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Map of Agricultural Potential in Bolivia

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Abstract:

In this paper we develop a high-resolution map of agricultural potential in Bolivia by combining existing economic and geographical information at the most disaggregated level possible. We assume that farmers know which crops are most suitable for their environment and circumstances, and therefore start by determining the most common crop/livestock in each municipality, as well as the average yields and prices for these crops. We then proceed to develop a high-resolution Production Cost Factor, which depends on physical conditions (e.g. slope, soil quality, precipitation, minimum and maximum temperatures, etc.) as well as legal restrictions (e.g. protected area, near river, etc.). This allows us to generate a map of the net annual agricultural value per hectare. Finally, we calculate the net present value of agriculture by taking into account how many years a plot is typically continuously cultivated in each municipality. The resulting shapefile with the Map of Agricultural Potential in Bolivia accompanies this paper and can be downloaded here: https://drive.google.com/drive/folders/1Oal7D_efneqASRJd_XzAhNTwRFkPeovi?usp=sharing

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JEL Classification: O13, Q10, R32

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1. Introduction

There is often a perceived conflict between biodiversity conservation and human development, but Bolivia is a large and geographically diverse country with plenty of room for both. The trick is to conserve the areas that are most valuable in terms of biodiversity protection, ecosystem services, and scenic beauty while cultivating the areas with the best soils, appropriate climate, and good accessibility.

While our understanding of biodiversity hotspots and conservation priorities have advanced substantially over the last several decades thanks to the work of biologists and conservation organizations (e.g. Myers et al., 2000; Ibisch & Mérida, 2003; Soria Auza & Hennessey, 2005; and CEPF (2021), very little is known about agricultural potential in different parts of the country.

In this paper we develop a high-resolution map of agricultural potential in Bolivia, which we hope will help make better decisions, for example on where to encourage rural settlements, where to grant deforestation permits, and where to create new protected areas.

The map is inspired by the global map of economic benefits from agricultural lands developed by Naidoo & Iwamura (2007), which integrate spatial information on crop productivity, livestock density, and prices to produce a global map of the gross economic rents per hectare from agricultural lands.

We use the same first steps, but at a finer geographical resolution, and then we add two more set of steps in order to arrive at the Net Present Value of the net economic benefits of potential agricultural lands. The second set of steps take into account variations in production costs in order to arrive at the net agricultural benefits per hectare. And the third set of steps calculates the Net Present Value by taking into account how many years these agricultural activities can typically be sustained in each location.

While this detailed map of net benefits is potentially more useful for decision making than the rough map of gross benefits by Naidoo & Iwamura (2007), it is by no means perfect. Neither is it deterministic. It represents the likely benefits that can be obtained at scale, with local knowledge and resources, at any given location, but it is perfectly possible to obtain much higher benefits per hectare (for example if resources were available to invest in greenhouses, irrigation, genetic modification, etc.). It is also possible to obtain much lower benefits (for example if the farmer is a recent immigrant with no knowledge of local conditions, or simply due to bad luck with the weather).

Thus, the map should not be used to make farming decisions on any specific site, but rather be used to guide the design of public policies aiming at the goal of living well in harmony with nature.

2. Methodology

The methodology used to develop the map includes the following major steps, which are developed in detail further below:

1) Determine the most common agricultural product in each municipality.
2) Determine the average yield of that crop in each municipality.
3) Determine the average price of the most common product.
4) Calculate the average gross value per hectare per year of the most common product in each municipality.
5) Assess the relative level of production costs, depending on physical and legal restrictions.
6) Calculate annual net value.
7) Calculate average duration of agricultural activities.
8) Calculate the net present value of agricultural activity per hectare.

2.1. Step 1 - The most common agricultural product in each municipality

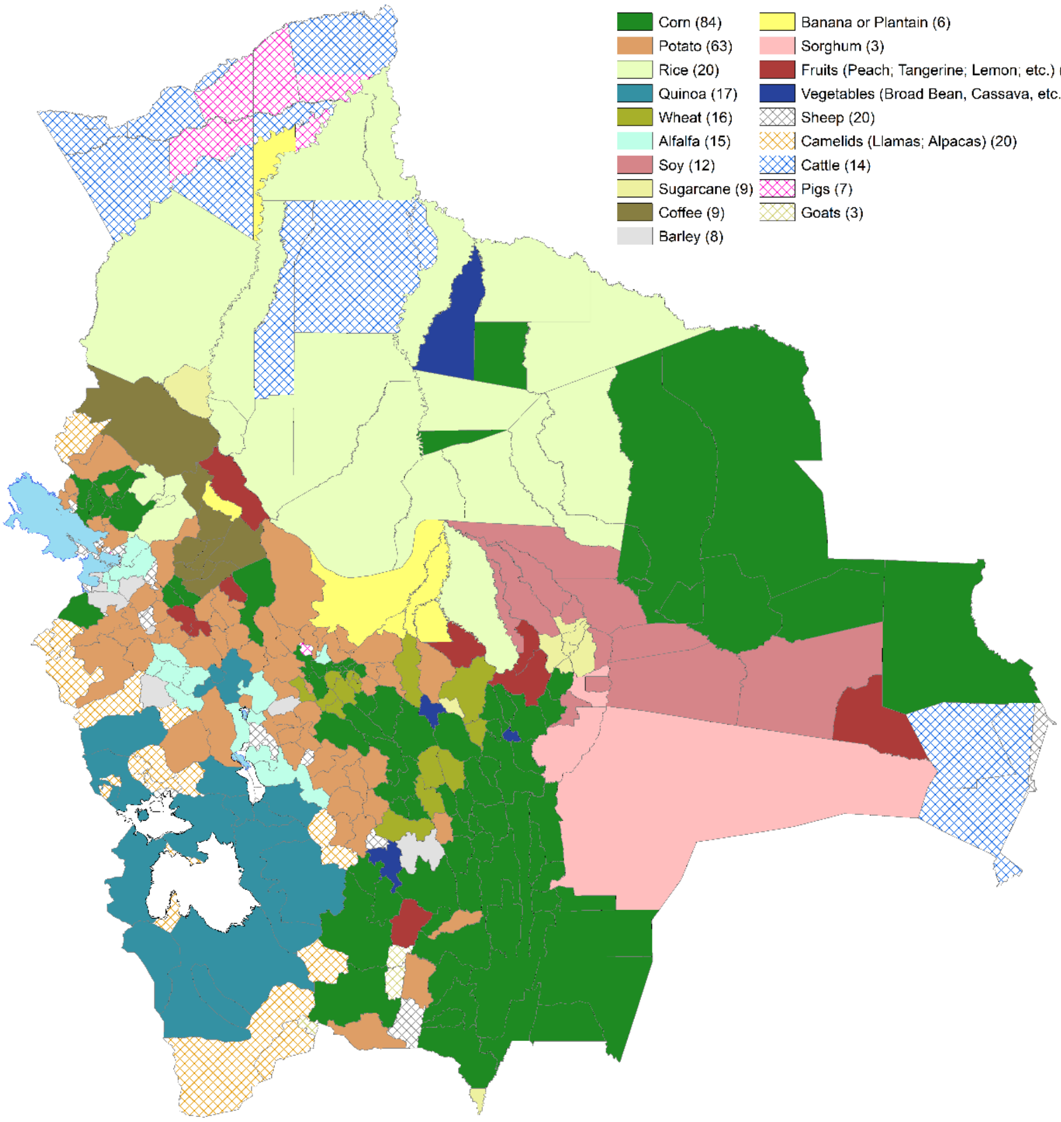
Due to dramatic altitudinal differences (ranging between 90 and 6,542 meters above sea level), Bolivia is a geographically diverse country with climates ranging from cold and dry to hot and humid, and everything in between. This variation means that different regions are appropriate for different crops. Some regions are not suitable for crops, but can still be used for livestock grazing.

Using information from the Integrated System of Production Information (SIIP) of the Ministry of Productive Development and Plural Economy (MDPyEP, n.d.), which contains data for more than 70 different crops cultivated in Bolivia,[1] we identified the dominant agricultural product (in terms of average cultivated area between 2016 – 2021) in each municipality. Some municipalities had very little agriculture (less than 500 hectares)[2], but instead relied on livestock grazing. Among the municipalities with hardly any agriculture, we found 20 municipalities where the main agropastoral land use was dedicated to sheep, 20 to llamas, 14 to cattle, 7 to pigs, and 3 to goats (see Map 1).

Since agriculture generally provides much higher income per hectare than livestock the map below gives priority to agricultural products, and only use livestock in case there is no significant agricultural activity in a municipality (less than 500 hectares).

[1] Information for 6 municipalities has not been found exploring SIIP data (Cochabamba, Colcapirhua, Chua Cocani, Huatajata, Oruro, Yunguyo del Litoral). For these municipalities information from Banco de Desarrollo Productivo (BDP) has been used to fill the main product information of these municipalities.
[2] Municipalities with less than 500 hectares according to SIIP were double-checked in other sources like BDP and MapBiomas, to confirm or discard them as agricultural or livestock.

Map 1: The most common agricultural product in each Bolivian municipality, 2016-2021



Source: Authors' elaboration based on information from MDPyEP (n.d.)

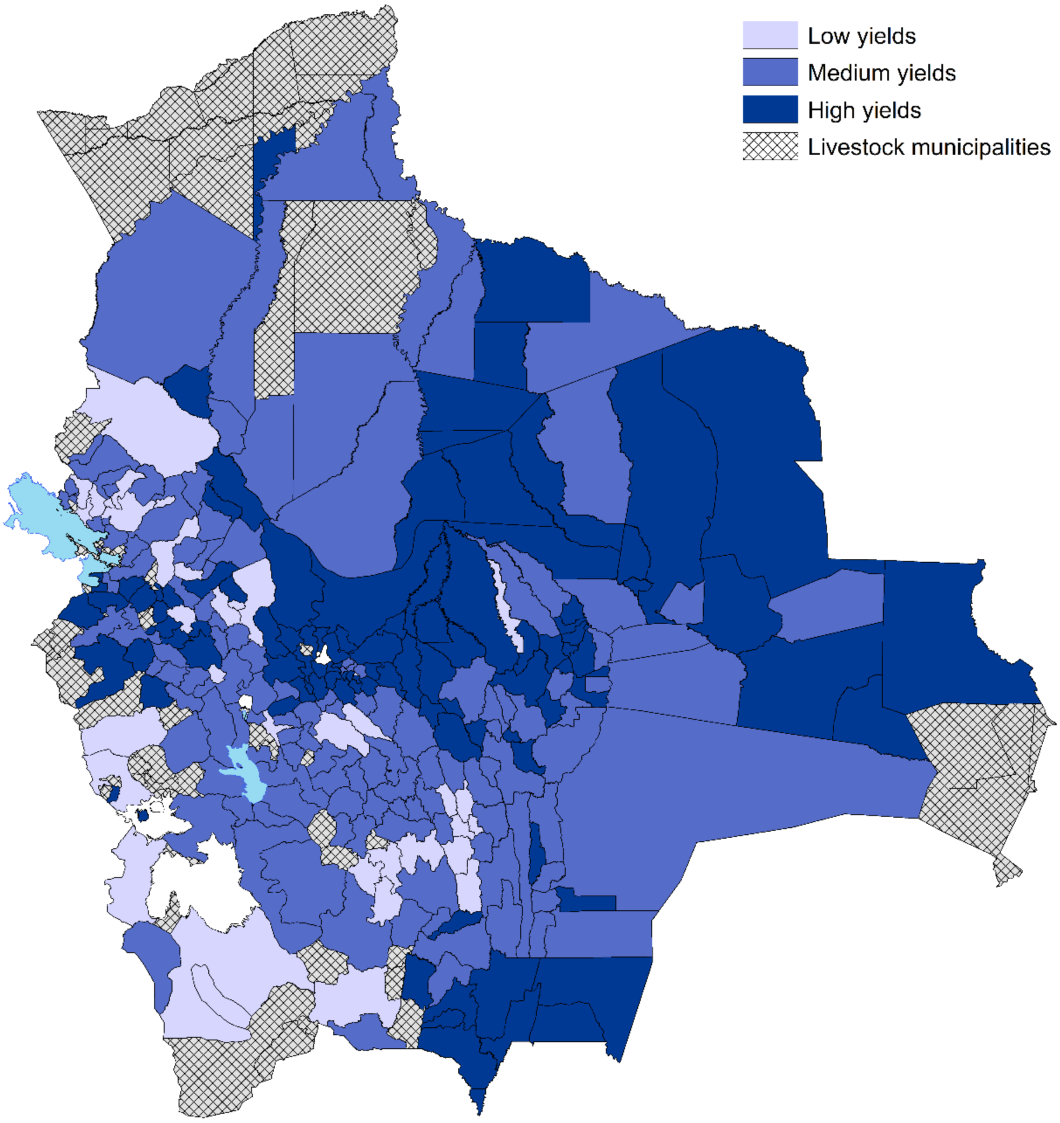
In 84 of the 339 municipalities in Bolivia, corn was the most widely cultivated crop, while potatoes were the most common in 63 municipalities. These were followed by rice (20 municipalities), quinoa (17), wheat (16), alfalfa (15), and soybeans (12 municipalities). Coffee and sugar cane are each the top crop in 9 municipalities, while barley is the most common in 8. The remaining municipalities have specialized in more unusual crops, usually specific fruits. For example, Camargo has specialized in peaches, while Bulo Bulo has specialized in pineapples.

2.2. Step 2 - Average yield of the most common crop in each municipality

The yields of the most common crops vary by municipality, because of differences in soil and climatic conditions. For example, potato yields are generally above 10 t/ha in the lowland department of Santa Cruz, while they are below 3 t/ha in the highland department of Oruro. Similarly, corn yields are typically above 4 t/ha in Santa Cruz, but below 2 t/ha in most highland municipalities.

For each of the main crops from Map 1, average yields per municipality were divided into quartiles, and the municipalities in the lowest quartile are considered “low yields”, the municipalities in the highest quartile “high yields”, and the rest “medium yields” (see Map 2).

Map 2: Average crop yield for the most common crop in each Bolivian municipality, 2016-2021



Source: Authors’ elaboration based on information from MDPyEP (n.d.).

2.3. Step 3 - Average producer prices for most common products, 2016-2018

Table 1 shows the average producer price for the most common crops in Bolivia during 2016-2018 (latest data available), according to data from FAOSTAT (https://www.fao.org/faostat/en/#data/PP).

Table 1: Average producer price for most common crops, 2016-2018 (USD/ton)

Most common products in terms of area (ha)	Number of municipalities	Producer prices, average 2016-2018 (USD/ton)
Corn	84	354
Potato	63	270
Rice	20	305
Quinoa	17	901
Wheat	16	346
Alfalfa	15	106
Soy	12	292
Coffee	9	1,305
Sugarcane	9	68
Barley	8	209
Banana	4	272
Sorghum	3	114
Plantain	2	182
Peach	2	640
Tangerine	2	182
Cassava	1	210
Broad Bean	1	299
Lemon	1	230
Orange	1	182
Pineapple	1	216
Common Bean	1	1,070
Tomato	1	239
Prickly Pear	1	526
Mango	1	183

Note: Due to lack of information for Bolivia, the prices for peaches, pineapples, plantains, lemons, oranges, beans and mango are from Peru, while the price for bananas are from Brazil. The price of alfalfa was nowhere to be found in the FAO data base, and was calculated from alternative 2023 data from Argentina with an agricultural exchange rate of 350 pesos/USD. Finally, the price of prickly pears (cactus fruits) could not be found, and we just assumed it was the same as regular pears.

Source: Authors' elaboration based on information from FAOSTAT (https://www.fao.org/faostat/en/#data/PP).

To calculate an estimated value per hectare for livestock municipalities, data was retrieved on the number of heads per hectare that can be produced, by type of animal, tons of meat produced per head, and price per ton of meat, which are shown in Table 2.

Table 2: Average yield (ton/head) and producer price (USD/ton) for most common livestock products, 2016-2021

Livestock product	Number of municipalities	Heads per hectare (estimated)	Tons of meat per head	Price (USD/ton)
Sheep	20	11	0.0198	1,630
Llamas	18	25	0.0442	715
Cattle	14	0.56	0.198	895
Pigs	7	11	0.059	460
Goats	3	0.45	0.0201	1,707
Alpacas	2	25	0.0442	715

Note: The heads produced per hectare were estimated from the latest agricultural census (INE, 2013) using records of municipalities with almost exclusive livestock production of the products mentioned in the table.

Source: Authors' elaboration based on FAOSTAT: Prices based on information from FAOSTAT (https://www.fao.org/faostat/en/#data/PP) Llamas and Alpacas prices were based on data from Peru due to lack of information for Bolivia. Yield/Carcass Weight based on information from FAOSTAT (https://www.fao.org/faostat/es/#data/QCL).

2.4. Step 4 – Calculate the average gross value per hectare per year of the most common product in each municipality

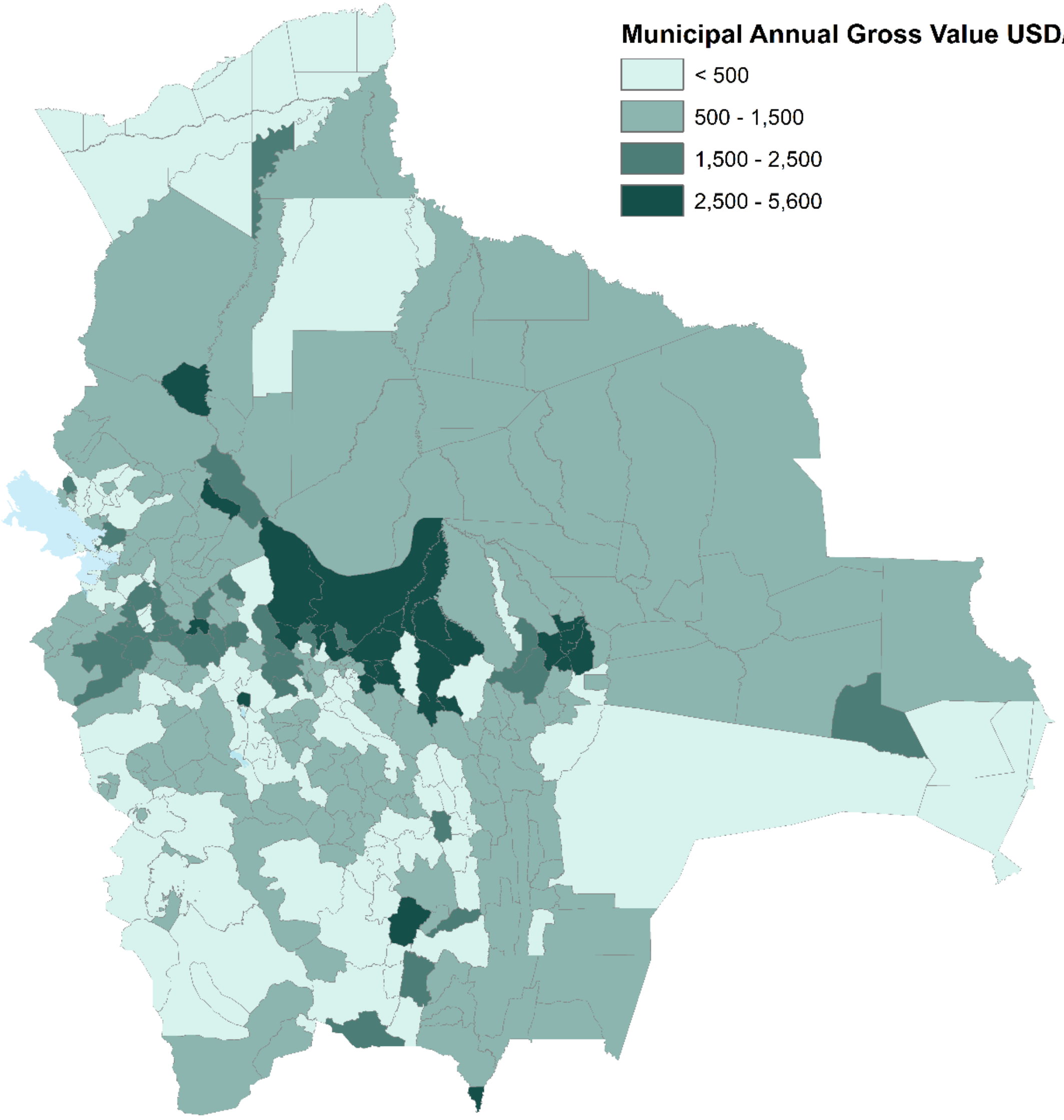
The average annual gross value per hectare for the most common product in each municipality is calculated by multiplying average yields (ton/ha) by average price (USD/ton) for agricultural municipalities and by multiplying stocking capacity (heads/ha) by yield (ton/head) by price (USD/ton) for livestock municipalities. Map 3 shows the resulting average gross value per hectare for the most common product in each municipality during the period 2016-2021.

The municipalities with the highest gross value per hectare are the ones specializing in fruits. At the top of the list are producers of bananas in the department of Cochabamba and one in La Paz, then pineapples and peaches. Sugar cane also has a gross value over 2,500 USD/ha/year in most places.

Municipalities below the median gross value are mainly in the southwest of the country, producing barley, alfalfa, and other products with low yields. The department of Pando, as well as several municipalities in the Chaco region also stand out with very low gross value per hectare.

Notice that Map 3 is based on the most common product in each municipality during the 2016-2021 period, and other products produced in the same municipality may produce either higher or lower gross values. We assume that the most common crop is representative for the calculation of potential revenues, but in reality, every municipality produces a range of agricultural products. In many municipalities, this average has been calculated based on only a small portion of the municipality area, as most of Bolivia is still covered in forest or other natural vegetation, so the map reflects potential, rather than actual gross values.

Map 3: Average annual gross value for the most common product in each Bolivian municipality, 2016-2021 (USD/ha/year)



Source: Authors' elaboration based on information from MDPyEP (n.d.) and FAOSTAT.

2.5. Step 5 – Assess the relative level of production costs, depending on physical and legal restrictions

The costs of cultivation can vary substantially within each municipality, depending on soil quality, climate, slope of the terrain, as well as legal restrictions.

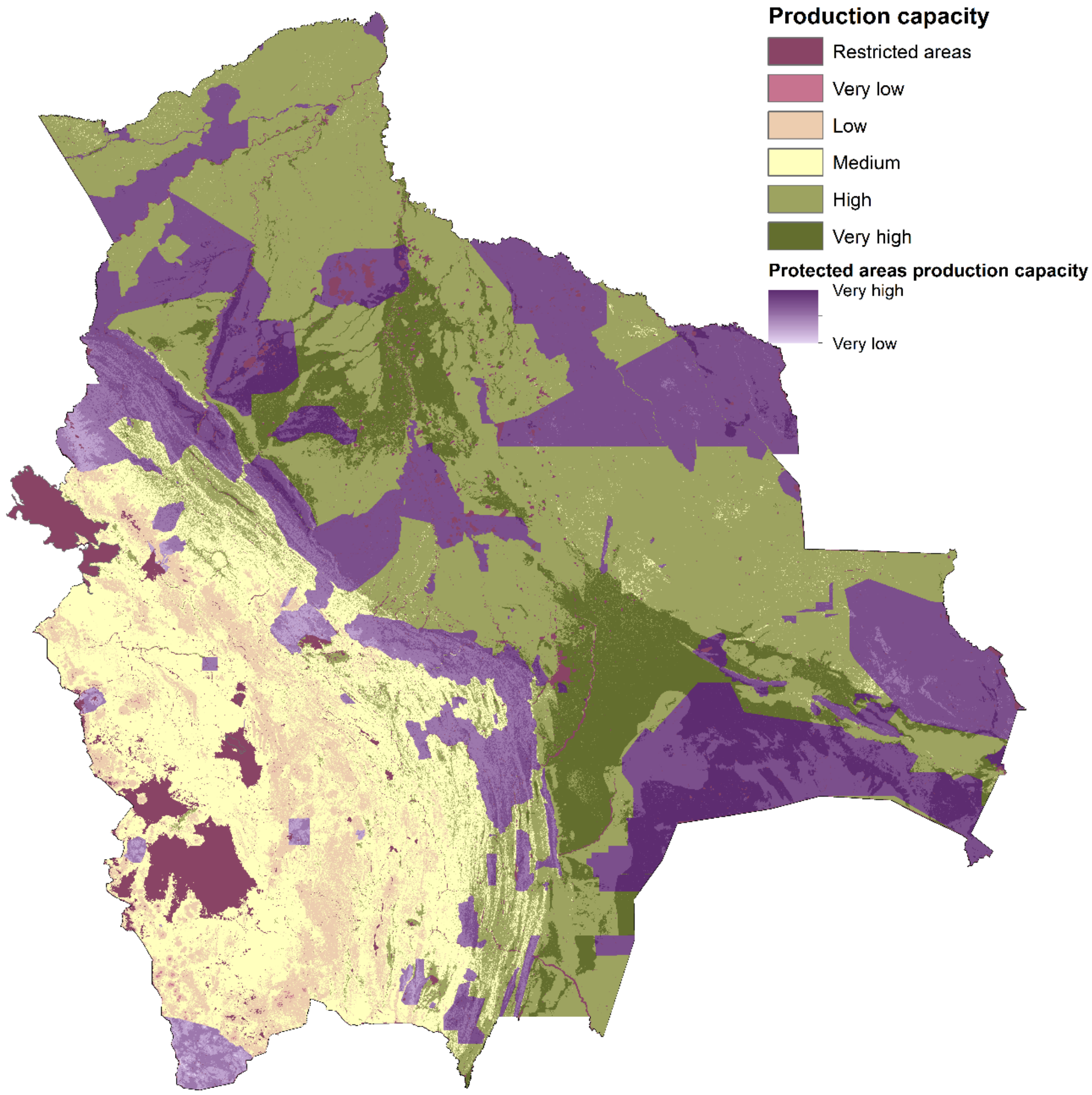
In this section, to develop a Production Cost Factor (PCF) which will be multiplied with the Gross Annual Value per hectare to arrive at Net Annual Value per hectare, we use the calculations of Choque et al. (2023), which develop a high-resolution map of agricultural aptitude, taking into account the variables of precipitation, temperature (maximum and minimum averages), soil classification, physiography, altitude, and slopes. Those variables were overlaid through a weighting method determined by statistical correlation and comparison. The areas covered by water bodies, urban infrastructure, and others, like salt flats, were ruled out for any consideration. A different approach was made for protected areas as they are not restricted by physical conditions but by special legal conditions, which constrain their use for commercial agricultural activities, but do allow subsistence farming.

The PCF is assumed to take on values between 0 and 0.5. If it is 0, production costs are prohibitively high, resulting in a Net Annual Value of 0 USD/ha. If the PCF is 0.5, production costs are low (50% of gross value), which would be the case in flat areas, with great soils, optimal precipitation patterns, and no legal restrictions.

The average value of the PCF is calibrated to be around 0.35 outside protected areas, which means that, on average, the net value per hectare is about a third of the gross value per hectare, as suggested by Leguia, Malky & Ledezma (2011).

Map 4 maps the resulting PCF. Physically restricted areas (such as cities, lakes and salt flats) are assigned a value of 0 due to its physically prohibitive restrictions. Protected areas are assigned a quarter of its original value, due to legal restrictions on the type of agriculture that can be carried out within protected areas.

Map 4: Pixel-level (30 m x 30 m) Production Cost Factor for Bolivia

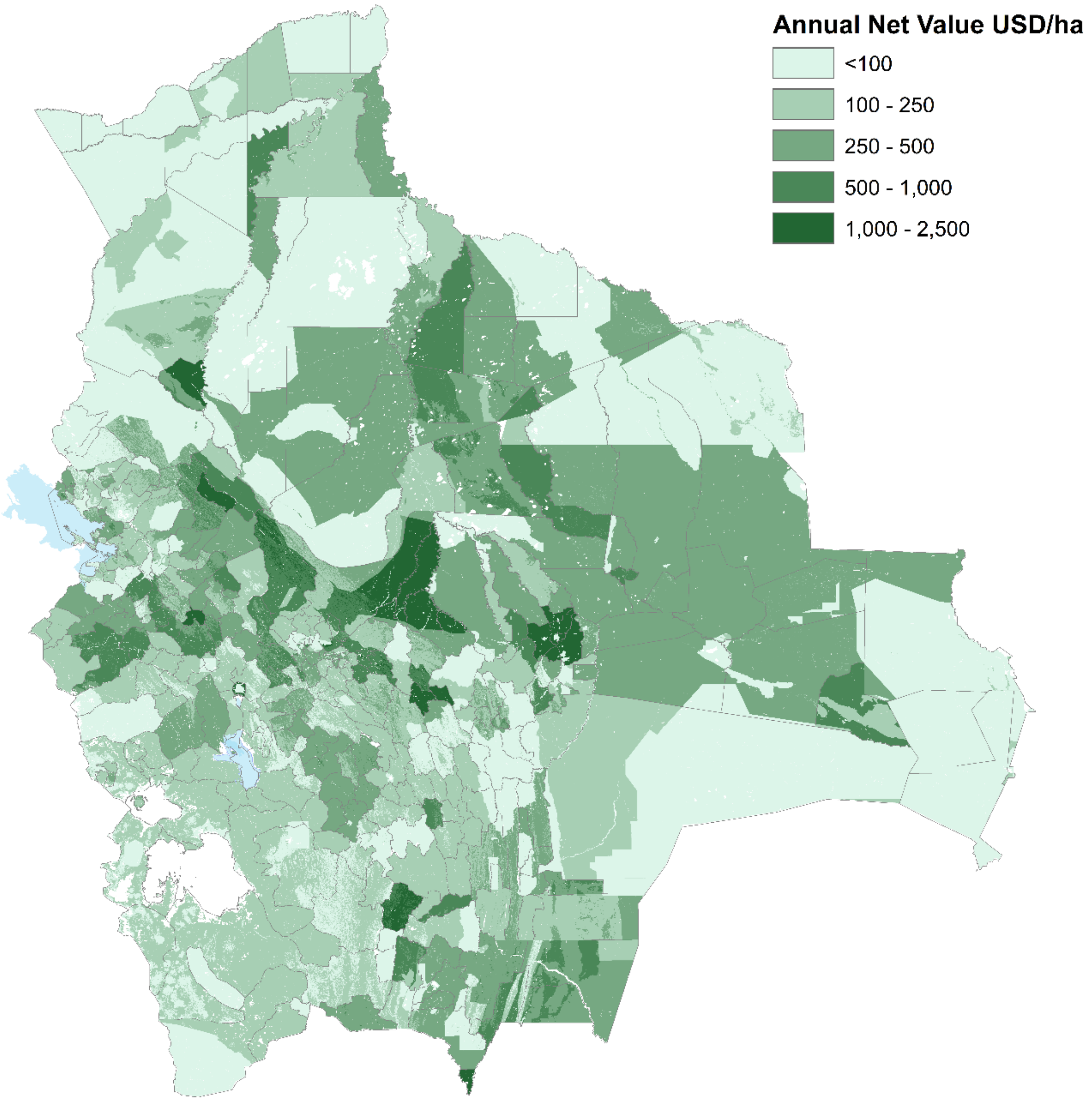


Source: Authors' elaboration based on information from Choque et al. (2023). Protected areas are from SERNAP (2015) and FAN (2023).

2.6. Step 6 – Calculate net annual value of agricultural activities

By multiplying the map of gross annual values with the map of the Production Cost Factors, we obtain a map of potential net annual values of agricultural production (see Map 5).

Map 5: Potential Annual Net Value of agricultural production in Bolivia, by pixel (USD/ha/year)



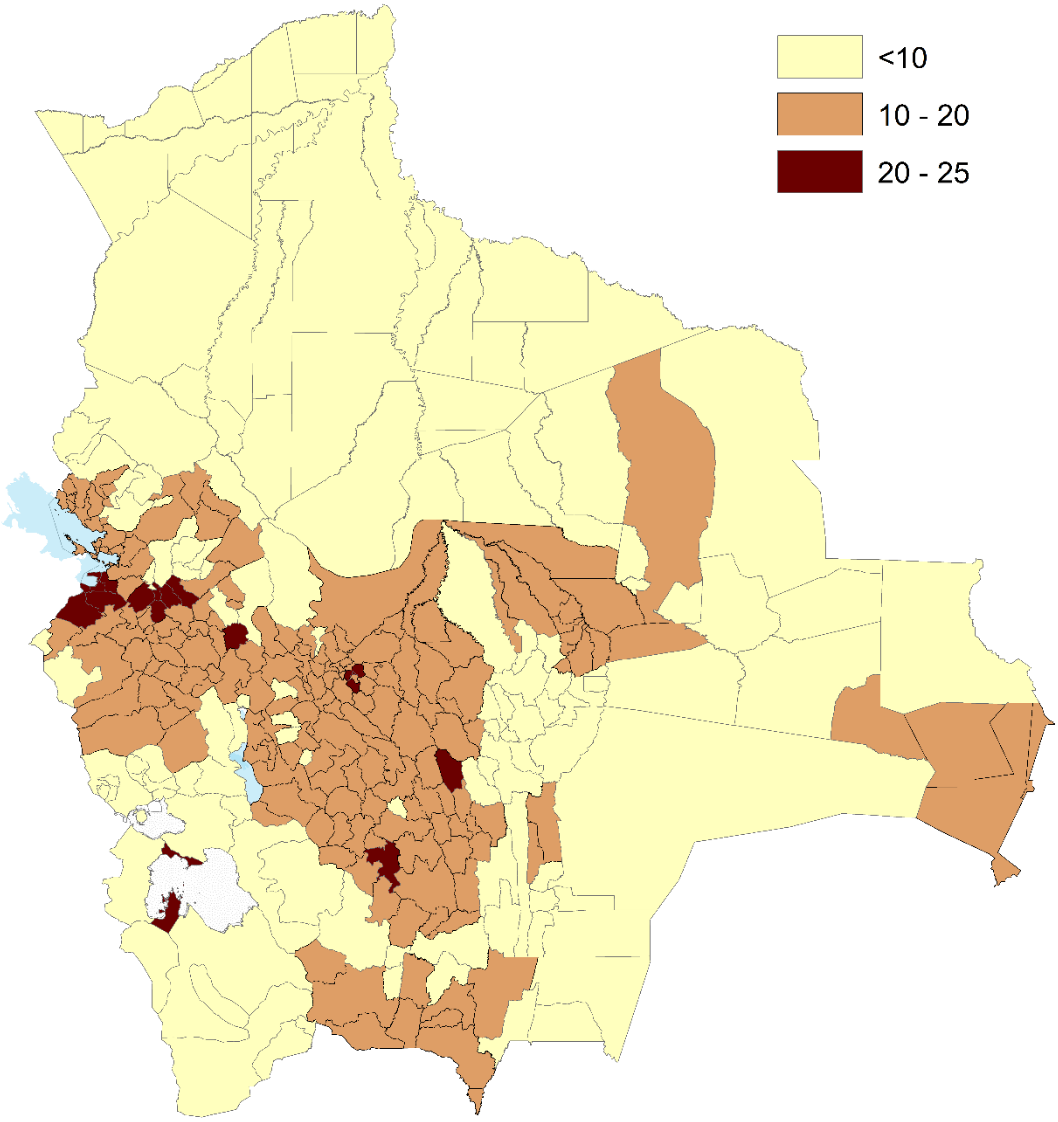
Source: Authors' elaboration based on information from MDPyEP (n.d.), FAOSTAT and Choque et al. (2023).

2.7. Step 7 - Average duration of agricultural activities

Some soils in Bolivia are too fragile to support continuous agricultural activities, and need to rest for some years to recover. In this section we use MapBiomas Bolivia annual land cover maps from 1985 to 2021 to calculate the average duration of agricultural activities for each pixel that were converted to agriculture sometime between 1985 and 2010.

Map 6 shows the average duration of the MapBiomas classes "Agriculture" and "Mosaic of uses". In most places agricultural land has been in continuous use for less than 10 years, but it is not uncommon to observe areas that have been in continuous agricultural use for 10 to 20 years, and in a few places even more than that. On average, for the whole country, once a pixel was converted into agricultural use, it remained in agricultural use for 8.3 years. Notice that these values are lower bounds, as pixels currently in use may continue for years into the future. For several municipalities, the number of agricultural pixels were too low to calculate reliable average durations, which is why we decided to use both agricultural land and mosaic land for these calculations.

Map 6: Average duration of agricultural production in pixels that have once been used for agriculture (years)

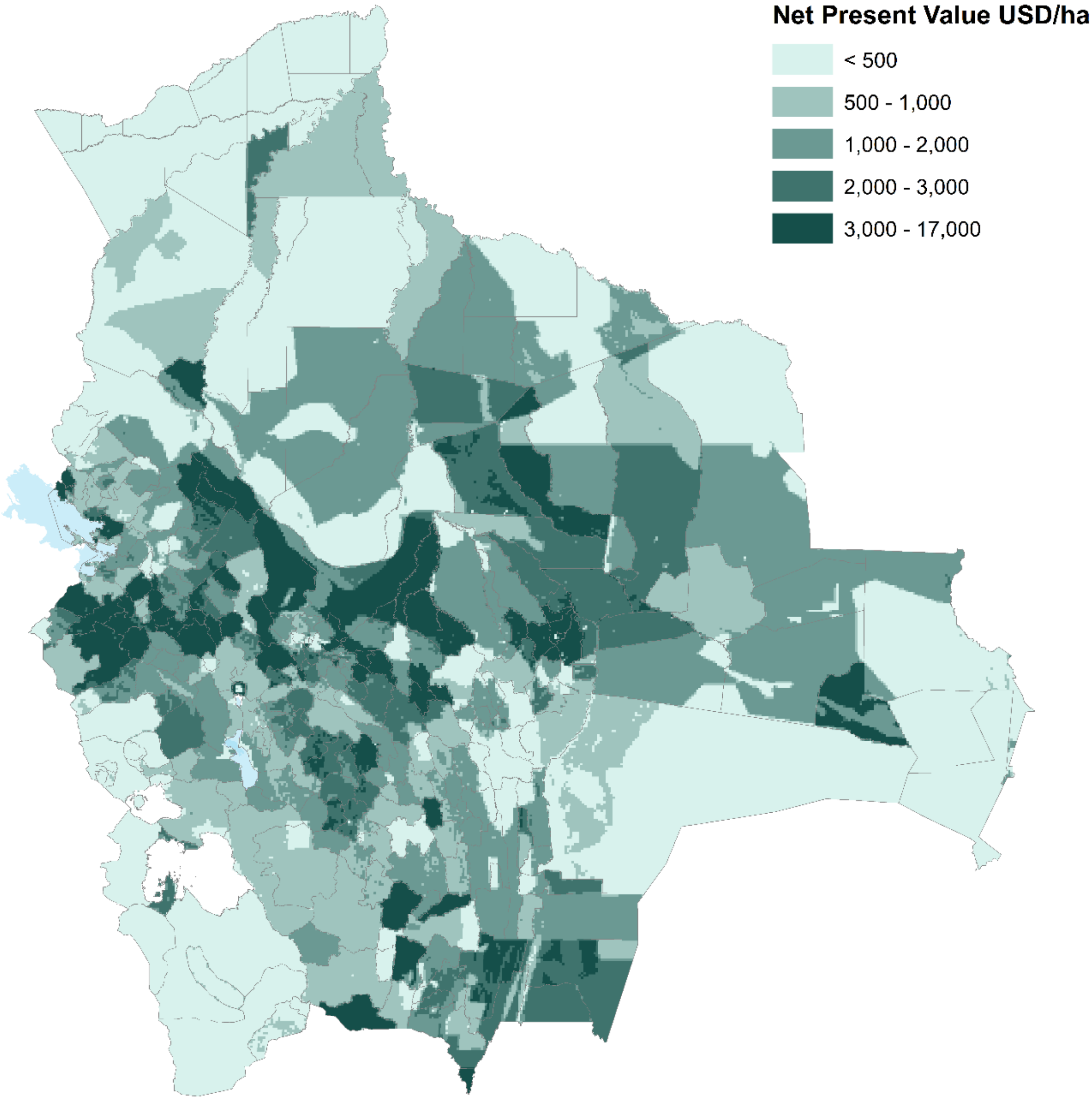


Source: Authors' elaboration based on information from MapBiomas (2023).

2.8. Step 8 - Net Present Value of agricultural activities

In the final step we calculate the Net Present Value (NPV) of agricultural activities by pixel, assuming that the annual net value is obtained for the number of years calculated in the previous step, and we apply a discount rate of 8.4%, following the recommendation of the Ministry of Development Planning (MPD, 2018) for long-run investments. Map 7 shows the final results in terms of the potential Net Present Value of agricultural activities in Bolivia.

Map 7: Net Present Value of agricultural activities in Bolivia, by pixel (USD/ha)



Source: Authors' elaboration based on information from MDPyEP (n.d.), FAOSTAT, Choque et al. (2023), MapBiomas (2023) and MPD (2018).

It is clear that agricultural potential varies greatly across the country. According to the final map, about 39% of all land has agricultural potential of less than USD 500/ha (net present value), while only 8% has potential of more than USD 3000/ha. The average is about USD 1300/ha.

Most high potential agricultural land (>3000 USD/ha) is concentrated in Cochabamba (31%), La Paz (28%), and Santa Cruz (20%). Very little high potential land can be found in Pando, Beni and Oruro. But some can be found in Chuquisaca (7%), Tarija (7%) and Potosí (5%).

The average potential is highest in Cochabamba (USD 4870/ha), and lowest in Pando (USD 265/ha). Santa Cruz, where most deforestation has occurred lately, has an intermediate average value of USD 1166/ha.

3. Conclusions and recommendations

In this paper we have developed a high-resolution map of agricultural potential in Bolivia. We assume that farmers know best which crops are most suitable for their environment and circumstances, so we start by determining the most common agricultural crop in each municipality during recent years, as well as the average yield and price of these crops. For municipalities that do not have significant agriculture, we instead use the most common type of livestock. This provides us with a municipal level map of gross agricultural potential per hectare per year.

However, within municipalities there are vast differences in production costs, depending on the physical characteristics of the land as well as legal restrictions. To take these into account, we develop a Production Cost Factor, which vary between 0 and 0.5. It is 0 where production costs are prohibitively high, and 0.5 where agricultural production conditions are ideal (flat land, easy access, good soils, favorable climate, etc.). This implies that under the best circumstances, production costs are half of the gross value. On average they are two thirds of the gross value, meaning that on average the net value per hectare is one third of the gross value per year.

In a final step, we calculate the present value of the net annual values, taking into account how many years the land is typically under continuous use in each municipality, as calculated from annual land use maps from MapBiomas Bolivia. We apply a discount rate of 8.4% as recommended by the Ministry of Development Planning.

The resulting map indicates the current agricultural potential of land, as measured by the Net Present Value of the most common agricultural activity in each location. The average is about USD 1300/ha, but about 39% of all land has agricultural potential of less than USD 500/ha, while 8% has potential of more than USD 3000/ha.

The great variation in agricultural potential should be taken into account when making land use decisions. The whole state of Pando, in the northernmost part of the country, for example, has very low agricultural potential, with an average net present value of only USD 265/ha. Since the standing rainforest in that region is easily 10 times more valuable (in terms of biodiversity protection, climate regulation, wood and non-wood forest products, etc.), this should clearly be prioritized for forest-based activities. The Chaco and Pantanal regions in the south-eastern part of the country has similarly low agricultural potential, making them ideal locations for conservation-based activities.

Notice, however, that even a low level of agricultural income can easily be higher than the income people typically generate from forested land (averaging less than USD 10/ha, but with substantial variation as well). In the absence of effective mechanisms to ensure optimal land use decisions (e.g. costly deforestation permits, annual conservation payments, punishment for illegal deforestation, etc.) people may rationally choose to deforest areas with even very low agricultural potential.

The Map of Agricultural Potential in Bolivia is intended to help devise mechanisms to encourage a more optimal use of land, facilitating an increase in agricultural production with minimal environmental harm.

The shapefile with the Map of Agricultural Potential in Bolivia accompanies this paper and can be downloaded here: https://drive.google.com/drive/folders/1Oal7D_efneqASRJd_XzAhNTwRFkPeovi?usp=sharing

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