Hydrol. Earth Syst. Sci. Discuss., 6, 5139–5176, 2009
www.hydrol-earth-syst-sci-discuss.net/6/5139/2009/

Hydrology and
Earth System
Sciences
Discussions

Soil bio-engineering for risk mitigation and environmental restoration in a humid tropical area

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Received: 6 July 2009 – Accepted: 8 July 2009 – Published: 29 July 2009

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Published by Copernicus Publications on behalf of the European Geosciences Union.

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Abstract

The use of soil bio-engineering techniques in developing countries is a relevant issue for disaster mitigation, environmental restoration and poverty reduction. Research on authochtonal plants suitable for this kind of works and on economic efficiency is essential for the divulgation of such techniques. The present paper is focused on this two issues related to the realization of various typologies of soil bio-engineering works in the humid tropic of Nicaragua.

In the area of Río Blanco, located in the Department of Matagalpa, soil bio-engineering installations were built in several sites. The particular structures built were: drainages with live fascine mattress, a live palisade, a vegetated live crib wall for river-bank protection, a vegetative covering made of a metallic net and biotextile coupled with a live palisade made of bamboo. In order to evaluate the suitability of the various plants used in the works, monitorings were performed, one in the live palisade along-side an unpaved road and the other on the live crib wall along a riverbank, collecting survival rate and morphological parameters data. Concerning the economic efficiency we proceed to a financial analysis of the works and once the unit price was obtained, we converted the amount in EPP Dollars (Equal Purchasing Power) in order to compare the Nicaraguan context with the Italian one.

Among the used species we found that Madero negro (*Gliricidia sepium*) and Roble macuelizo (*Tabebuia rosea*) are adequate for soil-bioengineering measure on slopes while Helequeme (*Erythrina fusca*) reported a successful behaviour only in the crib wall for riverbank protection.

In the comparison of the costs in Nicaragua and in Italy, the unit price reduction for the Central American country ranges between 1.5 times (for the vegetative covering) and almost 4 times (for the fascine mattress) if it's used the EPP dollar exchange rate.

Conclusions are reached with regard to hydrological-risk mitigating actions performed on a basin scale and through naturalistic (live) interventions: not only are they socially and technically attainable, even in hardship areas (by maximizing the contribu-

tion of the local labor force and minimizing the use of mechanical equipment), but they are also economically sustainable.

1 Introduction

Soil bioengineering, as well known, entails the use of live materials, specifically plant parts (cuttings, roots and stems), that serve as the main structural and mechanical elements in a slope protection system.

Live plants and other natural materials have been used for centuries to control erosion problems on slopes in different parts of the world. These natural remedies became less popular with the arrival of the Industrial Revolution (Gray and Leiser, 1982; Gray and Sotir, 1996). The stabilization of slopes through vegetation and soil treatment measures may be particularly appropriate in situations where an abundance of vegetative materials is present, and where labor, rather than machinery for installation, can be easily found (Schiechtl, 1985). Particularly it is important to analyze if, when faced with bank or slope instability situations, it is possible to intervene with methods adaptable by user communities.

In order to evaluate the transferability of bioengineering techniques, the situation in so called developing countries is analyzed, evaluating the indications given by major international cooperation agencies. For example, in FAO publications, such a technology is underlined as the most appropriate for watershed management, landslide prevention measures, vegetative and soil treatment measures and, generally, in land reclamation (Costantinesco, 1976; Sheng, 1977a, b, 1979, 1990; Bostanoglou, 1980; Marui, 1988; Schiess, 1994).

Currently, bioengineering is largely applied in mountain areas of Europe and North America, giving much data which enables safe planning for similar interventions. In developing countries, since only a few examples can be found, it is important to stress their future use according to the concepts of technology transferring and sustainable development (Anaya et al., 1977; Dickerson and Lake, 1989; Clyma et al., 1977).

During the last few years the employment of naturalistic rehabilitation techniques in the rural communities of developing countries has drawn the growing interest and involvement of a number of European research groups whose investigative task it is to identify the suitable plant species to be used in each geographical setting (Castillo and Müller-Sämann, 1996; Clark and Hellin, 1996; Burch and Lopez, 1999; Florineth, 2004; Ghimire and Karki, 2004; Sutili et al., 2004; Lammeranner et al., 2005; van Beek et al., 2005; Petrone and Preti, 2005, 2008; Bimala et al., 2006; Li et al., 2006; Petrone et al., 2006; Preti, 2007; Reubens et al., 2007).

In a previous study (Petrone and Preti, 2008) we set forward the experience we gathered during our work in León, Nicaragua) This experience confirmed both the technical feasibility of various types of soil bio-engineering interventions and the interest of the municipalities which were involved. We worked in an urban context where it was possible to operate only along the local rivers. Furthermore, the socio-economic conditions were quite different from those of the rest of the country, in terms of both the living conditions of the population and the greater availability of the materials which were needed for the operations. For all these reasons, the opportunity of extending the zone of intervention to the mountain and rural areas was approved with interest by the whole team.

The DIPECHO (Disaster Preparedness Echo) program is specifically aimed at implementing activities for improving the reactivity of local communities to natural disasters such as floods, landslides, earthquakes, or volcanic eruptions. However, interventions for mitigating small-scale-risks are planned as well. These interventions are aimed at promoting good practices for disaster mitigation. It is from such a perspective that the activities outlined in the present chapter were performed. They did not consist solely of the performance of the operations and of the related training, but also in both the subsequent monitoring and the analysis of their financial sustainability.

The aim of the work is to demonstrate that bioengineering stabilization interventions are the most appropriate because in agreement with the main concept of sustainable development, thanks to the use of local labor, local materials and the reproducibility of the intervention typologies.

The paper is structured as follows: in Sect. 2 we describe the study area, the involvement of local communities, the plants used and the implementation of the experimentation with monitoring and cost analysis; the obtained results are presented in Sect. 3 on the basis of the case studies (cuttings performance and statistical analysis, financial evaluation of the interventions); finally, these results are discussed and conclusions drawn in Sects. 4 and 5.

2 Materials and methods

2.1 Area description

The town of Río Blanco is located in the Department of Matagalpa, Central Nicaragua, 110 km east of the city of Matagalpa (the capital of the department bearing the same name) and 250 km north-west of Managua, the nation's capital (Fig. 1). Río Blanco extends for an area of km^2 700 and has a population of 33 195 inhabitants, 9254 of whom are located in the urban area, while the remainder are in the rural areas (the density amounts to 47 inhabitants/km^2) (AMUNIC-INIFOM, 1997).

The economy is based mainly on cattle breeding and agriculture. Nonetheless, it is the first of the two activities that is absolutely predominant.

Although the town's roads are in bad condition, a good paved road links it to the capital, Managua. In fact, the absence of viable road links concerns rural communities: almost all of them must be reached by rugged four-wheel drive vehicles, and in some cases traveling is feasible only during the dry season. In point of fact, only 8.5 of the 59.5 km of the roads are paved, while the rest of them are dirt track: 13 km of the latter are those usable just during the dry season.

Río Blanco is characterized by a humid-tropical climate; its rainy season lasts 9 months (precipitations range between 2400 mm and 2600 mm per year) and the average temperature ranges between 20° and 26°. Rain peaks occur during July and

August.

From an ecological standpoint, the area where Río Blanco lies, between the Atlantic and the Pacific belt, has been threatened by deforestation to create pasture lands, remove woodland and obtain arable land. It was in response to this phenomenon that in 1991 the reserve of the “Cerro Musún” was founded, with a territory of 4778 hectares and elevations from 300 to 1438 meters above sea level. Cerro Musún is made up of over 60 million-year-old volcanic rocks forming peaks which characterize the reserve. The highest of these peaks is called Musún and, apart from giving its name to the whole complex, it reaches 1438 m a.s.l.

The orientation of the massif is the same as the one of the regional fault, which crosses this area (*Matiguas fault*) and divides the Pacific volcanic belt from the alluvial plain which extends to the Atlantic.

The protected area was the object of studies focused on identifying the local biodiversity rate. Thanks to them, 284 species were identified, half of which were vegetable and the other half animal.

The typical vegetation of this area is represented by humid sub-tropical broad-leaved woods as well as by mountain woods.

According to the classification introduced by the Central American Hydrologic Project, the area is inside basin n.55 (Fig. 2), known as “Rio Grande De Matagalpa Basin”. In the town’s territory are also the sub-basins of the rivers Tuma, Paiwas and Wanawana, each one of which has a meander-like shaped grid.

Some of the waterways crossing the area are northbound and drain into Río Tuma, while those flowing south (among them is Río Blanco, which has given its name to the town) empty into Río Paiwas. It is from the area of Cerro Musún that seven of the twenty four sub-basins flowing through the town originate. Their streams all bring a year-round water tonnage.

Geologically, volcanic rocks resulting from violent eruptive phenomena of the past are emblematic of the area. The landscape is characterized by mountains ranging between 80 and 1438 meters of altitude above sea levels (the average is about

500 m a.s.l.) and whose average slope amounts to more that 50%.

Data of 2003 concerning soil employment are reported on Table 1. The aforementioned important role of cattle breeding for the economy is self-evident. Pastures are often on steep slopes which not only favor the waste of fertile soil, but also increase the formation of marked erosive processes.

A few words must be spent on the question of the potential use of the soil, i.e. of the activities which should be developed locally with full respect for the various areas' vocations. As mentioned above, types of land uses should be properly distributed as shown on the Table 2.

It is easy to notice how serious the problem of land use is with regard to Río Blanco (although the situation is paradigmatic of the whole country): the concentration of the land in the hand of a few large landowners leads to the formation of enormous pastures at the expense of an integrated use of the woodlands, both from a productive standpoint (of agroforestry and silvopastoral) and a land-protection point of view. Such a situation entails a lack of balance in each of the three axes of what is called "sustainable development", that is economic, social and environmental. Moreover, it triggers self-feeding processes where the poorest are accused of exploiting natural resources inappropriately for their survival. Often the response is to establish protected areas. Nonetheless, these latter are frequently imposed from above and without any true confrontation with the interested parties, who therefore see themselves as deprived of the fundamental resources for their livelihood. This is what happened in Río Blanco as well. Before enacting policies for land protection, it would be better to set going negotiations with landowners to work out a policy of conversion of land use to be more in line with eco-compatible productivity models, such as agroforestry and silvopastoral systems, not to mention enacting serious land reform for more equitable land distribution.

2.2 The involvement of local communities in defining and implementing the project

The adopted methodology scheme includes two general fields of analysis: the first one is related with technical aspects, and the second one relative to potential involving by the single farmer or the farming community.

Through joint experimentation with the people, beneficiaries received training and experience in the design, implementation and evaluation of experiments. In this way their capacity for innovation can be substantially increased and, for farmers to accept soil conservation technologies, the technology should enhance yields (FEDERACAFÉ and CENICAFÉ, 1975; Hudson, 1982; Kirby and Morgan, 1984; Bunch and Lopez, 1999; Bruscoli et al., 2001; Suarez Diaz, 2001; Johnson et al., 2003; Vishnudas et al., 2006). It is the increase in yield that convinces the farmers of the value of soil conservation, more than disaster mitigation or prevention and environmental restoration. If the yields have increased or costs have decreased, artificial incentives are not required. On the other hand if yields have not increased, no artificial incentive will make the adoption of the technology sustainable (Wilken, 1987; Rivera and Sinisterra, 2006).

The main target of the work methodology we used was to reach the highest level of involvement from the local communities in each step of the proposed activities (Chambers, 1992; Bruscoli et al., 2001; Petrone, 2006). We wanted to avoid the people's engagement in future replications of the project from being just "mechanical" repetitions; rather, we wanted them to have a clear overall vision of the whole series of efforts to accomplish so as to enable them to intervene on their own to carry forward the project to a definitive solution.

Thus, the work went forward according to the following steps:

- pre-selection of the possible sites by the soil bio-engineering experts, supported by both the project's personnel and the leaders of the various communities; the main criteria used for the choice were the communities' perception of the work's utility and the site's accessibility;

- purchase of the needed instruments and materials;
- theoretical education on soil bio-engineering techniques imparted to the inhabitants of the three selected communities (Río Blanco, Wanawas e La Isla). During these events we submitted the selected sites to the judgment of the Communities and we received positive feedback. Then, we organized the work to be done both logistically and in terms of labor supply. A particularly noticeable aspect was that a two-way learning experience occurred: since the Italian experts did not know what vegetable species could be the most suitable there, it was the local communities which provided such information. Due to the close relationship they still have with nature, they were able to indicate the best species in terms of cutting reproduction;
- signing of a Cooperation Agreement with the local Institutions of the selected communities as to the implementation of the various phases of the project;
- collection of both living vegetable matter (live cuttings and pegs) and inert matter (stones, ground, etc.) around the sites of intervention, and then beginning the work.

The project covered the costs for the purchase of the needed materials, tools and equipment (which were donated to the communities afterwards) as well as for the planning out and management of the work, while the communities gave their contribution by providing the labor force and vegetable material.

2.3 Plants used

Further to the meetings with local communities, the list of the species to use as cuttings was drawn up. The following criteria have been used to choose the vegetal species (Petrone and Preti, 2008):

- local plants;

- easily found in the area concerned;
- shoot propagation;
- high tolerance of differing soil conditions;
- not too large once adult.

With these factors in mind, the following species have been chosen:

- Helequeme (*Erythrina fusca*);
- Madero negro (*Gliricidia sepium*);
- Roble macuelizo (*Tabebuia rosea*).

The following is a brief description of the above-cited plants:

Erythrina fusca, member of the Fabaceaea family, is a deciduous tree thickly branched which at its maturity stage can reach 20 m in height and about 40 cm in diameter. It is a pioneer species which, in the wild, is frequent in the areas subjected to periodic flooding and along streams and waterways, generating pure stands. It requires average precipitations between 1500 and 3000 mm per year and average temperatures between 16 and 24 degrees. It is native to the humid tropic of Central and Southern America. It is the species with the widest distribution within the genus of *Erythrina*, as it can grow at an altitude between 0 and 2000 m. *Erythrina fusca* is commonly used as shadow tree in coffee and cacao plantations but it's also used for firewood, fodder and healing purposes;

Gliricidia sepium is a member of the Fabaceae family, it is a small to medium-sized tree, reaching heights between 6 and 20 m (10 m on average), very common in Mexico and Central America, it grows well with a temperature of 20–30°C, with precipitations between 900 and 1500 mm per year and a five month dry season, used for firewood, fodder and healing purposes (Petrone and Preti, 2008);

Tabebuia rosea, member of the Bignioniaceae family, is a medium-sized tree (it can reach 20 m in height), with straight trunk and a wide and irregular crown. As far as soil is concerned it is not very exigent, it has a good climatic adaptability and it easily colonizes untended fields. It is native to Central-Southern America and is very common all over the territory of Nicaragua. Its red wood is very appreciated in carpentry for furniture manufacture. *Tabebuia rosea* is also used for ornamental and healing purposes.

2.4 Implementation phase: jobs carried out at various sites

Soil bio-engineering installations were built in several sites inside the town of Río Blanco during a time period which started on 12 January 2006 and lasted until 26 February 2006. The particular structures we built were:

- Drainages with live fascine mattress (La Isla site).
- A live palisade (La Isla site) (Fig. 9a).
- A vegetated live crib wall for riverbank protection (Wanawas site) (Fig. 9c).
- A covering made of a metallic net and biotextile coupled with a live palisade made of bamboo (Río Blanco).

The vegetated live crib wall was set up after having first running a check for its stability against capsizing and sliding; this verification procedure produced satisfactory results, with security coefficients equal to 2.3.

Data sheets concerning every job were filled up. They have the double purpose of both describing the general features of the work performed and serving as a basis for future monitoring. The sheets' structure is based on the model proposed by Viterbo University with regard to censuses of soil bio-engineering jobs in Lazio (Preti, 2006; Regione Lazio, 2006; Preti and Milanese, 2007) – although some modifications were made in order to adapt the sheet to the local setting.

2.5 Monitoring and statistical analysis

These are the parameters we applied in measuring and monitoring the planted out cuttings of the various installations (Lammeranner et al., 2005; Petrone and Preti, 2008):

- survival rate, which is basically the percentage of cuttings that spawn shoots;
- length of terminal shoot (in both monitorings);
- diameter of terminal shoot (only in the last monitoring).

The extent of the second parameter is particularly important because it is directly correlated to the development of the rooting system. Therefore, such a property shows the ability of the cuttings to serve as retainers of the soil's superficial layer. As such, it constitutes an element for improving the latter's characteristics. On the other hand the diameter of the terminal shoot is important as it is connected to the flexibility of the shoot itself: above 4 cm the shoots show a reduced capacity to bend at the passage of the flow and consequently also their efficacy in bank stabilization (Regione Lazio, 2006). The first monitoring was performed in March 2007 while the second one in September 2007. We consider the data resulted from the monitoring of the live crib wall and from the live palisade, as the vegetative covering with biotextile and metallic net gave unsatisfactory results due to the lack of extra irrigation immediately after the planting (only one out of the 4 species, the Madero negro, survived with 10% of specimens), while due to its intrinsic characteristics, the live mattress does not allow a quantitative monitoring of the rooting percentage of the cuttings employed.

The collected data have been used in performing statistical tests in order to verify the following hypotheses:

- the various species have different survival rates;
- the development of the apical shoot is characteristic for every species;
- the development of the diameter of the shoots is characteristic for every species;

- both the survival and the development of a cutting depend on the installation where it was inserted.

2.6 Analysis of soil bioengineering intervention sustainability

The economic sustainability of risk-mitigating-interventions in the so called developing countries is a highly important issue. Therefore, we decided to perform a careful financial analysis of our work trying not to overlook any of the diverse components that make up the final price. In particular, we dealt with expense entries as follows:

- labor force: as the project designers were on site every day to supervise the works, it was not difficult to assess the actual time needed (according to the working conditions imposed by the local context) to complete the various jobs;
- materials: we filed all purchase invoices by matching each one of them to the installation job it related to; the materials offered by the Communities (e.g. the cuttings) were considered as their contributions and assessed at local market prices;
- rentals: in this case as well we used the various agreements we stipulated with the different parties (often belonging to the world of informal economy).

Thus we decided to follow the price-analysis scheme adopted by the soil bioengineering Manual of the Lazio Region (Regione Lazio, 2006). Sometimes it was adapted on the basis of the various needs and circumstances encountered.

Once the unit price was obtained, we converted the amount in EPP Dollars (Equal Purchasing Power). EPP is an artificial dollar whose purchasing power is equal in all countries, as its value corresponds to the weighted average of the world prices of 151 kinds of goods. This instrument is commonly used by international Organizations such as UNDP (UNDP, 2006) and International Monetary Fund, only to mention a few of them. It is a way of comparing prices paid in different geographic areas and understanding their actual entity (Petrone and Preti, 2008).

3 Results

3.1 Cuttings performance and statistical analysis

On the whole, the survival rate of the cuttings was of 45% after 12 months and 37% after 18 months. As far as the individual species are concerned the registered survival rates after 18 month since the installation of the live palisade were:

- Helequeme (*Erythrina fusca*): 14%
- Roble macuelizo (*Tabebuia rosea*): 63%
- Madero negro (*Gliricidia sepium*): 100%

The Chi-square test (*df* 2, $p=0.01$) revealed that the differences between the survival rates of the three species are statistically significant. If a deeper analysis of the Chi-square table is performed, we discover that two values, percentage of living cuttings of *Tabebuia rosea* and *Gliricidia sepium*, give the 66% of the total value for the Chi-square test. The comparison between the observed and expected values shows that the significativity is largely caused by the high percentage of living cuttings of the two species.

The survival rate of *Erythrina fusca* in the live crib wall was considerably higher, reaching 42% after 18 months since the planting. The Chi-square test ($df=1$, $p=0.01$) revealed that the difference between the survival rates is statistically significant.

As far as the development of the terminal shoots is concerned (see Fig. 3), the Madero negro resulted as the species with the highest growing rate, while *Erythrina fusca* and *Tabebuia rosea* showed comparable results. Due to inhomogeneity of variance a Kruskal-Wallis test instead of an Anova test was used and showed that the differences between the three species in the case of terminal shoots length are statistically significant ($p=0.01$).

The Least Significant Difference test yielded the following results: as far as the development of the terminal shoots is concerned there are not significant differences between *Erythrina fusca* and *Tabebuia rosea* (p=0.05); the differences between the length of the shoots of Madero negro and both *Erythrina fusca* and *Tabebuia rosea* are significant (p=0.05).

Also as far as the diameter of the shoots is concerned (Fig. 4), Madero negro showed the highest growing rate. Post-hoc comparisons using the Turkey-Kramer test (performed after an ANOVA test that showed a statistically significant difference between the three means) yielded the following result: the only difference statistically relevant in the diametrical growth is the one between Madero negro and *Tabebuia rosea* (p=0.05).

The analysis between the different growing rates of *Erythrina fusca*'s terminal shoots in live palisade and live crib wall, realized through a t Welch test with Satterthwaite method (due to inhomogeneity of variance a t Student test could not be used), showed the following results: the difference between the observed means is significant for p=0.01, both for the length and the diameter of the terminal shoots (see Figs. 5 and 6).

3.2 Financial analysis of the project's implementation stage

Data sheets concerning the analysis of the costs of the various installation jobs were filled up. Both the total and the unit costs were calculated in both Nicaraguan currency (Cordoba) and Euro (assuming an exchange rate of 20 Cordobas per Euro as at the time of the works). As mentioned above we consider also the contribution from the local Community in terms of labor force or materials. The total prices of the works are shown in Fig. 7.

It is interesting to compare the aforementioned costs with those to be defrayed in Italy. To do that, we will refer to the data provided in the soil bio-engineering Manuals of Regione Lazio reports (Regione Lazio, 2006) with regard to the Province of Rome:

- live fascine mattress on slope: 26.83 €/m
- live palisade: 28.67 €/m
- vegetated live crib wall: 213.90 €/m^3

- vegetative covering with biotextile and metallic net: 21.42 €/m^2

From these data, prices in equal-purchasing-power dollars can be obtained, both with regard to the Nicaraguan and the Italian context. Then, a more reliable comparison can be made. The Fig. 8 shows the reduction of price divergence as per exchange rate.

Then, we calculated the ratio between construction costs in Italy and in Nicaragua in order to assess which soil bio-engineering effort was quantitatively advantageous within the context of our study. The Table 3 shows those values in the two cases of currency exchange mentioned above. As may be noticed, the ratio ranges between 1.5 times (for the vegetative covering) and almost 4 times (for the fascine mattress).

4 Discussion

The behaviour of *Gliricidia sepium* and *Tabebuia rosea* in the live palisade (Fig. 9a and b), with regard to the survival rates, is more than satisfactory: they both showed rooting percentages exceeding 60%. We want to point out the exceptional result of *Gliricidia sepium* which after 18 months boasted of a 100% survival rate, confirming the results of a previous study (Petrone and Preti, 2008), which were however referred to a different climatic area: the area of Río Blanco, object of the present study, is classified as humid tropical forest, while the area of Léon, object of the previous study, was a dry humid forest. Therefore *Gliricidia sepium* shows considerable potential as species used in Soil Bioengeneering works for a wide range of climatic characteristics. The very bad result of *Erythrina fusca* in live palisade (survival rate 14%) can be attributed to the fact that this species is an hygrophyte: this characteristic, together with planting during the dry season, can explain what happened. In confirmation of this, it is appropriate to cite the survival rate of the same species which was 3 times higher in the live crib wall for riverbank protection (Fig. 9c and d).

As far as the vegetative development is concerned, also in this case *Gliricidia sepium* prevailed compared to the other two species, both for the length and the diameter of the terminal shoots.

Despite this, it is possible to consider undoubtedly satisfactory the behaviour of the three species from the point of view of the growing rate's trend. We point out in particular the result of *Erythrina fusca* in its natural habitat (on the banks of waterways) which after 18 months since the planting showed all the shoots with an average length of about 3 m and an average diameter of about 5.5 cm.

If these results are compared to the counterpart registered in the palisade for *Erythrina fusca* (average shoots' length below 90 cm and average diameter of about 2.2 cm), the hypothesis of a connection between a very good performance in the bank intervention and a high availability of water is reinforced.

The analysis of the interventions'costs allowed to reach a wider awareness of the financial bearableness of soil bioengineering in the "impoverished" better than "developing") countries in comparison to previous works (Petrone and Preti, 2005, 2008) which considered only the realization of vegetated live crib walls compared to classical interventions such as concrete walls and gabions. In the present study on the contrary, also other "lighter" kinds of vegetative covering interventions (vegetative covering with biotextile and metallic net) and stabilizing interventions (live fascines and live palisade) are included. As showed in the Table 3 all the works are more economic in Nicaragua, also considering the EPP exchange rate: in particular two works with a relevant use of manpower and live materials (fascines and vegetated live crib wall) revealed themselves very advantageous, while the gap is more reduced for the vegetative covering in which bars and wire nets are prevailing costs.

With regard to the effectiveness of the proposed technology, it can be stated that it would contribute to slope stabilization with the short-term objective of land protection, and with the long-term objective of integrated development. The assessment of the risk factors which might cause the failure of the technology is essential. First of all, it seems quite difficult to define the most appropriate typology of intervention as it strongly depends on the site conditions (botanical, climatological, morphological, etc.; Kuriakose et al., 2009). Moreover, it will be necessary to increase efforts in training technical personnel, as in some cases professional experience is required. Manageability depends on its persuasiveness in a set social context, and is consequently linked to subjective factors going beyond technical analysis. There are also other important aspects, such as the conditions in which all potential users will operate and the instruments that they will use in relation to the necessity imposed by the new technology. In our case, manageability seems to be the main characteristic of bioengineering, and it is the first step of our transferability proposal.

After defining the most suitable intervention typology, the realization phase seems not to present problems, thanks to the availability of materials and labor to be used for the construction. It results that manageability is quite effective in limited interventions, while as far as larger ones are concerned it is fundamental to ensure technical consulting during the first phase.

The link between the technology and the system must be evaluated, as the former must offer the conditions for the diffusion of the latter, multiplying its effects.

Since bioengineering transfer provides users with an instrument which guarantees stability it is strictly required to clearly show the objectives, the risks and the reproducibility of the technology to the local communities. In this phase, the information should be exchanged from the users to the technicians and vice versa: local communities should collect necessary information in data poor region in order to enable technicians to choose the best configuration (e.g. most suitable live materials), and public demonstrations and technical courses should be arranged in order to show to the users the new technology (Kuriakose et al., 2009). In the information gathering phase, users must be informed of all the elements concerning the technology, including the risks, among which there is the lack of a database relative to the application of bioengineering in impoverished countries, with the consequent difficulty in foreseeing definite results (Bruscoli et al., 2001).

5 Conclusions

This present study had the main purpose of addressing the species selection question, accomplished by conducting on-site tests on various native species, the cuttings of which were applied to several types of rehabilitation jobs. Among the used species we found that Madero negro (*Gliricidia sepium*) and Roble macuelizo (*Tabebuia rosea*) are adequate for Soil-bioengineering measure on slopes while Helequeme (*Erythrina fusca*) reported a successful behaviour only in the live crib wall for riverbank protection.

In addition to this kind of investigation, we also wanted to tackle the issue of the financial sustainability of the proposed soil bio-engineering activities. It was through a rigorous analysis of the various cost entries that some interesting conclusions were reached. In fact, the Equal Purchasing Power exchange rate allowed us to realize that the costs for carrying out the various engineering jobs were absolutely lower than in Italy.

Thus, a conclusion can be reached with regard to hydrological-risk mitigating actions performed on a basin scale and through naturalistic techniques: not only are they technically attainable, even in hardship areas, (by maximizing the contribution of the local labor force and minimizing the use of mechanical equipment), but they are also economically sustainable.

Acknowledgements. The work presented in this paper was performed within the framework of the project "Sistema de prevención antes desatres naturales en 7 comunidades rurales del area del cerro Musún" ("Natural disasters prevention system in 7 rural communities of the Cerro Musún"). This undertaking was introduced by the non-governmental organization COSPE and received European Union's DIPECHO funds.

References

Alcaldía Municipal de Río Blanco: SE, SINAPRED, INETER, COSUDE, SNV: Análisis de Riesgos del Municipio de Río Blanco, Managua, Nicaragua, 2005.

AMUNIC-INIFOM: Caracterización municipal de Río Blanco, 2008.

Anaya, G. M., Martinez, M. M. R., Trueba, C. A., Figueroa, S. B., and Fernandez, M. O.: Manual de Conservación de suelos y del agua, Chapingo (Mexico), Colegio de Postgraduados, 581 pp., 1977.

Devkota, B. D, Paudel, P., Omura, H., Kubota, T., and Morita, K.: Uses of Vegetative Measures for Erosion Mitigation in Mid Hill Areas of Nepal, Kyushu J. For. Res., 59, 265–268, 2006.

Bostanoglou, L.: Restauration et protection des pentes degradées, Conservation des resources manual, FAO Conservation Guide, 13/1, 1980.

Bruscoli, P., Bresci, E., and Preti, F.: Diagnostic Analysis of an Irrigation System in the Andes Region, Agricultural Engineering International: the CIGR Journal of Scientific Research and Development, III, 1–14, 2001.

Bunch, R. and Lopez, G.: Soil recuperation in Central America: Sustaining Innovation after Intervention, Gatekeeper Series n 55, International Institute for Environment and Development, London, 1999.

Castillo, F. J. A. and Müller-Sämann, K.: Conservación de suelos en ladera: Buscando nuevas alternativas, in: Memorias de un seminario nacional sobre actualización en conservación de suelos en laderas, Centro de estudios para la Conservación Integral de la ladera (CECIL), Santafé de Bogotá, Colombia, 87–106, 1996.

Chambers, R.: Rural appraisal: rapid, relaxed and participatory, IDS pubblications, University of Sussex, England, 1992.

Clark, J. and Hellin, J.: Bio-engineering for Effective Road maintainance in the Caribbean, Natural Resources Institute, The University of Greenwich, UK, 1996.

Clyma, W., Lowdermilk, M. K., and Corey, G. L.: A research development process for improvement of on-farm water management, Water Management Research Project, Colorado State University, Fort Collins, Colorado, USA, 1977.

Costantinesco, I.: Soil conservation for developing countries, FAO Soil Bulletin, 30, 74–86, 1976.

Dickerson, J. A. and Lake Jr., D. W.: Cost Effective Biotechnical Slope Protection Trials in New York, ASAE, Paper No. 892 654, 1989.

Federación Nacional de Cafeteros de Colombia (FEDERACAFÉ), Centro Nacional de Investigaciones de Café (CENICAFÉ) Manual de conservación de suelos de ladera, Chinchiná, Cenicafé, 267 pp., 1975.

Florineth, F.: Stabilization of gullies with soil – bio-engineering methods in the Alps and in

Nepal, in: Gully Erosion under Global Change, edited by: Li, Y., Poisen, J., and Valentin, C., Sichuan Science and Technology Press, Chengdu, China, 315–339, 2004.

Ghimire, S. K. and Karki, K. K.: Mitigation of soil erosion hazards through bio-engineering: a case study of Mid-Himalaya, Nepal, International Conference Eco-Engineering: "The use of vegetation to improve slope stability", Thessaloniki, 2004.

Gray, D. H. and Leiser, A. T.: Biotechnical Slope Protection and Erosion Control, Van Nostrand Reinold Company, New York, 271 pp., 1982.

Gray, D. H. and Sotir, R. B.: Biotechnical and soil bioengineering slope stabilization, A practical guide for erosion control, New York, John Wiley & Sons, Inc., 378 pp., 1996.

Hudson, N.: Conservación de suelos, Barcelona (España), Reverté S.A., 335 pp., 1982.

Johnson, N., Lilja, N., and Ashby, J.: Measuring the Impact of User Participation in Agricultural and Natural Resource Management Research, Agr. Syst., 78, 287–306, 2003.

Kirby, M. J. and Morgan, R. P. C.: Erosión de suelos, 1^{a} edición, México, Limusa S.A., 367 pp., 1984.

Kuriakose, S. L., van Beek, L. P. H., and Westen, C. J.: Parameterizing a physically based shallow landslide model in a data poor region, Earth Surf. Proc. Land., 34(6), 867–881, doi:10.1002/esp.1794, 2009

Lammeraner W., Rauch, H. P., and Laaha, G.: Implementation and monitoring of soil bio-engineering measures at a landslide in the Middle Mountains of Nepal, Plant Soil, 278, 159–170, 2005.

Li, X., Zhang, L. Q., and Zhang, Z.: Soil bioengineering and the ecological restoration of river-banks at the Airport Town, Shanghai, China, Ecol. Eng., 26, 304–314, 2006.

Marui, H.: Landslide prevention measures, FAO watershed management field manual, FAO naturelles en zones arides et semi-arides, Cahiers FAO: Conservation des sols: 115–135, Conservation Guide, 13/4, 135–153, 1988.

Petrone, A.: Realización de obras de mitigación con técnicas de ingeniería naturalistica en el Cerro Musún- Río Blanco, published in the framework of the DIPECHO Project "Sistema de prevención antes desatres naturales en 7 comunidades rurales del area del cerro Musún", Nicaragua, 2006.

Petrone, A. and Preti, F.: Ingenieria Naturalistica en Centroamérica, Manuali Tecnici per la Cooperazione allo Sviluppo, Istituto Agronomico per l'Oltremare, Società Editrice Fiorentina, Firenze, 108 pp., ISBN 88-89507-02-0, 2005.

Petrone, A., Matassoni, P., and Preti, F.: Sperimentazioni con talee di specie autoctone in interventi di ingegneria naturalistica in Nicaragua, Quaderni di Idronomia montana, Nuova Editrice Bios, Castrolibero, 26, 477–488, 2006.

Petrone, A. and Preti, F.: Suitability of soil bioengineering techniques in Central America: a case study in Nicaragua, Hydrol. Earth Syst. Sci., 12, 1241–1248, 2008, http://www.hydrol-earth-syst-sci.net/12/1241/2008/.

Preti, F. and Milanese, C.: Monitoring Ground Bio-Engineering Stabilization of Land-Slides in Lazio Region (Italy), in: Eco- and Ground Bio-Engineering: The Use of Vegetation to Improve Slope Stability Proceedings of the First International Conference on Eco-Engineering, 13–17 September 2004, Series: Developments in Plant and Soil Sciences, edited by: Stokes, A., Spanos, I., Norris, J. E., and Cammeraat, E., Springer, Vol. 103, ISBN-10: 1-4020-5592-7, ISBN-13: 978-1-4020-5592-8, 2007.

Preti, F.: Stabilità dei versanti vegetati, Cap. 10, in: Manuale 3 d'Ingegneria Naturalistica Sistemazione dei versanti, Regione Lazio, Roma, edited by: Sauli, G., Cornelini, P., and Preti, F., http://www.regione.lazio.it/web2/contents/ingegneria_naturalistica/manuale_versanti/Cap_10_10.pdf, 2006 (in Italian).

Preti, F.: Seguimiento de de trabajos de Ingenieria Biologica en Italia central, Cuadernos de Arquitectura del Paisaje, 2007.

Regione Lazio: Manuale di Ingegneria naturalistica – Sistemazione dei versanti, Ed. Emilmarc s.r.l., Roma, 2006.

Reubens, B., Windey, J., Danjon, F., Poesen, J., and Muys, B.: Root system architecture of woody species important for erosion control in Tigray, Northern Ethiopia, Proceedings 4th International Symposium on Dynamics of Physiological Processes in Roots of Woody Plants, 16–19 September 2007, Bangkor, UK, 2007.

Rivera, H. R. and Sinisterra, J. A.: Uso social de la Bioingeniería para el control de la erosión severa, CIPAV-CVC, 2006.

Schiechtl, H. M.: Vegetative and soil treatment measures, FAO watershed management field, 1985.

Schiess, M. P.: Conception et construction des routes dams les bassins versants sensibles, Guide pratique d'aménagement des bassins versants, Cahier FAO Conservation, 13/5, 155–172, 1994.

Sheng, T. C.: Approche d'aménagement intégré dans l'etablissement d'un projet de développement d'un bassin versant, Aménagement des bassins versants, Cahier FAO: Conservation des sols, 1, 11–18, 1977.

Sheng, T. C.: Protection des versant cultivés, Aménagement des bassins versants, Cahier FAO: Conservation des sols, 1, 179–213, 1977.

Sheng, T. C.: L'ensemencement par pulvérisation: procédés, exemples et perspectives a la Jamaique, Techniques spéciales de conservation, Cahier FAO: Conservation des sols, 4, 75–83, 1979.

Sheng, T. C.: Watershed survey and planning, Watershed management field manual, FAO Conservation Guide, 13/6(3–15), 132–140, 1990.

Suarez Diaz, J.: Control De Erosion en Zonas Tropicales, ISBN 958-33-2734-4, 2001.

Sutili, F. J., Durlo, M. A., and Bressan, D. A.: Bio-technical capability of "sarandi-branco" (Phyllanthus sellowianus mull. Arg.) and "vime" (Salix viminalis L.) for re-vegetation water corse edges, Ciencia Florestal, Santa Maria, Brasile, 14(1), 13–20, ISSN 0103-9954, 2004.

UNDP (United Nations Development Programme): Lo sviluppo umano rapporto 2006 – L'acqua tra potere e povertà, Legoprint, Lavis (Trento), 494 pp., ISBN 88-7885-099-3, 2006.

van Beek, L. P. H., Wint, J., Cammeraat, L. H., and Edwards, J. P.: Observation and simulation of root reinforcemente on abandoned Mediterranean slopes, Plant Soil, 278, 55–74, 2005.

Vishnudas, S., Savenije, H. H. G., Van der Zaag, P., Anil, K. R., and Balan, K.: The protective and attractive covering of a vegetated embankment using coir geotextiles, Hydrol. Earth Syst. Sci., 10, 565–574, 2006, http://www.hydrol-earth-syst-sci.net/10/565/2006/.

Wikipedia: http://upload.wikimedia.org/wikipedia/commons/c/c0/Nicaragua_rel_97.jpg, access: 28 July 2009.

Wilken, G. C.: Good Farmers: Traditional Resource Management in Mexico and Central America, UC Press, Berkeley, CA, 1987.

Table 1. Present use of soil in the town of Río Blanco (Alcaldía Municipal de Río Blanco et al., 2005).

Type of soil use	Percentage on total (%)
Woods	24.19
Pastures	72.30
Cultivated land	3.28
Urban land	0.23

Table 2. Potential use of soil in the town of Río Blanco (Alcaldía Municipal de Río Blanco et al., 2005).

Type of soil use	Percentage on total (%)
Woods	73.05
Pastures	20.71
Cultivated land	4.62
Protected areas	1.37
Urban land	0.25

Table 3. Ratio between construction costs in Italy and Nicaragua as a function of the adopted exchange rate.

	Ratio between fulfillment costs in Italy and Nicaragua (official exchange rate)	Ratio between fulfillment costs in Italy and Nicaragua (EPP dollar exchange rate)
Live fascine mattress on slope	16.66	3.95
Live palisade	9.85	1.90
Live crib wall	13.15	2.53
Vegetative covering with metallic net and biotextile	8.02	1.54

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Fig. 1. Location of the town of Río Blanco (http://upload.wikimedia.org/wikipedia/commons/c/c0/Nicaragua_rel_97.jpg).

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Fig. 2. Nicaraguan hydrographic basins (Alcaldía Municipal de Río Blanco et al., 2005).

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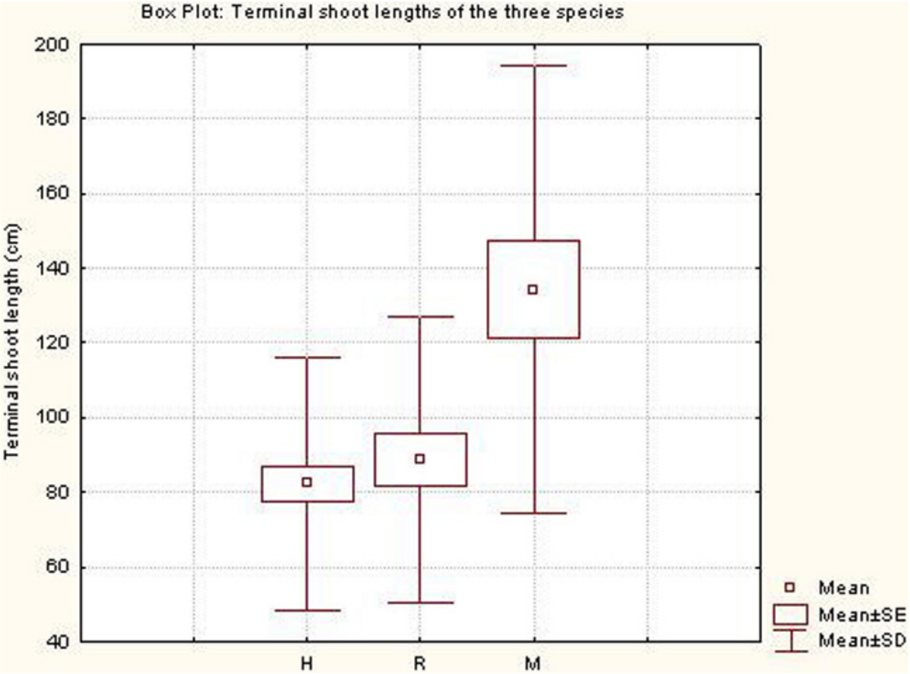

Fig. 3. Terminal shoot length for Helequeme (H), Madero negro (M) and Roble Macuelizo (R) 18 months after the construction.

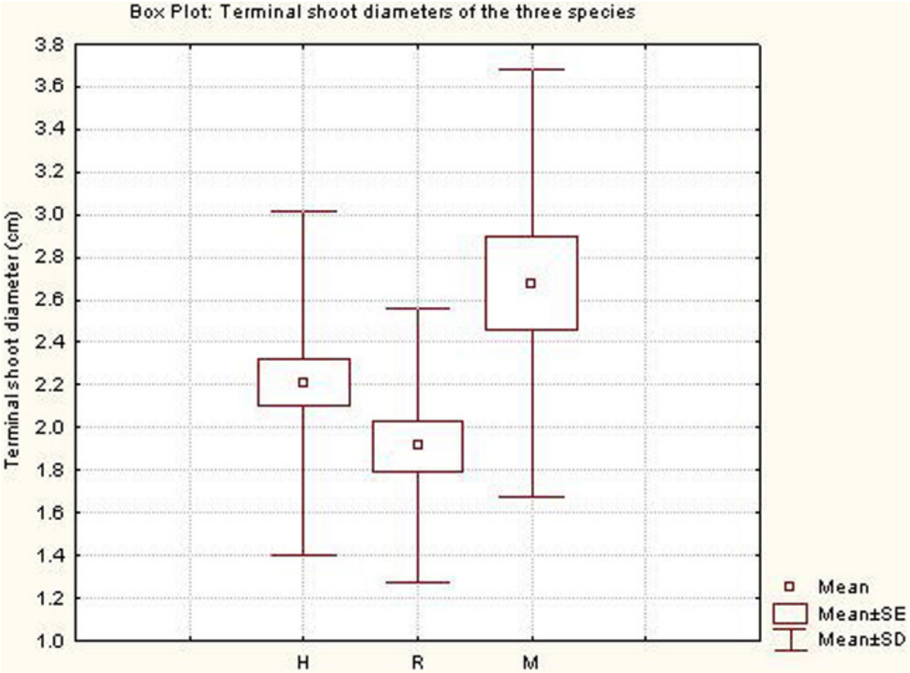

Fig. 4. Terminal shoot diameter for Helequeme (H), Madero negro (M) and Roble Macuelizo (R) 18 months after the construction.

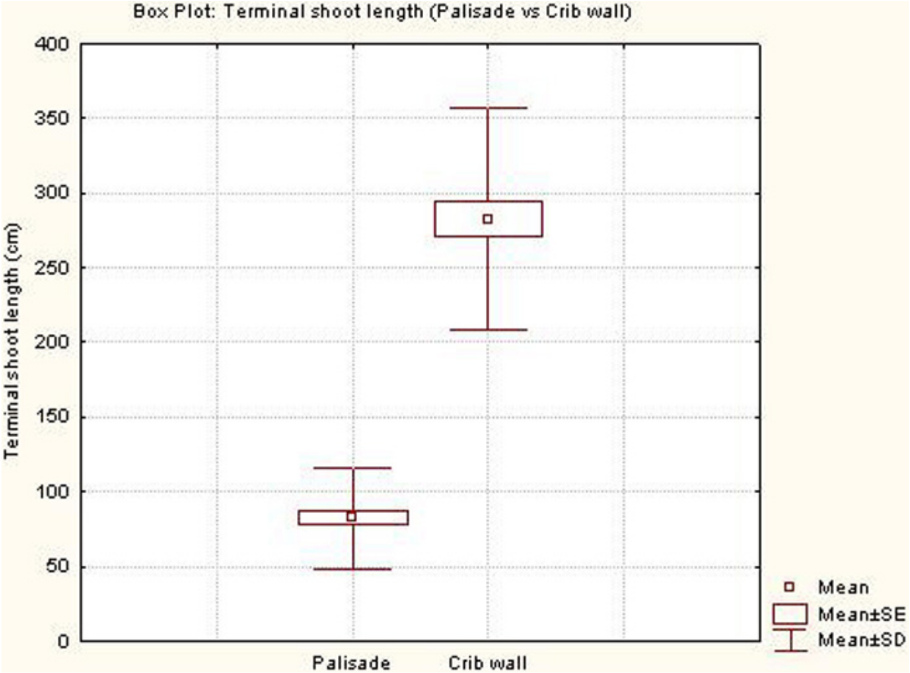

Fig. 5. Comparison between terminal shoot length of Helequeme (*Erythrina fusca*) in the live palisade and in the live crib wall 18 months after the construction.

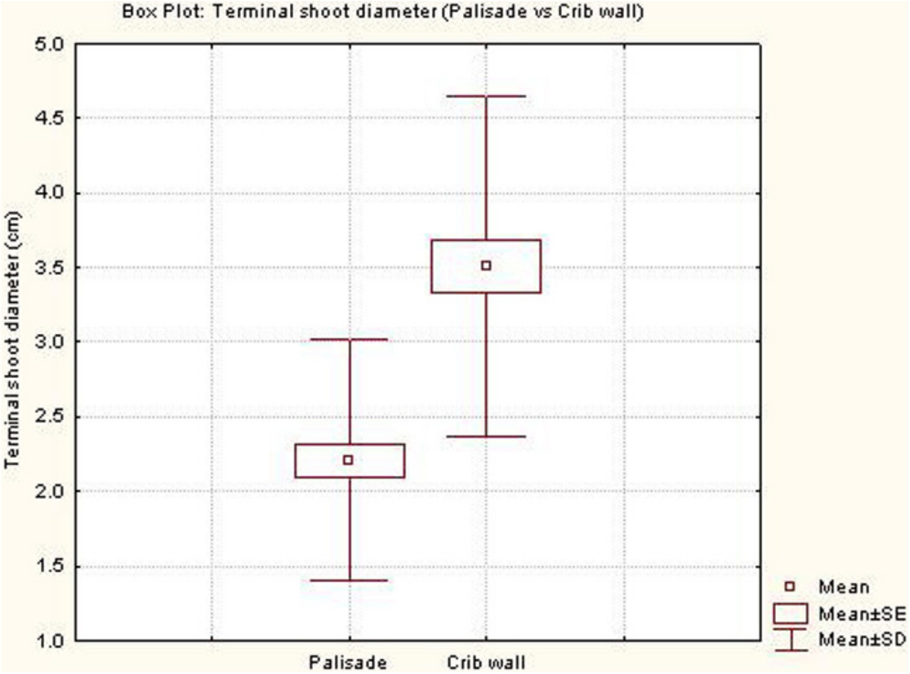

Fig. 6. Comparison between terminal shoot diameter of Helequeme (*Erythrina fusca*) in the live palisade and in the live crib wall 18 months after the construction.

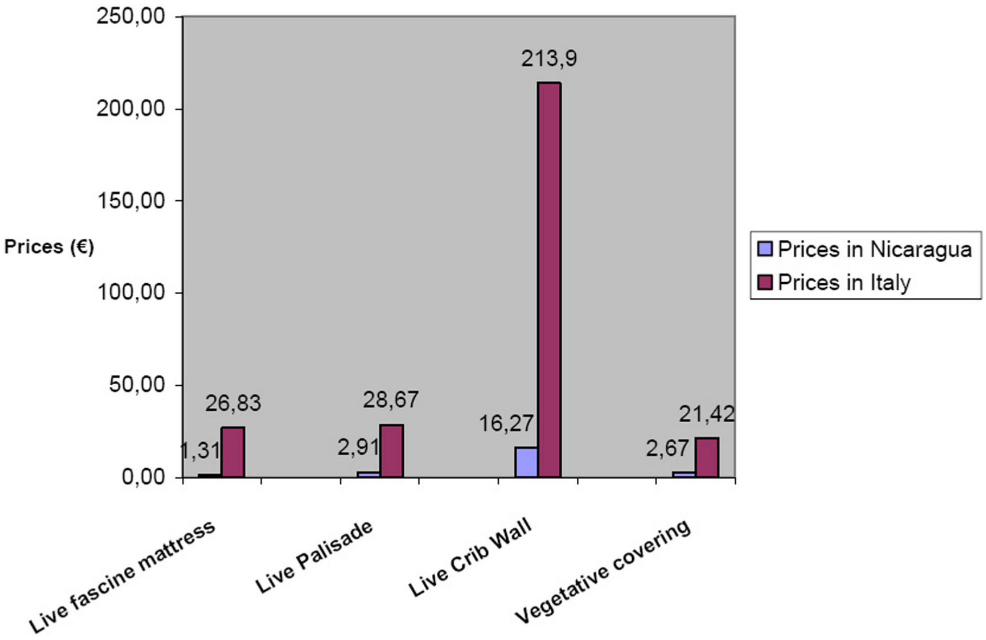

Fig. 7. Comparison between prices in Nicaragua and Italy (official exchange rate).

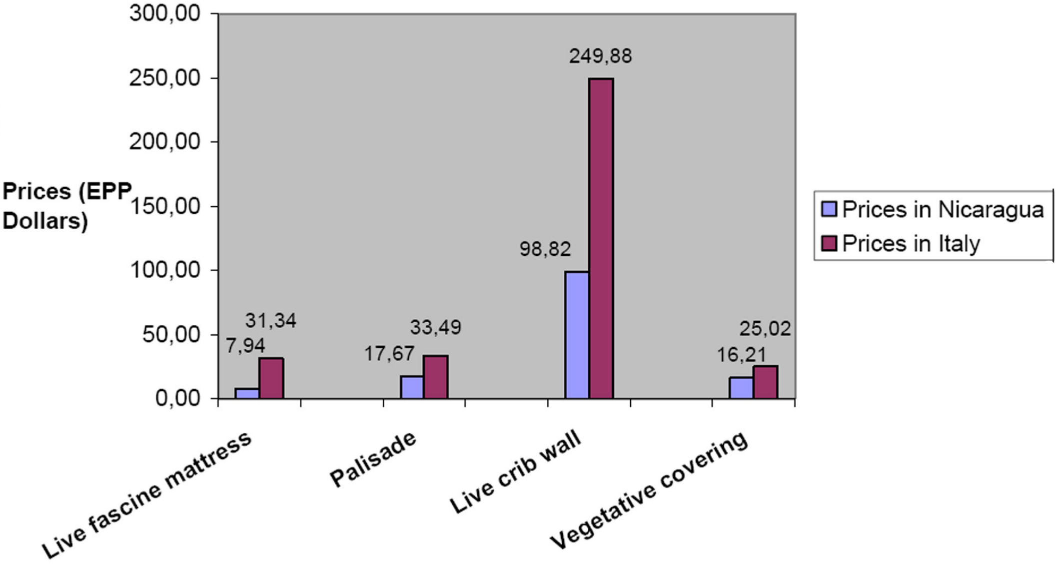

Fig. 8. Comparison between prices in Nicaragua and in Italy (EPP exchange rate).

Fig. 9a. The live palisade just after construction.

Fig. 9b. The live palisade 18 months after construction.

Fig. 9c. The vegetated crib wall along Wanawas river just after the construction.

Fig. 9d. The vegetated crib wall one year after the construction.