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Energy Use in Building in Front of Climate Change: An Analysis of the Adaptation Strategies of Corn Farmers in Benin

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Abstract

In Benin, maize production is important for food security and rural household incomes. However, it is subject to climatic variations that induce low yields and productivity levels. This innovative study categorizes the energy sources used in its production to identify levers for improving agricultural productivity. A survey of 230 maize growers in the communes of N'Dali, Sinende and Nikki was carried out. Data were collected using structured questionnaires on farming activities and input use, then converted into energy values using energy equivalence coefficients collected in previous studies. The results reveal a high level of awareness among maize growers (97.4%) of the impacts of climate change on maize production. In terms of the amount of energy derived from labor power, mechanical plowing stood out (133.02 MJ/ha), closely followed by animal-drawn plowing (53.04 MJ/ha) and harvesting (45.18 MJ/ha). In terms of inputs, NPK fertilizer stands out with an energy expenditure of 2238.87 MJ/ha, followed by urea with 1172.95 MJ/ha. Although increasing labor power remains the approach most adopted (61%) by growers to maintain the productivity of their farms, the results revealed a predominance of energy from agricultural inputs (94.91% of total energy), underlining the preponderance of inputs in overall energy requirements.

Keywords: adaptation strategy, Benin, climate change, corn, energy use

1. Introduction

Maize occupies a prominent place as the most widely grown staple cereal worldwide, with total annual production reaching 1187.8 million tonnes for the 2022-2023 crop year (Statista, 2022). Indeed, produced on some 197 million hectares, maize remains the world's second most-produced crop behind wheat (Woomer et al., 2024). Furthermore, although Africa accounts for 21% of the world's maize-growing area, its production represents only 7.4% of total world production, reflecting relatively low yields (Erenstein et al., 2022; Woomer et al., 2024). Average maize grain yields in Africa are just 2.1 t/ha, compared with 5.8 t/ha worldwide (Erenstein et al., 2022; Woomer et al., 2024).

Also ranked first among cereal crops in Benin, maize (Zea mays L.) is grown extensively throughout the country, occupying nearly 70% of cereal acreage and accounting for 78.3% of total cereal production (Miassi et al. 2024a). In addition, it secures second place by generating substantial income for rural households (Yabi et al., 2016). Furthermore, previous studies have highlighted yield trends ranging from around 1.3 t/ha (1995) to 1.5 t/ha (2021) (Grethe et al., 2020) at national level (in Benin), compared with a world average of 5.8 t per hectare (Woomer et al., 2024). Closing this maize yield gap is essential to ensure food security and nutrition in Benin.

To achieve this, Woomer et al (2024) point out that it is important not only to ensure the availability of inputs, but above all to find the best combinations of varieties and accompanying inputs. This solution seems appropriate, especially in a context where maize production is threatened by climatic variations. Others add to this the importance of various other agronomic and economic factors including investment in fertilizer, availability of nutrients and water, pest control, labor including other equipment (Cairns et al., 2021; Van Dijk et al., 2017). Each of these factors falls under the energy sources employed in agriculture characterized either as human (labor) or animal (animal traction) labor forces or as energy from agricultural inputs (Chel & Kaushik, 2011).

Indeed, some of these energy requirements are used in production, packaging of inputs (fertilizers, pesticides) and agricultural machinery, while others are used in land preparation, irrigation, harvesting and transport of agricultural inputs and products (Taki et al., 2018). Thus, although these energies represent enormous prospects for improving the level of agricultural productivity, they are not used effectively on farms, which justifies the inefficiency of producers (Passos Fonseca, 2010). This is also underlined by Akdemir et al (2023), who argue that optimizing the use of energy sources is essential to maximize production levels. Today, however, there is a lack of rural energy management in agricultural development policy (Mandelli et al., 2015).

Several previous studies (Akdemir et al., 2023; Hayran et al., 2023; Khanali et al., 2022; Kosemani & Bamgboye, 2021; Ozkan et al., 2004) have been carried out on energy source allocation patterns in agriculture. But this study sets itself apart by identifying and categorizing the energy sources used in maize production in Benin in a climate change context. This approach enables a more detailed and precise analysis of the level of use of each type of energy on maize farms. By identifying the most used energy category and their respective contributions to the maize production process, this research offers appropriate guidance on the energy needs that need to be addressed to improve production levels in Benin. The aim of this study is to determine how maize growers in Benin allocate energy sources in the context of climate change. It also highlights the main levers that could ensure the sustainability of production.

2. Methodology

2.1 Study Area

The study was conducted in the northern region of Benin, selected because of its climatic vulnerability (Yegbemey et al., 2014) and its concentration of agricultural production. Also, this region encompasses four of the country's eight agro-ecological zones, providing a diverse context to study agricultural practices and adaptation strategies. For the purposes of this research, 230 maize producers were selected in the communes of N'Dali, Sinende and Nikki because they belong to Benin's third agroecological zone (Figure 1). This agroecological zone is recognized as the country's main food production region, where maize remains one of the predominant crops (Baco et al., 2012). By specifically targeting this area, the study aims to deepen understanding of agricultural practices and dynamics related to maize cultivation in a specific ecological context. This will enable us to offer precise guidelines for developing effective adaptation strategies in this region of Benin.

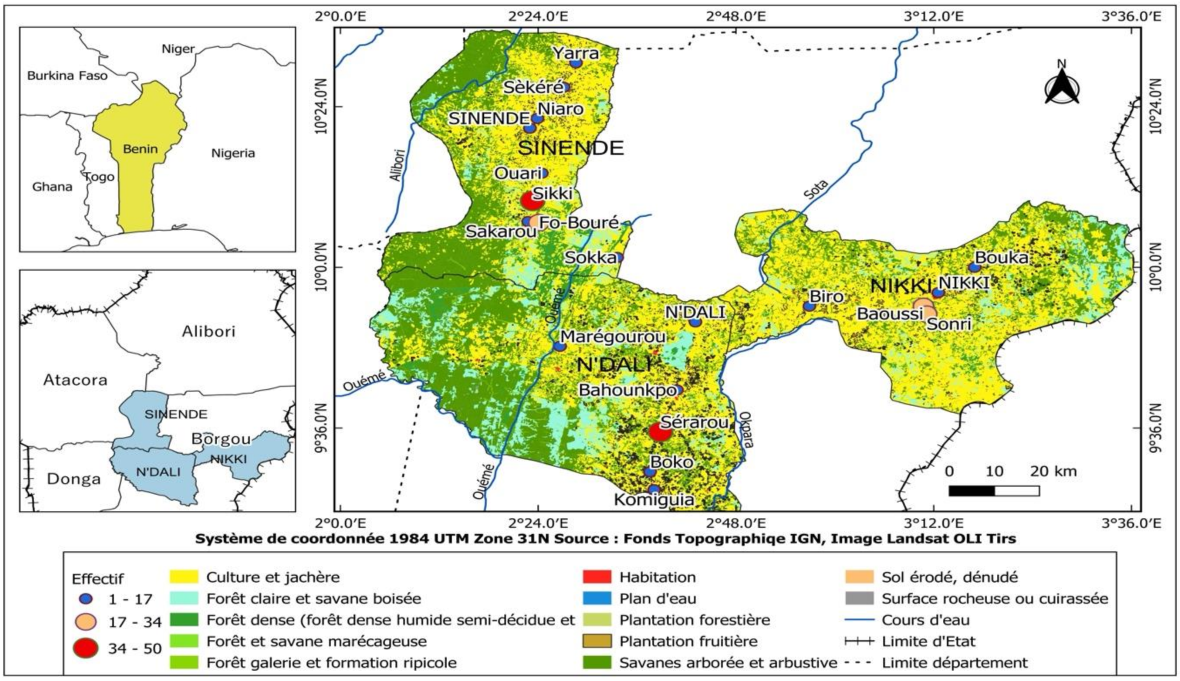

Figure 1. Presentation of the study area

2.2 Data Analysis

To understand the different management modes and main energy sources related to maize production, energy equivalent coefficients were calculated based on data from previous studies (Akdemir et al., 2023; Hayran et al., 2023; Kosemani & Bamgboye, 2021; Ozkan et al., 2004). In fact, two types of data were collected: data relating to labor and data relating to agricultural inputs used for maize production. As far as labor is concerned, the data collected relate essentially to the various activities or operations carried out to ensure maize production. This mainly includes labor engaged in technical itineraries (grubbing, manual plowing, weeding, harvesting, transport of harvested products, application of chemical inputs including fertilizers, herbicides and insecticides). This category also includes mechanical plowing (use of tractors) and animal-drawn plowing. Regarding data on agricultural inputs used, the study took into consideration the quantity of chemical fertilizers (NPK, herbicide and insecticide) used by each grower for maize production. Finally, the quantity of fuel used during the maize production campaign is also considered as a production input. All these activities were considered as energy resources associated with maize production and were all transformed into energy values using an energy equivalent factor (Table 1). The same strategy has been applied in similar studies by several researchers (Akdemir et al., 2023; Hayran et al., 2023; Kosemani and Bamgboye, 2021; Ozkan et al., 2004).

Human labor expenditure was calculated by multiplying the number of farm workers involved in the process by the total number of hours of activity performed by the number of farm workers, and then by the equivalent energy of one hour of human activity (equation 1).

$$\boldsymbol{E_{labor}} = \boldsymbol{e} * (\boldsymbol{N} * \boldsymbol{J} * \boldsymbol{D})$$

Where e = Equivalence of one hour of activity in terms of energy (MJ), N = Total number of farm workers, D = Total number of days and D = Total working time in a day (Bamgboye and Kosemani, 2015). The same formula was applied to determine the amount of energy deployed by machines and during animal traction but considering "*N*" as the number of tractors or animals put into activity.

Energy inputs from fuel use and chemical inputs (NPK fertilizer, urea, herbicide, pesticide) were calculated using conventional equations used in previous studies, as shown in equation (2) (Bamgboye and Kosemani, 2015).

$$\boldsymbol{E_i = Q_i * e}$$

With:

E: Energy emitted (MJ/ha); ***Q:*** Quantity of input (kg/ha); ***e:*** Energy equivalence (MJ/kg); ***i:*** the grower

Table 1 lists all these sources and the energy equivalence for each.

Table 1. Standard energy equivalent of production inputs

Inputs	**Unit**	**Energy equivalent (MJ/ha)**	**References**
Labor (Human)*	h	0,27	Akcaoz et al (2009); Bamgboye and Kosemani (2015); Bamgboye et al, (2006).
Fuel	liter	56,31	Akcaoz et al (2009); Akdemir et al (2023); Mani et al (2007); Mandal et al (2002)
Tractor 50 kw	h	64,3	Akcaoz et al (2009); Fluck (1985)
Animal traction	h	5,9	Ruiz-Vega et al (2015)
Fertilizer			
N	Kg	60,60	Akcaoz et al (2009); Akdemir et al (2023); Mani et al (2007)
P	Kg	11,1	Akcaoz et al (2009); Akdemir et al (2023); Mani et al (2007)
K	kg	26,8	Akcaoz et al (2009); Akdemir et al (2023); Mani et al (2007)
Chemical treatments			
Herbicides	kg	120	Bamgboye and Kosemani (2015) ; Singh (2002)
Insecticide	kg	278	Akcaoz et al (2009); Akdemir et al (2023); Meul et al (2007)

** Labor includes the following aspects: Grubbing, manual ploughing, weeding, harvesting, transport of harvested produce, application of chemical inputs (fertilization, herbicide and insecticide).*

Descriptive statistics and the mean comparison test were used to compare the quantities of energy from different sources to highlight the most energy-intensive activities in maize production in this area. However, a preliminary descriptive analysis (frequency calculation and Chi-square test) was carried out to assess growers' perceptions of climate change.

3. Results and Discussion

3.1 Analysis of Energy Source Management Methods

The results of the analysis of maize growers' perceptions of the manifestations and implications of climate change reveal significant trends within the different study areas (Table 2). Across the sample, a high proportion of growers claimed to be aware of the manifestations of climate change (98.3%). This knowledge was particularly marked in N'Dali (98.6%) and Sinende (100%). In addition, most growers in all communes perceive direct effects on maize production (97.4% overall). This perception is more pronounced in Sinende (100%) and N'Dali (98.6%) than in Nikki (91.2%).

Analysis of data relating to climatic events shows significant differences between communes ($p < 0.001$). Notably, in N'Dali, a large proportion of producers have been observing events for 1 to 5 years (73.9%), while in Nikki, a significant portion have more extensive observation experience (34.6% for 6 to 10 years). Similarly, the diversity of manifestations of climatic variations reveals significant differences between the communes studied, as shown by the results of the chi-square test ($p < 0.001$). In N'Dali, disruptions to rainfall (55.1%) and seasonal calendars (34.8%) are the most widespread manifestations, while in Nikki, growers mainly mention disruptions to temperature levels (19.2%) and seasonal calendars (26.9%). Sinende stands out for its high proportion of seasonal calendar disruptions (52.4%) compared to other events. These results concur with several other studies also carried out in Benin, in which the population claims to perceive climate change through several aspects. These aspects include the decrease and irregularity of rainfall, the late or early start of the rainy season, the early cessation of rainfall and the high frequency of pockets of drought during the season (Yegbemey et al., 2014; Fadina & Barjolle, 2018).

Finally, the consequences of climate change vary between communes ($p < 0.001$). In Sinende, declining water availability (52.4%) is more frequently reported, while in Nikki, declining production yields (78.9%) predominate. However, in N'Dali, there is a more balanced distribution between the consequences observed, particularly the drop in yields (55.7%) and water availability (44.3%). These variations underline the importance of taking local realities into account when developing climate change management methods in each commune. These consequences have also been addressed in various previous research studies (Hartter et al., 2012; Molua, 2010; Mwalusepo et al., 2015). These previous works thus reinforce the recognition of the impacts of climate change on agriculture, underlining the urgency of actions and adaptations in this context.

Table 2. Maize growers' perceptions of climate change, manifestations and implications

Perception of climate change		**Communes**						**Total**	
		N'Dali		**Nikki**		**Sinende**			
		N	%	N	%	N	%	N	%
Knowledge of CC events	Yes	69	98,6	54	94,7	103	100	226	98,3
	No	01	1,43	03	5,26	0	0	04	1,74
	Chi-deux	**64,129*****		**43,86*****				**212,35*****	
Demonstrations in corn production	Yes	69	98,6	52	91,2	103	100	224	97,4
	No	01	1,43	05	8,77	0	0	6	2,61
	Chi-deux	**64,129*****		**37,12*****				**204,73*****	
Duration (years) of event observation	[1-5]	51	73,9	30	57,7	69	67	150	67
	[6-10]	18	26,1	18	34,6	34	33	70	31,2
	[11-15]	0	0	04	7,69	0	0	04	1,79
	Chi-deux	**14,84*****		**19,54*****		**11,22*****		**143,18*****	
Type of event: Disturbance	Rain	38	55,1	28	53,8	38	36,9	104	46,4
	Temperature	06	8,7	10	19,2	11	10,7	27	12,1
	Seasonal calendars	24	34,8	14	26,9	54	52,4	92	41,1
	Other	01	1,45	0	0	0	0	01	0,4
	Chi-deux	**50,25*****		**10,31****		**27,52*****		**133,32*****	
Consequences	Lower production yields	39	55,7	45	78,9	46	44,7	130	56,5
	Decline in water availability	31	44,3	10	17,5	54	52,4	95	41,3
	Other	0	0	02	3,51	03	2,91	05	2,17
	Chi-deux	**0,7**		**55,05*****		**43,83*****		**108,48*****	

3.2 Analysis of Energy Used in Production

The results of the energy assessment on maize farms reveal some significant trends. Overall, the data indicate a low rate of energy use for all activities related to maize production (Table 2). On the other hand, activities such as weeding (79.6%), herbicide application (73.5%), manual ploughing (74.8%), pesticide application (90%) and transport (70.4%) show a marked similarity with predominant energy use in the 0-5 MJ/ha range (Table 3). These results reflect a common trend in these farming practices. This convergence also suggests a similarity in energy requirements for these specific activities.

Finally, some activities stand out for their different and wider energy intervals. Mechanical ploughing (54.3%) and animal-drawn ploughing (82.2%) have energy requirements of between 100-200 MJ/ha and 0-100 MJ/ha respectively (Table 3). This suggests that these two activities are the ones that require the most commitment or effort from growers in terms of labor power. These variations highlight the heterogeneity of energy requirements in these specific farming practices, underscoring the need for targeted approaches to optimize energy efficiency in each context.

Table 3. Breakdown of energy requirements by farming activity

	Grass clearing and mowing			Weeding	
Energy (MJ/ha)	**N**	**%**	**Energies (MJ/ha)**	**N**	**%**
0-10	85	37	**0-5**	183	79,6
10-30	116	50,4	**5-15**	07	3,04
30-50	16	6,96	**15-30**	16	6,96
> **50**	13	5,65	> **30**	24	10,4
	Herbicide			**Harvest**	
0-5	169	73,5	**0-15**	54	23,5
5-15	37	16,1	**15-30**	96	41,7
15-30	20	8,7	**30-50**	35	15,2
> **30**	4	1,74	> **50**	45	19,6
	Manual ploughing			**Fertilization**	
0-5	172	74,8	**0-5**	87	37,8
5-15	41	17,8	**5-15**	108	47
15-30	07	3,04	**15-30**	29	12,6
> **30**	10	4,35	> **30**	06	2,61
	Pesticide treatment			**Transport**	
0-5	207	90	**0-5**	162	70,4
5-15	13	5,65	**5-15**	45	19,6
15-30	09	3,91	**15-30**	18	7,83
> **30**	01	0,43	> **30**	05	2,17
	Mechanical ploughing			**Animal-drawn ploughing**	
0-100	77	33,5	**0-100**	189	82,2
100-200	125	54,3	**100-200**	24	10,4
200-400	15	6,52	**200-500**	11	4,78
> **400**	13	5,65	> **500**	06	2,61

The results of the average energy requirements per agricultural activity reveal significant disparities. The highest average energy requirement is observed for operations such as mechanical ploughing using farm machinery (mechanical traction), with an average of 133.02 MJ/ha. This is closely followed by operations or activities such as animal-drawn ploughing (53.04 MJ/ha) and harvesting (45.18 MJ/ha). In contrast, lower energy requirements are recorded for activities such as weeding (6.34 MJ/ha), transport (5.91 MJ/ha), herbicide application (5.66 MJ/ha), manual ploughing (4.97 MJ/ha) and pesticide treatments (1.55 MJ/ha) (Figure 2).

Comparative analysis of the means, using the Mann-Whitney test, leads to the conclusion that there are significant differences in energy expenditure between agricultural activities (Figure 2). Thus, activities whose means have the same letters are significantly identical (Figure 2). In fact, this pairwise comparison (Mann-Whitney test) shows that animal traction and harvesting operations do not differ significantly in terms of energy expenditure (Figure 2). Similarly, average energy consumption for transport and herbicide application are statistically similar. The amounts of energy derived from the other activities are significantly different from each other and from the energy of the previous operations listed. These results are partially consistent with the findings of Ruiz-Vega et al. (2015), who specify that growers use more agricultural machinery with a greater amount of energy (11800 MJ/ha). On the other hand, other aspects, notably labor dedicated to fertilization (2212 MJ/ha) and manual plowing (64.35 MJ/ha) are significantly higher than animal traction (12.2 MJ/ha) in terms of energy quantities (Ruiz-Vega et al., 2015).

The implications of these findings for the management of farms where maize is grown are particularly relevant to the most energy-intensive farming activities, such as "mechanical traction". Careful management and optimization of energy resources, particularly for the most energy-intensive farming activities such as "mechanical traction", are therefore crucial. Firstly, these energy-intensive activities can account for a significant proportion of total production costs on corn-producing farms. By taking an attentive approach to energy consumption, farmers can potentially reduce these costs, which has a direct impact on the overall profitability of these farms. This detailed understanding of energy needs by activity provides a sound basis for implementing sustainable farm management methods, thus contributing to the achievement of long-term sustainability objectives.

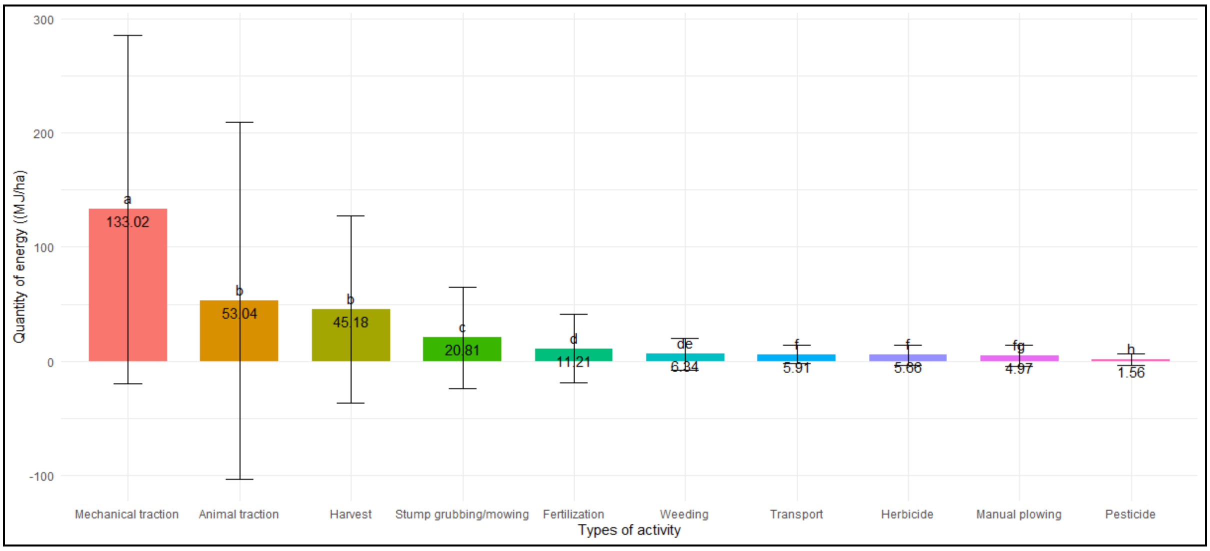

Figure 2. Comparison of average energy requirements by agricultural activity

3.3 *Quantity of Energy Generated by Agricultural Inputs*

The results for energy expenditure on agricultural inputs (chemical fertilizers, herbicides and insecticides) reveal significant differences (Table 4). For herbicide, most farmers (61.7%) used between 100 and 300 MJ/ha of energy, indicating a preference for the use of moderate quantities of herbicides. However, a considerable proportion (22.2%) were in the 300 to 500 MJ/ha range, leading to the conclusion that some growers opt to use large quantities of herbicide to maintain their plots. In this context, growers' interest in herbicides is not negligible. This could be attributed to the fact that, by increasing their acreage, herbicide use enables them to maintain their plots more rapidly. These results differ from the observations made by Kosemani and Bamgboye (2021) in their research, which indicates low herbicide use by growers, representing only 3.88% of the total amount of energy used in maize production. As far as insecticides are concerned, the vast majority (93%) of farmers have lower energy requirements ranging from 0 to 300 MJ/ha. It is therefore plausible that farmers are seeking to minimize insecticide use, probably in response to growing concerns about negative impacts on biodiversity, human health and water quality.

Results for the use of chemical fertilizers such as NPK (nitrogen, phosphorus, potassium) and urea show distinct patterns. Regarding NPK application, most farmers (84.8%) used energy quantities in excess of 1000 MJ/ha, suggesting intensive use of this fertilizer. Also, for urea, a significant proportion of farmers (47.4%) fell within the range of energy expenditure above 1000 MJ. These results indicate a marked preference among farmers for the intensive use of chemical fertilizers, particularly NPK. This preference may be explained by farmers' perception of the benefits of these fertilizers in terms of optimizing crop yields. Similarly, the results for energy from fuel use, both for running farm machinery and for moving agricultural produce, show different trends. Indeed, a large proportion of farmers (80%) show the lowest energy expenditure of between 1,000 and 1,200 MJ/ha, indicating a low dependence on fuels for their maize production. This observation highlights the low level of mechanization of farming activities on these maize farms.

Table 4. Breakdown of energy expenditure on agricultural and production inputs

Energy (MJ/ha)	**Herbicide**		**Energy (MJ/ha)**	**Insecticide**	
	N	**%**		**N**	**%**
0-100	18	7,83	**0-300**	214	93
100-300	142	61,7	**300-500**	05	2,17
300-500	51	22,2	**500-700**	10	4,35
>500	19	8,26	**> 700**	01	0,43
	NPK			**Urea**	
0-300	12	5,22	**0-300**	14	6,09
300-600	06	2,61	**300-600**	21	9,13
600-1000	17	7,39	**600-1000**	86	37,4
> 1000	195	84,8	**> 1000**	109	47,4
			Carburation		
1000-1200	184	80			
1200-1300	32	13,9			
1300-1400	07	3,04			
>1400	07	3,04			

The results of average energy expenditure for the various agricultural inputs reveal significant disparities between categories (Figure 3). At the top of the list, NPK fertilizer stands out with an average of 2238.87 MJ/ha. A multiple comparison of means using the Mann-Whitney test shows that the energy expenditure associated with NPK fertilizer differs significantly from that of other inputs (Figure 3). This trend testifies to its intensive use in agricultural practices, underlining its importance in crop fertilization, but also the energy implications associated with its application. On the other hand, urea ranks second with an average of 1172.95 MJ/ha, marking a similarity with fuel-related energy expenditure (1167.08 MJ/ha). This preference for fertilizers such as NPK and urea has also been highlighted by other researchers (Abikou et al. 2023; Yabi et al., 2017).

In contrast, other inputs such as plant protection products (herbicides and insecticides) show comparatively lower energy averages, at 286.87 and 43.13 MJ/ha respectively. This observation may be explained by growers' preference for more traditional farming practices, such as manual weeding, rather than the intensive use of chemicals such as herbicides. The use of manual weeding may result from several considerations, including the desire to minimize environmental impacts, to ensure better crop quality or to respond to growing consumer concerns about chemical residues in agricultural products. So, despite the availability of chemical alternatives, growers seem to be opting for more eco-responsible methods, thus having a positive impact on their overall energy requirements.

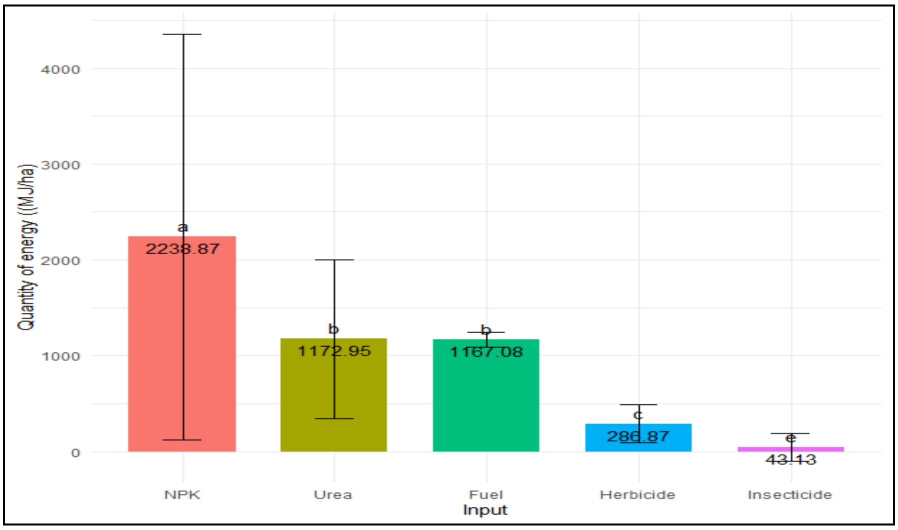

Figure 3. Comparison of energy quantities from input use

3.4 Comparison of Energy from Labor and Agricultural Inputs

The results of the comparison of total energy, whether derived from inputs, labor or a combination of the two, reveal significant differences (Figure 4) (a). Indeed, all activities and the use of agricultural inputs result in an average energy expenditure of 6369.59 MJ/ha. This amount of energy is lower than that obtained in other studies carried out on maize. These include studies by Kosemani and Bamgboye, (2021) (9502 MJ/ha) in Nigeria, Canakci et al. (2005) (11366 MJ/ha) in Turkey, Lorzadeh et al. (2011) (29307 MJ/ha) in Iran and Lawal et al. (2014) (31500MJ/ha) in Nigeria. This divergence could be linked to several factors, including variation around farming practices at the level of different farms, particularly in the use of agricultural inputs, geographical context and level of development.

Moreover, most of this energy expenditure is attributed to agricultural inputs alone, with an average contribution of 6081.88 MJ/ha, or 94.91% of total energy (Figure 4) (b). The share of labor power in total energy remains very low (5%). This observation highlights the preponderant importance of inputs in the overall contribution to the energy requirements of maize production in Benin. Indeed, these results corroborate those of Kosemani and Bamgboye (2021), Lawal et al. (2014), Lorzadeh et al. (2011). At the end of their studies, these researchers also concluded that agricultural inputs, in particular fertilizers, account for most of the energy expenditure to ensure maize production. This dominance of inputs in total energy can be explained by the increased dependence of farms on modern inputs, especially chemical fertilizers and pesticides. These results underline the need for thoughtful, sustainable management of inputs, given their significant weight in total energy consumption.

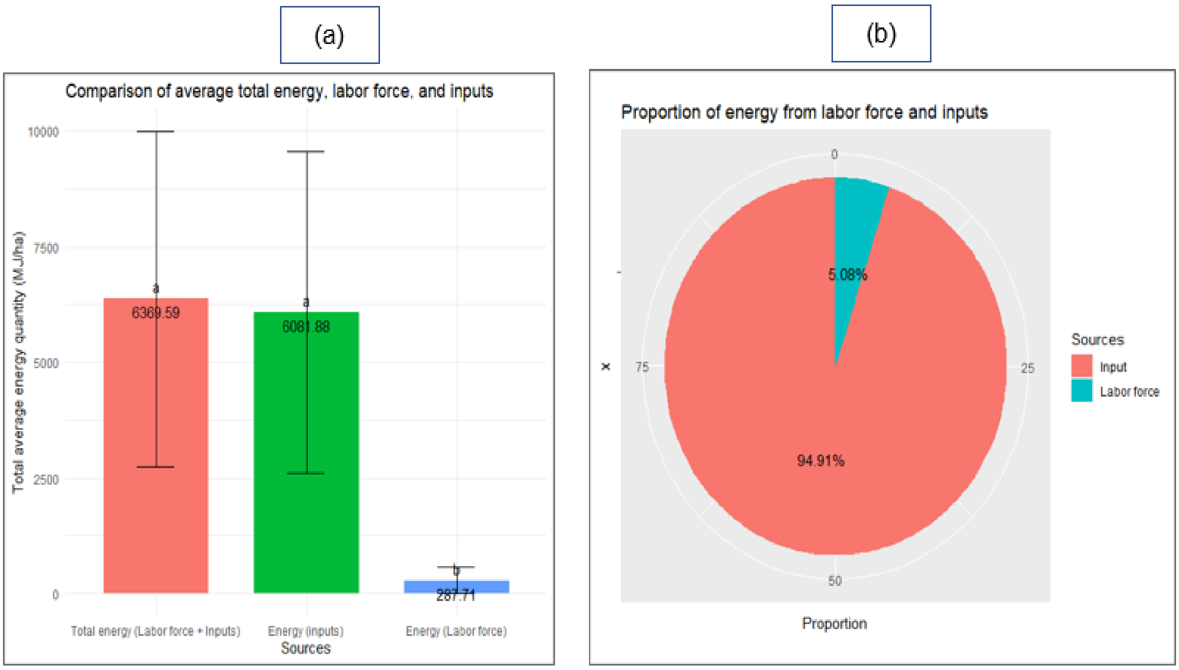

Figure 4. Comparative analysis of average total energies

3.5 Main Management Methods

Faced with the challenges posed by climate change, farmers have adopted various management approaches to maintain the productivity of their farms (Table 5). Among these approaches, two major solutions emerge: increasing agricultural inputs, such as fertilizers and pesticides, and increasing the labor force. These two management approaches reflect crucial choices made by farmers to mitigate the effects of climate change on maize production and guarantee the sustainability of their farming practices. Indeed, analysis of the results reveals significant variations between the communes of N'Dali, Nikki and Sinende. Regarding the management methods adopted, there is a marked disparity in the increase in inputs, with a notable proportion in Nikki (61.4%) compared to N'Dali (32.9%) and Sinende (31.1%). A similar trend can be observed in the increase of the workforce, where Sinende has a higher adoption rate (68.9%) than N'Dali (67.1%) and Nikki (38.6%). These discrepancies highlight the diversity of approaches adopted by farmers in each commune to cope with climate change (Assoumana et al.,2016; Sutcliffe et al., 2016; Gebreeyesus, 2017).

Furthermore, regarding the duration of adoption of management methods, most growers began using these methods within the last five years (0-5years), especially in N'Dali (85.7%). In Nikki, this proportion rises to 78.9%, while in Sinende it reaches 80.6%. These results indicate a general trend towards the relatively recent adoption of these management or adaptation methods, underlining farmers' heightened awareness of recent climatic challenges.

Table 5. Change management methods and adoption times by the farmers

Adaptation		**Communes**						**Total**	
		N'Dali		**Nikki**		**Sinende**			
		N	%	N	%	N	%	N	%
Management modes	Increased inputs	23	32,9	35	61,4	32	31,1	90	39,1
	Increased workforce	47	67,1	22	38,6	71	68,9	140	60,9
	Chi-deux	**0,0059****		**0,112**		**1,8e-4*****		**0,00123****	
Duration (years) of management system adoption	[0-5]	60	85,7	45	78,9	83	80,6	188	81,7
	[6-10]	9	12,9	9	15,8	20	19,4	38	16,5
	> 10 years	1	1,43	3	5,26	0	0	4	1,74
	Chi-deux	**< 2,2e-16*****		**1,605e-12*****		**5,381e-10*****		**< 2,2e-16*****	

4. Discussion

The conclusions drawn from this study on the perceptions of maize growers in northern Benin highlight a high level of awareness of climate change. Indeed, over 98% of participants surveyed claimed to have knowledge of the manifestations of this phenomenon. These results corroborate previous findings from other studies conducted both in Benin (Fadina and Barjolle, 2018; Gnangle et al., 2012; Loko et al., 2013) and in several other African countries (Fosu-Mensah et al., 2012; Mustapha et al., 2012; Muzamhindo et al., 2015; Ouédraogo et al., 2010). This underlines the importance of local awareness and understanding of climate change for effective adaptive management. The main changes observed are mainly associated with rainfall disturbances, including delays, early cessation and poor distribution of rainfall, as well as alterations to seasonal calendars. In addition, rising temperatures and the occurrence of extreme events such as flooding have also been noted. Similar findings have been reported in various studies conducted in Benin (Fadina and Barjolle, 2018; Houssou-Goe, 2008; Loko et al., 2013), Niger (Assoumana et al., 2016), Nigeria (Mustapha et al., 2012; Oyekale et al., 2012) and Kenya (Gebreeyesus, 2017).

Regarding the consequences of this phenomenon, the results highlight specific concerns, such as declining water availability and lower production yields. Indeed, rising temperatures, combined with rainfall disruptions, notably decreasing rainfall, exert a significant influence on decreasing yields of crops such as maize (Gebreeyesus, 2017). Thus, the delay in the onset of rainfall affects crop sowing dates and leads to poor crop performance, forcing farmers to develop specific adaptations (Gebreeyesus, 2017).

Indeed, to cope with this situation, all the producers interviewed have developed adaptation strategies based on their resource management methods. This high level of strategy adoption is also highlighted by the work of Fadina and Barjolle (2018), testifying to the necessity and resilience of producers in the face of the challenges posed by climate change. Furthermore, maize growers generally use two distinct management approaches. Some opt for intensification of agricultural inputs such as chemical fertilizers, insecticides and pesticides, while others favor increased labor, including mechanical traction, animal traction and plot maintenance. These choices reflect the diversity of strategies adopted to cope with climatic challenges and underline the complexity of management decisions taken by farmers. The intensification of agricultural inputs has been frequently mentioned in several studies as an adaptation mode increasingly adopted by producers (Assoumana et al.,2016; Gebreeyesus, 2017; Sutcliffe et al., 2016). As such, this approach aims to mitigate the negative effects of climate change (Gebreeyesus, 2017). Regarding the high rate of adoption of the management approach aimed at increasing the work force, this can be explained primarily by the success enjoyed by efforts to promote draught animals in certain countries, especially in West Africa, including Benin (Daum et al., 2023). These results confirm those obtained by Callo-Concha et al. (2012), who reported that in northern Benin, agricultural acreage is increasing thanks to the intensive use of animal traction. This trend indicates that efforts to promote draught animals have been effective and have influenced the management choices of maize producers in the region. On the other hand, this finding is not the same as that of Fadina and Barjolle (2018), who stipulate that growers give greater preference to the use of agricultural inputs such as improved varieties, chemical fertilizers and pesticides, as well as agroforestry practices. This disparity in results could be explained by the distinct geographical context of their study, conducted in southern Benin, where production levels are relatively low compared with the north, where production is essentially concentrated (Yegbemey et al., 2014). Thus, in the context of low production in the south, farmers may not feel the need to increase the labor force, particularly using mechanization or animal traction. This divergence shows that management choices can be profoundly influenced by local realities and the distinct characteristics of production zones.

However, even if most of the growers’ favor increasing the work force, this does not necessarily mean that this is the most energy-intensive management method on maize farms. In fact, this was observed with a clear predominance of input use in terms of the amount of energy generated. Indeed, the results indicate that almost 95% of total energy expenditure on farms comes from the use of agricultural inputs. These results corroborate the observations of Akdemir et al (2023), who point out that activities such as ploughing, hoeing, harvesting and transport each contribute to less than 10% of total energy consumption on maize farms. However, these results are at odds with the findings of Yilmaz et al (2005), who indicate that the energy consumption of agricultural machinery remains higher on small farms. This disparity can be explained by changes in farming practices over time. In this respect, the results obtained reflect a paradigm shift towards approaches more focused on the use of inputs (seeds, chemical fertilizers, etc.) better adapted to the current challenges of climate change (Fadina and Barjolle, 2018). This transition to input-based management therefore influences the distribution of energy consumption on farms.

However, among these agricultural inputs, the intensive use of NPK fertilizer stands out with higher energy expenditure. This observation suggests that the management mode favoring fertilization intensification is specifically associated with the frequent use of NPK fertilizer, underlining its central role in farming practices. These results concur with the findings of several other researchers who have also noted that, in terms of agricultural inputs, producers in North Benin use NPK more and then urea (Abikou et al. 2023; Yabi et al., 2017).

Finally, it is important to note that the impact of NPK on the environment is significant. The use of chemical fertilizers, often in the form of NPK, is largely due to the fact that growers are increasingly adopting adaptive strategies aimed at improving soil fertility. This is crucial given the continuing soil degradation observed every year. These mineral fertilizers increase maize yields, thereby boosting overall production volume (Miassi et al., 2024b). In addition, farmers are concerned about the environmental impact of insecticides and herbicides, as these chemicals can spread to other fields and waterways, causing pollution that affects production volumes (Miassi et al., 2024b). Furthermore, the results reveal that, unlike increasing the labor force, increasing the use of agricultural inputs is the most effective strategy for optimizing resources. This suggests that high-input farming methods may be a promising approach to enhancing farm resilience and sustainability in the face of climate challenges. However, some pesticides, due to their toxicity, are linked to neuronal loss (neuropathy), oxidative stress, cytoskeletal disruption, calcium overload or mitochondrial damage, which can lead to necrosis or apoptosis (Costa et al., 2008). According to Fangninou et al. (2019), effects on human health result from skin contact (handling of pesticide products), inhalation (inhalation of dusts or aerosols) or ingestion (pesticide contamination of food or water).

5. Conclusion

This study, focusing on the perceptions of maize growers in northern Benin and the effectiveness of their management methods in the face of climate change, reveals some interesting results. Indeed, rainfall disturbances, rising temperatures and seasonal calendar instabilities have a significant impact on water availability and crop yields. This encourages farmers to develop diversified adaptation strategies. The diversity of management approaches adopted by farmers, ranging from input intensification to labor force expansion, reflects the complexity of management decisions. The study highlights that intensification of agricultural inputs, particularly NPK fertilizer, appears to be a more coherent and potentially cost-effective solution for enhancing the resilience and sustainability of maize farms in the face of climatic pressures. However, persistent challenges, such as difficulties of access to improved varieties, financial and technological constraints, highlight the need for integrated approaches to alleviate these interrelated constraints in the agricultural context.

With the rapid progress of technology in agriculture, many organizations, institutions and stakeholders are striving to digitize farming and reduce human labor. While these current trends are promising for sustainable economic development, technological advances such as agricultural mechanization do not necessarily guarantee environmental protection or human well-being.

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Authors contributions

YEM, ŞA, HŞ, HA and KFD: Writing, Review & Editing; YEM and ŞA: Project administration, Funding acquisition; YEM and KFD: Investigation, Data curation; KFD: Sampling & investigation; ŞA, HŞ and HA: Project Supervision.

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The authors declare no conflict of interest.

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