Decision support system for optimal developement and sustainability in rural areas of Peruvian Andes

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Abstract

Sustainability is a key issue for many countries and a difficult task for being combined with development. Measuring tools providing information on sustainable indicators are only the first step towards a sustainable development. Initially, technical support and advice are needed having the complicity of the community as an inexcusable requirement. This paper presents the preliminary findings of a cooperation project between the Universidad Nacional Santiago Antunez de Mayolo (UNASAM, Perú) and the University of Lleida (UdL, Spain) about the implementation of a Decision Support System (DSS) for a development (quasi)optimal and sustainable in Huapra, a rural community of Peruvian Andes. Findings presented are related to the methodology followed to assess sustainable development that included a survey of different variables serving at the selection of indicators. Indicators were classified in economic, environmental and social. An initial number of 18 indicators was selected. Assisted by a principal components analysis (PCA) the interactions between indicators were analysed. Among main indicators only nine of them, measurable in rural communities over time with a humble budget were retained. The development of the DSS implies a facility to gather, record and process data, calculate and monitor indicators and evaluate the sustainability of the Huapra community. For public institutions, the data generated can be used to compare trends over time or to compare results with targets. This is a pilot project aiming at the extension to other rural communities in the Andes. Acceptance of the measuring methods developed may be a powerful contribution towards creating sustainable practices in rural communities in the Andes.

1. INTRODUCTION

Sustainability is a key issue for many countries and a difficult task for being combined with development. Sustainable development is even more delicate in poor areas where people have to improve its own way of life day by day overtaking their lack of resources. Most of these people live in rural communities where their economy strongly relies on peasant agriculture. Peasant agriculture is the primary source of staple food in developing countries (Rosset, 2001). The agricultural sector has to deal with rapidly increasing population pressures, with a changing biophysical environment through land degradation and climate change, with rapid technological advancements. These facts and the interactions of economic, social and environmental objectives make the sustainable development of rural areas more complex (Reijntjes et al., 1992).

At present, many developing countries have seen a noticeable rise of income due to the exports of natural resources towards developed countries or new economies like China, India or Brazil. That is the case of Peru like other Latin-American countries where e.g. mining has brought a lot of foreign investments provoking an important economic development. In this context, we will focus on sustainable development in rural communities of the Peruvian Andes, suffering the pros and cons of the mining activity nearby, characterised by peasant agriculture and a predominance of the Quechua language. Agricultural and environmental policies available to governments generally fall into two categories: regulations and incentives (Just and Antle, 1990). In order to mitigate social inequalities and incentive sustainable development, the Peruvian government makes mining corporations to pay taxes. Mining tax is addressed at Universities to promote research as well as the development of peasants living in mining regions. However, above all in these regions, the clash among educational, agricultural and environmental goals engenders conflicting agricultural, environmental, research, and development policies directed toward agriculture and natural resources. To characterize rural development as sustainable, the concept of sustainability has to be made operational and appropriate methods need to be designed for its long-term measurement (Heinen, 1994). Sustainability should be assessed on the basis of three aspects: economic, social, and ecological sustainability, which all need to be considered simultaneously (Shearman, 1990; Heinen, 1994; Hansen, 1996). Developing indicators for sustainable development can be an effective way to make such a complex concept measurable (Rigby et al., 2001). We defined an indicator as a tool to quantitatively measure an issue. So far, several methods have been developed for identifying sustainability in agriculture (de Wit et al., 1995; Hanegraaf et al., 1998; Callens and Tyteca, 1999; Webster, 1999; Rigby and Caceres, 2001; Sands and Podmore, 2000; Sulser et al., 2001). The approaches vary in the basic techniques, assumptions and the spatial and temporal scales they operate on (Bell and Morse, 1999). Most of these approaches, however, do not focus on peasant agriculture and related side effects with respect to all (i.e., economic, social, and ecological) aspects. The Framework for Assessing the Sustainability of Natural Resource Management Systems (MESMIS as acronym derived from the Spanish) proposed by López-Ridaura et al. (2002) is one of the methods proposed to assess sustainable development in complex socio-environmental systems. The MESMIS operative structure is a six step cycle: (1) description of the situation; (2) involving stakeholders in a participatory process to identify and define relevant economic, social, and ecological attributes or issues; (3) selection and (4) quantification of suitable sustainability indicators; (5) aggregation of indicator information into an overall contribution to sustainable development and (6) conclusions and recommendations. It is along the iteration of the proposed cycle that the progress in a sustainable development has to be observed.

The aim of this paper is to present a preliminary version of a DSS for development and sustainability in rural areas of Peruvian Andes. This research has been supported by the Universidad Nacional Santiago Antunez de Mayolo (UNASAM, Perú) and the University of Lleida (UdL, Spain) seeking the development and international cooperation. For this case study, we take the community of Huapra as reference. The idea is to replicate the study among other similar communities in Peru. Therefore, a framework for assessing sustainability partially based on MESMIS methodology is set up. The first loop of the methodology, a prototype of the site of the project and plans for future iterations are presented.

2. MATERIALS AND METHODS

2.1.The Huapra community

Huapra community is settled in the district of San Miguel de Aco, province of Carhuaz, region of Ancash. There are 201 inhabitants being the peasant agriculture the main activity. Population is becoming older because young people prefer the opportunities offered out of the community. Farms, locally named “chacras” are inherited and divided among the descendants of a family. The risk of a surplus of chacras and scarce production of staple products is worrying in the near future. The total surface of the community is of 200 ha being 150 ha available for agricultural use. Livestock production is underdeveloped being water the main limitation to increase crop and livestock production. Educational level is low even regarding crop production techniques or water management as examples.

2.2.Survey to identify the situation

The sustainable development of a rural community has to consider agriculture production, economics, environmental and social impact. The goal of this survey was to identify and analyse the performance on selected sustainability indicators to better represent sustainable development. We collected data during 2012 and 2013 from most of the member of the Huapra community (102 from 201), and, therefore, we coded most sustainability indicators for comparison reasons. We retained those that were available and data were accessible and quantifiable.

A couple of researchers assisted by students of Agronomical Engineering visited the community and collected the necessary data through a questionnaire of 40 items (Appendix A). The role of the head of the community was very important to encourage peasants to take part in the research. The survey helps us to rank of attributes for sustainability and consisted of three steps:

1. Developing a preliminary outline for determining main sustainability indicators
2. Making a list of attributes that determine sustainability
3. Assessing the relative importance of sustainability attributes

During the survey, the respondents were asked to rank the listed sustainability attributes. Two ranking methods were used -interval ranking and ordinal ranking (Churchill, 1999). In interval ranking, the respondents were asked to rank each attribute relevant to a particular aspect according to its perceived importance. A Likert scale of 1 to 5 was used, with 1 being not important for sustainability and 5 being very important. In ordinal ranking the respondents were asked to put the list of attributes in order of importance. This procedure facilitated later the use of amoeba diagrams.

2.3.Selection of sustainability indicators

After the survey, we analysed the different answers of participants and for each dimension: economic, social and environmental, we defined possible sustainability indicators and subsequently selected final sustainability indicators assisted by experts and stakeholders. In the end, indicators have to be (a) relevant, that is, they have to express something about the issue, (b) simple, they have to be understandable for users, and (c) sensitive and reliable, they have to react to changes in the system and different measurements must lead to the same outcome. Furthermore, (d) it must be possible to determine a target value or trend, and (e) data have to be accessible.

2.4.Assessing the relative importance of sustainability attributes

As a result of the chosen approach in the previous section, many sustainability attributes were likely to be listed. It was recognized that some attributes might overlap and that those attributes that appeared to be dependent on others should be excluded as far as possible to avoid redundancy. In cooperation with experts on the concerning aspect of sustainability, seemingly dependent and independent attributes were indicated. In the second questionnaire sent to the same set of experts and stakeholders, respondents were asked first whether seemingly dependent attributes should be omitted or be used as separate attributes. Furthermore, sustainability indicators represented by numeric variables were included in a principal component analysis (PCA). We observed the variability explained by each indicator and analysed several components in order to discover possible interactions between indicators. All statistical analyses were performed using SAS (SAS Institute Inc., 1999).

3. RESULTS

First we will present the comprehensive list of attributes that determine sustainability in dairy farming, followed by the results of assessing the relative importance of sustainability attributes. These results are presented according to each aspect of sustainability.

3.1.Economic indicators

Suggested attributes for economic indicators are listed in Table 1. Income refers to additional income from activities other than agriculture, e.g. some peasants work part time or time to time in mining. Crop planning refers to rudimentary strategies for planning crop production as crop rotation or assignment of plots within a chacra.

Technical assistance refers to the willingness or availability to look for technical assistance when problems happen. Coverage of staple products refers to the production of enough food to maintain the family. Finally, agro-biodiversity refers to the use and combination of different crops.

N°	Indicator	Dimension
1	Crop production	*Economic*
2	Income	
3	Crop planning	
4	Technical assistance	
5	Coverage of staple products	
6	Agro-biodiversity	
7	Family integration	*Social*
8	Poverty level	
9	Educational level	
10	Diseases suffered	
11	Biodiversity	*Environmental*
12	Water availability	
13	Prevention of soil erosion	
14	Waste management	
15	Prevention and management of diseases	
16	Quality of water	
17	Lever of soil fertility	
18	Preserving techniques	

Table 1. Draft of first indicators selected from the survey

3.2. Social indicators

Social indicators are difficult to measure. Twelve questions were related to this dimension and four indicators were proposed. Some can be measured by constructing an indicator of a quantitative variable (i.e., poverty level), others of a qualitative variable (i.e., diseases suffered). It is clear that not all of these attributes are independent. For example, poverty level is correlated positively with diseases suffered and negatively with educational level.

3.3. Environmental indicators

A total of 13 questions were devoted to environmental dimension. Again, not all indicators proposed are independent. Biodiversity, for example, was mentioned as a separate indicator, whereas it is affected by water and waste management (i.e., eutrophication), among other things. Water availability was important because only few chacras had water at a hand. Prevention and management of diseases was not only important for plants, but also for animals (i.e. rabbits grown at home showed a great mortality that it could be prevented). Waste management refers to liquids and solids. Preserving techniques refer to any action oriented to combine livestock and crop production or to enrich the soil with natural products.

3.4.Analysis and selection of sustainability indicators

The list of 18 indicators presented in Table 1 was considered excessive to follow the MESMIS methodology. However, an amoeba diagram was useful to represent many of the indicators and get an idea of the sustainability of the system. As observed in Figure 1, all indicators remain far from the external border of the circle related with sustainability. Many of the indicators are in the middle or near the centre, far from the sustainability concept.

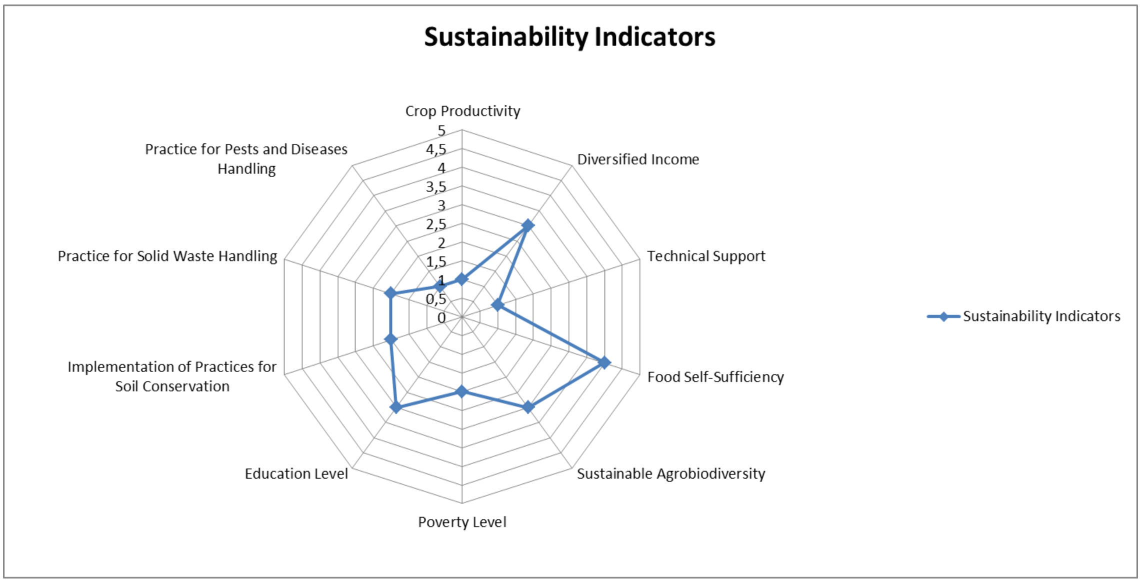

Figure 1. Amoeba diagram of ten indicators

The main inconvenient was the lack of quantitative measures regarding some indicators. Some indicators were not quantifiable into an effective way over time like waste management; others were too expensive to get representative measures of the system like water or soil quality requiring chemical analyses. For this reason the number of indicators was reduced to nine (Table 2). The decision was taken in a meeting with experts and discussed with stakeholders. The assessment over time and the availability of objective measures were considered important criteria for indicators' selection.

N°	Indicator	Measure	Dimension
1	Production	*Total product*	*Economic*
2	Technical assistance	*# visits*	
3	Coverage of staple products	*# products*	
4	Treatment of water	*Index*	*Social*
5	Social participation	*#times*	
6	Poverty level	*index*	
11	Biodiversity	*Vegetal coverage*	*Environmental*
12	Soil and erosion	Slope	
13	Water: quantity&quality	Index	

Table 2. Final selected indicators

3.5. Development of the DSS

The DSS is developed following the standard structure as shown in Figure 2. It contains three subsystems: the model, the data management and the interface. The interface serves to communicate the application with the user that can be connected by internet (http://huapra.hedesk.org/). The interface contains public and private parts. Public parts refer to the information of the project and current development. Private parts allow the user with password to manage the database, indicators and run the model.

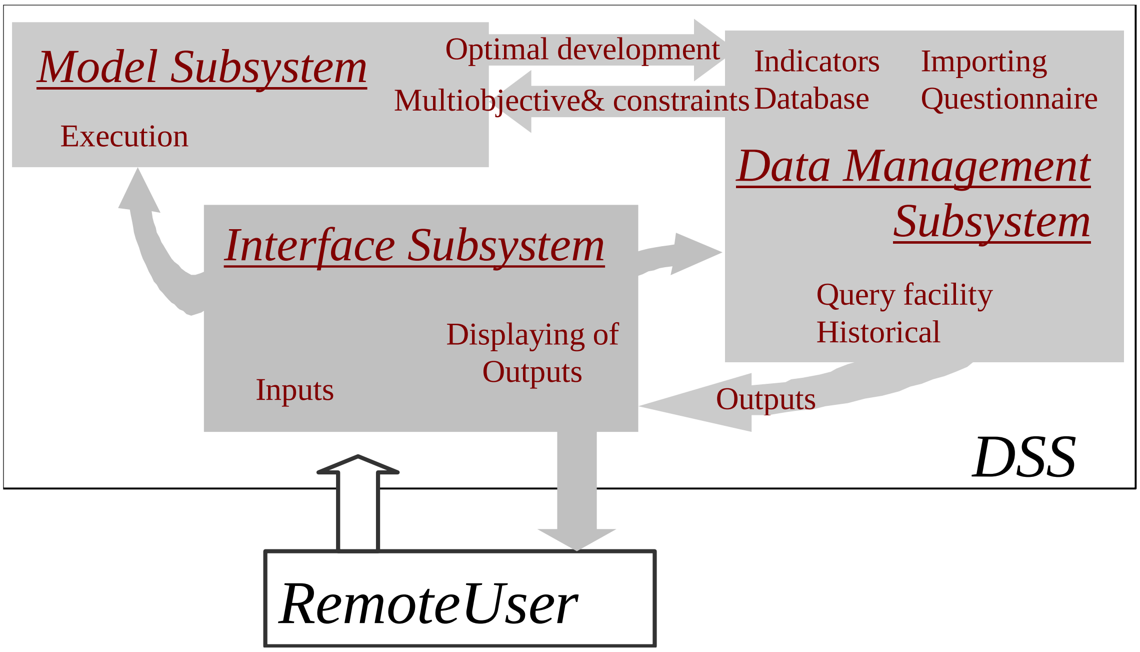

Figure 2. Structure of the DSS

The database subsystem has been thought to register all data and information relevant to the project and giving access through internet to registered people. The survey was performed on site, visiting the community but it is also available online. The last subsystem is the model subsystem that contains a multi-objective programming model to optimise a multi-objective function which decision variables are the sustainability indicators. The optimal solution of the model represents a target for the system. Periodically the sustainability can be evaluated and compared with the target. Optionally, this target can be recalculated and produce new targets.

4. GENERAL DISCUSSION

The objective of this study was to develop a DSS to facilitate the evaluation of the sustainability in rural communities of the Peruvian Andes. The MESMIS methodology was followed in a six step cycle: (1) description of the situation; (2) involving stakeholders in a participatory process to identify and define relevant economic, social, and ecological attributes or issues; (3) selection of sustainability indicators have to be (a) relevant, (b) simple, and (c) sensitive and reliable; (4) quantification of suitable sustainability indicators, being possible to determine a target value or trend; (5) aggregation of indicator information into an overall contribution to sustainable development and (6) conclusions and recommendations have to be accessible. It is along the iteration of the proposed cycle that the progress in a sustainable development has to be observed. These criteria should guarantee a clear assessment process.

In general, many possible sustainability indicators do not meet all the fore above mentioned criteria. This is a well-known problem in sustainability indicators literature, as outlined by de Kruijf and van Vuuren (1998). We have to consider that the search for indicators and indicator systems is an evolutionary process. In the current study several possible sustainability indicators were rejected due to not meeting one or more criteria. Accessibility and reliability of data were sometimes problematic, especially because we gathered historical farm data by questionnaire. In this case, the database maintenance is important although the availability of students ready to collect data and introduce them into the system can be expensive.

In our research, we asked experts and stakeholders to identify sustainability indicators. This ensured that most peasant activities and all their side effects were taken into account. Nonetheless, stakeholders, in general, have insufficient knowledge on these specific aspects of sustainability being crucial the role of experts. Differences in the indicators of economic and ecological sustainability found in this paper and those in other studies are mainly a result of the chosen system (i.e., peasant agriculture) and differences in spatial scale (i.e., community vs. region). Results of the method presented are only valid in the community of Huapra. The method, however, can be used for other agricultural sectors, for other countries and for other time periods. The main benefit of the method used is that it gives insight into the sustainability indicators that are important for a particular community. This knowledge can be applied by the heads of the community and policy makers to develop new rural systems and peasant policies.

The next step in this research consists of determining a target value for economic, social and environmental sustainability and evaluating again the system to quantify the progress. These indicators can be used for developing policy with respect to rural communities in the Peruvian Andes. Usually policy making focuses on only one indicator at a time (e.g., water pollution), and the effect of the policy on other indicators is not taken into account. By using a multiple criteria, decision-making model that includes all sustainability attributes, the effect of new policy on the economic, social and environmental sustainability can be improved. An optimal policy is dependent on the weights of the many indicators, which can differ among stakeholders.

5. CONCLUSION

In this paper, we introduced and applied a method to evaluate sustainability development in rural areas of the Peruvian Andes. We have presented a DSS developed to extend the present study to other communities. We have identified a set of nine sustainability indicators to evaluate sustainability of the Huapra community in Peru. The selection of these indicators has been affected by the availability over time and the reliable quantification. The economic, social and environmental dimensions are covered by three indicators respectively. Furthermore, the number of respondents was sufficient to identify a comprehensive list of indicators. The development of the DSS implies a facility to gather record and process data, calculate and monitor indicators and evaluate the sustainability of the Huapra community. For public institutions, the data generated can be used to compare trends over time or to compare results with targets. This is a pilot project aiming at the extension to other rural communities in the Andes. Acceptance of the measuring methods developed may be a powerful contribution towards creating sustainable practices in rural communities in the Andes.

6. ACKNOWLEDGEMENTS

The authors wish to thank all members of Huapra community who made this research possible and also the financial support of the Universidad Nacional Santiago Antunez de Mayolo (Project entitled "Desarrollo de un Modelo Matemático Computacional para la Evaluación de la Sostenibilidad del Sistema Agrfcola de la Comunidad de Huapra",) and the University of Lleida (Project #16 entitled Model de desenvolupament agrari sostenible per la comunitat camperola (indígena) de Huapra (Perú)). Lluís M. Plà also acknowledges the financial support of the Spanish Research Program (AGL2009-12026).

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Appendix A. Questioner for members of Huapra community

PROYECTO: "DESARROLLO DE UN MODELO MATEMÁTICO COMPUTACIONAL PARA LA EVALUACIÓN DE LA SOSTENIBILIDAD DEL SISTEMA AGRÍCOLA DE LA COMUNIDAD DE HUAPRA"

Datos Generales:

Nombre: …………………………………………………………….……..

Edad: …………………………………..

Sexo M ☐ F ☐

Número de hijos: …………………

Número de personas que viven con usted: …………………………

Grado de instrucción:………………………………..

I. Indicadores Económicos

1. Cuál ha sido su nivel de producción que usted ha obtenido de sus parcelas en el 2011?[1]
   a) Muy alta
   b) Alta
   c) Media
   d) Baja

2. Cual ha sido su ingreso económico en el 2011 por su la actividad agropecuaria (cultivos, ganadería y forestal)?
   a) 2000 a 4000 soles
   b) 1000 a 2000 soles
   c) 500 a 1000 soles
   d) 200 a 500 soles
   e) Menor a 200 soles

3. Con que área de terreno dispone usted en total?:…………………………………

4. Qué cantidad de cultivos usted siembra para el mercado?
   a) 04 a más cultivos
   b) 03 cultivos
   c) 02 cultivos
   d) 01 cultivo
   e) Sólo cultivos para autoconsumo

Especifique que cultivos:…………………………………………………………………

[1] Mide la percepción de la producción del sistema

5. ¿Cuál es el área cultivada promedio de papa, maíz y trigo con que usted cuenta? [2]

Papa: _________________
Maíz: _________________
Trigo: _________________
Otros: _________________
En descanso:____________

6. ¿Cuánto produce por hectárea su chacra con relación a estos cultivos?

Papa: _________________
Maíz: _________________
Trigo: _________________
Otros: _________________

7. Cuantas visitas de asistencia técnica tiene su chacra al año

   a) 7 a más visitas al año
   b) 4 -6 visitas al año
   c) 2 -3 visitas al año
   d) 01 visita al año
   e) Nunca es visitado

8. Si lo han visitado, quien le ha dado la asistencia técnica:______________________

9. Qué cantidad de lo que produce en su chacra lo usa como alimento?

   a) 100%
   b) 60 - 79%
   c) 40 - 59%
   d) 20 - 39%
   e) < 19%

10. Que hace con los excedentes de la producción de su chacra?

   a) Se vende
   b) Se intercambia-trueque
   c) Lo usa como semilla

11. ¿Cuenta usted con animales menores en su unidad productiva y en qué cantidad?

Gallina ☐ cuy ☐ conejo ☐ pato ☐

Otro: ☐
Especificar:__________________________________

12. ¿Cuenta usted con animales mayores y en qué cantidad?

Vacunos ☐ Ovejas ☐ Chanchos ☐ ☐
caballo ☐

Otro:
Especificar:__________________________________

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[2] Respuesta en hectáreas o metro cuadrado

13. Cuantos animales vendió el 2011……………………y a cuanto vendió…………

14. Qué cantidad de arboles existen en su chacra?: …………………………………

Que especies tiene?...

15. Cuantos árboles vendió el 2011:……………………y a cuanto vendió……….

II. Indicadores Sociales

16. Cuantos soles gastas mensualmente para mantener a tu familia que vive contigo?
    a) En alimentación S/………..
    b) En ropa S/………………..
    c) En educación S/…………..
    d) En salud S/……………

17. Quienes trabajan en tu chacra?
    a) Toda tu familia
    b) Papa y alguno de los hijos
    c) Papa y mama y alguno de los hijos
    d) Mama y alguno de sus hijos
    e) Solo la mama
    f) No participan
    g) Contratan

18. Quien es el responsable del manejo de la chacra
    a) Papa
    b) Mama
    c) Hijos

19. Con qué servicios básicos cuenta en su casa:
    a) Agua potable, desagüe y electricidad
    b) Agua potable y desagüe
    c) Solo agua potable
    d) Solo desagüe
    e) Solo electricidad
    f) Agua potable y electricidad

20. Cuentan con centro educativo? Si ☐ No ☐

Cuantos de tu familia estudian: ……………………………

21. Cuenta con centro de salud? Si ☐ No ☐
22. Donde se atiende si se enferma:…………………………………..
23. Cuantas veces se enfermó durante todo el 2011………………..

24. ¿Qué técnicas usa para manejar tu chacra?
- Conservas tu suelo ☐
  Como?……………………………….
- Controlas las plagas ☐
  Como?..
- Aplicas abonos orgánicos ☐
  Como?...
- Asocias y rotas los cultivos ☐
  Como?...
- Usas el agua adecuadamente ☐
  Como?...
- Usas fertilizantes sintéticos ☐
  Como?..

25. Cuál es el número de prácticas[3] agronómicas que son aplicadas en su chacra?
   a) >11 o más prácticas utilizadas
   b) 8 - 10 prácticas
   c) 5 - 7 prácticas
   d) 3 - 4 prácticas
   e) < 2 prácticas

26. Cuáles son las técnicas que más utilizadas en el manejo de tu chacra[4]

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27. ¿Pertenece a alguna asociación de productores?
   Si ☐ No ☐

Si su respuesta es afirmativa indique el nombre de la organización:……………………………………y cuantos lo integran……………

III. **Indicadores Ambientales**

28. Usted hace uso de fertilizantes y venenos? Si ☐ No ☐

29. Que hace con los envases de los venenos o plaguicidas……………………..

30. Donde vota los desechos después de lavar la mochila fumigadora
   a) En la sequia

[3] Las Practicas agronómicas son: Preparación del suelo, siembra, deshierbo, abonamiento, aporque, control de plagas, riego, etc.

[4] Abonamiento, aplicación de plaguicidas o remedios, uso de abonos orgánicos, control natural de las plagas, cultivos asociados, rotación de cultivos

b) Lo deja en el campo
c) Lo quema
d) Lo entierra

31. Cuál es la disponibilidad de agua para regar su chacra?
a) Abundante
b) Suficiente
c) Medio
d) Bajo

32. Aplica alguna técnica de uso adecuado del agua de riego?
a) Riego por goteo
b) Riego por aspersión
c) Riego por gravedad
d) Riego por surcos en contorno.

33. Alguno vez se ha contaminado el agua de riego? Si ☐ No ☐
Quién lo ha contaminado………………………………………………………

34. Cuál es la productividad de tu suelo?
a) Muy buena
b) Buena
c) Regular
d) Mala

35. Como evitas la pérdida de tu suelo[5] en su parcela?....................................
………………………………………………………………………………………

36. Que hace con su desecho domiciliario?
a) Lo quema
b) Lo bota al campo
c) Lo recicla
d) Prepara abonos orgánicos
e) Lo entierra en un hueco
f) Recoje el recolector

37. Que hace con los desechos de los animales.
a) Usa directamente al campo
b) Prepara compost
c) Usa como abono foliar
d) Prepara bioles

38. Que prácticas de manejo de plagas y enfermedades practica en su chacra?
a) Aplicación de plaguicidas
b) Trampas de luz
c) Trampas amarillas
e) Control biológico
f)Extractos de plantas

39. Usted ha reforestado en el último año: si ☐ No ☐

[5] Prácticas de Conservación de suelos: Terrazas de formación lenta, Terrazas de banco, Zanjas de infiltración, cobertura vegetal, agroforesteria, etc.

Que especies de árboles...

40. Usted quema los rastrojos de los cultivos? Si ☐ No ☐

Porque?..…………………………………………..
....