																								
13																								
14																								
15																								
16																								
17																								
18																								
19																								
20																								
21																								
22				19	0.8		0.2																	
23																								
24																								
25																								
26																								
27																								
28																								
29																								
30																								

El Jicaral Village, May, 2014

Unit: mm · hr^{-1}

Day \ Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1				0.2																				
2																								
3																				21	0.6			
4		0.2																						
5																	0.2							
6																								
7																								
8																0.2	0.2	22	19	2.8	1.8	0.2		
9												0.2												
10																								
11																								
12																					3.2	0.2		
13																						0.2	27	2.8
14	0.8	1.2		0.2																				
15																4	2.6							
16									0.2													7.4	1	
17				0.2																		9.2	1.2	0.4
18						0.2																		
19																				0.2	0.2	0.2		
20																								
21		0.2													19	1.4								
22																			21	8.6	1.2	0.2	0.2	
23																				14	1.4	0.8		0.4
24		0.2																		2.4	5.2	2.8	4	4
25	1.6	0.4		1	0.6	0.2		0.2																
26																		2.6	3	2.2	0.2			
27																0.4	1	50	9.8	9.2	2.8	3.6	4.4	
28				0.2														2.2	2	4	2.4	0.4		
29							0.2												0.2	0.4	0.6	0.2		
30																0.6	3	3.6	13	4.4	4	1.2	0.2	
31			0.2														0.8	1.8	1.8	7.4	5	2	3.6	

El Jicaral Village, June, 2014

Unit: mm · hr^{-1}

Day \ Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1			0.2																					
2																				4.4	0.2		0.2	
3																		0.2	0.6		0.2			
4																23	16	2.4	2.4	2.8	1.8	0.6	0.6	
5		2.4	5.2	0.6	0.4									1.2	2.8	0.2								
6		1	1.6	0.2												0.2	0.6		0.6	1.6	0.4			
7														5.8	1								0.2	
8					0.2												9.4	3.4	0.4					
9	2.6	0.2					0.2	0.2							1.6	17	8.6	0.2			5.4		0.2	3.4
10	0.8	0.2	1.8	2.8	0.1										1.6	1	5.8	9	1.6	1.2	0.2		0.2	
11																		0.2						
12															17	0.6		5.2	2.6	0.4	0.2			
13		0.2																3.8	16	14				
14	0.2																							
15																		26	4.4	0.2				
16									0.2										0.2		8	5.8	0.4	
17						0.2										0.4	2.6	0.4	2.6	21	1.6	1	1.2	1.2
18	0.6							0.2												5.2	2.4	0.8		
19							0.2												2.4	9.2	3	1.4	0.2	
20			4.6	6.2		0.2										0.4	7.2	0.2	1	3.8	2			1
21	0.2	0.2																3.6	5.2	4.4	1.8	2.6	1	
22			0.2																					7
23	8.8	2.4				0.2											1.6	0.8				0.2		
24			0.2	0.8	0.8																1.4	8	5	1
25	0.6	0.8	1	8.2	0.8	1.2							0.2				1.2							
26																			0.2			9	23	3.4
27	1.2	0.2																			5.4	6	0.8	0.6
28							0.2																	
29														1	2.4	7.2	0.2				1.2	1.2	1	1.4
30	1.6	2.4	0.4	0.2																				

El Jicaral Village, July, 2014

Unit: mm · hr^{-1}

Day \ Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																								
2							0.8																	
3																				1.4	2	0.8		
4					0.2										0.6	0.4					0.2	1	0.6	0.2
5	2.8	9.8	3.6	0.2												0.6		0.2	0.4					0.2
6	0.2	0.2	0.2		0.2										0.2	2.4	0.2							
7					0.2											2.2				0.6				
8							0.2																	
9																					1.4	0.4	0.2	
10				0.2																				
11																								
12																								
13																	0.4			1	12	11	4.8	0.2
14	0.2		0.2																					
15																	3.6		3.6	1.4	0.2			
16				0.2																				
17																								
18																		0.4	0.6	1.4				
19																								
20																0.2	5.6	54	11	1.2				
21				0.2																				
22																								
23																		1.2	1.2	9.4	9	2.4		
24					0.2															16		1.4	2.8	0.8
25											0.2								6.6	7			1	
26			0.2																					
27																19	23							
28	0.2	1.6					0.2																	
29																		3	2.8	6.2	0.2			
30		0.2																		0.4		6.4		
31								0.2													2.8	0.2		

El Jicaral Village, August, 2014

Unit: mm · hr^{-1}

Day \ Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																								
2																			0.6	16				
3						0.2														14	0.8	0.2	0.4	
4				0.2														1.2	2	0.4	1.8	0.2		
5																	0.4	0.6	1.8	2.6	2.4	2.2	0.4	
6																								
7																								
8																								
9						0.2	9.2	6.6																
10																		4.2	8.8	11	0.4			
11							0.2							3.6	32	1				0.2			0.2	1.6
12	15	3					0.2								0.2		0.6	2.6	4.2	5.8	1	0.4		
13																	0.4		0.2			0.6		0.2
14	0.2																3.4	0.2						
15															0.2	0.2			8	9.6	9.2	1.6		
16				0.2																				
17																						0.2	12	2.4
18	3.4	1.4	0.2	0.2																				
19																6	1.6				0.4	2.4	1.4	0.6
20																	0.2	2.6		0.2				
21											0.2					1	8.4	19	3.4	2				
22				0.2														6.6	0.2		1	4.8	1	
23																					1.2		0.2	0.2
24	0.2																					3.2	2.4	1.4
25	0.6																0.8	2.6	0.4	6	0.8	0.2		
26					0.2																			
27																						0.2		
28																								
29	0.8	14	1.6	0.2	0.2																1.4	2	0.6	3.2
30																		6.2	7	5	6.8	1		
31	0.2													0.2	4	9.2	33	3.2	5.4	13	4	3.2	4.2	1.4

El Jicaral Village, September, 2014

Unit: $mm \cdot hr^{-1}$

Time (h) / Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	2.2	0.2	0.8	2.6												0.2	4.4	6	2	1.2	0.4	0.2		
2		0.2																	1.6	3.6	5.8	4.6	0.6	
3														0.6			0.8	4	0.6	0.2				
4																					2	1.8		1.4
5	0.2	0.2					0.2											1.8						
6																	5.2		8.4					
7																			9.8	16	0.2			
8															0.6	0.2	0.4	7.6	0.4					
9			0.2												0.2	0.2		1.6	4.8	3	5.6	9.2	5.4	8
10	4	0.2																		1	4.2	5.6	2.4	1
11	0.2		0.2													0.2	3.4	1.6	1.6	19	6.2	1.8	0.4	0.4
12																								
13																				0.4	1.2	1	1.8	2
14	1.4	0.2														0.2	1.8	3.2	0.6					
15																		4.2				8.4		
16																						6.6		
17					0.2																			
18																								
19																								
20			0.2		3.8	7.2											0.4	0.6	17	15	10			
21				0.2																	0.6			
22						0.2												0.8	0.2					
23		0.2															4.4	12	2	0.4	2	0.2		
24			0.2														4.6			0.2				
25																								
26																			2.8			0.2	1.4	
27							0.2									1.6		5	6.4	1.2	5			
28				0.2													1.6	1.6	4.8	1.8	2		0.2	1.6
29			0.2													3.8	0.8		10	2.8	12	2.6	1.8	
30					0.2										0.2			5	2.8	2.4	1.6			

El Jicaral Village, October, 2014

Unit: mm · hr^{-1}

Day \ Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1					0.2											2.2	0.6	0.6	7.6	3.8	0.6	0.6	1.6	2.4
2		1.4	3.6	1.8	1.6	0.8																	1.2	3
3	4.4	2.8	2.2	0.8																		0.2	2.8	18
4							0.2												0.2					
5																							1.6	3.2
6	21	4.6	3																					
7										0.2						22	5.8	0.2	1	0.8		0.2		
8								0.2																
9																		5.6	0.4	2.2	1.8	0.2		
10					0.2																			
11																			0.2	0.4	3.8	0.2	6.8	2.2
12																								
13																								
14																								
15																								
16																								
17															1.2	3.2	2.6	2.4	2.4	0.6	0.8	4.6	4.4	6.6
18	4.8	4.4	5.8	4	6.8	8.8	7.6	7.8	15	13	11	18	17	8.4	5	3.6	3.8	2	0.4	4	5.2	2.6	5.4	12
19	4.2	2.4	1.2	3.2	1	0.4	0.6	1.2	0.4	0.6	1	0.6	4	1.4					0.2		0.2			
20																								
21	0.2	2.2	0.4																		3.2	4	3.6	2.6
22	3.2	0.6	0.4		0.2			0.2																
23																								
24																								
25																								
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29																								
30																								
31																								

El Jicaral Village, November, 2014

Unit: mm · hr^{-1}

Day \ Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																								
2																								
3																								
4																								
5																								
6																		0.4	0.4					
7																								
8																								
9																								
10	2	2.4																						
11																								
12						0.4										1.4	0.8							
13		0.2																34	0.2		23	2.4	1.4	0.4
14	0.2																							
15																								
16																								
17																								
18																								
19																					2.6	0.2		
20								0.2									0.4							
21																								
22																								
23																								
24																								
25																								
26																								
27																								
28																								
29																								
30																								

El Jicaral Village, December, 2014

Unit: mm · hr^{-1}

Day \ Time (h)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1																								
2																								
3																								
4																								
5																								
6																								
7																								
8																								
9																								
10																								
11																								
12																								
13																								
14																			5.2	2		0.2		
15																								
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24																				0.8	1	0.2	3.8	2.6
25	0.6	1	0.2	0.6	0.4				0.2		0.2													
26				0.2																				
27																								
28																								
29																								
30																								
31																								

Appendix 1 Land degradation assessment data

1. Land degradation assessment data

Three meshes are presented, including data about the calculation of steepness and slope, elevation in every cell and values of Δd for calculating slopes.

Steepness (meters)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
a	16	10	17	25	22	13	4	22	14	17	14	19	22	18
b	13	12	18	24	23	15	8	20	16	21	9	11	17	14
c	10	15	19	17	25	19	15	13	15	21	13	12	14	12
d	11	16	18	18	22	20	18	22	30	34	21	12	11	11
e	14	17	18	17	21	18	18	17	15	19	11	11	11	9
f	16	16	16	15	19	18	18	11	11	22	23	16	10	9
g	18	16	15	14	16	16	18	13	18	14	14	11	16	14
h	18	19	20	19	18	17	14	13	14	10	9	5	13	17
i	18	25	26	25	18	14	12	13	13	12	12	2	10	21
j	12	19	22	23	17	13	9	11	9	7	17	7	5	16
k	12	16	21	22	15	11	8	10	8	8	18	8	3	16
l	13	16	21	21	14	10	9	11	8	9	20	14	9	18
m	16	16	21	21	10	6	7	9	8	10	18	16	12	19
n	17	18	22	22	9	4	8	9	8	10	17	16	14	19

Elevation map (masl)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
a	802	796	809	834	854	864	864	862	845	831	826	831	836	836
b	793	792	809	832	851	860	861	861	844	831	814	814	820	820
c	784	791	808	828	845	853	856	856	843	831	811	805	807	807
d	776	789	805	820	834	844	850	850	843	831	811	798	795	795
e	773	787	802	812	824	832	841	841	828	813	797	790	786	784
f	770	784	795	803	814	823	832	832	824	816	809	779	784	775
g	768	779	788	795	805	814	821	821	821	816	809	795	790	780
h	763	773	781	789	798	805	808	808	808	803	802	795	793	785
i	754	761	770	780	788	794	797	797	795	794	794	795	795	790
j	737	744	755	770	780	785	787	787	784	782	793	795	795	791
k	729	733	747	763	772	778	779	779	776	776	788	791	791	791
l	723	726	741	757	767	771	772	772	769	770	783	788	789	789
m	720	720	736	753	761	764	764	763	761	763	774	780	782	782
n	714	715	732	751	758	760	760	757	754	756	764	770	773	773

Values of Δd for calculating slopes in every cell

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
a	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5	70.5	70.5	50	70.5	70.5	70.5
b	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5	70.5
c	50	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5	70.5	50	70.5	70.5	70.5
d	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5
e	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5
f	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5	70.5	70.5	50	50
g	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5	70.5
h	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	50	50	70.5	70.5
i	50	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5	50	70.5	70.5
j	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5
k	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5
l	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5	50	70.5	70.5	70.5	70.5	70.5
m	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	50	70.5	70.5	70.5	70.5	70.5
n	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5

Appendix 2 Soil physical and chemical properties analysis data

- Particle Size Distribution
- Specific Gravity
- Water Content
- Ignition Loss
- Electrical conductivity (EC)
- pH

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Appendix 2. Soil physical and chemical properties analysis data

PHYSICAL AND CHEMICAL PROPERTIES ANALYSIS

(LEPTOSOL SAMPLES)

Particle Size Distribution (PSD)

0.2～2 mm		Sieving			**Above 2.0 mm**			
Sample No	Plate No	Plate mass（g）	Dry soil + plate mass（g）	**Gravel + Coarse sand mass（g）**	Sieve weight	Sample + sieve	**Gravel (g)**	**Coarse sand (g)**
1	17	136.6900	139.3300	**2.6400**	72.37	72.82	**0.45**	**2.1900**
2	74	109.8600	112.6500	**2.7900**	72.37	73.05	**0.68**	**2.1100**
3	77	118.3000	120.7000	**2.4000**	72.37	72.61	**0.24**	**2.1600**

< 0.02 mm		Pipet						
Sample No	Can No	Can mass（g）	Dry soil + can mass（g）	**Silt + clay mass（g）A**	Sodium HexametaphosphateB	A-B	×50	**Silt mass（g）**
1	49	76.7148	76.7964	0.0816	0.01632	0.06528	3.264	**1.600**
2	46	76.4290	76.5126	0.0836	0.01632	0.06728	3.364	**1.715**
3	16	76.7174	76.7985	0.0811	0.01632	0.06478	3.239	**1.610**

< 0.002 mm		Pipet					
Sample No	Can No	Can mass（g）	Dry soil + can mass（g）	**clay mass（g）A**	Sodium HexametaphosphateB	A-B	**×50**
1	45	76.5743	76.6239	0.0496	0.01632	0.03328	**1.664**
2	42	76.7844	76.8337	0.0493	0.01632	0.03298	**1.649**
3	39	76.9107	76.9596	0.0489	0.01632	0.03258	**1.629**
							clay

0.2～0.02 mm		**Aspiration**		
Sample No	Plate No	Plate mass（g）	Dry soil + plate mass（g）	**Fine sand mass（g）**
1	17	136.6900	139.16	**2.47**
2	74	109.8600	112.4	**2.54**
3	77	118.3000	120.82	**2.52**

Particle Size Distribution (Continuation)

Gravel (g)	Coarse sand（g）	Silt（g）	Clay（g）	Fine sand（g）
0.45	2.19	1.60	1.66	2.47
0.68	2.11	1.72	1.65	2.54
0.24	2.16	1.61	1.63	2.52

Particle size distribution	All mass (g)	gravel (%)	Coarse sand (%)	Silt (%)	Clay (%)	Fine sand (%)
Sample 1	8.37	5.4	26.2	19.1	19.9	29.5
Sample 2	8.69	7.8	24.3	19.7	19.0	29.2
Sample 3	8.16	2.9	26.5	19.7	20.0	30.9
	8.41	5.4	25.6	19.5	19.6	29.9

Particle size distribution

Gravel (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Total (%)
5.4	25.6	29.9	19.5	19.6	100

Specific Gravity

PN number	PN mass (g)	PN + Soil (g)	PN + Water + soil (g)	Temp (ºC)	PN + water (g)	Temp (ºC)	Sample (g)
53	25.14	30.59	88.13	22.3	84.75	22.2	5.45
67	29.78	34.91	87.19	22.5	84.04	22.3	5.13
73	30.34	34.72	89.64	22.5	86.97	22.3	4.38
				22		22	

Wa	Gs	G20	temperature	Gw	Gw20
84.75	2.632850242	2.631705563	22	0.9978	0.998234
84.04	2.590909091	2.589782647	22	0.9978	0.998234
86.97	2.561403509	2.560289893	22	0.9978	0.998234
		2.593926034			

Water content and Ignition Loss

WATER CONTENT

	M0	M1	M2	
CAN no.	**Can weight**	**Can + Soil sample**	**Can + soil dried**	**WC (%)**
14	77.0633	90.4371	87.8003	0.245580702
20	76.2944	94.6773	90.9806	0.251712492
36	76.3138	95.4617	91.7012	0.244388266
				0.247227153

IGNITION LOSS

	Mc	Ma	Mb	M1	Ms	
Porcelain/lid number	**Porcelain weight**	**Porcelain + Sample weight**	**Weight after 800ºC**	**Reduction of sample mass**	**Sample mass**	**Li (%)**
1/753	22.5085	35.5413	32.1812	3.3601	13.0328	25.78187343
99/838	22.3778	33.4259	30.541	2.8849	11.0481	26.11218219
160/960	27.1621	38.1518	35.3604	2.7914	10.9897	25.40014741
						25.764734

Electrical Conductivity and pH

Sample No.	EC	Unit	Temp.	pH	Temp.
1	17.75	μS/cm	22.5	5.84	21
2	13.38	μS/cm	22.5	5.9	21
3	15.57	μS/cm	23.1	5.7	21.6
	15.57	μS/cm		**5.81**	

Physical and chemical properties analysis for leptosol samples (Summary table)

Soil	Specific gravity	Particle size distribution, %					Soil texture	pH	EC µS/cm	IL %
		Gravel	Coarse sand	Fine sand	Silt	Clay				
Leptosol	2.59	5.4	25.6	29.9	19.5	19.6	SCL	5.81	15.5	25.76

Appendix 4 Amount of soil loss during the raindrop experiment

Soil loss in the stainless cores without application of animal waste slurry

	Can No.	Diameter (cm)	Height (cm)	Can weight	Filter paper	Soil + Filter + can	wet soil weight	dried soil (before experiment)	Remaining soil in can	Soil loss (%)
Control	30	1.105	0.99	2.7149	0.5435	4.4455	1.1871	1.01722365	0.9292	8.649694779
	32	1.1	0.98	2.6879	0.5492	4.4287	1.1916	1.021079692	0.9442	7.526979288
	33	1.1	0.98	2.7014	0.5505	4.4516	1.1997	1.028020566	0.9642	6.209126831
	34	1.095	0.97	2.6874	0.5349	4.3226	1.1003	0.942844901	0.9049	4.025144146
	35	1.105	0.97	2.6845	0.5342	4.424	1.2053	1.032819195	0.9401	8.979846687
	36	1.105	0.995	2.7088	0.552	4.443	1.1822	1.01302485	0.9117	10.00044584
	37	1.1	0.99	2.6817	0.5575	4.4924	1.2532	1.07386461	1.0434	2.83667274
	38	1.105	0.995	2.7294	0.5294	4.4786	1.2198	1.045244216	0.9802	6.224902846
	39	1.105	0.99	2.7091	0.5462	4.4046	1.1493	0.984832905	0.9180	6.783606804
	40	1.105	0.995	2.712	0.5369	4.4418	1.1929	1.022193659	0.9867	3.4707706

Soil loss in the stainless cores applying mixture of animal waste slurry and soil

	Can No.	Diameter (cm)	Height (cm)	Can weight	Filter paper	Soil + Filter + can	wet soil weight	dried soil (before experiment)	Remaining soil in can	Soil loss (%)
Incorporated	41	1.1	0.99	2.6845	0.5536	4.6827	1.4446	1.193884298	1.1895	0.368617149
	42	1.1	0.99	2.7212	0.5559	4.6378	1.3607	1.124545455	1.1179	0.595222074
	43	1.105	0.99	2.7092	0.5479	4.5106	1.2535	1.035950413	1.0223	1.322039674
	44	1.105	0.985	2.6842	0.5487	4.5505	1.3176	1.08892562	1.0755	1.235970814
	45	1.105	0.975	2.6942	0.5486	4.7661	1.5233	1.25892562	1.2513	0.604301756
	46	1.09	0.98	2.6937	0.5501	4.5662	1.3224	1.092892562	1.0645	2.596907534
	47	1.105	0.99	2.694	0.5529	4.6738	1.4269	1.179256198	1.1731	0.521668708
	48	105	0.99	2.6605	0.5413	4.5746	1.3728	1.134545455	1.1047	2.633778061
	49	1.1	0.995	2.7123	0.5404	4.6287	1.376	1.137190083	1.1183	1.660733567
	50	1.1	0.98	2.699	0.5568	4.6999	1.4441	1.193471074	1.1731	1.70504963

Soil loss in the stainless cores applying animal waste slurry on the soil as a surface crust

	Can No.	Diameter (cm)	Height (cm)	Can weight	Filter paper	Soil + Filter + can	wet soil weight	dried soil (before experiment)	Remaining soil in can	Soil loss (%)
Surface crust	51	1.1	0.99	2.7173	0.5581	4.4263	1.1509	0.986203942	0.9852	0.101398905
	52	1.105	0.99	2.7167	0.5501	4.4946	1.2278	1.0520994	1.0501	0.190096107
	53	1.105	0.98	2.7165	0.5347	4.4201	1.1689	1.001628106	0.9989	0.269561126
	54	1.12	0.985	2.7136	0.5357	4.4447	1.1954	1.024335904	1.0199	0.429546595
	55	1.105	0.98	2.7008	0.5435	4.3483	1.104	0.946015424	0.9427	0.348831522
	56	1.09	0.985	2.7188	0.5421	4.4885	1.2276	1.051928021	1.0473	0.437292278
	57	1.105	0.99	2.6843	0.529	4.4342	1.2209	1.046186804	1.0445	0.162494881
	58	1.1	0.995	2.7304	0.5544	4.4796	1.1948	1.023821765	1.0219	0.185579176
	59	1.1	0.99	2.7247	0.5523	4.4735	1.1965	1.025278492	1.0234	0.185315504
	60	1.1	0.98	2.686	0.5529	4.4535	1.2146	1.040788346	1.0405	0.028824304

Soil loss in the raindrop experiment (summary)

	Control	Incorporated	Surface
	8.649694779	0.368617149	0.101398905
	7.526979288	0.595222074	0.190096107
	6.209126831	1.322039674	0.269561126
	4.025144146	1.235970814	0.429546595
	8.979846687	0.604301756	0.348831522
	10.00044584	2.596907534	0.437292278
	2.83667274	0.521668708	0.162494881
	6.224902846	2.633778061	0.185579176
	6.783606804	1.660733567	0.185315504
	3.4707706	1.70504963	0.028824304
ave	6.470719056	1.324428897	0.23389404
max-ave	3.529726783	1.309349165	0.203398238
ave-min	3.634046316	0.955811748	0.205069735
Sd	2.427433221	0.830510308	0.13558613

Appendix 4 Amount of soil, total nitrogen and total phosphorus losses during the surface runoff experiment

Soil losses during the surface runoff experiment

	Time (min)	Can Code	Can Mass (g)	Can + Dried Sediment Mass (g)	Dried Sediment Mass (g)	Soil Loss Concentration (mg/L)	Discharge Amount (L)	Specific Load (g/m^2)	Average
Control	10	31	77.0910	77.3144	0.2234	22340.00	0.66	514.37	
		k1	41.0774	41.2651	0.1877	18770.00	0.66	432.17	444.84
		49	77.1207	77.2892	0.1685	16850.00	0.66	387.96	
	20	42	76.7849	76.8405	0.0556	5560.00	0.52	99.89	
		40	76.7537	76.7948	0.0411	4110.00	0.52	73.84	78.81
		k26	41.4393	41.4742	0.0349	3490.00	0.52	62.70	
	30	28	77.4192	77.4256	0.0064	640.00	0.52	11.61	
		a60	41.9402	41.9462	0.0060	600.00	0.52	10.88	12.94
		24	76.8945	76.9035	0.0090	900.00	0.52	16.33	
	40	a28	39.7625	39.7686	0.0061	610.00	0.50	10.53	
		a55	42.6289	42.6370	0.0081	810.00	0.50	13.99	12.26
		m13	41.1522	41.1593	0.0071	710.00	0.50	12.26	
	50	11	76.3265	76.3284	0.0019	190.00	0.49	3.21	
		m1	40.2621	40.2635	0.0014	140.00	0.49	2.37	2.48
		a50	38.6643	38.6654	0.0011	110.00	0.49	1.86	
	60	1	75.6264	75.6310	0.0046	460.00	0.47	7.46	
		a56	41.6785	41.6824	0.0039	390.00	0.47	6.33	7.30
		k17	39.7059	39.7109	0.0050	500.00	0.47	8.11	
Incorporated	10	m9	40.7974	40.8073	0.0099	990.00	0.48	16.58	
		a62	43.2449	43.2545	0.0096	960.00	0.48	16.08	16.13
		6	76.5866	76.5960	0.0094	940.00	0.48	15.74	
	20	a64	41.9326	41.9401	0.0075	750.00	0.56	14.65	
		27	76.5868	76.5937	0.0069	690.00	0.56	13.48	13.74
		k19	39.9095	39.9162	0.0067	670.00	0.56	13.09	
	30	16	76.7158	76.7212	0.0054	540.00	0.52	9.80	
		k18	38.6585	38.6637	0.0052	520.00	0.52	9.43	9.67
		k12	40.9322	40.9376	0.0054	540.00	0.52	9.80	
	40	m11	40.6233	40.6277	0.0044	440.00	0.51	7.83	
		k15	40.1743	40.1786	0.0043	430.00	0.51	7.65	7.59
		39	76.9098	76.9139	0.0041	410.00	0.51	7.29	
	50	a2	39.2042	39.2086	0.0044	440.00	0.52	7.91	
		a61	42.7588	42.7633	0.0045	450.00	0.52	8.08	8.02
		a46	39.6983	39.7028	0.0045	450.00	0.52	8.08	
	60	a37	39.0553	39.0587	0.0034	340.00	0.50	5.93	
		a19	38.6869	38.6900	0.0031	310.00	0.50	5.41	5.47
		a63	42.1486	42.1515	0.0029	290.00	0.50	5.06	
Surface	10	m6	40.6818	40.6865	0.0047	470.00	0.43	6.97	
		k7	40.9006	40.9058	0.0052	520.00	0.43	7.71	7.46
		m7	40.8167	40.8219	0.0052	520.00	0.43	7.71	
	20	m4	41.8935	41.9107	0.0172	1720.00	0.47	27.90	
		29	76.5957	76.6090	0.0133	1330.00	0.47	21.58	24.22
		30	77.0171	77.0314	0.0143	1430.00	0.47	23.20	
	30	19	76.5157	76.5243	0.0086	860.00	0.48	14.25	
		37	76.9452	76.9541	0.0089	890.00	0.48	14.75	13.53
		20	76.2930	76.3000	0.0070	700.00	0.48	11.60	
	40	44	76.7268	76.7318	0.0050	500.00	0.49	8.55	
		m20	41.3900	41.3947	0.0047	470.00	0.49	8.03	8.26
		k8	41.5238	41.5286	0.0048	480.00	0.49	8.21	
	50	23	76.4951	76.4981	0.0030	300.00	0.49	5.11	
		a77	40.4594	40.4621	0.0027	270.00	0.49	4.60	4.99
		15	76.5780	76.5811	0.0031	310.00	0.49	5.28	
	60	12	77.1944	77.1973	0.0029	290.00	0.46	4.60	
		46	76.4281	76.4304	0.0023	230.00	0.46	3.65	4.02
		a74	43.1402	43.1426	0.0024	240.00	0.46	3.81	

	Time	Cumulative amount	Minimum	Maximum
Control	10	444.84	387.964	514.369
	20	523.65	62.702	99.892
	30	536.59	10.884	16.327
	40	548.85	10.534	13.987
	50	551.33	1.861	3.215
	60	558.63	6.327	8.111
Incorp	10	16.13	15.740	16.578
	20	29.87	13.089	14.652
	30	39.55	9.433	9.796
	40	47.14	7.295	7.828
	50	55.16	7.905	8.085
	60	60.63	5.058	5.931
Surf.	10	7.46	6.968	7.710
	20	31.69	21.575	27.902
	30	45.22	11.600	13.533
	40	53.48	8.034	8.262
	50	58.48	4.597	4.994
	60	62.50	3.651	4.021

Control: Controlled plot
Incorporated: Slurry mixed with soil
Surface crust: Application of slurry on the surface

Total nitrogen losses during the surface runoff experiment

	Sampling Time	Reading Value	Concentration (mg/L)	Discharge (L)	Load (g)	Specific Load (g/m^2)	Average
Control	10	1.83	21.96	0.66	0.014	0.101	
		1.93	23.16	0.66	0.015	0.107	0.103
		1.84	22.08	0.66	0.015	0.102	
	20	0.70	8.40	0.52	0.004	0.030	
		0.64	7.68	0.52	0.004	0.028	0.030
		0.74	8.88	0.52	0.005	0.032	
	30	0.39	4.68	0.52	0.002	0.017	
		0.33	3.96	0.52	0.002	0.014	0.015
		0.34	4.08	0.52	0.002	0.015	
	40	0.25	3.00	0.50	0.001	0.010	
		0.28	3.36	0.50	0.002	0.012	0.011
		0.27	3.24	0.50	0.002	0.011	
	50	0.16	1.92	0.49	0.001	0.007	
		0.19	2.28	0.49	0.001	0.008	0.007
		0.15	1.80	0.49	0.001	0.006	
	60	0.19	2.28	0.47	0.001	0.007	
		0.16	1.92	0.47	0.001	0.006	0.007
		0.18	2.16	0.47	0.001	0.007	
Incorporated	10	1.13	11.40	0.48	0.005	0.038	
		1.06	12.48	0.48	0.006	0.042	0.040
		1.08	11.52	0.48	0.006	0.039	
	20	0.84	8.40	0.56	0.005	0.033	
		0.72	7.80	0.56	0.004	0.031	0.033
		0.87	8.88	0.56	0.005	0.035	
	30	0.47	6.72	0.52	0.003	0.024	
		0.48	8.28	0.52	0.004	0.030	0.027
		0.46	7.20	0.52	0.004	0.026	
	40	0.22	5.76	0.51	0.003	0.021	
		0.28	5.64	0.51	0.003	0.020	0.020
		0.27	5.28	0.51	0.003	0.019	
	50	0.21	3.72	0.52	0.002	0.013	
		0.18	4.08	0.52	0.002	0.015	0.015
		0.16	4.32	0.52	0.002	0.016	
	60	0.23	2.88	0.50	0.001	0.010	
		0.22	3.24	0.50	0.002	0.011	0.011
		0.21	3.60	0.50	0.002	0.013	
Surface crust	10	0.95	13.56	0.43	0.006	0.040	
		1.04	12.72	0.43	0.005	0.038	0.039
		0.96	12.96	0.43	0.006	0.039	
	20	0.70	10.08	0.47	0.005	0.033	
		0.65	8.64	0.47	0.004	0.028	0.032
		0.74	10.44	0.47	0.005	0.034	
	30	0.56	5.64	0.48	0.003	0.019	
		0.69	5.76	0.48	0.003	0.019	0.019
		0.60	5.52	0.48	0.003	0.018	
	40	0.48	2.64	0.49	0.001	0.009	
		0.47	3.36	0.49	0.002	0.012	0.011
		0.44	3.24	0.49	0.002	0.011	
	50	0.31	2.52	0.49	0.001	0.009	
		0.34	2.16	0.49	0.001	0.007	0.008
		0.36	1.92	0.49	0.001	0.007	
	60	0.24	2.76	0.46	0.001	0.009	
		0.27	2.64	0.46	0.001	0.008	0.008
		0.30	2.52	0.46	0.001	0.008	

	Time	Cumulative amount (g/m^2)	Minimum	Maximum
Control	10	0.1034	0.1014	0.1069
	20	0.1333	0.0277	0.0320
	30	0.1488	0.0144	0.0170
	40	0.1598	0.0104	0.0116
	50	0.1666	0.0061	0.0077
	60	0.1735	0.0062	0.0074
Incorporated	10	0.0396	0.0383	0.0419
	20	0.0723	0.0305	0.0348
	30	0.0993	0.0244	0.0301
	40	0.1191	0.0188	0.0205
	50	0.1336	0.0134	0.0156
	60	0.1450	0.0101	0.0126
Surface	10	0.0389	0.0378	0.0403
	20	0.0705	0.0281	0.0339
	30	0.0892	0.0183	0.0191
	40	0.0998	0.0090	0.0115
	50	0.1073	0.0066	0.0086
	60	0.1157	0.0080	0.0088

Control: Controlled plot
Incorporated: Slurry mixed with soil
Surface crust: Application of slurry on the surface

Total phosphorus losses during the surface runoff experiment

	Sampling Time	Reading Value	Concentration (mg/L)	Discharge (L)	Load (g)	Specific Load (g/m^2)	Average
Control	10	0.24	2.88	0.66	0.002	0.013	
		0.25	3.00	0.66	0.002	0.014	0.020
		0.62	7.44	0.66	0.005	0.034	
	20	0.09	1.08	0.52	0.001	0.004	
		0.04	0.48	0.52	0.000	0.002	0.003
		0.07	0.84	0.52	0.000	0.003	
	30	0.00	0.00	0.52	0.000	0.000	
		0.01	0.12	0.52	0.000	0.000	0.000
		0.01	0.12	0.52	0.000	0.000	
	40	0	0.00	0.50	0.000	0.000	
		0	0.00	0.50	0.000	0.000	0.000
		0.00	0.00	0.50	0.000	0.000	
	50	0.00	0.00	0.49	0.000	0.000	
		0.00	0.00	0.49	0.000	0.000	0.000
		0.00	0.00	0.49	0.000	0.000	
	60	0.01	0.12	0.47	0.000	0.000	
		0.01	0.12	0.47	0.000	0.000	0.001
		0.02	0.24	0.47	0.000	0.001	
	Percolation						
Incorporated	10	0.14	1.68	0.48	0.001	0.006	
		0.12	1.44	0.48	0.001	0.005	0.005
		0.13	1.56	0.48	0.001	0.005	
	20	0.22	2.64	0.56	0.001	0.010	
		0.22	2.64	0.56	0.001	0.010	0.010
		0.22	2.64	0.56	0.001	0.010	
	30	0.23	2.76	0.52	0.001	0.010	
		0.23	2.76	0.52	0.001	0.010	0.010
		0.23	2.76	0.52	0.001	0.010	
	40	0.21	2.52	0.51	0.001	0.009	
		0.22	2.64	0.51	0.001	0.009	0.009
		0.23	2.76	0.51	0.001	0.010	
	50	0.21	2.52	0.52	0.001	0.009	
		0.22	2.64	0.52	0.001	0.010	0.009
		0.22	2.64	0.52	0.001	0.010	
	60	0.18	2.16	0.50	0.001	0.008	
		0.18	2.16	0.50	0.001	0.008	0.008
		0.18	2.16	0.50	0.001	0.008	
Surface crust	10	0.41	4.92	0.43	0.002	0.015	
		0.43	5.16	0.43	0.002	0.015	0.015
		0.42	5.04	0.43	0.002	0.015	
	20	0.37	4.44	0.47	0.002	0.014	
		0.39	4.68	0.47	0.002	0.015	0.015
		0.39	4.68	0.47	0.002	0.015	
	30	0.19	2.28	0.48	0.001	0.008	
		0.20	2.40	0.48	0.001	0.008	0.008
		0.20	2.40	0.48	0.001	0.008	
	40	0.16	1.92	0.49	0.001	0.007	
		0.15	1.80	0.49	0.001	0.006	0.006
		0.15	1.80	0.49	0.001	0.006	
	50	0.11	1.32	0.49	0.001	0.005	
		0.11	1.32	0.49	0.001	0.005	0.005
		0.12	1.44	0.49	0.001	0.005	
	60	0.07	0.84	0.46	0.000	0.003	
		0.08	0.96	0.46	0.000	0.003	0.003
		0.09	1.08	0.46	0.000	0.003	

	Time	Cumulative amount	Minimum	Maximum
Control	10	0.0205	0.0133	0.0343
	20	0.0234	0.0017	0.0039
	30	0.0237	0.0000	0.0004
	40	0.0237	0.0000	0.0000
	50	0.0237	0.0000	0.0000
	60	0.0242	0.0004	0.0008
Incorporated	15	0.0052	0.0048	0.0056
	30	0.0156	0.0103	0.0103
	45	0.0256	0.0100	0.0100
	60	0.0350	0.0090	0.0098
	90	0.0444	0.0091	0.0095
	120	0.0519	0.0076	0.0076
Surface	15	0.0150	0.0146	0.0153
	30	0.0299	0.0144	0.0152
	45	0.0378	0.0076	0.0080
	60	0.0441	0.0062	0.0066
	90	0.0487	0.0045	0.0049
	120	0.0518	0.0027	0.0034

Control: Controlled plot
Incorporated: Slurry mixed with soil
Surface crust: Application of slurry on the surface

Appendix 6 Water content on animal waste samples

DRIED GOAT DUNG FEMALE

	M0	M1	M2	
CAN no.	**Can weight**	**Can + Soil sample**	**Can + soil dried**	**WC (%)**
8	77.0112	77.4649	77.4303	0.0825579
11	76.3284	77.0658	77.0079	0.0852097
12	77.1974	78.096	78.0254	0.0852657
				0.084344

DRIED GOAT DUNG MALE

	M0	M1	M2	
CAN no.	**Can weight**	**Can + Soil sample**	**Can + soil dried**	**WC (%)**
17	76.394	77.1292	77.0705	0.0867701
24	76.8927	78.0592	77.9618	0.0911047
27	76.592	77.45	77.3806	0.0880041
				0.088626

FRESH GOAT DUNG FEMALE

	M0	M1	M2	
CAN no.	**Can weight**	**Can + sample**	**Can + dried sample**	**WC (%)**
32	76.65	82.15	78.72	166.19
44	76.73	82.78	78.99	167.05
46	76.43	84.89	79.46	179.27
				170.84

Amount of total nitrogen (T-N) on animal waste samples

Sample	*Amount of Sample (g)*	*Reading Value (mg/L)*	*Y*	*T-N*	*Average T-N*	*X10^-5*	*(mg/kg)*
Dried dung (Female) (June 2015)	0.01	1.83	2.20	1098.00	832.00	0.01	**8320.00**
	0.01	1.16	1.39	696.00			
	0.01	1.17	1.40	702.00			
Dried dung (male) (June 2015)	0.01	1.62	1.94	972.00	999.00	0.01	**9990.00**
	0.01	1.71	2.05	1026.00			
Fresh dung (Female) (December 2015)	0.01	0.85	1.02	510.00	513.00	0.01	**5130.00**
	0.01	0.86	1.03	516.00			

Amount of total phosphorus (T-P) on animal waste samples

Sample	*Amount of Sample (g)*	*Reading Value (mg/L)*	*Y*	*T-P*	*Average T-P*	*X10^-5*	*(mg/kg)*
Dried dung (Female) (June 2015)	0.01	0.71	0.852	426	424	0.00424	**4240.00**
	0.01	0.7	0.84	420			
	0.01	0.71	0.852	426			
Dried dung (male) (June 2015)	0.01	0.91	1.092	546	544	0.00544	**5440.00**
	0.01	0.9	1.08	540			
	0.01	0.91	1.092	546			
Fresh dung (Female) (December 2015)	0.01	0.95	1.14	570	574	0.00574	**5740**
	0.01	0.97	1.164	582			
	0.01	0.95	1.14	570			