


POLICY BRIEF No. 79

Economic and environmental evaluation of a silvo-pastoral system in Colombia: An ecosystem service perspective

Authors
Danny Sandoval, Fernando Florez, Karen Enciso, Mauricio Sotelo, Stefan Burkart
Alliance of Bioversity International and CIAT

Miller Escobar / CIAT

Introduction

Beef, dairy, and dual-purpose systems have considerable environmental impacts, such as deforestation related to the establishment of grazing areas and methane (CH_4) emissions by ruminants. To counteract this, technological innovations must focus on both economic and environmental sustainability. In that regard, silvo-pastoral systems (SPS) are a valuable option for achieving this goal. The Alliance of Bioversity International and CIAT, over the past decade, has worked on researching such systems and supporting their adoption and scaling in tropical cattle systems. Part of this work focused on the implementation of a silvo-pastoral trial at the Alliance's Americas Hub, with the objective of comparing both economic and environmental benefits of implementing a SPS for beef cattle with an improved grass monoculture.

The present document provides an economic and environmental evaluation of the trial and suggests potential impacts that come along with adopting SPS at a larger scale. The evaluation consists of two main components: i) economic evaluation, which estimates the potential improvements in profitability of beef production in a SPS, and ii) environmental evaluation, which estimates the economic value of environmental benefits and ecosystem services

KEY MESSAGES

- Silvo-pastoral systems (SPS) are a valuable option for cattle production. When analyzing the economic results obtained in this study, we find that silvo-pastoral systems lead to higher Net Present Values and Internal Rates of Return, as well as lower risks of obtaining economic losses. By including the economic value of avoided methane emissions and the microclimatic regulation silvo-pastoral systems provide in the calculation of benefits, the economic indicators further improve considerably.
- Including legume-based diets in silvo-pastoral systems has the potential to reduce methane emissions generated by ruminants. Our study shows that methane emissions can be reduced by 8% when compared with diets obtained from a grass monoculture. This reduction is valued at US$ 6.12 per cattle head.
- SPS are providers of shade, which is obtained from the trees, and thus contribute to microclimatic regulation within the production system. This offers thermal comfort to animals, especially in high-temperature areas, and leads to improvements in meat and milk production, both in quantity and quality. Our study shows that the microclimatic regulation generated in a silvo-pastoral system generates an economic value of 2,026 US$ ha/year.

related to the implementation of a SPS. The economic-environmental value is integrated into the economic evaluation to provide a coherent analysis of economic and environmental sustainability.

Data and description of treatments

The mentioned silvo-pastoral trial aimed at evaluating animal live weight gain under two different scenarios: a grass monoculture (M) and a silvo-pastoral system (SPS). Each treatment was carried out in an area of 2 hectares, which were divided into 6 plots (0.33 ha each) for rotational grazing. The technologies used in the monoculture treatment were *Urochloa brizantha* cv. Toledo and *Urochloa* hybrid cv. Cayman. Both technologies were also used in the silvo-pastoral treatment and combined with the legume *Leucaena leucocephala*. Thus, there were a total of four treatments, namely SPS Toledo, SPS Cayman, M Toledo, and M Cayman. In each treatment, the grass-legume proportion was 70-30. The tree density was 2,000 *Leucaena* trees per hectare, of which 25% were used for shade and the remaining 75% for browsing. The live weight gain measurements were made during one year between April 2021 and April 2022.

Leucaena leucocephala is a shrub legume species with a growth between 7 and 18 meters. It has a high regrowth capacity after browsing and severe pruning, flexibility of the branches without tearing, high palatability, and high fixation of atmospheric nitrogen, which benefits the associated grasses. It performs satisfactorily at altitudes ranging from the sea level to 1,600 masl, with annual precipitation levels between 500 and 3,000 mm (distributed unimodally or bimodally), and supports temperatures ranging between 25 and 30 °C. Although it tolerates droughts well, it does not respond well to shade (Murgueitio et al., 2016; Peters et al., 2011). It requires between 800 and 1,500 hours of sunlight per year and adapts to neutral or alkaline soils and stony terrains. It does not tolerate waterlogging, acid soils with high levels of aluminum saturation, and strong or prolonged frosts (-4 °C) (Murgueitio et al., 2016).

Urochloa brizantha cv. Toledo is a perennial grass, derived directly from the accession *Urochloa brizantha* CIAT 26110 (Lascano et al., 2002). It adapts to a wide spectrum of climates, grows well in sub-humid tropical conditions with dry periods between 5 and 6 months and an average annual rainfall of 1,600 mm, and in humid tropical conditions with rainfall above 3,500 mm per year. Although it adapts to acid soils of low fertility, it develops best in soils of medium to good fertility. It has presented susceptibility to attacks by cercopids or spittlebugs (Lascano et al., 2002).

Urochloa hybrid cv. CIAT BR02/1752 (Cayman) is a hybrid developed by CIAT, evaluated and selected by the Papalotla Tropical Pastures Research Center (CIPAT in Spanish), and commercialized by Grupo Papalotla, a forage seed company from Mexico. It is a moisture tolerant grass that adapts to soils with a tendency to waterlogging. It grows in a tattered manner and produces a large number of stolons. Its growth habit is modified in the presence of humidity and at an early age it develops decumbent stems, which produce shoots and roots at the nodes, thus allowing the absorption of nutrients and the generation of oxygen to the plant in poorly drained conditions. In addition to its waterlogging tolerance, it is characterized by its drought tolerance, high palatability, stoloniferous growth, and resistance to pests and diseases. It also supports higher animal stocking rates (Grupo Papalotla, 2019).

A total of 14 Brangus animals were distributed among the two treatments (SPS and M) at a proportion of 50%. The average entry age of the animals was 18.6 months, respectively 19.1 and 18.1 months for the M and SPS treatments. The average entry weight of the animals in the M treatment was 349 kg whereas in the SPS treatment it was 345 kg. The occupation and rest periods were 12 and 45 days, respectively. Regarding the stocking rate, since each treatment was comprised of 2 hectares, 3.5 animals were grazing one hectare under each treatment.

Regarding the environmental evaluation, it was possible to evaluate the environmental benefit of reducing CH_4 emissions and the ecosystem service of micro-climatic regulation. For the reduction of CH_4 emissions, the results of Gaviria-Uribe et al. (2020) were consulted, who estimated CH_4 emissions under different grass monoculture and SPS diets. For micro-climatic regulation, a measurement of the area covered by shade in the SPS was made on September 1, 2022.

CIAT/JL Urrea

Methods

Economic evaluation

This study is based on a discounted cash flow model. Three indicators were estimated, namely the Net Present Value (NPV), the Internal Rate of Return (IRR), and the Cost-Benefit ratio (B/C). Additionally, a Monte Carlo simulation model was generated using the @Risk tool to estimate the probability of economic losses in each of the treatments. These indicators were obtained assuming the most probable values for the different specified models which are associated with the benefits and costs of each treatment under analysis. The analysis follows the comparison of the profitability of the indicators obtained for all the treatments (SPS Toledo, SPS Cayman, M Toledo and M Cayman). The costs evaluated for the systems are classified into establishment and maintenance costs, opportunity costs, operating costs related to animal health and supplementation, and labor costs. Benefits are obtained from the commercialization of animals whose profitability parameters depend on the response of the animals to each of the treatments evaluated. The average of the representative market rate in Colombia between January and August 2022, 3,992 COP/US$, was used as exchange rate.

Environmental evaluation

The environmental evaluation consists of the economic valuation of environmental benefits and ecosystem services of the SPS treatments in comparison with the M treatments. Regarding environmental benefits, the reduction of CH_4 emissions was identified as positive effect coming along with the SPS Cayman treatment when replacing the M Toledo treatment. Regarding ecosystem services, three stand out: i) micro-climatic regulation, resulting from the supply of shade by the Leucaena trees, ii) storage and capture of carbon in the tree biomass, and iii) nitrogen fixation in the soil. In this study, only the environmental benefit of reducing CH_4 emissions and the ecosystem service of micro-climate regulation were valued, since measurements are not yet available for carbon storage and capture and nitrogen fixation in the soil.

For the valuation of the reduction of CH_4 emissions, the market price method (MADS, 2016) was applied, consulting the prices of carbon dioxide equivalent (CO_2 eq.) from the main global Tradable Emission Permit Systems and economic instruments such as CO_2 taxes. For the valuation of the micro-climate regulation ecosystem service, the avoided cost method (MADS, 2016) was applied, estimating the installation and maintenance cost of a gray infrastructure covering an equal amount of space that is covered by the shade of the trees within of the SPS treatment. The gray infrastructure chosen as a reference is shadow mesh since it is the most common infrastructure used in cattle systems.

Results

Economic evaluation

When comparing the M treatments with the SPS treatments we can observe some significant differences both in productive and economic terms (Table 1), allowing for higher stocking rates, significant improvements in live weight gains, and increases in animal productivity in the SPS treatments. Likewise, the income increases by around US$ 500 in the SPS treatments. Costs, however, are higher in the SPS treatments which is related to the establishment of the trees. The highest cost can be observed for SPS Cayman, exceeding the establishment cost of M Cayman by 26%.

Table 1. Summary of main costs and income of the different treatments

Economic indicator	M Toledo	M Cayman	SPS Toledo	SPS Cayman
Animal stocking rate (# animals)	3.0	3.0	4.0	4.0
Live weight gain (kg/animal/y)	159.25	159.25	239.81	239.81
Animal productivity (kg/ha/y)	723	723	1,078	1,078
Income from beef sales (US$)	1,501.84	1,501.84	2,007.33	2,007.33
Pasture establishment costs (US$)	468.69	647.04	482.72	814.13
Pasture maintenance costs (US$)	70.93	87.68	52.61	68.39
Pasture renewal costs (US$)	76.94	106.96	79.66	103.56
	-	-	15.03	15.03

The economic results are negative for both M treatments, respectively disparate for the SPS treatments. The SPS Toledo treatment shows an overall positive result while for the SPS Cayman treatment it is negative, which due to the higher establishment costs associated with this treatment. When considering the results obtained for environmental benefits of avoided methane emissions and micro-climatic regulation, the economic indicators improve considerably (Table 2).

Table 2. Economic indicators for the different treatments

Economic indicator	Evaluation criteria	M Toledo	M Cayman	SPS Toledo	SPS Cayman
Economic benefit	NPV mean (US$)	-268.05	-527.96	35.10	-218.49
	IRR mean (%)	-4.39	-0.06	0.58	-2.39
	Risk (prob NPV<0) (%)	67.16	80.95	48.84	59.56
	B/C ratio	1.00	0.99	1.03	1.02
Economic benefits + avoided methane emissions	NPV mean (US$)	-	-	259.97	6.38
	IRR mean (%)	-	-	3.00	-0.23
	Risk (prob NPV<0) (%)	-	-	39.27	50.07
	B/C ratio	-	-	1.04	1.03
Economic benefit + micro-climatic regulation	NPV mean (US$)	-	-	29,342.24	29,088.65
	IRR mean (%)	-	-	260.42	228.89
	Risk (prob NPV<0) (%)	-	-	0.00	0.00
	B/C ratio	-	-	2.95	2.91

Finally, Figure 1 presents the distributions obtained for the NPV generated with the Monte Carlo simulation exercise. It can be observed how the probabilities of obtaining positive results for the NPV improve for the SPS treatments compared to the M treatments. These probabilities improve when considering the environmental benefit of avoided methane emissions and the ecosystem service of micro-climatic regulation, resulting in a 100% probability of obtaining a positive NPV due to the avoided cost of installing gray infrastructure for shading.

Environmental evaluation

Reduction of CH_4 emissions

Based on the results of Gaviria-Uribe et al. (2020), the SPS Cayman treatment achieves a reduction in methane emissions of 0.03 g CH_4 per g of live weight gain, which is equivalent to a reduction of 0.63 g CO_2 eq. per g of live weight gain compared to the M Toledo treatment. If this diet was used in a larger SPS, for example, with 1,000 cattle heads, a reduction of 145 tons CO_2 eq. would occur (Table 3).

After consulting the most important carbon markets in the world (ICAP, 2022), the carbon tax in Colombia (Asocarbono, 2022), the minimum price recommendation for carbon credits of the International Monetary Fund (Parry et al., 2021), and the general equilibrium model with the Tradable Emission Permit System in Colombia of the National Planning Department (Sousa et al., 2018), we identified an average price per ton of CO_2 eq. for 2022 of 45.25 US$/t.

In this way, the estimation of the economic value of the environmental benefit of reducing CH_4 emissions with the SPS Cayman treatment leads to a value of US$ 6.12/cattle head. Given that the stocking rate of the experimental plot is 4 cattle heads, there is a total economic value of US$ 24.49, which is equivalent to an annual benefit of US$ 28.83. If this treatment was replicated at a larger scale with 1,000 cattle heads, an economic value of US$ 6,122 could be generated (Table 4).

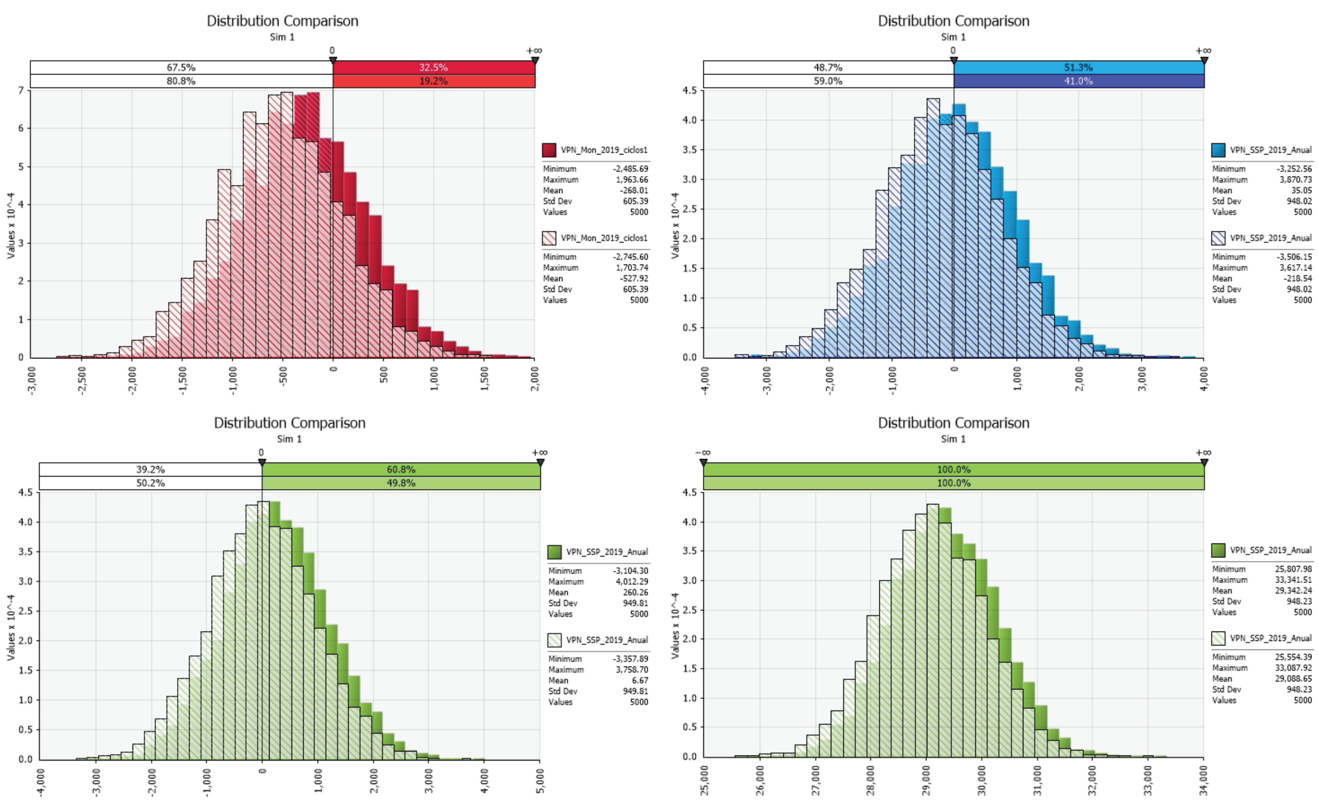

Figure 1. NPV distributions for the different treatments

Table 3. Estimation of the reduction of CH_4 emissions in a SPS treatment

Diet	M Toledo	SPS Cayman
CH_4 g/g live weight gain	0.36	0.33
CO_2 eq. / CH_4 IPCC	21	21
CO_2 eq. g/g live weight gain	7.56	6.93
Live weight gain (g/d)	273	742
Emissions (g CO_2 eq./d)	2064	5142
Entry weight per animal (kg)	220	220
Sales weight per animal (kg)	450	450
Time needed to reach sales weight (d)	842	310
Emissions generated until sales weight (t CO_2 eq.)	1.739	1.594
Extrapolation (system with 1,000 cattle heads)	1,000	1,000
Emissions of the overall system (t CO_2 eq.)	1,739	1,594

Source: own elaboration based on Gaviria-Uribe et al. (2020)

Table 4. Estimation of the economic value of reducing CH_4 emissions in a SPS

Parameter	M Toledo	SPS Cayman
Emissions of the overall system (t CO_2 eq.)	1,739	1,594
Price (US$)	42.25	42.25
Cost (US$)	73,460	67,338
Benefit (US$)	0	6,122
Benefit/cattle head (US$)	0	6.12
Animal stocking rate	3	4
Time needed to reach sales weight (d)	842	310
Total benefit (US$)	0	24.49
Annual benefit (US$)	0	28.83

Micro-climatic regulation

Regarding the micro-climatic regulation ecosystem service, we found that the SPS treatments have an area covered by tree shade of 12,082 m^2, which is equivalent to a shade coverage of 60.4%. After consulting 10 suppliers of shadow mesh in the Valle del Cauca department (Colombia), we identified average costs for a) m^2 of shadow mesh of US$ 0.78, b) a pole for installation of US$ 5.49, and c) daily labor of US$ 9.24. The lifespan of this installation was estimated with 3 years.

Thus, if the shade cover of trees in the SPS treatments were replaced by shadow mesh, a total cost of US$ 12,158 would occur, which is equivalent to US$ 4,053 per year and US$ 2,026 per hectare per year. If the SPS treatments were replicated in an area of 1,000 ha, an economic value of the micro-climatic regulation ecosystem service of US$ 2,016,414 per year would be achieved (Table 5).

CIAT/JL Urrea

Table 5. Estimation of the economic value of the micro-climatic regulation ecosystem service in a SPS

Item	Unit	Unit value (US$)	Quantity	Total value 3 years (US$)	Annual value (US$)	Annual value/ha (US$)	Annual value 1,000 ha (US $)
Shadow mesh	m^2	0.78	12,082	9,471	3,157	1,578	1,578,425
Poles	unit	5.49	483	2,651	884	442	441,830
Labor	Days	9.24	4	37	12	6	6,159
		Total value of ecosystem service (US$)		12,158	4,053	2,026	2,026,414

Conclusions

Our study shows that the economic indicators of a monoculture grass beef system improve when it is being transformed into a SPS. In fact, the studied monoculture systems (Toledo and Cayman), without the inclusion of *L. leucocephala* in a silvo-pastoral setup, show negative economic indicators. Although the productive parameters for the evaluated silvo-pastoral treatments were not the best in terms of live weight gain and stocking rates, the obtained positive economic profitability indicators show that these treatments can be profitable even under unfavorable conditions. When the economic value of the environmental benefits and ecosystem services is included, the silvo-pastoral treatments considerably improve their economic profitability indicators, in addition to reducing the risk of obtaining negative economic results.

Our study also shows that the implementation of a SPS with *U.* hybrid cv. Cayman + *L. leucocephala* is desirable both in terms of economic and environmental sustainability. The adoption of this technology in larger production systems could generate significant environmental value. For example, its adoption in a beef cattle production system with 1,000 animals could generate a reduction of up to 145 tons of CO_2 eq. valued at US$ 6,122 until the animals have reached their sales weight. Likewise, such system provides a tree shade cover of 60.4%, and, in an area of 1,000 ha, this would generate an economic value of >2 million US$.

There also exist other ecosystem services in SPS, such as soil nitrogen fixation and carbon storage and capture by trees, which could not be included in our analysis due to missing estimations on their ecological values. It is thus recommended to conduct studies that focus on the estimation of ecological values of these and other ecosystem services so that they can be included in future assessments.

Despite their environmental and economic benefits, adoption levels of SPS are still low among cattle producers both in Colombia and other Latin American countries. It is necessary to promote this type of systems that generate both economic and environmental value. One promotion strategy could be linking SPS to programs for Payments of Ecosystem Services (PES) or carbon credits that allow producers to fully or partially monetize the value of ecosystem services and environmental benefits generated by adopting this technology and obtain an additional income from the sale of beef and milk. It is also recommended to design financial instruments that offer better conditions of access to credit for producers who wish to finance the costs of establishing SPS in consideration of the future environmental value that they will generate.

Acknowledgements

This work was conducted as part of the OneCGIAR Initiative on Livestock & Climate (L&C). We thank all donors who globally support our work through their contributions to the CGIAR System. CGIAR is a global research partnership for a food-secure future. Its science is carried out by 15 Research Centers in close collaboration with hundreds of partners across the globe. We gratefully acknowledge funding from Biotechnology and Biological Sciences Research Council project Advancing sustainable forage-based livestock production systems in Colombia - CoForLife (BB/S01893X/1).

References

Asocarbono. (2022, February). DIAN expide nueva resolución de impuesto al carbono en Colombia. Asocarbono.org. bit.ly/3Whecoj

Gaviria-Uribe X; Bolivar DM; Rosenstock T S; Molina-Botero IC; Chirinda N; Barahona R; Arango J. 2020. Nutritional quality, voluntary intake and enteric methane emissions of diets based on novel Cayman grass and its associations with two leucaena shrub legumes. Frontiers in Veterinary Science 7: 579189. doi.org/10.3389/fvets.2020.579189

Grupo Papalotla. (2019). CAYMAN Brachiaria híbrido cv. CIAT BR02/1752. Ciudad de México: Papalotla.

International Carbon Action Partnership ICAP. (2022). ICAP Allowance Price Explorer. ICAP Allowance Price Explorer. bit.ly/3kqsoy4

Lascano C; Pérez R; Plazas C; Medrano J; Pérez O. 2002. Pasto Toledo (Brachiaria brizantha CIAT 26110) Gramínea de crecimiento vigoroso para intensificar la ganadería colombiana. Villavicencio: Centro Internacional de Agricultura Tropical (CIAT). hdl.handle.net/20.500.12324/36716

MADS. (2016). APPLICATION GUIDE FOR ENVIRONMENTAL ECONOMIC VALUATION (Vol. 1). www.minambiente.gov.co

Murgeitio, E., Uribe, F., Molina, C., Molina, E., Galindo, W., Chará, J., González, J. (2016). Establecimiento y manejo de sistemas silvopastoriles intensivos con leucaena. Cali: Fundación CIPAV.

Parry, I., Black, S., & Roaf, J. (2021). Proposal for an International Carbon Price Floor Among Large Emitters. IMF Staff Climate Notes 2021/001, 1–21. bit.ly/3kmMSrN

Sousa, R., Álvarez-Espinosa, A. C., Rojas Pardo, N., Melo Leon, S. F., Romero Otalora, G., Riveros Salcedo, L. C., Calderon Diaz, S. L., & Vazao, C. (2018). Mitigación del cambio climático con un Sistema de Comercio de Emisiones en Colombia: primeros hallazgos económicos. bit.ly/3IS8HJ

About the authors

Danny Sandoval is economist, M.Sc. student and research associate at the Tropical Forages Program, Alliance Bioversity & CIAT. d.sandoval@cgiar.org

Fernando Flórez is economist, M.Sc. in Economics and research associate at the Tropical Forages Program, Alliance Bioversity & CIAT. j.f.florez@cgiar.org

Karen Enciso is economist, M.Sc. student and former research associate at the Tropical Forages Program, Alliance Bioversity & CIAT. k.enciso2912@gmail.com

Mauricio Sotelo is agricultural engineer, M.Sc. in Agronomy and research associate at the Tropical Forages Program, Alliance Bioversity & CIAT. m.sotelo@cgiar.org

Dr. Stefan Burkart is an economist, social scientist, and theme leader, Tropical Forages Program, Alliance Bioversity & CIAT. s.burkart@cgiar.org

Correct citation

Sandoval, D.; Florez, J.F.; Enciso, K.; Sotelo, M.; Burkart, S. (2022) Economic and environmental evaluation of a silvo-pastoral system in Colombia: An ecosystem service perspective. Policy Brief No. 79. Cali (Colombia): Alliance of Bioversity and CIAT. https://hdl.handle.net/10568/126338

CIAT/M Escobar

CONTACT

Stefan Burkart
s.burkart@cgiar.org

INITIATIVE ON Livestock and Climate

CGIAR

Biotechnology and Biological Sciences Research Council

Alliance Bioversity & CIAT

alliancebioversityciat.org

CGIAR

cgiar.org

December 2022