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Agricultural Innovations and Adaptations to Climate Change in the Northern Cameroon Region

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Abstract: Adaptation to climate change has remained a major socio-ecological issue in the Northern Region of Cameroon since 1973. Presently, this region is subject to the severe chaos of drought, floods, and ecosystem degradation, causing harm and disrupting climatic patterns. Climate change results in the drying of surface water and crops, threatening food security and the well-being of households. It has a serious impact on the entire agricultural production system at global scale. Here, it is suggested that successive adjustments to deeper systemic and transformational adaptations through efforts from NGOs, the Government, and donors, as well as innovations, are necessary to offset the negative impact of climate change on the agricultural value chain. Therefore, this research aimed to identify adaptation strategies and practices for rural communities and households, who suffer from limited access to these agricultural innovations, for a transformative adaptation. Through surveys and focus group discussions carried out in several villages in the Northern Cameroon Region, this study provides empirical data on emerging agricultural innovations in contrasting socio-economic, agricultural, and ecological contexts. Our findings demonstrate that agricultural innovations fostered at the village level have several characteristics that contribute to adaptation and mitigation of the impact of climate change. To begin with, conservation agriculture is very interesting, because crop residues left on the soil protect it from rainfall and dry winds, and gradually add humus to the top soil. In addition, agroforestry plays an important role for the household regarding ecosystem services, including food supply, soil fertility, protection from erosion, regulation of water regime, and sociocultural value. Generally, heads of households (83%) were more involved in innovative initiatives than other social strata, resulting in unequal access and proximity to agricultural innovations. Furthermore, the results highlight a significant lack of coordination and poor visibility of permanent structures supporting agricultural innovations at local level, weakening the sustainable transformation of adaptation. From a scientific perspective, this study could help build a conceptual relationship between agricultural innovation and sustainability transformation, i.e., a climate-smart agriculture. In practice, it provides levers that can be used to multiply and expedite agricultural innovation processes, water conservation, and livestock sustainability, thus contributing to the sustainability of the whole agricultural system in Cameroon and within the Sahel region of Africa.

Keywords: agriculture; adaptation; climate change; innovation; North Cameroon

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1. Introduction and Background of the Study

The concept of adaptation to climate change refers to actions that contribute to reducing vulnerability to the current or expected effects of climate change, such as climate extremes and risks. Adaptation is a process of adjustment of natural and human systems to an observed or anticipated climatic stimulus, to these effects, and impacts, with a view of limiting or eliminating potential damage or taking advantage of the opportunities created by climate change or variability [1,2]. Adaptation can be a set of changes in the procedures, practices, and structures of smallholder agriculture. This aims at limiting the actual or potential damage caused by climate change [3]. Seen from the perspective of climate change, adaptation would be closely linked to innovation, because innovation can be understood either as a construction of the mind or as a change [4]. Considering the significant ecological challenges of the study area, especially those linked to the impacts of climate change (the deterioration of production potential and reductions in median agricultural yields of 2% per decade [2]), several authors have recommended agricultural innovations as a means of fighting against climate change [5–9]. As such, several innovations have been introduced and implemented in the Northern Cameroon region, with strong adaptation potential. These innovations are seen as adaptation measures implemented at the local level, considering the uses and needs of rural communities. They include the planting of climate-sensitive crop varieties and more drought-resistant trees; the practice of regenerative or conservation agriculture; improvements in water storage and use; and the implementation of agroforestry practices against extreme weather events, such as floods and heat waves. However, these local responses in terms of agricultural innovations do not allow for lasting change.

Within the literature, local responses to the impacts of climate change have been analyzed by classifying them as "incremental", because they refer to minor modifications to existing practices and knowledge [10–12]. At the scale of change and current climate variability, transformational responses are increasingly necessary to avoid the pitfalls induced by extreme climatic hazards, and the situation of maladaptation [7,13,14]. Maladaptation refers to an adaptation process that results directly in an increase in vulnerability to climate variability and change, and/or an impairment of current and future adaptive capacities and opportunities. In the context of maladaptation, climate change increases vulnerability rather than reducing it [1,2]. As mentioned by Grigorieva et al. [15], it is important to detect maladaptation before it happens by determining the main factors affecting farmers and community adaptation. Such a situation has been observed in the North Region of Cameroon, where vulnerability is increasing due to the low contribution of innovations available in the region. This maladaptation problem justifies this paper, which aimed to question to what extent agricultural innovations could truly contribute to adaptation to climate change? What are the determinants that are missing from existing agricultural innovations to enable sustainable changes to the adaptation to climate change? The objective of the study was to analyze the agricultural innovations that have emerged and the determinants of their contributions to transforming adaptation, with an emphasis on systemic theories and approaches. Such an objective can allow us to move from incremental adaptation (i.e., successive adjustments) to deeper systemic and transformational adaptation [7,8,12,16,17]. Specifically, (i) we characterized the adapted agricultural innovations that have been promoted by showing their contribution to climate adaptation. Then (ii), we analyzed the determinants of an effective and sustainable transformation of the adaptation to climate change. Finally (iii), this study contributes to achieving the objectives of the agricultural sector in Cameroon, developing agriculture resilient to climate change and improving the adaptation capacities of farmers [18].

Study Analysis Framework

The present study is structured around two main concepts, namely agricultural innovation and transformative adaptation. Agricultural innovation was at the heart of the adaptation analysis and required multi-actor approaches [19,20]. The multiple stakeholder approach was configured around three main analysis scales, notably the micro or local scale concerning the beneficiaries, i.e., farmer organizations or local communities [21], directly affected by climate change and variability. The medium or meso scale is made up of those who provide support to beneficiaries through multiple interventions. These are indirectly impacted by climate variation. The macro or regional scale consists of the key actors who have the capacity to instigate change. This is the political level, characterized by negotiations and advocacy to encourage adaptation, with a view to reducing risks and the vulnerability of populations [22], because adaptation cannot be implemented without institutions, policy technology, and financial resources [23]. Innovation is at the heart of climate adaptation, and this is why some authors [24] consider innovation as adaptation and adaptation as innovation. Innovation therefore becomes essential to intensifying adaptation to climate change. Several authors [25,26] have shown that research on agricultural innovation needs to rely increasingly on a participatory approach and include more actors (public and private sectors and NGOs) if it wishes to succeed socially and economically, instead of just looking at farmers and rural households. In Benin, many authors [27] have pointed out that the involvement of new actors with knowledge and skills in agricultural innovations is likely to boost the adaptation to climate change. This requires considering multi-actor or multi-stakeholder dimensions in the innovation process. Innovation therefore becomes a product of a multi-actor process. These multiple actors provide services in support of innovations for the transformation of adaptation, with a view to a transitioning towards transformative resilience.

The concept of transformation provides insurance for a sustainable and bright future. The transformative [7,28] and transition [29,30] concepts used in this study suggest a more fundamental change. There were also used by the IPCC in their fourth and fifth assessment reports [2]. In view of the above, the present study is not limited to examining the incremental adaptation implemented to mitigate the effects of climate change. It also involves moving towards a systemic adaptation centered on multi-actor approaches, as presented above. The same is true for transformational adaptation, which remains the ideal means for building true community resilience [7].

2. Materials and Methods

2.1. Study Area

This study was carried out in the Northern administrative region of Cameroon (Figure 1), more precisely at the three intervention sites of the ReSI-NoC project, to strengthen the innovation systems in these dry territories. This project was structured around agro-sylvopastoral innovation support in the Northern Cameroon Region. The project took place in three of the four administrative divisions of the North Region, namely Benue, Faro, and Mayo-Rey. In these three divisions, the project was split into thematic areas of intervention. These included the South of Garoua, which is a metropolis with a high potential for resource degradation.

The second thematic zone was in the immediate vicinity of protected areas. Hence, this Northern Region is endowed with three national parks and 28 hunting zones known as cynegetic interest zones (CIZ), which are areas experiencing regular tensions and conflicts linked to access to land and natural resources. The last thematic zone of the project was situated at the pioneering front of cotton and food crop production. This area is characterized by a significant tendency to clear natural vegetation (shrub and tree savanna) to establish new agropastoral farms. All the villages surveyed belonged to these three thematic zones, as shown in Figure 1.

According to the National Determined Contribution [31], the study area is located in the Sudano-Sahelian agroecological zone (North Cameroon Region). The climate is dry with 6–7 months of rainy season, against 5–6 months for the dry season (Figure 2). The Touboro and Tchollirè locations show a general increase in temperature starting from January, peaking around March–April, and then gradually decreasing. The temperature ranges from approximately 24 °C to 30 °C throughout the year. Garoua and Poli, similarly to Touboro and Tchollirè, also experience an increase in temperature starting from January and peaking around April, with a sharper peak and slightly higher temperatures, sometimes exceeding 35 °C. The temperature then decreases as the months progress. The Touboro and Tchollirè locations show rainfall that starts to increase significantly from May, peaking in

August, and then sharply declining by October, indicating a clear wet season from May to September–October. The Garoua and Poli rainfall patterns in these areas also start to increase from May, with peak rainfall in July–September. The transition from the dry to wet seasons is quite abrupt, similarly to in Touboro and Tchollíré, with a sharp drop in rainfall as the year ends (Figure 2).

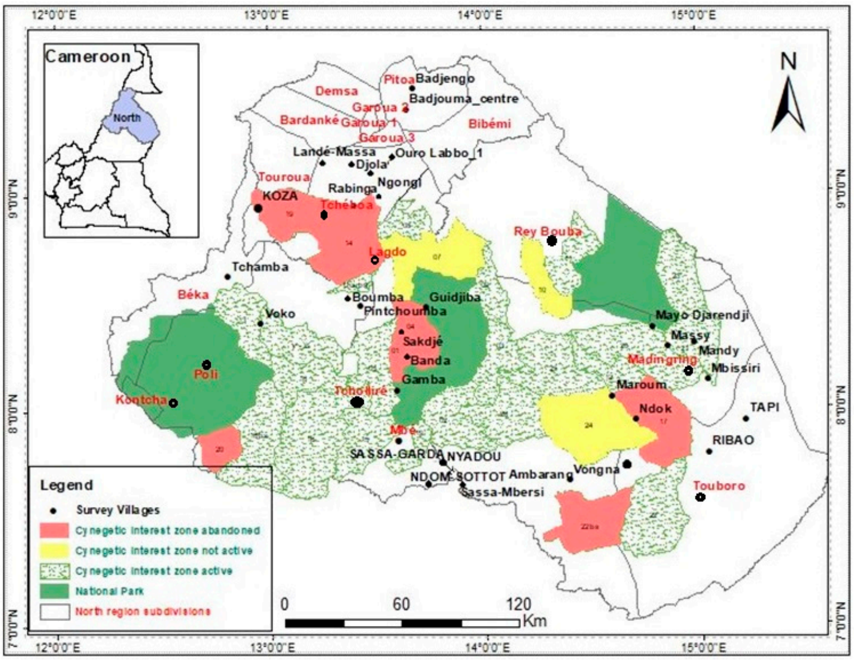

Figure 1. Location map of the study area.

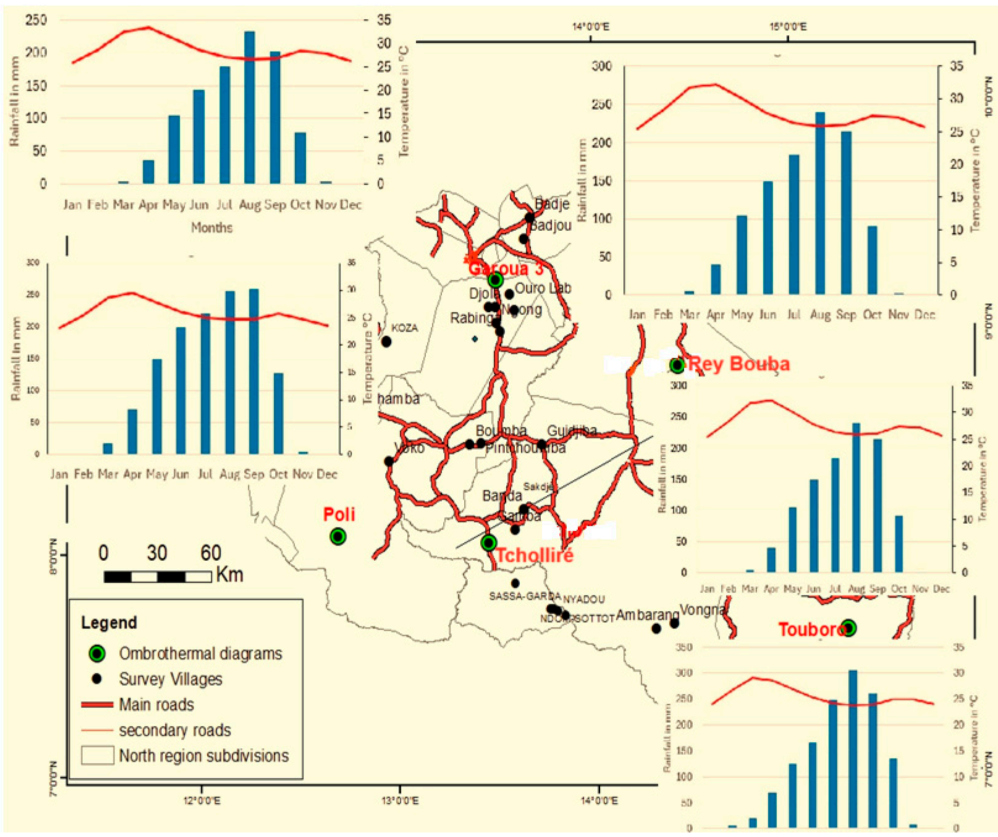

Figure 2. Climate regime of the North Cameroon region.

The region will experience an estimated temperature increase of +0.7 °C by 2025, +1.2 °C by 2035, +2.5 °C by 2055, +3.6 °C by 2075, and +4.8° C by 2100. Concerning precipitation, scenarios generally predict a drier climate in this Sudano-Sahelian zone, with a decrease in rainfall of −2 to 0% by the end of the year. Projections for 2025–2035 show an increase of 1 to 10% by 2075 and 1 to 5% by 2100 (Table 1), with a concentration of rain in space and time [32,33]. Specifically, the study area is subject to great sensitivity to rainfall variation [34,35]. Producers have identified several climatic hazards, including variation in the crop calendar (early cessation of rains), agricultural and meteorological drought, and floods. These unfavorable climatic conditions are managed with great difficulty by agropastoral populations.

Table 1. Projections of climate parameters at different time horizons from 2021 to 2100.

Projected Climate Parameters	Scenarios	Time Horizons			
		2021–2040	2041–2060	2061–2080	2081–2100
Rainfall (500–1000 mm) trend scenario in %	RCP 2.6	−2 to 1	0 to 1	0 to 5	1 to 2
	RCP 4.5	−2 to 0	−1 to 4	0 to 5	0 to 1
	RCP 8.5	−1 to 1	−1 to 3	5 to 10	2 to 5
Temperature (25–35°) trend scenario in °C	RCP 2.6	0.5 to 1	1 to 1.5	3.5 to 4	4 to 4.5
	RCP 4.5	0.7 to 1	1.5 to 2	4 to 4.5	4.5 to 5.5
	RCP 8.5	1 to 1.5	2 to 2.5	4.5 to 5	5.5 to 6

Source: adapted from MINEPDED [33].

2.2. Data Collection

2.2.1. Climate Change

Information on climate (precipitation, max and min temperatures, and relative humidity) was collected from the National Meteorology Department, National Observatory on Climate Change, Meteoblue online, and the Regional Delegation of Agriculture and Rural Development. It is worth mentioning that such data are scarce and fragmented. These data are gathered in Table 2.

2.2.2. Agricultural Innovation and Actor Identification

Through the methods of tracking innovations, notably an online documentary review of project and program reports, multi-stakeholder workshops organized in the North Cameroon region, and semi-structured interviews, several agricultural innovations were identified. The sites at which these innovations were identified constituted the study sample. The scale of these different innovation sites was that of the village, because it is considered the main space for interventions by stakeholders, particularly those from the private sector, NGOs, and cooperation organizations [21]. These actors participate in the implementation of agricultural innovations, as well as their support. Part of the data for this study were collected within the framework of a baseline study carried out in 33 villages with 587 households. The choice of villages was guided by the innovations identified in the area. The collection of information was carried out through direct interviews with the heads of households, who could be either women (22.53%) or men (77.47%); and migrants (41.20%) or natives (58.80%). In addition to these baseline villages, four other villages were surveyed as part of this study. In these villages, there was a discussion on clarifying the content of the agricultural innovations observed. A drone and a camera were used for this purpose to image the content of agroforestry practices, grassy and wooded strips, as well as micro dams.

Table 2. Monthly measured climate parameters.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Garoua Station: 202 m 8°28′ N 13°23′ E												
Mean Temp	29.2	32.1	34.8	36	34.1	31.5	29	27.7	28.8	30.9	32.1	29.5
Max Temp	38	39	40	44	37	36	34	32	34	36	37	38
Min Temp	21	25	26	28	27	25	24	23	23	25	23	21
Precipitation	0	0	2	44.1	108.4	135	205.3	247.9	190	63.3	1.6	0
Rel. hum.	32	28	30.5	47.5	63	74	78	78.5	77.5	70.5	52	37
Poli Station: 436 m 8°29 N 13°15 E												
Mean Temp	23.2	24.6	28.1	29	28.2	26.2	25.9	25	25	25.9	25.1	25.8
Max Temp	33	35	38	37	34	31	29	29	30	32	34	33
Min Temp	19	21	25	26	25	23	22	22	22	22	21	19
Precipitation	0	2	18	79	176	224	233	295	307	225	5	1
Rel. hum.	49	39	41	63	71	79	81	84	85	76	62	53
Rey Bouba Post: 252 m 8°40′ N 14°10′ E												
Mean Temp	27	28.5	32	33	31	28.5	26.5	26.5	26.5	27.5	27.5	26
Max Temp	34	36	39	39	36	33	30	30	30	32	35	34
Min Temp	20	21	25	27	26	24	23	23	23	23	20	18
Precipitation	0	0	6	46	100	130	176	214	172	64	6	0
Rel. hum.	33	25	21	44	59	73	81	82	82	70	49	37
Tchollíré Post: 382 m 8°24′ N 14°10′ E												
Mean Temp	25.5	28	31	32.5	31	28.5	27.2	26	26.5	27.5	27	26.5
Max Temp	34	36	39	39	36	33	31	30	31	32	34	33
Min Temp	17	20	23	26	26	24	23	22	22	23	20	18
Precipitation	0	1	24	71	130	186	277	306	276	87	4	0
Rel. hum.	35	31	40	62	67	75	80	83	83	72	55	41
Touboro Post: 515 m 7°46′ N 15°21′ E												
Mean Temp	24.5	26.5	30	30.5	29	26.5	25	25	25.5	26	26.5	25
Max Temp	34	36	38	37	34	31	29	29	30	31	34	34
Min Temp	15	17	22	24	24	22	21	21	21	21	19	16
Precipitation	0	0	14	73	101	170	262	348	260	100	8	0
Rel. hum.	40	33	40	61	68	78	80	84	83	74	57	50

2.2.3. Support of Innovation Processes and Community Participation

Two types of tools were used for interviews, including a household questionnaire and a village checklist. The first tool was denser in terms of the volume of information and collected detailed parameters on agricultural production systems in households, while the second focused on data at the village level. The interviews were focused on identifying the main activities of the respondents (agriculture, livestock breeding, and other types of activities), the manifestations and impacts of climate change, the identification of new agricultural practices in response to climate change, the performance of each of these innovative practices, and the actors who implemented and disseminate these technologies. In the data collection, the Likert scale was used (satisfied, not satisfied) to assess the level of satisfaction with innovation support services.

2.3. Data Analysis

2.3.1. Analysis of Agricultural Innovation

From the data collected, a qualitative analysis was carried out using content analysis to extract the perceptions (meaning) of agricultural innovations by the respondents using Excel 2013 and SPSS v25 software. Much attention was paid to the occurrence of meaning in the respondents' speech. Moreover, the use of quantitative analysis made it possible to calculate proportions (percentages) and means. Graphs and tables were constructed to visualize innovative practices adapted by the households against climate change. In addition, quantitative analysis was applied to determine the level of participation of households in the process of agricultural innovation [35].

2.3.2. Innovation Support Analysis

Based on the works of many authors [36–38], an innovation support service matrix was used to build a table of the global support provided by actors in relation to households. This work also helped classify support innovations at local level.

3. Results

3.1. Agricultural Innovations for Incremental Adaptation to Climate Change in the Northern Region of Cameroon

From the beginning of the 1990s, the Northern Cameroon Region has benefited from the gradual appearance and development of climate-smart innovations. These innovations include the capacity to respond to current ecological challenges, particularly those linked to climate change, through the triptych of adaptation, mitigation, and productivity. This is the case for (1) conservation agriculture, which allows the maintenance of soil humidity against drought; (2) rain erosion control techniques, which limit the leaching of organic matter from the soil; (3) the conservation management of soil water at the level of watercourses, which promotes the maintenance of the water table for a long periods; and finally, (4) agroforestry practices, which reduce deforestation and allow carbon storage. In the present research, we emphasized the contribution of the internal characteristics and potentialities of these climate-smart innovations to adaptation to climate change.

3.1.1. Conservation Agriculture Innovations

Conservation agriculture methods aim at maintaining soil fertility, or even improving it. In practice, this requires minimal soil disturbance; banning clearing, ridging, plowing, or heavy mechanical weeding; and maintaining good soil cover through the conservation of plant residues on the soil surface without burning and crop rotation. Rotation as a practice involves the cultivation of seasonal speculations that may change over the years. It is based on the principle that plant soil nutrient and moisture requirements are not the same for all cultivated plants. The objective of rotation is to improve the physicochemical characteristics of the soil, with a view to promoting water infiltration; reducing runoff, erosion, and soil compaction; and restoring soil fertility through organic matter intake. The types of rotation observed include sewing cereals in the first year, legumes in the second year, and cotton in the third year. In addition to rotation, producers also practice crop association on the same plots. This is the case for cereal + *bracharia* + grass or *Stylosanthes* combinations. Such a practice helps improve soil fertility by fixing nitrogen and facilitating soil aeration. In addition to these practices, we also observe composting, which is a natural process of decomposition of organic matter by microorganisms under well-defined conditions.

Organic raw materials, such as crop residues and animal waste, are applied to soils as fertilizer. The objective is to improve the quality of organic matter, to make it more capable of improving the physicochemical and biological properties of the soil, to increase its productivity. In addition to cultivation under plant cover, these are the practices most implemented by producers, as shown in Figure 3. Cultivation under plant cover also allows soil moisture to be conserved and water evaporation to be reduced, and the result is an increase in crop yields.

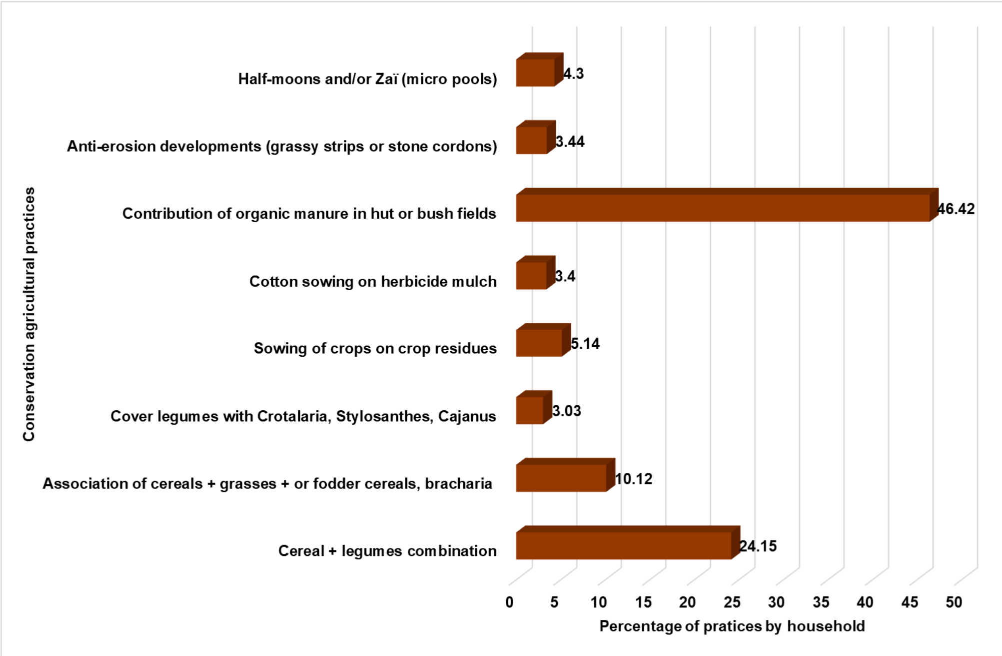

Figure 3. Use of conservation agriculture practices by households at ReSI-NoC project sites.

3.1.2. Innovations through Agroforestry Practices

Following the great drought which struck the African Sahel countries, including the northern part of Cameroon, in the mid-1970s, Cameroon, like the other states of the sub-region located on the edge of the Sahara Desert, decided to implement activities combating desertification. With this challenge in mind, Cameroon, since COP 21 in Paris, has seized all opportunities offered to take part in two main initiatives: the "Great Green Wall (GMV)" and "Restoration of Forest Landscapes in Africa (AFR100/Bonn Challenge)" [39].

Agroforestry practices are part of technical innovations introduced in the North Cameroon region after the great drought of the 1970s. They were implemented in collaboration with projects such as Green Sahel Operation (GSO), which consists of mass planting of trees to combat desertification. In addition, for this aim, Cameroon created the Provincial Committee for the Fight against Drought (CPLS) in 1975, related to strategies taken at the African level. Apart from this successful Green Sahel Operation, a sylvopastoral trial was set up near the Laf forest reserve in 1985, with a view to assessing sustainable management techniques for degraded wooded savannas [40]. Furthermore, in the 1980s, the integration of trees into crops was examined using two approaches: (i) an evaluation of the existing situation, with the interest mainly focused on the traditional association of *Faidherbia albida* with different cultural practices; and (ii) the testing of new systems including exotic species (fast-growing and/or multi-use) within crops according to supposedly more "rational" schemes (alley-cropping, windbreaks, hedges) [40]. In the 1990s, agroforestry, as a discipline, became part of development practice [41].

Since 1990, among other actions, fertility management and the place of trees in the village [42] have been developed, as well as extensive attention being devoted to evaluating the role of fallows based on *Acacia polyacantha* and *Cassia siamea* on the biogeochemical cycle of depleted ferruginous soils. Around 1996, the Agricultural Export Diversification Project (PDEA) made *Acacia senegal* a tree of particular interest to produce Arabic gum. During the same period, the Peasant Development and Land Management program (DPGT) was set up and used a tree approach in rural areas through research and development. By relying on SODECOTON and benefiting from funding from the French Development Agency (AFD) and the Cooperation Assistance Fund (FAC), it was possible to launch important actions to promote trees in agrarian systems. All these works were carried out in collaboration with the Institute of Agronomic Research for Development (IRAD). The themes of restoring fertility and combating erosion dear to the DPGT were only weakly taken up by farmers and agroforestry, helping to reduce conflicts among farmers and breeders [43]. During the same period, the IRAD benefited from financial and scientific support from the Regional Center for Applied Research for the Development of the Savannas of Central Africa (PRASAC). The PRASAC helped to resolve the difficulties of the DPGT by launching comparative on-farm experiments on the management of tree resources in combination with agriculture. In the 2000s, the Water, Soil, and Tree (ESA) project was launched to support the testing of different agroforestry systems. From the above, we can deduce that afforestation is an adequate response to climate crises and the restoration of degraded areas.

To achieve this, several actors have become involved through projects and programs. Stakeholder engagement in agroforestry activities is linked to sustainability challenges dominated by the effects of climate change and deforestation/degradation. The Northern Region of Cameroon has a diversity of actors who provide support to face the main environmental threats. These actors are from the public and private sectors, civil society, and farmer organizations. Agroforestry appears to be an important innovation promoted by all stakeholders, including related techniques such as afforestation and improved cropping systems. Several agroforestry practices have been adopted by the households interviewed in the ReSI-NoC baseline study, as shown in Figure 4.

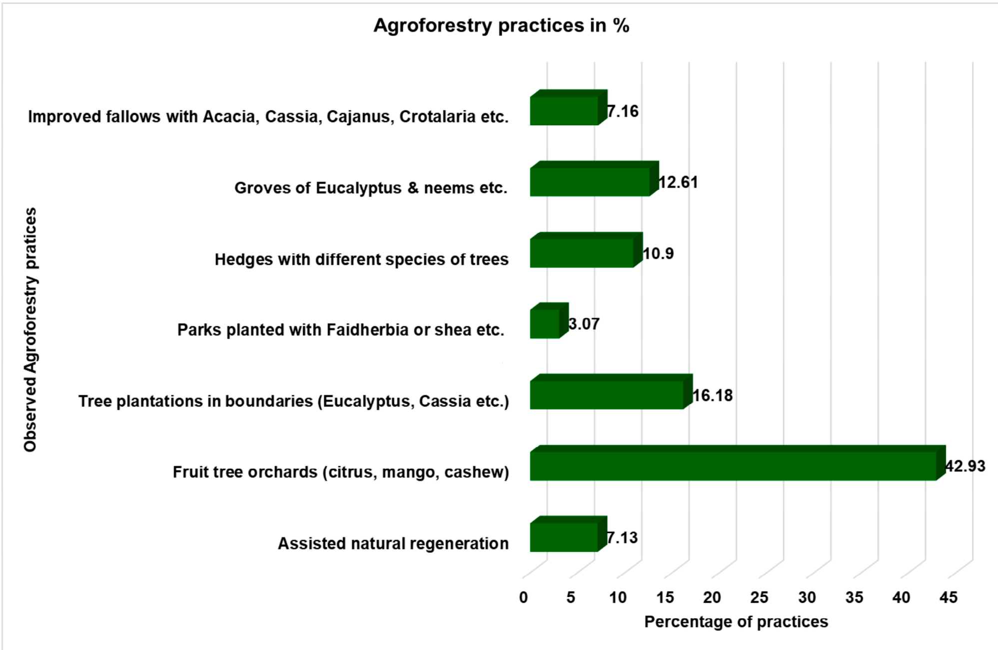

Figure 4. Agroforestry practices by households in the ReSI-NoC project sites.

Among agroforestry practices, those which contribute the most to the fight against climate change are hedgerows and wooded strips surrounding agricultural plots (Figure 5). They help to protect against violent winds and water erosion in crop fields.

Figure 5 shows trees (*Azadirachta indica* or neem) around an agricultural plot. Neem trees constitute a fence and mark the boundaries of the plot. Inside the plot, one can observe fruit trees like mango and cashew.

Figure 5. Agricultural plot surrounded by hedges in Bamé. (Source: Tchuenga, February 2022).

3.1.3. Water Conservation

Climate change has caused a significant shortage in the volume of surface water in Northern Cameroon. Groundwater levels have also been impacted. The successive droughts of 1972 and 1983 impacted the groundwater table, resulting in difficulties in recharging and quick drying up of wells. However, the availability of surface water in this Sudano-Sahelian region is also associated with strong seasonal and regional variability. Seasonal flowing rivers, called "Mayos", are observed in the region. They are subject to a tropical Sahelian regime, with sudden annual floods and very pronounced low water levels. The regime of watercourses is more linked to the duration of the dry season (07 months) and the length of the rainy season (05 months). The river networks are numerous and vital for the populations. However, the extension of the dry season leads to the complete drying up of surface water, with considerable impacts on agro-pastoralism. It will therefore be necessary to invest in measures and technologies aimed at saving water for consumption and adapted to the future. Thus, water-saving measures are likely to become increasingly important when facing the rapid population growth and prevailing drought. It is in this sense that the deadlock, or the temporary retention micro-dam ("*bief*" in French), has been promoted as an innovative technology. This is a temporary water retention micro-dam intended to promote the infiltration of water into the ground. The word "*bief*" was introduced in the northern zone of Cameroon in 1984, to circumvent legislation on dams and due to the lack of an appropriate word designating both a temporary reservoir and aquifer recharging [44].

The "*biefs*" are like micro-dams built with the following objectives, as summarized by Djombaye [44]: (i) stopping and gathering the water in one place to constitute a permanent or temporary surface water reserve; (ii) slowing down river water in one area, to force it to infiltrate and replenish the water table. It was with this aim that "*biefs*" or deadlocks were built in the region. There are several types of deadlocks, including masonry stone, concrete (Figure 6) and reinforced concrete, gabion, stone and earth, and dry stone (blocked). It is a device built downstream of watercourses to limit the flow rate of the course. This device retains water from November at the end of the rainy season until April/May, which marks the end of the dry season (Figure 6).

Thus, near these "*biefs*", water wells can be easily built following the recharging of the water table. The device maintains water from November to April or even May (end of the dry season) for certain villages. These reaches have enabled the development of market gardening activities that did not previously exist (results from the survey). Market gardening (tomatoes, onions, salad, off-season corn, and vegetables) contributes to the diversification of income-generating activities for populations and the fight against food insecurity (Figure 7). In some villages, the reach is used for household activities (Figure 7), because the effect of drought has contributed to the drying up of water points and wells.

Figure 6. Masonry (**A**,**B**) in Ndock and stone wedged "*biefs*" (**C**) in Sabongari. (Source: Tchuenga, March 2022).

Figure 7. Out-of-season vegetables and maize produced near the deadlocks of Douka Longo (Source: Tchuenga, March 2022).

Most of these practices are developed and disseminated by various actors among communities in the Northern Region. According to them, these innovations have a strong potential to tackle various climate problems, as shown in Table 3. There are numerous water conservation practices, as well as access to water in the dry season, in the region.

These agricultural innovations have developed the technical skills and technical adaptation capacities of the households that use them. Almost 35.50% of households are satisfied with these technical innovations. However, despite all this progress, the results from the baseline study show that 55% of women and 50% of men still struggle to easily manage climatic shocks and adversities.

Conservation agriculture, agroforestry, and water conservation are integral components of climate-smart agriculture (CSA), which aims to increase agricultural productivity sustainably, enhance resilience to climate change, and reduce greenhouse gas emissions. These innovations have significant implications for adaptation, mitigation, and productivity within the framework of climate-smart agriculture (Table 4). Overall, integrating conservation agriculture, agroforestry, and water conservation into climate-smart agriculture creates more sustainable and resilient agricultural systems, helping farmers adapt to climate change, while contributing to environmental conservation. Implementing these practices requires support from policies, research, and education, to ensure that farmers have the knowledge and resources to adopt and benefit from climate-smart agriculture. Consequently, these practices can lead to more sustainable and resilient agricultural systems, contributing to food security and environmental sustainability in the face of climate change.

Table 3. Contributions of climate-smart innovations to adaptation.

Climate-Smart Innovations	Promoters of Innovation	Climate Problems Adressed by Innovation	Characteristics of Innovation Favourable to Adaptation
Water conservation (Zaï, Reach)	SODECOTON	Drought and early drying up of rivers.	Recharging the water table and diversifying agricultural activities. Rehabilitation of the productivity of poor agricultural lands.
Erosion control techniques (grassy and wooded strips)	SODECOTON	Water erosion contributing to the leaching of organic matter from crop plots.	Blockage of runoff of organic matter by grasses and plants on plot boundaries.
Agroforestry practices (fallow, assisted natural regeneration, reforestation associated with crops)	SODECOTON, GIZ, ABIOGeT, CERAF, PAECE CORP, MINFOF, MINEPDED	Erosion of crop plots, violent winds, drop in agricultural yield, extreme heat.	Hedges constitute effective windbreaks which protect crops and generate carbon stocks. Ecosystem goods and services. Improved soil fertility.
Conservation agriculture (crop association and rotation, organic manuring, sowing under plant cover).	SODECOTON/FODER, CARE International,	Drying of the soil and decline in fertility.	Cultivation under plant cover maintains soil humidity favorable for plant growth. The crop association maintains soil fertility (corn and soya; soya and cowpea).

Table 4. Agricultural innovation practices among the pillars of CSA.

Climate-Smart Agriculture	Conservation Agriculture	Agroforestry	Water Conservation
Adaptation	3	2	3
Mitigation	1	3	2
Productivity	3	3	3

1—less contribution, 2—contributes significantly, 3—contributes more significantly.

However, beyond the availability of agricultural innovations, many households face difficulties in adapting to climate change, which means that the presence and use of agricultural innovation is insufficient to transform adaptation.

3.2. Weaknesses of the Effectiveness of Agricultural Innovations in the Transformation of Adaptation to Climate Change

Two parameters are essential for more effective adaptation to climatic shocks, i.e., the level of household participation in innovative initiatives, and the support for the agricultural innovations implemented.

3.2.1. Household Participation in Innovative Initiatives

The term participation means the active involvement of a wide range of households in the adaptation or innovation process implemented by the leaders of innovation projects in the region. Participation is a factor of the appropriation, integration, and dissemination of knowledge. Agricultural innovations are the result of collective construction. This is why the analysis of the participation of communities (households) in innovative initiatives is crucial.

Regarding the age of participants, one can find in Figure 8 that 33% of participants were under 40 years old, while 67% were above 40 years old.

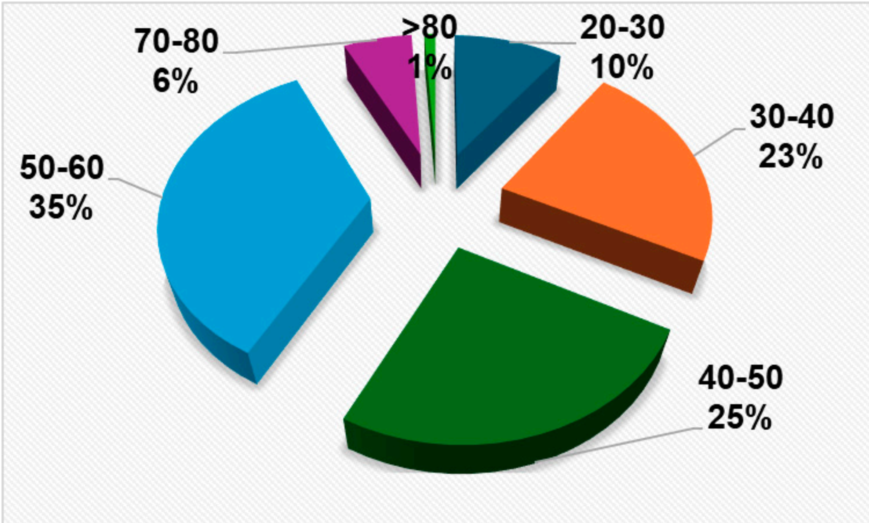

Figure 8. Participant age groups.

Despite the efforts of the organizations that support agricultural innovations in villages, approximately 62% of households in the study area had not been informed of the existence of activities related to agricultural innovation. In addition, it is generally the heads of households (83.10% men) who are increasingly involved in the process of implementing and testing innovations. In terms of women's participation, only 38% are taking part. In addition, 16.90% of young girls and 26.76% of young boys participate in activities related to agricultural innovations. These statistics reflect the unequal participation in innovative initiatives by gender. Moreover, it reflects limited access to information on adaptation strategies or even proximity to information. Poor access to information is one of the causes of maladaptive situations, hence the increasing the vulnerability of households to climatic extremes.

Therefore, a disparity exists in the choice of beneficiaries for innovative interventions regarding the different types of actors operating in the area (Figure 9). The focus put on the head of the family does not guarantee the transfer of information about innovations to other members of the family or the community. This contributes to weakening the flow of information within the community. Hence, there is a need to bring together all members of the household for initiatives to have a higher rate of adoption. In addition, within the village, the number of households must be representative of the community. The choice of a single leader or head of household presents a lot of risks for the dissemination of information related to innovations. The lack of participation of some households is explained by the non-compliance with the criteria set by the promoters to benefit from their interventions, little interest on the part of the beneficiaries, a lack of time, and insufficient financial means. In addition to these constraints, we can add more general factors such as poverty, low levels of literacy, cultural taboos, and problems of communication and awareness among populations.

Finally, in the participation process, a diversity of actors are involved, because innovation is a social construction (group, community, association, NGO, etc.) and not an individual construction. There is a diversity of organizations which are involved in the promotion of innovative initiatives. They belong to different categories, as shown in Figure 9. Thirty eight percent (38%) of the actors belong to the public sector, while 34% fall in the parapublic category. These are followed by international and national NGOs (10% and

8% respectively). We also noticed the presence of cooperation agencies (6%) and producer organizations (4%).

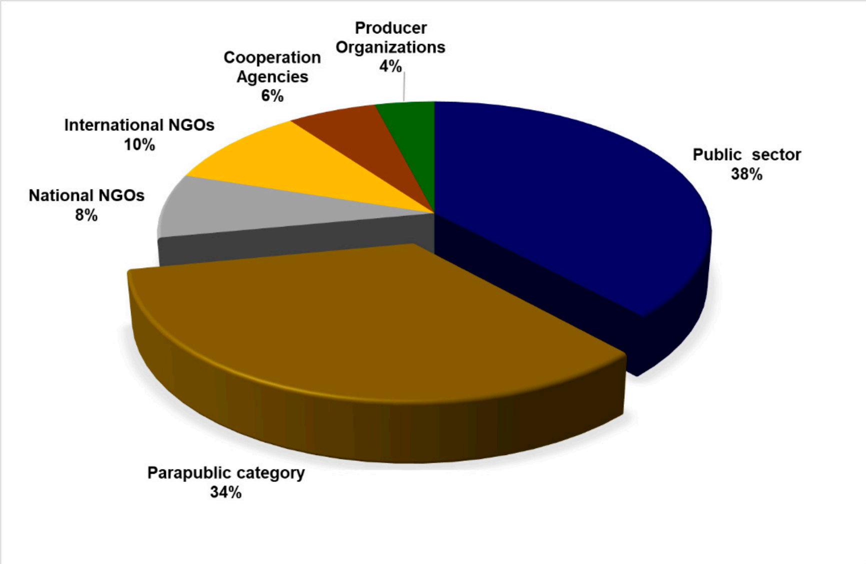

Figure 9. Actors disseminating innovative initiatives.

These innovation project leaders are involved in different phases of the adaptation or innovation process, including the initiation and implementation (experimentation) phases of initiatives. As such, different types of support are offered (Table 4).

3.2.2. Support for Agricultural Innovations

Since the 1990s, projects and programs have been the main mechanisms for supporting agricultural innovations in the Northern Cameroon region. They offer several forms of support to innovations, for example, awareness raising, training, local supervision, provision of various inputs, provision of materials and equipment, access to credit, and financing of micro-projects (Table 5). Regarding these services, 80.52% of households in the baseline study were satisfied with these services, while 19.48% were not satisfied.

Table 5. Forms of support for agricultural innovations by stakeholders.

	Intervention Approach							Total
	Awareness Raising	Training	Local Supervision	Donation of Inputs	Donation of Equipment	Access to Credit	Financing of Micro-Projects	
Number of households	191	140	130	41	18	74	11	232
Percentage	82.33	60.34	56.03	17.67	7.76	31.09	4.74	

Table 4 illustrates the number of households following each intervention approach and calculated by percentage. This makes it possible to highlight the weight of each intervention approach and the level of participation of the actors among the total of 232 interview participants.

Approaches based on training, awareness-raising, local supervision, and access to credit were the most used in innovation projects (Table 4). It is worth mentioning that this type of support has replaced the role that was previously played by government structures like IRAD and MINADER (Ministry of Agriculture and Rural Development). These structures form the pillars of the national agricultural research and innovation system. However, the agricultural innovation support mechanisms offered are unsustainable and inefficient. The short lifespan of projects and programs supporting agricultural innovations segments the support for innovation or adaptation over time. As soon as an actor has finished their intervention, a new actor arrives and often intervenes in the same region, introducing the same innovations with different approaches. This will lead to confusion among farmers and livestock owners, who do not know whom to contact for information. Furthermore, one can observe duplication of interventions and a geographical imbalance in the provision of services in support of agricultural innovations. Hence, there is a need for coordination within the areas of intervention.

4. Discussion

The present work highlights two major results. The first suggests that the agricultural innovations implemented in the region have appropriate capacities to respond to climate change. However, these agricultural innovations alone are insufficient for transforming adaptation to build true community resilience. Secondly, obstacles hindering the effective contribution of agricultural innovations to climate change adaptation in the region have been identified. First, there is a dominance of men (heads of households) interacting with initiatives, to the detriment of other social groups. This overrepresentation does not always guarantee the transmission of the acquired knowledge to other members of the family. Therefore, support for agricultural innovation through support services tends to focus primarily on technical aspects. In this section, we discuss these two results by comparing them to general results from the climate change adaptation literature.

4.1. Implications of Agricultural Innovations in Incremental Adaptation to the Impacts of Climate Change in the Northern Cameroon Region

Three innovations for adaptation to climate change were analyzed for the contribution of their internal characteristics to responding to climatic hazards. These included conservation agriculture, water erosion control techniques, water conservation in rivers, and agroforestry practices. Tchuenga et al. [45] highlighted conservation agriculture as an agroecological practice allowing adaptation to climate variability at Bangangté in the Western Cameroon region. These included crop association practices, which are cultivation practices used since the dawn of agriculture [46,47]. Moreover, intercropping in conservation agriculture is a method of cultivating multiple crop species. It enhances crop diversity and resistance to unexpected weather conditions. This approach can help address climate-change-related crop cultivation issues in northern agriculture. Intercropping leads to increase yields, nutrient and protein self-sufficiency, soil preservation, pathogen pressure reduction, and water dynamics regulation [48–50]. In addition, an intercropping system minimizes soil work; covers it for extended periods, especially during the rainy season; and uses crop rotation or association, including cowpeas, groundnuts, fodder crops, and service crops like stylosanthes, mucuna, and crotalaria [51]. There are ongoing research works on this type of crop association, to define the best crop densities, geometries, and the fertilizers to use in such cases [52,53]. Agricultural innovations have proven promising for adaptation in five West African countries including Ghana, Mali, Niger, Senegal, and Burkina Faso. The same agricultural innovations were analyzed in the context of climate change and variability in Ghana by Parthey et al. [5], with an emphasis on climate-smart agriculture. Grigorieva et al. [15] considered climate-smart agriculture practices a strong adaptation strategy. Climate-smart agriculture practices include adaptations and mitigation practices which aim to increase productivity, reduce GHG emissions, improve resilience, and promote national food security and development goals [54,55]. These practices take into account environmental, social, and economic aspects, involving institutional, policy, and technological practices [56].

Conservation agriculture, including crop association practices, is considered an agroecological practice allowing adaptation to climate variability [45–47]. The economic aspects of these practices are also very important to sustain farmers, because to face to climate uncertainties, agricultural innovations constitute a strategy to improve adaptation for better agricultural productivity, i.e., increasing financial revenues [57]. Hence, in the last 10 years, farmers have gradually experienced real developments linked to a combination of the efficiency of production factors, the fight against climate change, and the preservation of biodiversity. The present study marks the first transformative phase of adaptation, which consists in stopping "maladaptation" to the future impacts of climate change [15]. Maladaptation reinforces the vulnerability of the community to the effects of climate change. But in the transformative process, agricultural innovations play a key role in adaptation to climate change [58]. This is based on an evaluation of agricultural innovations in their contribution to adaptation which, instead of reducing vulnerability, reinforces it in the face of the effects of climate change. However, there are some bottlenecks that constrain agricultural innovations for strengthening the climate resilience of producers in Northern Cameroon.

4.2. Existing Blockages in the Contribution of Agricultural Innovations to Climate Change

To move from situations of incremental adaptation to transformational adaptation, it is imperative that (i) communities participate fully in the process of innovation and adaptation, and (ii) permanent structures supporting agricultural innovations provide adequate services, so that adaptation is sustainable and effective. This result of strengthening community participation in climate change adaptation projects has been highlighted in the literature by several authors [25,59–63]. This will enable integrated management of the risks linked to climate change and bring about transformational changes. At the level of participation, we observed limits to the broader integration of all social components in innovative initiatives at the local level. Such a problem of access to information was also observed in several Sub-Saharan African countries [64,65]. This situation invites us to further explore the way in which stakeholders in innovation or adaptation processes (project managers and donor organizations) conceptualize and idealize community participation. Nevertheless, in climate adaptation studies, such studies have not yet been conducted. Speaking of adequate services in the context of climate change in the Northern Cameroon Region, the most commonly provided are awareness-raising, capacity building, knowledge exchange, technical support, and improved access to resources. These services also appear in the literature on innovation support services [37,63,66]. Furthermore, the World Meteorological Organization (WMO) global climate services framework has recognized the importance of integrating capacity building as a climate service. Some authors [66] have also recognized that advisory services are crucial for environmental issues, particularly those linked to climate change, because access to information can increase the adaptive capacity of agricultural producers [67]. In terms of sustainability, it is necessary to integrate new services, notably coaching and stimulating creativity [67–69]. These new services have the transformative capacity to adapt to climate change, but are rarely provided.

This study demonstrates the weakness of permanent structures (low visibility) in supporting agricultural innovations. And yet, because of the complexity of innovation linked to climate change, the literature has shown that organizations, particularly local ones, participate in the dissemination and support of agricultural innovations [28,70–73]. By further structuring these organizations and developing their functional capacities (coordination), they will be able to contribute more effectively to sustainable change in adaptation to climate change.

5. Conclusions

Overall, this study intended to analyze the agricultural innovations that have emerged and the determinants of their contributions to transforming adaptation, with an emphasis on systemic theories and approaches. Thus, surveys of households and analyses of the content of questionnaires were carried out. Hence, eight agricultural practices and seven agroforestry practices were investigated, because the objective was to identify the practices and techniques used by households to adapt to climate change in the survey villages. The results indicated that international organizations and NGO programs have promoted agricultural innovations in the region with a high potential for climate change adaptation.

However, these agricultural innovations often lead to non-long-term sustainability changes, due to non-permanent projects and programs. Additionally, the choice of participants during the innovation process, particularly men (83% heads of families), weakens the expected changes at the household level. Knowledge is retained at his level and other members do not benefit from the information flow.

This research can be seen as a single contribution among others to the national adaptation plan (NAP) to climate change, focusing on implications and the necessity to support adjustments induced by agricultural innovations for the long-term sustainability of the national agricultural system. This requires a professionalization of the adaptation task and a capacity development strategy for the different stakeholders involved in adaptation. It examined transition mechanisms and transformational processes, detecting existing fragilities based on the case of the Northern Cameroon region. Furthermore, such research needs to be conducted in other agroecological regions of the country by researchers and organizations/partners, to contribute to the sustainable resilience of Cameroon's agricultural sector, i.e., to climate-smart agriculture.

Author Contributions: G.T.S.T. took the lead in the conceptualization, methodology, and mapping, and analyzed and drafted the paper after field investigations. M.T. was involved in field investigation, conceptualization of the figures and tables, and validation, as well as drafting the paper. P.I.T.N., A.D., S.D.B., and F.S. were involved in reviewing, editing, and analyzing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the framework of the Institute of Agricultural Research for Development (IRAD) and the decision N°000001/MINRESI/B00/C00/C10/B30 of 23 January 2019 outlining the conditions for research authorizations for scientific purposes, monitoring procedures, and controls in Cameroon. According to this decision, the Institute of Agricultural Research for Development (IRAD) has a mandate to carry out research and does not need a research permit issued by the Ministry of Scientific Research and Innovation (MINRESI). This study originated from a consortium of ICRAF, CIFOR, CIRAD, and IRAD that did not need informed consent during the project execution because IRAD, as a national institute of agricultural research, has a formal mandate and conducts research in accordance with the decision and research ethics. Also, ICRAF has an agreement with MINRESI to conduct research in Cameroon. ICRAF follow the same decision and research ethics. The study did not involve medical or biometric data or minors. Participants were free to stop studying at any time, as per research rules.

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: The data presented in this study are available on request from all authors.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

ABIOGeT	Actions pour la Biodiversité et Gestion des terroirs
AFD	Agence Française de Développement—French Development Agency
AFR	African Forest restoration
CARE International	Cooperative for Assistance and Relief Everywhere Inc.
CERAF	Centre des Ressources Agroforestières
CIFOR	Centre for International Forestry Research
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CIZ	Cynegetic interest zones
COP	Conference of the Parties
DPGT	Développement Paysannal et Gestion des Terroirs—Peasant Development and Land Management

ESA	Eau, sol et arbre—Water, Soil and Tree
FAO	Food and Agriculture Organization
FAC	Fonds d'Aide à la Coopération—Aids Cooperation Fund
FODER	Fonds pour le Développement Rural: Rural Development Fund
GMV	Grande Muraille verte—Great Green Wall
GIZ	Deutsche *Gesellschaft für Internationale Zusammenarbeit* (German technical Cooperation)
GSO	Green Sahel Operation
ICRAF	International Centre for Research in Agroforestry
IRAD	Institut de Recherches Agronomiques pour le Développement –Institute for Agricultural Research and Development
MINADER	Ministère de l'Agriculture et du Développement Rural-Ministry of Agriculture and Rural Development
MINFOF	Ministère des Forêts et de la Faune—Ministry of Forestry and Wildlife
MINEPAT	Ministère de l'économie, de la planification et de l'aménagement du territoire-Ministry of Economy, Planning and Regional Development.
MINEPDED	Ministère de l'Environnement, de la Protection de la Nature et du Développement durable-Ministry of Environment, nature protection and Sustainable Development
NGO	Non-Governmental Organization
PDEA	Projet de Diversification des Exportations Agricoles—Agricultural Export Diversification Project
CPLS	Comité Provincial de Lutte contre la Sécheresse—Provincial Committee for the Fight against Drought
PRASAC	Pôle régional de Recherche Appliquée au développement des Savanes d'Afrique centrale -Regional Center for Applied Research for the Development of the Savannas of Central Africa
ReSI-NoC	Renforcement des systèmes d'innovation dans le Nord Cameroun
SODECOTON	Société de Développement du Coton –Cotton Development Corporation
SPSS	Statistical Package for Social Sciences
WMO	World Meteorological Organization

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