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Land-use changes by Old Colonies Mennonites in Mexico with Sentinel 2 and Trends Earth

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ABSTRACT

The purpose of this article is to demonstrate land-use changes from forest to agriculture in Ejido Salamanca in the southern state of Quintana Roo in Mexico. This transformation from forest to agriculture was caused by Mennonites -an ethnic group originally from Chortitza today southern Ukraine-, that arrived in Mexico in 1922 from Canada. This land-use demonstration is based on satellite images Sentinel 2 of the Copernicus Program and a plugin called Trends Earth. As a result, we have shown a land-use change from forest to crops could have a stable result and organic carbon soil loss. Even though, these negative changes, have gained great productivity results (ha/ton production) in corn, soy, red bean, and sorghum and contribute to agriculture productivity in Quintana Roo and the zero-hunger goal.

Keywords: Mennonites, Old Colony Mennonites, Mexico, Sentinel 2, NDVI, NDWI, Trends Earth.

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I. INTRODUCTION

Most of the patterns of living observed in contemporary colonies of Mexico and South America were developed and established in the XIX century while they were living in Russia for almost 100 years from 1788 to 1870 in Colonies named Chortitza, Berghtal, and Molotschna [1, p. 7]. Most of their way of living was caused to protect themselves from thefts and violent groups, especially semi-independent Cossack groups that controlled most of the province of New Russia or Novorossia [2, p. 51]. Because of this threat, they decided to build houses close to each other making a village in the same way as they were doing in Russia. So, each property had 700 m of front yard and 1 km long, in this area they built a house and cultivated their food, as you could see in Fig. 1 taken from [3, p. 75], a Mennonite Community in Russia, in Molotschna in 1874, and, from these experiences, their way of life is related to extensive agriculture.

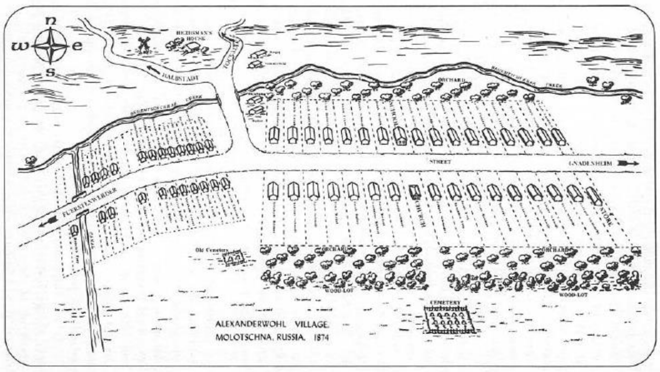


Fig. 1. Village Layout of the Alexanderwohl Mennonite Community in Russia (taken from [3]).

Mennonites arrived in Manitoba state in Canada from Russia in 1870 decade [4], [5]. During First World War, the Canadian government demanded local education for all citizens, therefore some Mennonites decided to migrate [5]. At that moment, during First World War, Canada was afraid of foreign groups and on March 10, 1916, the Manitoba government-imposed English as the only language of instruction in schools, which became known as the "School Attendance Act" for all children between seven and fourteen years old. So, private schools had to meet the same standards as public ones. But Mennonites were teaching in Low German (Plautdietsch) in their own schools so, in the fall of 1918, these schools were closed [6, p. 884], [5]. Logically, some Mennonites felt betrayed by the Canadian government because they have signed an agreement called *Privilegium*, which stipulated respect for their way of life, and their own private education system [7].

This was the main reason to leave Canada, and President Obregon accepted to sign a *Privilegium* in Mexico, so on March 7, 1922, a group of 215 Mennonites arrived at Valle Bustillos in the state of Chihuahua migrating from Manitoba in Canada [8], then about 6,000 Mennonites from Old Colony and Sommerfelder not only from Manitoba also from Saskatchewan traveled across the western United States to El Paso and then into Mexico [7, p. 40], [9]. Then, they migrated to Paraguay in 1927 [10, p. 133], Belize in 1957 [11, p.335], and recently to Bolivia [12]. In 2017, 300 Mennonites arrived in Colombia, they bought 16,000 ha near 90 km from Puerto Gaitan in the department of Meta [13].

In a conclusion, Mennonites have the same cultural practice language, religion, work, and agriculture models, all of them strengthened while they were living in Russia and have developed this way of life through different countries in the American continent, finally is a way of land colonization and a way of living based on extensive agriculture [14].

In another side, Earth observation data and geospatial information has become a powerful tool to analyze the different changes over the land. NASA ARSET has promoted an online course to teach how to use Trends.Earth. This is a plugin that works with multiple versions of QGIS and aims to evaluate two Sustainable Development Goals - SDG, SDG number 11 which corresponds to "Sustainable cities and communities" and SDG number 15 which corresponds to "Life on land" in relation to ecosystems. In this paper, we are using SDG number 15:

> "Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
> Each SDG has specific targets addressing different components, in this case, Target 15.3 aims to:
> By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought, and floods, and strive to achieve a land degradation-neutral world.
> The progress towards a land degradation neutral world will be assessed using indicator 15.3.1: proportion of land that is degraded over the total land area" [15].

Also, this study uses Sentinel Satellite images from European Space Agency Program that through a Scihub were freely available. Studies with Sentinel Images are contemporary because the Sentinel 2A mission was born on June 23rd, 2015, and Sentinel 2B was born on June 7th, 2017. These missions last for around 7.25 years and both spacecraft are 786 km orbit highest from the Earth, covering the same area every 5 days [16]. Some advantages of Sentinel images are related to its 13 bands and 10 m pixel resolution that allows for making better visible vegetation analysis. Sentinel 2 use is increasing in different areas, some examples: are crops [17], mangroves in Colombia [18], precision agriculture [19], and biomass measure [20].

Other studies have identified agriculture as an important driver of forest loss in the world while the United Nations Food and Agriculture Organization estimates 815 million people were suffering from chronic undernourishment in 2016, and almost most of them are in developing countries. But also, developing countries must accomplish biodiversity goals. For example, studies identified agriculture as an important driver of forest loss in the Andes [21], and the loss of croplands contributes to new forests and increases habitat for many species [22]. Other studies explained how Andean subsistence agriculture is vulnerable to socioeconomic and climate changes [23], [24], in this case, Mennonites agriculture showed the capability of adaptation to different climate temperatures, from the lowest winter in Canada to the highest level of temperatures in Belize or Campeche in Mexico. Through a century, Mennonites have transformed Mexico, for example, very dry land in Chihuahua into one of the most important agro-industrial corridors.

We propose the Mennonite model of agriculture that transforms the forest into croplands and contributes to reducing people's hunger in the world, in this case, even though this seems a paradox, helps to achieve SDG number 2 which is zero hunger.

II. Study Area Location and Context

Fig. 2 presents the geographical location of Ejido Salamanca of Municipality of Bacalar, centered around 18°40′45″N, 88°29′10″W, 15 m above sea level (asl) in the southern state of Quintana Roo (demarcated at the bottom left corner), Mexico.

From west to east 8.88 km and from south to north is 10.05 km even though it is not a perfect square as the shapefile showed. It is approximately 5.000 ha of crops, pastures, and forests. Recently Salamanca has become the most productive center with the highest productivity of hybrid corn in Quintana Roo state, 4.5 Ton per ha and, they have a significant production of soy [25].

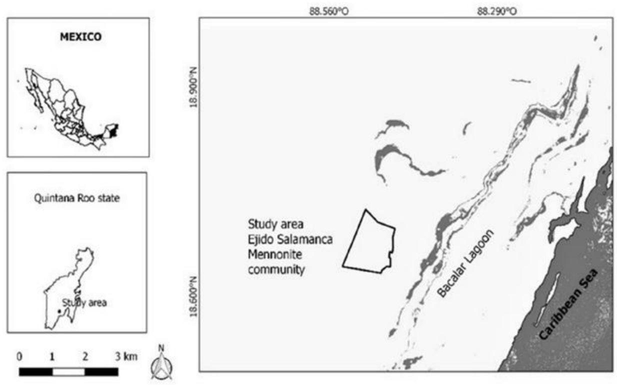


Fig. 2. Map of the location of the study area: Ejido Salamanca at Quintana Roo state in Mexico.

In the year 2010, Mennonites bought around 5,000 ha of land from Bacalar's owners. Also, they recruited a local consultant firm of agronomists and biologists which presented a document to local government institutions asking for a land-use change. Before this document, the Secretary of Environment and Natural Resources - SEMARNAT authorized a change of land use to an area of 960 ha through document No. 04/SGA/372/2003 date November 21st of 2003, and document No. 03/ARRN/0892/2003 date December 17th of 2003. Then, with this document Mennonite community asked SEMARNAT for the second land use approval, which corresponds to 4,04 ha, oriented to three large areas: agricultural, forest, and conservation (ecological corridors) to meet Mexican official norm NOM 062 SEMARNAT 1994 [26]. According to official norms and SEMARNAT authorizations, Salamanca is 4,040 ha as follows:

- 2,420.34 ha agricultural corresponds to 59.91%.
- 1,452.72 ha forest corresponds to 35.96%.
- 166.94 ha conservation (ecological corridors) corresponds to 4.13%.

III. Materials and Methods

A. Fieldwork

Carroll has spent time with this community at Ejido Salamanca in August 2012, February and July 2014, and

April 2018. The author has done fieldwork after finishing his doctoral thesis and explored some other issues in relation to agriculture as described in Fig. 3 which have dates and coordinates.

B. *Satellite Data*

We have downloaded four products for this study for the years 2015, 2016, 2018, and 2020 described as follows:

- Image 20151003 (the year 2015, month 10, day 03) Sentinel 1C without atmospheric correction.

Product start time: 2015-10-03T16:38:16.027Z and product stop time: 2015-10-03T16:38:16.027Z.

This product has a 9.8025% cloud coverage assessment.

Specific details about this product can be found in Sentinel at Copernicus' scihub int the following web address: (https://scihub.copernicus.eu/dhus/odata/v1/Products('62b0e322-3756-42a6-b15a-1aa105176243')/$value).

- Image 20160210 (the year 2016, month 02, day 10) Sentinel 1C without atmospheric correction.

Product start time: 2016-02-10T16:24:12.029Z and Product stop time: 2016-02-10T16:24:12.029Z.

This product has a 6.8711% cloud coverage assessment.

Specific details about this product can be found in Sentinel at Copernicus' scihub int the following web address: (https://scihub.copernicus.eu/dhus/odata/v1/Products('4696d275-a2f5-4deb-b7c8-9274c2b8a53c')/$value).

- Image 20180515 (the year 2018, month 05, day 15) Sentinel 1C without atmospheric correction.

Product start time: 2018-05-15T16:18:29.027Z and product stop time: 2018-05-15T16:18:29.027Z.

This product has a 14.1281% cloud coverage assessment.

Specific details about this product can be found in Sentinel at Copernicus' scihub int the following web address: (https://scihub.copernicus.eu/dhus/odata/v1/Products('9127643f-9b74-46d3-b542-f2f64bdd5009')/$value).

- Image 20200519 (the year 2020, month 05, day 19) Sentinel 1C without atmospheric correction.

Product start time: 2020-05-19T16:19:11.024Z and product stop time: 2020-05-19T16:19:11.024Z.

This product has a 36.98% cloud coverage assessment.

Specific details about this product can be found in Sentinel at Copernicus' scihub int the following web address: (https://scihub.copernicus.eu/dhus/odata/v1/Products('89a1fdb9-26f9-4e9c-a1e2-39108bb4a4af')/$value).

C. *Satellite Data Processing*

We have analyzed the following bands of Sentinel 1C images: Band 2 (490 nm), Band 3 (560 nm), Band 4 (665 nm) in the visible spectral (VNIR), and Band 8 (842 nm) in spectral SWIR.

To each satellite image of Sentinel 2 was applied an atmospheric correction with Semi-Automatic Classification complement [27] and then a reprojection from EPSG:32616 – WGS 84 / UTM zone 16N to EPSG:4326 - WGS 84 in QGIS and reflectance data to obtain the following indexes. Values of NDVI and NDWI for each year were processed in R Studio.

Also, Normalized Difference Water Index – NDWI [28] in a mathematical expression is defined as follows:

$$NDWI = \frac{\text{rgreen} - \text{rSWIR}}{\text{rSWIR}}$$

where rgreen and rSWIR are the reflectance registered from a given direction by the sensor in the green and short-wave infrared ranges respectively. In Sentinel 2 rgreen is equivalent to Band 3 and rSWIR is equivalent to Band 8, so the equation can be written as follows:

$$NDWI = \frac{\text{Band 3} - \text{Band 8}}{\text{Band 3} + \text{Band 8}}$$

Fig. 3. Photos with dates and coordinates of crops in Salamanca.

In the same way, Normalized Difference Vegetation Index – NDVI is a measure of healthy and quality vegetation [29] and its mathematical expression is described as follows:

$$NDVI = \frac{\text{rSWIR} - \text{rRed}}{\text{rSWIR} + \text{rRed}}$$

In Sentinel 2 rSWIR is equivalent to Band 8 and rRed is Band 4, so the equation for NDVI will be written as follows:

$$NDVI = \frac{\text{Band 8} - \text{Band 4}}{\text{Band 8} + \text{Band 4}}$$

D. Trends.Earth Plugin processing

Trends.Earth algorithm is based on the following remote sensors and datasets:

- **“NDVI information is based on:** Sensor/Dataset: AVHRR/GIMMS, Temporal: 1982-2015, Spatial: 8km, Extent: Global, License: Public domain.

Sensor/Dataset: MOD13Q1-coll6, Temporal: 2001-2016, Spatial:250 km, Extent: Global, License: Public domain.

- **Soil moisture information is based on:** Sensor/Dataset: MERRA 2 1980-2016, Temporal: 1980-2016, Spatial: 0.5×0.625°, Extent: Global, License: Public domain.

Sensor/Dataset: ERA, Temporal: 1979-2016, Spatial: 0.75°x0.75°, Extent: Global, License: Public Domain.

- **Land Cover information is based on:** Sensor/Dataset: ESA CCI Land Cover Temporal: 1992-2018, Spatial: 300 m Extent: Global, License: CC by-SA 3.0.
- **Soil Carbon information is based on:** Sensor/Dataset: Soil Grids (ISRIC), Temporal: Present, Spatial: 250 m, Extent: Global, License: CC by-SA 4.0” [15].

IV. Results and Discussion

A. Normalized Difference Vegetation Index – NDVI

Chlorophyll concentration and foliage define together NDVI values, which are in a continuous range between -1.0 and 1.0. Even though a continuous value of negative values close to -1.0 would indicate sparse vegetation such as rock, snow, and/or sand, was defined as no vegetation <= -0.667. So, values between -0.667 and -0.333 would explain the presence of sparse vegetation; values between -0.333 and 0.333 would explain the presence of land for sowing; values between 0.333 and 0.667 would explain moderate vegetation growing crops and grasslands; values greater than 0.667 would explain crops to harvest, and values close to 1 explain healthy vegetation and dense vegetation.

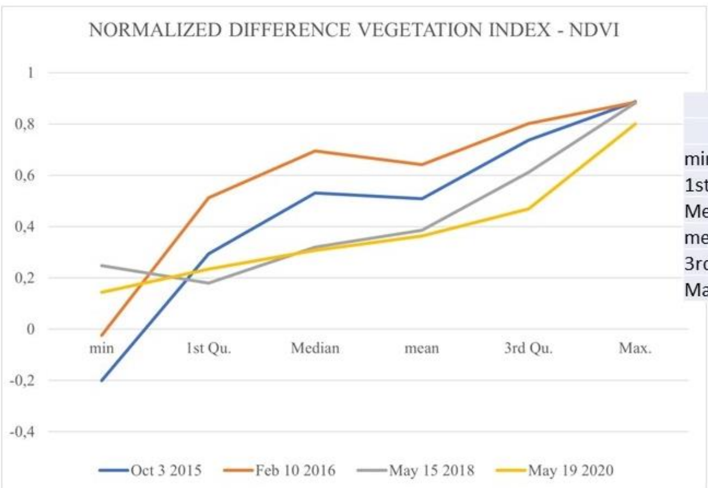
In Fig. 4, we present values of NDVI of each satellite image, minimum value, 1st quarter, median, mean, 3rd quarter, and maximum value. Even though curves are similar, observe some values above others, specifically images of October 2015 and February 2016 have higher values than figures of May 2018 and May 2020 because higher values of NDVI represent growing and harvesting crops, while lower values of NDVI represent land that has been prepared for sowing.

Fig. 5 shows that major transitions detected in our analyses for 2015, 2016, 2018, and 2020 satellite images were between areas classified as crops which included pastures and main crops such as corn, soy, bean, and sorghum. Also, we identified higher values of NDVI surrounding the total area which corresponds to dense vegetation and forest.

B. Normalized Difference Water Index – NDWI

The NDWI takes continuous values in the range between -1.0 and 1.0, where values close to -1.0 are no water, water stress, or absence of moisture, and values close to 1 explain the presence of bodies of water such as rivers, lagoons, and/or artificial bodies of water. In Fig. 6, curves are very close to each other indicating the absence of bodies of water. In the curves, maximum values of NDWI are between 0 and 0.026. Agriculture techniques include drawing water from wells. Mennonites are recognized in the region for their technique of making water wells.

Fig. 7 presents the results of NDWI for 2015, 2016, 2018, and 2020 satellite images with R.



NDVI SALAMANCA	Oct 3 2015	Feb 10 2016	May 15 2018	May 19 2020
min	-0,2002874	-0,02410731	0,2482981	0,142857
1st Qu.	0,2936303	0,5123087	0,1795761	0,2339364
Median	0,5314637	0,6945108	0,3201581	0,3069231
mean	0,5086481	0,6415036	0,3859598	0,3634284
3rd Qu.	0,737117	0,8010408	0,6112692	0,4681574
Max.	0,8878254	0,8851377	0,8818819	0,80094

Fig. 4. Curves and Table of Normalized Difference Vegetation Index in Salamanca.

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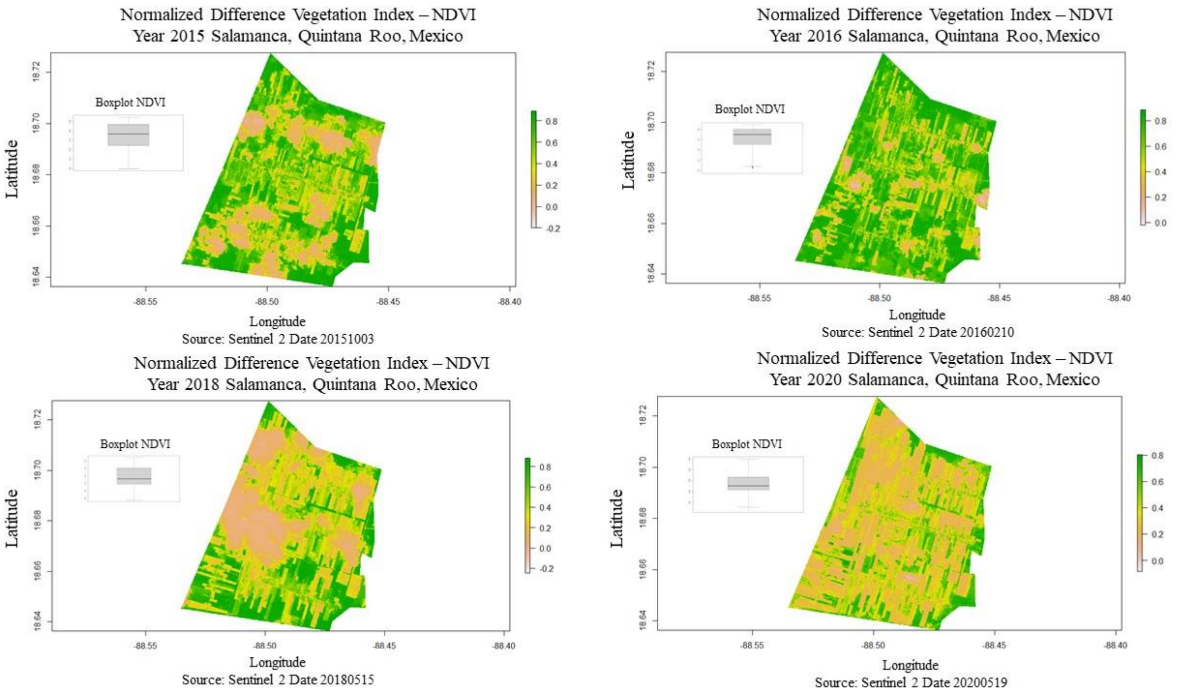
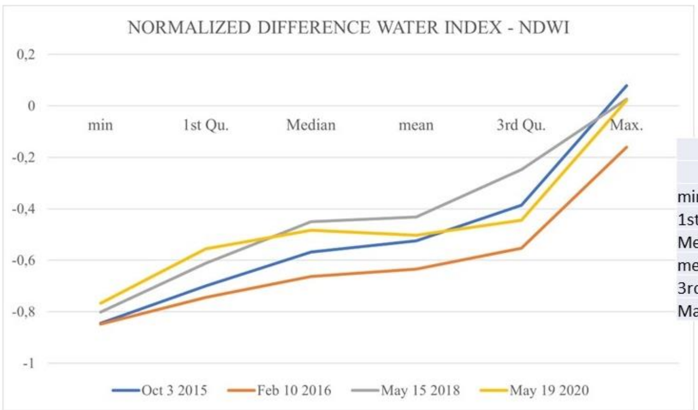


Fig. 5. Normalized Difference Vegetation Index in Salamanca for the years 2015, 2016, 2018 and 2020.



NDWI SALAMANCA				
	Oct 3 2015	Feb 10 2016	May 15 2018	May 19 2020
min	-0,8452314	-0,848101	-0,8013402	-0,7674539
1st Qu.	-0,6994992	-0,7442283	-0,6112257	-0,55588063
Median	-0,5678487	-0,6629792	-0,45	-0,4832918
mean	-0,5248709	-0,6340163	-0,4321035	-0,5025535
3rd Qu.	-0,3856159	-0,5534884	-0,2473703	-0,444383
Max.	0,0789619	-0,1604076	0,02640402	0,02097187

Fig. 6. Curves and Table of Normalized Difference Water Index in Salamanca.

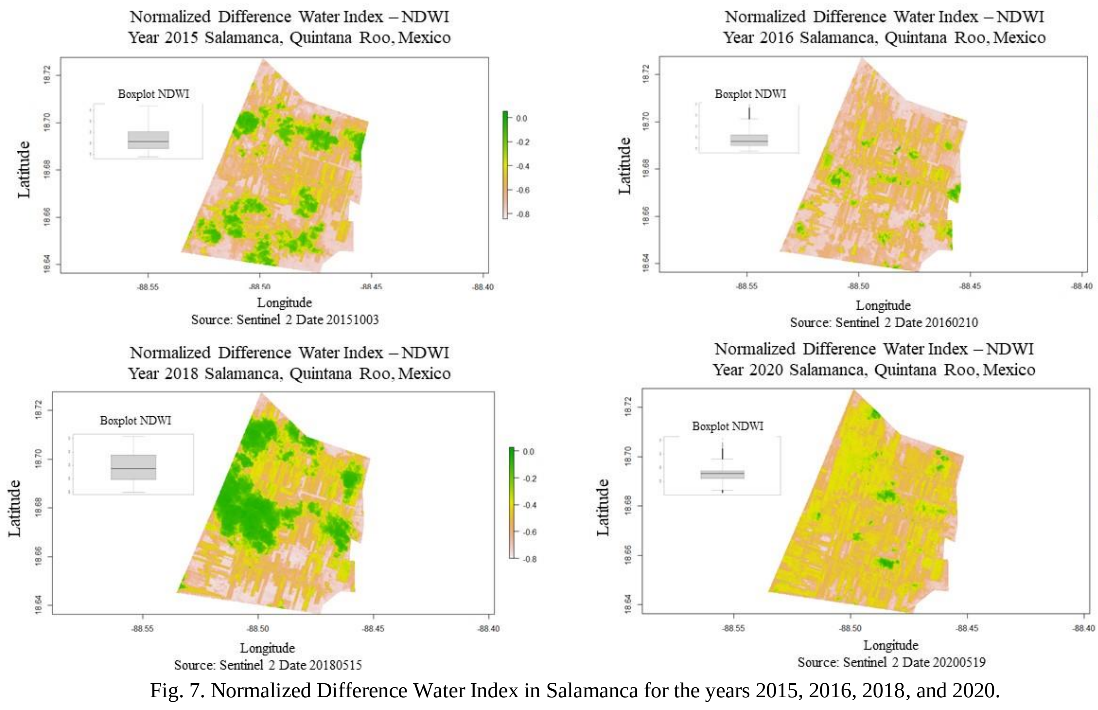


Fig. 7. Normalized Difference Water Index in Salamanca for the years 2015, 2016, 2018, and 2020.

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C. Soil Organic Carbon's change 2001 and 2015

Fig. 8 shows a loss of soil organic carbon (tons/ha). In 2015 you can appreciate that values go to zero represented as dark green and black, while in 2000 figures show Salamanca with green and yellow colors which mean more soil organic carbon. This is a result of using agrochemicals in the agriculture model. A recommendation will be to reduce this use and avoid soil depletion.

D. Changes in Land Cover

In the following Fig. 9 Trends.Earth analysis showed that in 2001 Salamanca was tree covered with only a few parts of grasslands and crops. While, in 2015 with the Mennonites agriculture model, this proportion of tree-covered was substantially reduced to a few parts, and instead, croplands and grassland cover the more part of the community area.

In Trends.Earth plugin we have modified variables give them for default. Based on our local knowledge of the conditions in the study area and the land degradation process occurring there, we have modified the table available in Trends.Earth plugin which transitions correspond to degradation (-sign in red color), improvement (+ sign in green color), or no change in terms of land condition (zero).

In the first model, a restricted model, the same as default, our input variables assume that any change from forest to grassland will be in a negative effect and from forest to cropland also will give us a negative effect. In the following Fig. 10, a negative effect is remarked in red color and a positive effect is remarked in green. While a neutral effect is a remarked with a zero number.

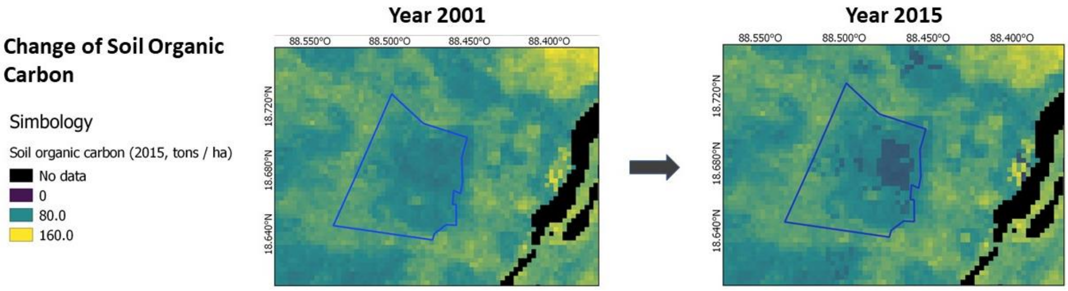

Fig. 8. Change of Soil Organic Carbon from the year 2001 to the year 2015.

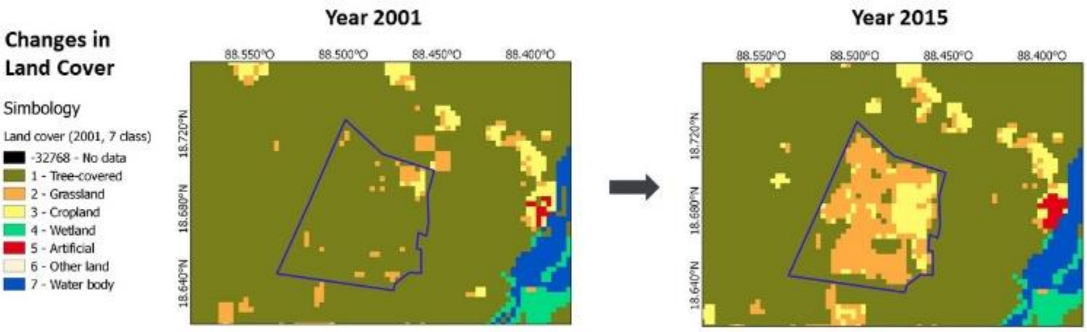

Fig. 9. Changes in Land cover from the year 2001 to the year 2015.

Land Cover Degradation

RESTRICTED MODEL (Forest to grassland is a negative effect and forest to cropland is a negative effect)

	Forest	Grassland	Cropland	Wetland	Artificial area	Bare land	Water body
Forest	0						0
Grassland		0					0
Cropland			0				0
Wetland				0			0
Artificial area					0		0
Bare land						0	0
Water body	0	0	0	0	0	0	0

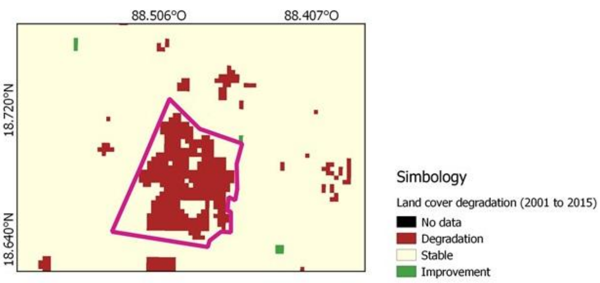

Fig. 10. Degradation in Land Cover with restricted model,

Land Cover Degradation

LESS RESTRICTED MODEL Forest to grassland is a neutral effect (zero) Forest to cropland is a neutral effect (zero)

	Forest	Grassland	Cropland	Wetland	Artificial area	Bare land	Water body
Forest	0	0	0				0
Grassland		0					0
Cropland			0				0
Wetland				0			0
Artificial area					0		0
Bare land						0	0
Water body	0	0	0	0	0	0	0

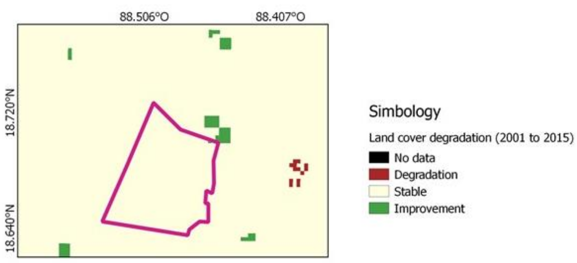

Fig. 11. Degradation in Land Cover with a less restricted model.

Then, in the second model in Fig. 11, the less restricted model, we will assume that from forest to grassland is going to have a neutral effect and from forest to cropland is also going to have a neutral effect. We have done this assumption because we consider that agriculture extensively has the purpose of feeding people and in this way, Mennonites are making a neutral effect on land change transformation.

V. Conclusions

To compare year-by-year agriculture indexes such as NDVI which explain the health of plants must be necessary to download images of the same period. In that way, if February is a month of harvesting beans, it must be necessary to analyze the same period in other images. Inconvenience arrived with a high cloud coverage percentage, even though we have downloaded the four best images for these years in this study area and with less cloud coverage, the years 2015 and 2018 cloud coverage made noise in the results and was not able to download a good image for the year 2019.

Also, the values of NDWI could give information to the farmer and policymakers about what type of crops will be better to seed. If values of NDWI are very low as we have observed in the results, the best crops could be those that require less water.

Finally, even though satellite images of 10 m of resolution such as Sentinel 2 and Trends Earth's algorithm are better to understand changes in large areas, this study case gives an overview of a decade of changes in land use from forest to crops caused by Mennonites, a specific ethnic group which has great knowledge in extensive agriculture. To analyze specific changes in crops and their productivity we recommend precision agriculture based on unnamed aerial vehicles or drones and more fieldwork data.

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