INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue IV, April 2025

Climate Change as It Impacts A Sub-Saharan Staple: A Case Study of Bamenda, Cameroon's Colocasia Esculenta

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DOI : https://doi.org/10.51583/IJLTEMAS.2025.140400022

Received: 16 April 2025; Accepted: 18 April 2025; Published: 03 May 2025

Abstract: In this paper, I demystify the causality of Bamenda's prominent weather elements, especially in conformity with her annual solar-zenith times, a function of sheer latitudinal location. Then I investigate the sensitivity of climate (change) impacts there on colocasia yields, and annual colocasia planting times (growing degree days), in the event to clear the fog of confusion enshrouding the minds of researchers regarding the disappearance of the plant. Research on the afore-cited growing plight has uncovered data that is skewed toward drastic weather trends, an effect of global climate change, as its main cause; it is answerable for the slothful but assured diminution of this once perennial crop. This paper, thus, as is my design, actively challenges Bamenda's climate as pertains to this event, strongly critiquing any material that bespeaks or even hints otherwise. In order to corroborate the aforementioned hypothesis, a somewhat extensive comparative analytic study was carried out around the Mankon, Mendankwe, and Nkwen environs, but with special emphasis on the Mankon area, as it is the embodiment of Bamenda's both peasant and beau-monde societies. Data was collected on sunshine, temperature and precipitation. Also, colocasia yields were simulated pertaining to management conditions of both (i) before what is now considered, at least nationally, as effective climate change in action, and (ii) in present ('climate change') times. Distortions, as were ascertained, in carbon dioxide, oxygen and nitrogen proportions in the soil, make it a recalcitrant carbon store for colocasia esculenta. Also, an until now concealed fact of the plant's greater dependency on reliable water supply relative to good soil-nitrogen levels was revealed. A warming/ drying trend thus, a direct effect of global warming, is proving a pernicious effect on the crop. I therefore conclude that the recent disappearance of colocasia esculenta in the Bamenda area skew more toward impactful climate change ramifications than to its overexploitation.

Key Words: Climate change, colocasia esculenta, Bamenda, nitrogen, growing degree days, carbon dioxide, solar-zenith times

I. Introduction:

It is plausible to say climate change denialism, though abstract and impalpable, is becoming the greater threat to human existence than climate change effects in themselves. Why? Because not only is the event of climate change denialism gaining traction among the preponderance of our societies' elite, it is backed, endorsed and even ADVOCATED by some of the most potent organizations of our time. What's more, the birthed irony lies in the fact of the specialty of a handful of these organizations, the likes of those owned by the Koch Brothers of United States of America: their direct or indirect affiliation to food production. Some, with lofty sounding names like *Heartland Institute*, *Americans For Prosperity*, etc, run companies that decimate the ecosystem, leaving total ecological devastation in their wake, in the name of increasing food production, but at the expense of the cultivation of most third world staple food crops. The Indonesian island of Sumatra, for example, one of the last places on earth where tigers, elephants and orangutans could be found together, was deforested by fire and transformed into a palm plantation (Before the Flood, 2015). The degree and ecological implications of such a carbon explosion gives a shudder of repulsion. And this is just one amidst a sea of other examples.

Studies done by the IPCC in 2001 and 2007 have shown that global warming, as a consequence of greenhouse gas emissions, affects precipitation patterns, increases temperature and directly affects climate related extreme events, like droughts, heavy rainfall, floods and heat waves. Agriculture is one of the sectors most vulnerable to climate variability and change, an effect of its being very sensitive to slight weather pattern alterations (P Leo, 2016). According to Nelson et al (2010), climate change effects have exacerbated the challenges associated with food production.

Lobell et al (2007), in his research on some major crops in California (U.S.A.), found that rainfall affects more than 60% of the observed variability in yields for most crops. In the same way, another study by Cooper et al (2008) revealed that not only were the seasonal rainfall totals and their season-to-season variability important, but so too was the within-season variability, as it has, per his research, a major effect on crop productivity. On the other hand, Muchow et al (1990) confirmed that lower temperatures increase the length of time for crops like maize to intercept radiation for its growth. Also, Lobell and Asner (2003) found that there is about a 17% decrease in corn and soybean yield for each degree increase with regard to growing season temperature in the U.S.A. (P Leo, 2016).

Albeit compelling evidences of climate change like the roaring wild fires of California in January-February of 2025, and flooding of parts of rural Germany in 2021, may be at a much lesser degree in Sub Saharan Africa, subtler but far graver consequences there abound due to global climate and overall ecological neglect, as man's insatiable quest for convenience perforates our planet.

I, in this paper, argue that the repercussions of such neglect and abusiveness to climate are not only suffered by those around the perpetrations, talk less of by the perpetrators themselves. In fact, shielded from this bionomical detonation by their deep pockets

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue IV, April 2025

and swollen coffers, these economic entrepreneurs inadvertently redirect the full impact of contemporary climate change effects on the poor of India, South East Asia, South America and sub-Saharan Africa. And today, one the most conspicuous backlashes of this ecological alteration is the cry of desperation, the lamentation, of local farmers in the region, a function of the diminution in the production of certain staple food crops. The immenseness and profundity of this quandary is seen in the event of its having attracted the attention of a notable figurehead like Melinda Gates of the *Gates Foundation*; she has been jolted into action, touching mostly Sahelian nations.

The Sub-Saharan nations most affected by this climate change-related food crop depletion include Ghana, Nigeria and Cameroon, among others. It is thus my conviction, based on a cross examination, that Cameroon, being internationally accepted and commended as African-in-miniature, 'fits the bill' to mirror this entire West African predicament to the world at large. And in Cameroon, no better case/scenario than that of the disappearance of a certain plant in and around the Cameroonian town of Bamenda could be found.

Again, I am convinced that an examination of the responsiveness of Bamenda's ecology to recent climate change effects will endorse an apprehension and appreciation of my hypothesis.

The Nature Bamenda's Climate

Bamenda, capital of Cameroon's North West Region, is one of the main and most influential towns in the country. Located on 5°56′N/10°10′E and with an elevation of 1,614 m*asl*, it has a population of about 2,600,000 inhabitants (as of 2019). Bamenda's geographical position as Cameroon's principal urban settlement on her Western Highlands relief region makes her the food basket of the entire country, as crops respond readily and positively to the generally cool, market gardening-friendly climate of surrounding rural environs (like *Santa* sub-division). Although relatively lower in altitude to the said surrounding villages, Bamenda town still remains farther from sea level (1,614 m) compared with most situations on some contemporary relief regions of Cameroon. This site, thus, has placed Bamenda under the Mountain Cameroon Type of Equatorial climate, with seven months of rains (usually April, May, June, July, August, September and October), and 3 months of no rains with very low Relative Humidity, less than 50% (January, February and December). The months of March and November usually straddle both seasons. The town owes one extra month of the rainy season (7 instead of 6) to her height above sea level, which has allowed orology to influence orographic rainfall by easing warm air ascent. The strength of the rising warm air masses is endorsed by the prevalence of anabatic winds which fan especially the more elevated Mendankwe area during the day, explaining the presence of the less reliable cumulus clouds over the area for much of the year. The fact that the Adamawa Plateau (another relief region in Cameroon), which is only several tens of kilometers northeast of the Western Highlands, has only 6 rainy months thanks to a relatively lower altitude, underscores the effect of elevation on precipitation. Like most non-temperate and non-polar regions of the world, Bamenda's rain or rainy season is usually frontal; that is, it is the direct result of the north-crossing movement of the Inter-Tropical Convergent Zone (ITCZ), at times referred to as the 'heat equator' (D Waugh, 2005), as the sun both comes to zenith at and crosses over Bamenda as it 'heads for' the Tropic of Cancer. This move by the ITCZ means warm, moist trade winds from the south (Atlantic Ocean) would invade the continent and trail it up north, and inevitably blow across the town of Bamenda, bringing with it rains that should be what is left from the real zone of action (ITCZ, now at about 15°N). This zone of action, also referred to as the air mass discontinuity, is usually not the recipient of most of the rainfall when at the tropics proper (rain is more intense farther south during the Northern Hemisphere's summer), because of the uplift of the warmer continental air masses at and around the solar-zenith point. (But with increasing distance from the zone of convergence, or to an extent, the solar-zenith point, moister maritime air masses become relatively 'warmer' compared with continental air masses, and so are the ones forced to rise, form taller clouds, and hence, produce more rain. This partially explains why Bamenda experiences less cloud cover and rainfall relative to places closer to 0° especially at this time of year. The event, however, of areas experiencing more rains with increase distance from the ITCZ occurs only over the land surface, and more so, only when the ITCZ is 'around' the Tropics of Cancer and Capricorn, due to their naturally being zones of high pressure, and thus, higher temperatures, compared with equatorial zones.) Hence, the fact that these frontal rains form from shallow clouds compared to convectional rains explains why they are relatively less intense and shorter-lasting in Bamenda. Taking, however, both the measurements of the theoretical dates for the solstices and equinoxes and Bamenda's latitudinal location – 5°56'N (ignoring, however, the precession of the equinoxes), it is calculated that the sun is in zenith in Bamenda on approximately April 12 - 13 and August 28 – 29. (The *Motions of the Sun Laboratory* machine of the University of Nebraska, however, simulates these dates to be April 3 – 4 and September 5 - 6). According to popular opinion and statistical data, the latter which shall be disclosed later in this study, August has mostly been the single rainiest month in the town of Bamenda, a notion which confirms the mathematical conclusion of the latter Bamenda solar-zenith period (August 28 – 29).

The Sun Over the Bamenda Area

When the sun is directly over a place, diurnal ambient temperatures abound. Parcels of warm air called thermals rise to an elevation of about 15,000m around the equator (D H Johnson, 1969) and cool adiabatically (the maximum height of ascent of the rising thermals decreases with the different pressure cells toward the poles – D. Waugh, 2005), and the area which was heretofore a subtropical high pressure cell gradually 'mutates' into a region of low pressure; a new area of inter-tropical convergence is thus established some distance from the equator. Over Bamenda, like over most other areas, the rising thermals could either be saturated or dry, a fact which goes to influence their rate of ascent, and rate and type of cooling. This convectional cooling only works to strengthen the air-sucking potency of the depression created by the rising, less dense air. This depression causes trade winds from

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the north-east called northeasterlies (usually called harmattan) and southwesterlies (or 'monsoon' winds) from the southwest to converge over Bamenda, an aeolian meeting which culminates in either the subsidence of the northeasterlies (cold front) or the over-climbing of the monsoons (warm front). However, areas at and around the equator experience such frontal effects for most of the year due to their closer proximity to the sun – the double maxima effect. Bamenda, thus, being closer to 0° than to 23.5°N, has far more rainy days per year and greater humidity than regions at and around 23.5°N.

The warm, moist monsoons rise (slide over the cooler, denser, converse-facing air mass), their moisture cools and condenses, and intensely precipitates back over the Bamenda area. The months between April and August, and then the month of September, usually see relatively less intense showers because the heat equator would have moved away from the area. Bamenda, as is most of West Africa, is largely under the influence of these northeasterly trade winds during the Northern Hemisphere's winter; and during this time, except for a narrow strip along the Atlantic coast, West Africa generally experiences the dry season.

Climate Change in Bamenda

The above-explained had been the convention in Bamenda – at least until the effects of global climate change began progressively encroaching in, with increasing commanding manifestation, on this fairly large Cameroonian town: distortions in urban/rural air pressure; slashed humidity; drastic/extreme weather patterns – with fickle weather changes and modifications; greater unpredictability and unreliability of rains even in the rainy season; soaring ambient temperatures which fuel encroaching desertification on once evergreen hillsides and meadows (the *Ntamulung* and *Natcho* areas in Mankon). At present, the rains, as is the main complaint of local farmers and 'buyam-sellams' in *Commercial Avenue* (Bamenda's Central Business District), are no longer judiciously managed (to conform with planting times) throughout the rainy months by the weather, but squandered during a smaller number of those months, leaving the other months almost totally dry, working to now give the town a longer dry season.

Additionally, Bamenda is much hotter now than before. Once known as 'The Cool City', Bamenda now seems to be succumbing to a spree of convulsive heating. Mean monthly diurnal temperatures as high as 28.5°C were recorded there in February of 2019, the highest that year and thus far; mean monthly night-time temperatures of about 20°C were recorded the following month. Such exorbitant temperatures could only have been a figment of the 'Bamenda man's' imagination as recently as only the mid 2000s.

Further compounding this climate change woe is the fact of the town's soaring levels of particulate matter; according to the World Health Organization (2020), Bamenda is the town with the greatest concentration of PM2.5 in West Africa.

Most of the people of the Bamenda region, as is the case with all the other areas affected by monsoon rains, are farmers, or at least, assume occupations that directly relate to agriculture; their lives thus depend, to a reasonable degree of accuracy, on these yearly (monsoon) rains. And so any scheduling failure like an early or even a late arrival of the rains may cause widespread starvation and even an economic disaster (Riehl et al, 1958).

Albeit many in and around Bamenda yet find these changes in weather and climate subtle, the welfare of one particular plant – a crop, a delicacy, colocasia esculenta, rides low, as the plant faces endangerment; colocasia has been vanishing with, hitherto, no clue to (an) accurate and justifiable reason(s) for its disappearance.

Colocasia Esculenta

Colocasia esculenta, commonly known as *taro*, is a tropical plant cultivated and grown primarily for its edible corms. It is probably one of the world's oldest crops; archaeological studies indicate its usage as early on as 28,000 years ago in the Solomon Islands (Chair et al, 2016). Contrary to popular belief, the plant actually has its origins traceable back to Asia (Gnanasekaran et al, 2018). Today the crop is largely produced in and exported from sub-Saharan countries, the likes of Cameroon (1,700,000 tonnes), Nigeria (6,607,000 tonnes), Central African Republic (100,000 tonnes) and Ghana (2,088,330 tonnes) (F.A.O, 2018), albeit the time and manner of its spread to Africa is yet unknown; and needless to say, Bamenda leads the way in *taro* production in Cameroon. According to Onwueme (1994) the most abundant content of the *taro* corm is moisture (63-85%), although this varies with variety, growth condition and harvest time; carbohydrates follows moisture in terms of quantity (13-29%); other contents like proteins, fat, crude fibre, ash, vitamin C, and even thiamine, trail behind with far lesser percentages. *Taro* is naturally a perennial monocotyledonous herb, but for practical purposes it is harvested after 5-12 months of growth. It grows to a height of 1-2m consisting of a central corm lying just below the soil surface, from which leaves grow upward, roots grow downward, and cormels (daughter corms and runners) grow laterally (Gnanasekaran et al, 2018). Although *taro* is very adaptable, it needs a rich soil for its optimum development and yield. When grown under less than ideal conditions, it responds well to mulching or to applications of nitrogen, phosphorus and potassium. Under good conditions and with good varieties, yields of up to 15 tons/acre can be obtained; experiments in Hawaii, however, have given yields of nearly 50 tonnes/ha on heavily fertilized plots (Ubalua et al, 2016).

Colocasia esculenta can survive through years via cormels or suckering. Lebot (2009) established six major growth phases in *taro*: root formation, shoot development, increase in corm size, rapid dry matter accumulation in aerial parts, predominant corm and cormel growth to maturity stage, and finally, corm and cormel dormancy. Temperature, as shall further be discussed in subsequent chapters, is the main driving force behind the plant's reaching a given growth stage. Phase one, being the most significant, is the establishment of the plant with root formation and leaf production. This phase usually lasts from 1 to 3 weeks after planting (WAP) until a functional root system can feed the plant (Lebot, 2009). At the same time, between 2 and 6 days after planting (DAP) depending on the soil moisture, propagules rapidly produce new roots with which the plant starts absorbing and utilizing soil water

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and nutrients. Successful establishment of the plant is a very important stage in crop production and can be determined by propagule quality. In Colocasia esculenta propagules, size is essential for successful establishment, since at this stage, the plants are entirely supported by available water and nutrients from the propagules. Thus, the greater the weight of the propagules, the earlier it will produce roots to anchor the young plant, and the sooner it will begin its uptake of water and nutrients (P Leo, 2016).

The Nature of The Problem (Colocasia Esculenta Disappearance)

In Cameroon, a number of issues are currently affecting staple food production, *taro* being at the forefront. These issues include: rural exodus, with youth migration to urban centres (central business districts) culminating in decreased agricultural yield, since youths constitute the main supply of the rural work force; growing reliance on food imports; increasing population pressure which results in less arable land for cultivation; rising food prices; political instability (the status quo in Bamenda); land tenure issues; and inefficient governance and incentives around agricultural productivity (P Leo, 2016).

In addition, climate variability and change are beginning to affect *taro* production both directly, via impacts on growing conditions, as well as indirectly via interactions with the aforementioned issues. Thus, it is important to consider both climate variability and change in crop production in order to ensure future sustainability of food production. Climate variability is when variations in climate conditions (average, extreme events, etc) in time and space scale beyond that of individual weather events, but not persisting for extended periods typical of decades or longer (Hay et al, 2003). Climate change on the other hand means the fluctuations and changes in mean conditions in the climatic parameters (P Leo, 2016).

The Problem of Colocasia Esculenta In Bamenda

Commonly referred to by the 'Bamenda man' as 'Achu coco', colocasia has always been a prized procession as it, over the decades, has been one of the staples in Bamenda, either eaten directly with any choice sauce, or pounded and then savoured with 'yellow soup', a spicy concoction of profound cultural significance. In fact, the latter form of consuming of the tuber was somewhat regarded as sacred, as it spelled and teleported, in mind, those who partook of the repast to the roots of Bamenda's main cultural diversities – Mankon, Mendankwe, and Nkwen; it deepened the immersion of the native's psychological trajectory as they ate. Of course, even the texture and flavour of the colocasia plant, when well cooked, spoke for its self, a haunting and despairing reminder to the superstitious of a sore and imposingly conspicuous loss in progression. Then slowly but steadily, the plant's production levels began to dwindle with absolutely no precedent. And over the years, there has been the progressive replacement of taro on the ridges of local agricultural sites around Bamenda with the cassava plant (manioc). Somehow it seems like manioc possesses a resistance that taro is yet deficient in. With one glance at these ridges one would infer that the waning taro output only just matches correspondingly low inputs to guarantee its proverbial perennial repute. The locals, however, swear that this is not the case; they say 'it is the last straw on the camel's back when one's spine is breaking in the searing heat of sun' only to realize that their efforts and investments have been 'slighted by fate and Mother Nature.'

Further compounding this woe is the fact that I.R.A.D. (Bambili), a prominent institution for the hybridization of food crops, has been especially silent on the issue of colocasia. Not too long ago, though, I.R.A.D. triumphed with the cases of Irish potatoes and beans, among several others. Yet unknown is whether this silence is equivocal.

Clearly, the taro problem is not just one of today. Negligence on the general wellbeing of the crop dating from as far back as before the 1970s, manifest in the form of very little attention being paid to its vulnerability during conferences and other forums to drastic and fickle weather patterns, began to herald pending, inevitable doom for the plant: according to Ubalua et al (2016), Ezedinma presented a 'pathetic paper' on taro research in Nigeria, noting that at the 4th symposium of the International Society for Tropical Root Crops held in Cali, Columbia, in 1976, only 3 scientific papers were presented on cocoyam (colocasia) compared to 35 on cassava (manioc), 11 on potato and 5 on yams; at the society's symposium in Douala, Cameroon in 1983, there were 6 papers on cocoyam while cassava had 27 and yam 14; also, much recently at the 16th International Society for Tropical Root Crops (ISTRC) held in Abeokuta in 2011, only 23 scientific papers were presented on cocoyam compared to 95, 45 and 60 for cassava, sweet-potato and yam respectively. This age-old callous and spiteful attitude toward colocasia esculenta kicked-off a trend of nonperformance regarding growing degree days, and how these should have been revised in the face of growing poor climatic interference.

To temporarily deal with this problem, however, the 'Bamenda man' has, as a form of improvisation, turned to the use of a common form of *Musa paradisiacal*, a starchy tropical banana-like fruit locally referred to as 'achu banana'. This fruit is cooked, smashed and served with taro to make up for the lack in taro quantity. Sadly enough, though, the greater quantity of food is achieved, nonetheless, but at the expense of sheer palatability.

Scientific Procedure:

A General Look

I shall begin this chapter by enumerating some of the ways in which climate change has a pernicious effect on agriculture. Food production as a whole is profoundly affected by climate change. Climate change affects food production in four main ways: through temperature, water, extreme weather and carbon dioxide (F.A.O., 2018).

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With temperature increase, production of staples like corn are expected to increase at first, in direct response to growing degree days, then decrease sharply as the average growing temperatures keep getting warmer. For corn alone, a decrease could be about three percent per year or 300,000,000 bushels, enough to feed 40,000,000 people (F.A.O., 2018). Pests, on the other hand benefit from this heat, resulting in more and more plant diseases spread by insects. Heat-loving worms and bacteria like tobacco mosaic are already spreading through Europe's upper-mid west in the wake of climate change-fueled soaring temperatures.

Water has a somewhat complicated relationship with crops as it is all about the right amount at the right time. If the rains come too early or too late, most food crop growth would be stunted. Irrigation systems may help here, but their sources may dry up as droughts increase. In the Mississippi Delta region for example, this aspect could put 75% of the rice crop at risk. And as sea levels rise, crops could face a salt water problem. Droughts could be brought on by more erratic rainfall, part of a pattern of increasingly extreme weather. And when extreme weather brings violent downpours, there's this other issue: run-off would increase soil erosion. All these pieces of the climate puzzle – floods, drought, etc, can affect crops and livestock at key moments in their development, turning even a productive season into a disaster. For example, 2011 was the most extreme weather year on record, with sixteen extreme weather incidents that cost over $ 1billion. 2012 was a close second, as severe storms continued to cost more billions. 2015 witnessed the Asian monsoons ravish Nuh village of Haryana (India), with onion farmers receiving half the year's rainfall in just five hours, damaging their crops irreparably (Before the Flood, 2016). Another example was in August 2021, when the Henan Region of China was flooded to capacity as result of being deluged with a year's worth of rainfall in just three days.

All of these changes circle back to the key driver of climate change – increased carbon dioxide, which has its own effect on agriculture. Carbon dioxide helps plants grow; more of it could even actually be of more help to crops. But it also helps weeds and invasive species grow even more. Even so, crops that survive the weeds could then have their nutritional value compromised, some having their protein levels drop by more than ten percent. So, if depleting food production is not enough, increased CO_2 levels guarantees the less nutritious state of surviving crops.

According to N M Innocent (2015), it had been predicted that increased temperatures are expected to reduce crop yields and increase levels of food insecurity even in the moist tropics; and that due to these risks, farmers have been adjusting their farming practices.

Study Area

The Mankon area was the principal site for my study, with the Mendakwe and Nkwen areas used for the comparison of analyses. As per the 2018 population census, the area's count was 1,918,853 people, with a density of about 110/km2. Although these divisions are separated from each other by far less than 50 km, differences in elevation and wind exposure account for differences in local climates; for example, temperature and orographic precipitation (N M Innocent, 2015). The relief of the Mankon, Mendakwe and Nkwen areas is characterized by massifs and petit mountains. A cool temperate-like climate, influenced mainly by the mountainous terrain and rugged topography also characterizes mostly the Nkwen area.

Figures 1.0 and 1.1 show the situation of Bamenda in Cameroon, and the relative locations of Mankon, Nkwen and Mendankwe respectively.

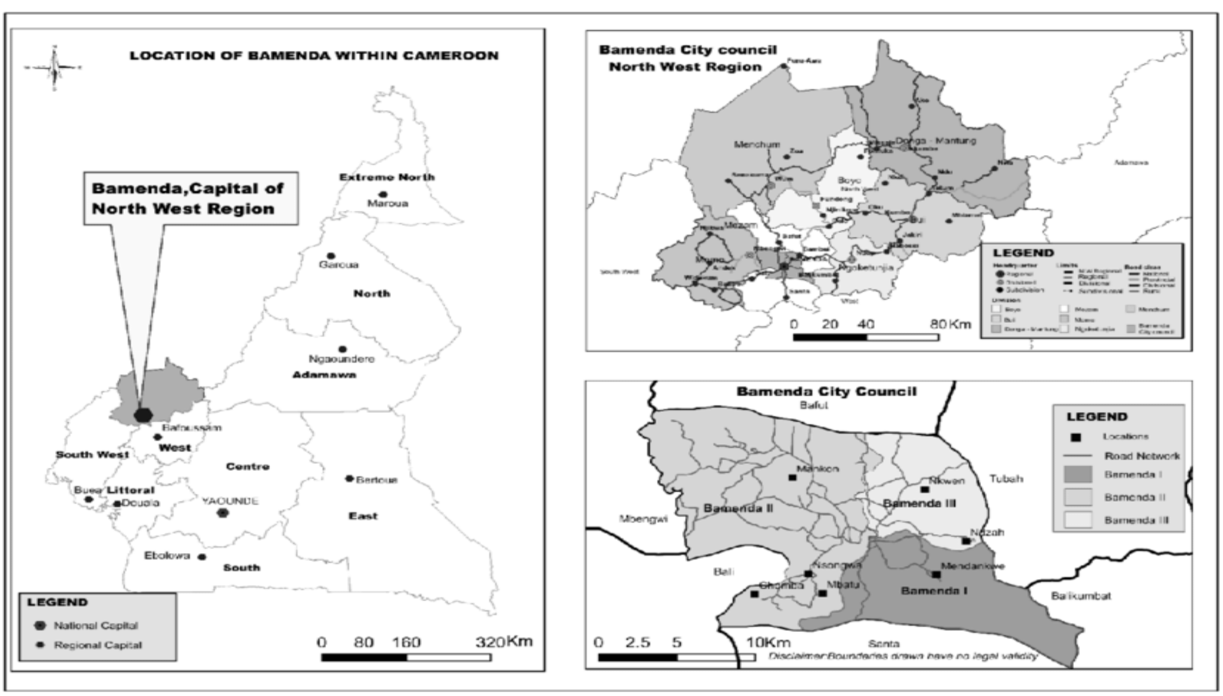

Figure 1.0: Maps to show position of Bamenda in Cameroon and in the Northwest Region

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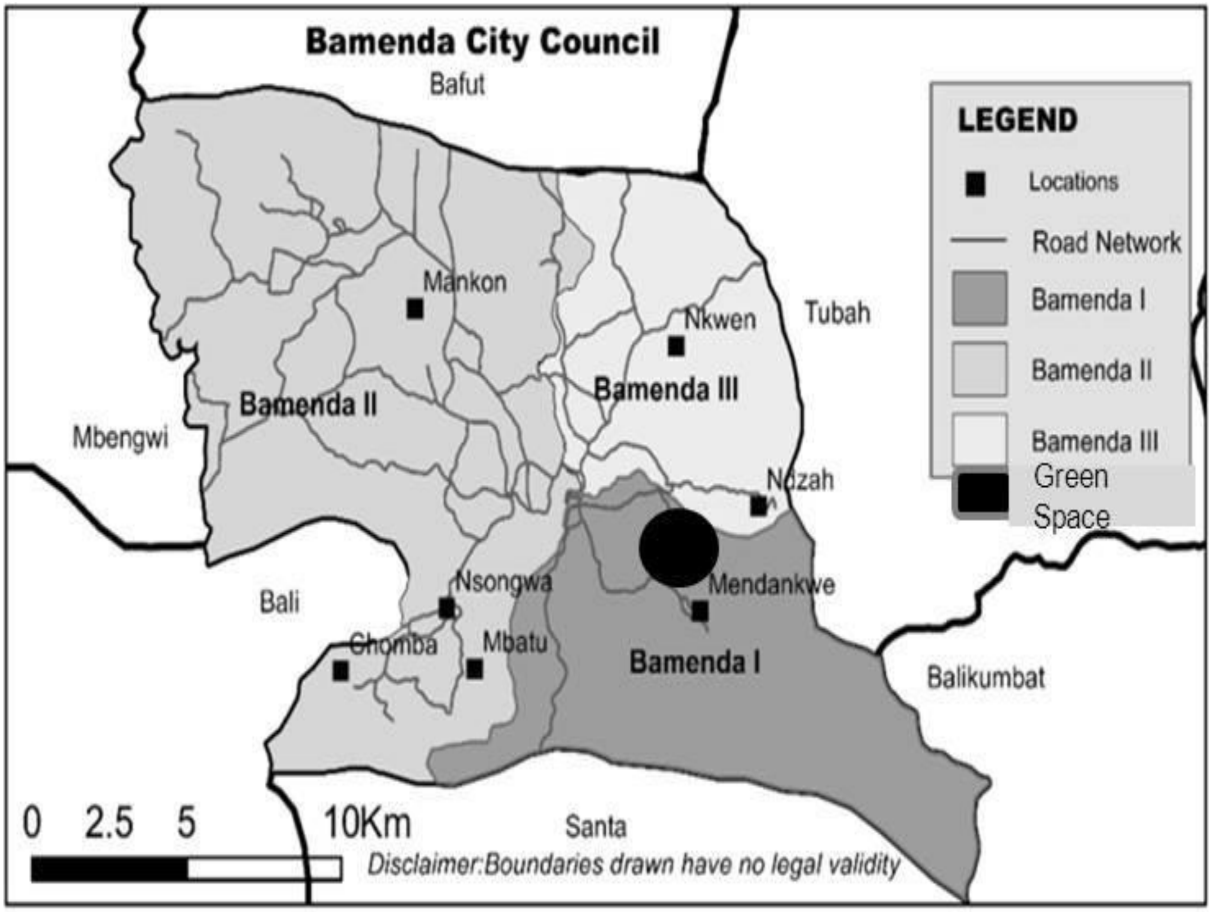

Figure 1.1: Relative locations of Mankon, Nkwen, and Mendanke

The Alabukam quarter of Mankon was used for pre-climate change simutation, while the post climate change simulation was conducted in the Mendanke and Nkwen areas.

I was keen, as I trod across fields in Mankon that were famed for being '*taro* lands', to note several dried *taro* bulbs scattered here and there, as they presented but a dreamy suggestiveness of past apex production. In frustration, the Mankon people frantically blamed each other's 'over exploitation' of the crop as the main reason for its disappearance. I explained to those who were patient enough to listen, that the taro crop is a perennial (lasting three or more seasons, and self-renewing) plant; over exploitation as a cause for its dwindling output would be out of the question.

Data was then collected on the main elements of weather (sunshine, temperature and precipitation) in the event to ascertain results which would back my hypothesis. I simulated colocasia yields under conventional 1750 - 1840 conditions in Cameroon. Then I did the same under conditions of greater rainfall unreliability, higher temperatures and greater atmospheric/soil carbon dioxide concentrations intermingled. With temperature, one of the most reliable ways to prove lower taro output with soaring ambient temperatures was to use the evidence of growing degree days. A recognition of the manner and rate at which these elements of weather fluctuate in the course of the year will justify local decisions to correspondingly adjust taro planting times, as the sowing of the crop must be to make for its taking full advantage of the rainy days and moderately warm temperatures.

The vegetation calendar in Bamenda is strongly influenced by the pattern of rainfall, especially by its seasonality. The welfare of taro largely depends on rainfall patterns as rains provide the crop with the moisture they need. Since Bamenda can reasonably be attributed to the tropics, its rainfall pattern should not, according to convention, vary much throughout the year; it would however be seasonal in its incidence. It is worth recalling that rainfall intensity and duration in Bamenda both increase from January to August, when they experience a somewhat slight drop. They then tend to plummet sharply from late September through to December and January. Peak rainfall is often experienced in the month of August (861.8mm), with rainfall occurring almost all days of the month (Hall et al, 1998).

Bamenda generally has moderate temperatures that vary throughout the year, ranging from 17^0 to 26^0C. Very low temperatures are experienced in the mornings and nights of the dry season, especially in December. Paradoxically, midday temperatures may soar during the rainy season to about 24.9^0C (Hall et al, 1998).

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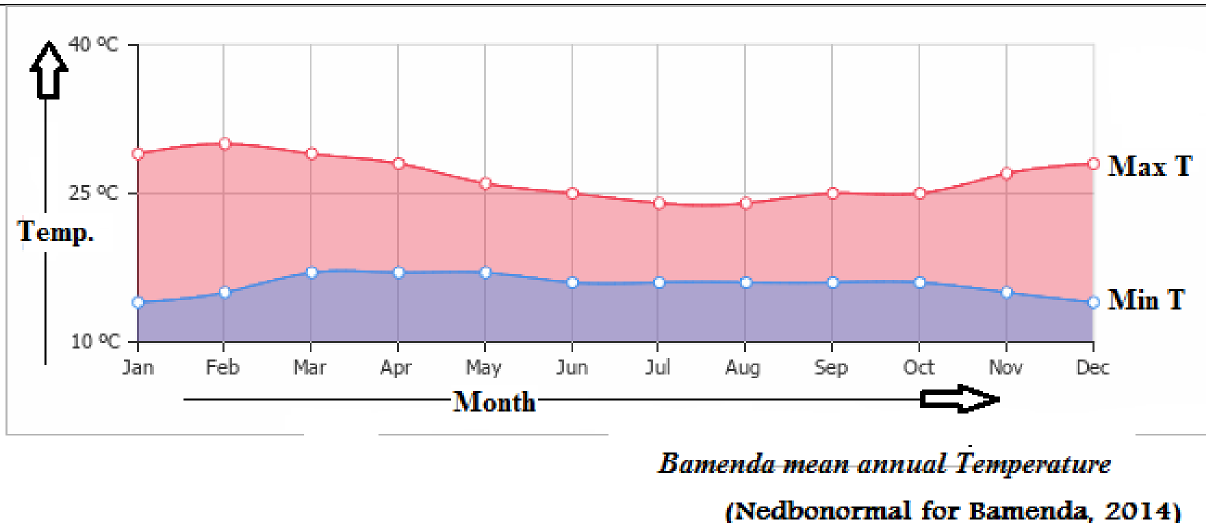

Figure 1.2: Maximum and minimum temperatures in Bamenda for 2014

Temperature

Temperature variability is of great significance especially as concerns colocasia esculenta, because it greatly influences all stages of the plant's growth and development: shooting, germination, early growing, flowering and fruiting. The diverse nature of Bamenda's flora and even the past flowering of taro in the area could be attributed to its moderate temperatures, which were ideal for active soil bacteria like the denitrifying and nitrogen-fixing bacteria.

Table 1.0 below shows temperatures in Bamenda through a 23-year span, from 1985 to 2007. In order to ascertain whether there has been a drying or cooling trend in the town, I gauged the conformity Coefficient of Variation to the average temperature for those select years

Table 1.0: temperatures in Bamenda from 1985 to 2007

YEAR	ANNUAL T*C X	$X - \overline{X}$	$(X - \overline{X})^2$
1985	24.2	3.6	12.96
1986	20.3	3.3	10.98
1987	21.2	0.6	0.36
1988	20.3	-0.3	0.09
1989	20.7	0.1	0.01
1990	21.0	0.4	0.16
1991	19.7	-0.9	0.81
1992	19.5	1.1	1.21
1993	21.5	0.9	0.81
1994	23.1	2.5	6.25
1995	22.8	2.2	4.84
1996	22.8	2.2	4.84
1997	25.4	4.1	16.81
1998	20.4	-0.2	0.04
1999	22.8	2.2	4.14
2000	21.0	0.4	2.25
2001	18.5	-2.2	0.01
2002	19.1	-1.5	0.81

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2003	20.5	-0.1	0.01
2004	21.5	0.9	0.81
2005	22.5	1.9	3.61
2006	21.5	0.9	0.81
2007	22.6	2.0	4.0
	$\sum X = 474.8$		$\sum (X - \bar{X})^2 = 81.17$

$$\text{Mean}\ (\bar{x}) = \frac{\sum x}{N} = \frac{474.8}{23}$$

$$\bar{x} = 20.6°C$$

$$\text{but Standard Deviation}\ (\S) = \sqrt{\frac{\sum (x - \bar{x})^2}{N}}$$

$$\S = \sqrt{\frac{81.71}{23}} = 1.9$$

$$\text{Coeff of Variation}(V) = \frac{\S\,(100)}{\bar{x}}$$

$$V = \frac{1.9(100)}{20.6} = \underline{\underline{9.2\%}}$$

From the above computation, the mean was found to be 20.6^{0}C, and the Coefficient of Variation, 9.2%, meaning the overall deviation of temperature in Bamenda is only 9.2% from the mean of 20.6^0. This relatively low value is insurmountable evidence pointing to an increase in temperature, a product of climate change.

Evidence of Growing Degree Days (GDD) and how it affects Colocasia Planting Times

GDD are a measurement of the growth and development of plants as well as insects during the rainy season (Fraser et al, 1998). Development does not occur unless temperature is above a minimum threshold value. Each plant species is sensitive to a certain temperature, known as the base temperature. When the air temperature is above the base temperature for a length of time, the species would develop and grow; and when it dips below the base temperature, development stops or slows. Due to temperature variations throughout the growing season, calendar days are not the best method in predicting the timing of plant development. Instead growing degree days assign a heat value to each day based on how each day's temperature differs from the plant's base temperature. If, for example, the average temperature is one degree higher than the base temperature, that would be one growing degree day – and so on (Fraser et al, 1998). The growing season for agricultural products is determined to a large extent by the length of time temperatures remain above the base or threshold temperature of the crop. Base temperature varies from one plant type to another. Because each plant has a total heat requirement to reach different stages of growth, I looked at accumulations of the growing degree days of colocasia esculenta throughout the season. Taro thrives best at temperatures between 20 to 30°C. This implies that the growing season for *taro* are the days with mean temperatures that are above the 15°C threshold for the crop; anything too close to 30°C and the crop finds it a little 'too hot' to do well. Acridity-causing microscopic needle-like raphides of *calcium oxalate monohydrate* begin to 'deal' with the consequences of drying fluids (S H Sohmer, 1999). In practice, 25°C has been the limit somewhat for perfectly secured and assured growth of Taro, with 26°C being the most it can take for the most part. *Table 1.1* below shows present temperature (°C) and rainfall (mm) distribution throughout the months of the year in Bamenda (Nedbonormal for Bamenda, 2019) in a bid to ascertain the months taro growth has now been limited to from being an almost "all-year-round crop".

Table 1.1: Temperature (°C) and rainfall (mm) distribution throughout the months of 2019 From *table 1.1* above, the once perennial taro now has only about 85 days of (monitored) growth a year, spanning midsummer (July) to the conclusion of the fall (mid October). The Bamenda people seconded this finding, confirming that rising diurnal temperatures have compromised the plant's chance at a fair growth, carefully stripping it of its title as 'perennial'.

Month	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
mm	**9**	**32**	**125**	**174**	**178**	**250**	**341**	**382**	**340**	**252**	**48**	**11**
°C	**22.1**	**22.7**	**23.0**	**22.6**	**21.8**	**20.9**	**20.0**	**20.1**	**20.5**	**20.8**	**21.5**	**21.6**

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°C Max	**15,6**	**16.0**	**17.5**	**17.5**	**17.0**	**16.5**	**16.1**	**16.1**	**15.8**	**15.9**	**16.3**	**15.6**
°C Min	**28.7**	**29.4**	**28.5**	**27.7**	**26.7**	**25.3**	**24.0**	**24.2**	**25.2**	**25.8**	**26.8**	**27.7**

As a result of this, local farmers who have not yet mastered the fickleness of Bamenda's weather are perplexed at the poor output that greets them during harvest time. Having procured fresh, healthy corms, having meticulously pursued the plant's planting procedure, having 'observed' the plant's growth, they meet total devastation at the end, as the crop's output is not in the least commensurate with what has been put in by the expectant farmers. And this has been a growing plight in the Bamenda areas of Mankon, Nkwen and Mendankwe, and probably beyond. This growth will pursue unless something is done to check it.

Consequently, taro planting times have been revised, at least from individual or family levels, to concur with GDD, from being cultivated almost all year round.

This is however vehemently opposed to the computation of the maximum and minimum temperatures of the day to obtain the base or threshold temperature for a plant as delicate as colocasia esculenta. It is due to the fact that the highest temperature of the day is usually during sunlit hours, and vice versa.

That is

$$\frac{T\,Max + T\,Min}{2} = T\,Base$$

Taking the mean of the highest and lowest temperatures for *taro* means that the lower night time temperatures automatically make it immune to the unbearably high temperatures of hot dry season days (winter in the temperate and polar areas of the Northern Hemisphere) in the Bamenda area. Was this plausible, there would not have been such an acute diminution in the crop's turnout such as is experienced in that area today. More weather-resistant crop species and weeds, however, can fare well with such T. Base computation. And in the case with weather-resistant crop species, T. Base would be thus computed based on the following assumptions:

There is only one significant base temperature that operates throughout the life of a plant.

Day and night time temperatures are of equal importance to plant growth.

The plant's response to temperature is linear over the entire temperature range.

Rainfall

N M Innocent (2015) presents a solid argument that precipitation trends during the growing season from February to April in the Western Highlands of Cameroon have been declining somewhat in the past seasons since 1980, from a former mean annual precipitation of about 2400 – 3000mm. See *table 1.2* below:

Table 1.2: Rainfall distribution from 1983 to 2007 to show a generally decreasing trend

YEAR	ANNUAL RAINFALL (mm) X
1983	2784
1984	2550
1985	2047
1986	2313
1987	1442
1988	2505
1989	1460
1990	2560

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1991	1460
1992	2575
1993	1564
1994	2671
1995	2817
1996	2433
1997	2389
1998	1393
1999	1615
2000	1562
2001	2106
2002	2149
2003	1251
2004	1397
2005	1550
2006	1746
2007	2450
TOTAL	$\sum X = 46285$
MEAN	$\overline{X} = 1851.4$

As earlier mentioned and as depicted by *table 1.2* above, the Bamenda area has been inured to progressive rainfall unreliability in the past years. The reason for this as a meteorological implication of a changing climate had been hinted upon in the introduction: taro in Bamenda had been used to much water all through the planting and growing seasons. There, however, has not necessarily been a significant decline in the annual amount of rainfall in the course of the year; rather, there is a sort of progressive unequal attribution of the rains throughout the conventional rainy months. So, this rate of climatic transition is far too rapid for taro to adapt to; its death and subsequent dwindling production are the most probable culmination.

In truth, there is misleading information regarding rainfall variability in Bamenda, especially around the Mankon, Mendankwe and Nkwen areas. The use of the *Coefficient of Variation* as a means of depicting present rainfall variability in such a climate change-sticken zone as Bamenda at times proves ineffectual. Unlike with the case of temperature (as seen above), comparing the obtained result for the *Coefficient of Variation* with the mean rainfall for a succession of years may impel one to draw a false conclusion of minimal rainfall variation. This is because unpredictability and unreliability of rainfall occur as an offshoot of global warming (rising temperatures on a global scale), which causes climate change. *Table 1.2* above for the monthly distribution of rainfall in Bamenda is irrefutable evidence of gross unevenness in present rainfall distribution, an effect of present climate change.

Sunshine

Sunshine as an element of weather is a dire perquisite for vegetal growth, and thus is indispensable for the wellbeing of colocasia esculenta. Greater amounts of solar radiation penetration of the atmosphere to the ground surface orchestrate for correspondingly higher ambient temperatures by way of conduction, convection and re-radiation around the ground surface. However, this ambient temperature effect can only be guaranteed by the presence of condensation nuclei of human ozone to trap escaping re-radiation. Thus, the timing for the presence of these nuclei is of great significance as the growth rate of *taro* and other crops highly depends thereon. When there is a high concentration of these nuclei almost all year round, the amount of penetrating solar insulation is compromised, and so are basic photosynthesis, soil nitrogen fixing, and amount of ambient heat necessary for the different stages of the crop's growth (Hall et al, 1998).

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YEAR	ANNUAL SUNSHINE DAYS X
1994	315
1995	317
1996	314
1997	322
1998	340
1999	335
2000	335
2001	204
TOTAL	$\sum X = 2491$
MEAN	$\overline{X} = 311.36$

Table 1.3: Annual sunshine days in Bamenda from 1994 to 2001

The table above shows that that there was negligible fluctuation in the number of rainy days in Bamenda from 1994 to 2000; that was followed by a conspicuous decline in that number, from 335 days to only 204. And it can be attributed to the emergence of the industrial sector and general urbanization in that town with multifaceted anticipation for the 21st century. Consequently, there was a corresponding rise in both CO (carbon monoxide) and CO2 amounts with obvious effects, like a relatively greater screening of the town's solar insulation and the thickening of the condensation nuclei over the area. This worsened as the years went by (Hall et al, 1998). What's more, the greater heat in the Bamenda area was no longer accounted for on the most part by solar rays (indirectly), but by the combined effects of clogged vehicles in the streets, increased deforestation, and the erection of taller structures which tampered with air circulation (especially in Commercial Avenue and Nkwen). This gross increase in temperature sparked off a growth spree for weeds (which will thrive under almost all conditions) at the expense of taro. Weeds consume a lot of soil nitrogen during growth, doing so at a much faster rate than nitrogen-fixing bacteria can work to replace the nitrogen. To make matters worse, the urbanization requirement of deforestation and the consequent ambient heat generated on its account kill off these significant soil bacteria. Colocasia esculenta is singularly noted for its absolute dependence on soil nitrogen for all its stages of growth (P Leo, 2016); a shortage of soil nitrogen in and around Mankon, Nkwen and Mendankwe translates into its dwindling output in those areas. *Figures 1.3* and *1.4* show areas of taro cultivation in the Bamenda area.

Figure 1.3: Taro cultivation in Nkwen

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Figure 1.4: Site of local taro cultivation in Alabukam, Mankon

Climate Change Interactions with Colocasia Esculenta Production

Climate change was defined by IPCC, (2017) as a change in the state of the climate that can be identified (for example, by using statistical tests) by change in the mean and/or the variability of its properties, and that persists for an extended period, typically decades, or longer.

Climate change will affect the bio-physical processes that support the agricultural systems both in negative and positive ways. The agriculture system is highly sensitive to climate conditions since crop production is largely driven by favourable weather conditions. The increase in atmospheric CO_2 concentrations, higher temperatures, changes in annual and seasonal precipitation patterns and in the frequency of extreme events will affect the volume, quality and stability of crop production, and the natural environment in which crop production takes place.

Climate change is real and is already affecting crop production, livestock production and people, their livelihoods and ecosystems, and thus presents a great development challenge for the global community in general and for the poor people in the developing countries (Khanal, 2009). Additionally, it also indicates a major challenge to scientist and policy makers. In the Bamenda area, the overall impact of Climate change is accepted to negatively affect crop production.

Effect of Increasing Temperature

Temperature is fundamental in determining crop quality, quantity and where it can be grown. According to Master`s *et al*., (2009) due to the fundamental relationship in biology and ecology any changes in temperature because of climate change will have large impact on crop production. In general, in tropical areas, a temperature change will have a negative impact on food production, and thus influence production patterns (IPPC, 2017). Some crops might benefit directly from increase in temperature while others might benefit indirectly through the effect of temperature on water demand and supply for plants, high pest reproductive rates, and dispersal of insects and plant diseases, and the spreading of weeds into different latitude habitats.

Increase in temperature, will also affect both the physical and chemical properties in the soil, and thus affect crop production. Increase temperature may accelerate the rate of release of CO2 resulting in less than optimal conditions for plant growth. When temperatures exceed the optimal level for biological processes, crops often respond negatively with regards to growth and yield (Otitoju, 2018). In C3 plants such as taro, an increase in temperature means an increase in water absorption for the plant, making irrigation of the utmost necessity especially during dry season. Heat stress will also affect the whole physiological development, maturation and finally yield of cultivated crops (Khanal, 2019; Rosegrant *et al.*, 2018).

In addition, in the Bamenda area, despite the limited availability of historical and published literature in quantifying the effects of increasing temperature over time on food crops, there were observe impacts of increasing temperature on agriculture crops

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(Wairuru *et al*., 2012). For example, in Mankon, the increasing temperatures there have increased pest incidence which affects root crop such as yam (FAO, 2008). In the same way with the projected temperature increases of 28.8 °C in 2050 and 29.7 °C in 2080 for the Bamenda area, heat tolerance thresholds of crops are likely to be reached and will most likely induce heat stress, wilting and crop failure there (FAO, 2008). Consider these examples distant geographical locations : in the Solomon Islands taro production has been reported to decrease in response of increasing temperature (Talo, 2008); in Papua New Guinea (PNG) increasing temperature was observed to increase coffee rust infestation which affects coffee production, likewise an increase in temperature above 34°C in PNG affect tuber formation in sweet potato (Wairuru *et al*., 2012).

Effect of increasing Rainfall

Rainfall is important for plant growth and productivity. The increase in rainfall or precipitation would affect crop productivity. It is important to note that in the sub-Saharan African countries, both commercial and subsistence agriculture are based on rain-fed agricultural systems. Changes in rainfall pattern could have an impact on crop production.

Intensive rainfall creates conditions favourable for pest and diseases, to spread and damage plants and alongside severe impacts with water logged soils, and thus decreasing production. Increase rainfall and humidity could provide ideal conditions for plant pathogens to increase in number (FAO, 2008).

Furthermore Wairuru *et al*., (2012) emphasized that variability in rainfall and changes in rainfall pattern in sub-Saharan Africa will affect the normal planting times and dates, harvest periods, yield storage and reduce overall crop yield.

Effect of increasing Carbon dioxide (CO_2)

Many studies have addressed the responses of on different crops because changes in CO_2 have a significant impact on crop yield. CO_2 is essential for plant growth as it plays a significant role in photosynthesis. Several scientists have repeatedly confirmed that crop species with large below ground sink, especially those with an apoplastic mechanism of phloem loading, such as roots and tubers, are those which benefiting from the responses in increasing atmospheric CO_2 (Miglietta *et al*., 2000). In general prediction from crop models show that increased CO_2 should increase productivity of C3 plants. Allen and Prasad, (2004) also confirmed that increase in CO_2 will also increase crop yield as a result of increase photosynthesis. The effect of elevated CO_2 on plant growth and yield depends on the photosynthetic pathway, species, growth stage and management regime, such as water and nitrogen application (Master`s *et al*., 2009).

Additionally, the increase in CO_2 may have some effects on crop phenology, even though stages of development are represented principally by temperature, time and photoperiod. Crops with a C3 photosynthetic pathway like taro respond markedly to increasing CO_2 concentrations. Allen and Prasad, (2016) suggest that an increase in CO_2 concentration will increase the photosynthetic of C3 crop species by 30 - 50%.

Increase in temperature, carbon dioxide and rainfall interaction

Weather is the key source of uncertainty affecting crop yield especially in the context of climate change. Thus the interactive effect of increasing temperature, carbon dioxide and rainfall may be detrimental to crop production. Among those weather variables, temperature and rainfall were the two most important factors which affect crop yield (Runge, 1968). In the future the combining effect of both temperature and precipitation change will at least modify or limit the direct CO_2 effect on plant growth (Master`s *et al*., 2009).

Carbon dioxide and temperature interactions have been observed for vegetative growth where the fertilization effect of CO_2 is greater at warmer temperatures than at cooler ones. In the same way, studies have shown that increased temperatures may have direct effect on CO_2, where during flowering it lowers CO_2 effect on such crops as cereals, by reducing its number, size and quality while indirectly increasing the water demand for the crop. Additionally, findings from Easterling *et al*., (2007) have shown that rain fed wheat yield increase when grown at 450ppm CO_2 with a temperature increase up to 0.8°C; but beyond a temperature of 1.5°C yield declines.

Model Development

Simulation models have been developed to estimate the effect of climate variability and projected climate change on the production of crops and other components in crop production (McKeon *et al*., 2009). A model is a simplified representation of paddock/field production of a specific crop. Models have been developed that allow aggregation of production impacts to represent whole-farm conditions, and further aggregation has occurred to produce national scale impacts on production. Crop modelling as defined by Mabhaudhi (2012) is the dynamic simulation of crop growth by numerical integration of constituent processes with the help of computers. Crop models are simple representations of a crop and they are important tools used by researchers to solve problems relating to crop production. Crop models have been used successfully to predict growth and yield of crops (Jones and Ritchie, 1990.) They can be used either at the regional or farm level, and can assist farmers in planning and decision making, yield forecasting, evaluating the effects of climate change, as well as identifying research gaps (Mabhaudhi, 2012). According to Maria, (1997) a good model should be simple, easy to understand and can be tested. It is also important to note that crop models are not substitute of field experiments. They can help in lessening the overall costs of field experiments with regard to space and time when calibrated and validated with data from field experiments (Mabhaudhi *et al*., 2014). Models are useful tools which can be integrated with knowledge across disciplines and can be promoted by researchers as the way forward in research (Single *et al.*, 2010). One of the main aims of crop simulation models is to estimate productions as a function of weather, soil and crop management. This is done to provide the effect of changes on soil characteristics and weather patterns separately when analyzed.

Crop simulation models needs be parameterized and validated against local conditions. Thus, to run a model such as the DSSAT model under Bamenda climate conditions, it needs to be parameterized from the first principle. Therefore, trials have to be established to generate primary variables for the model.

APSIM

APSIM is known as Agricultural Production system simulator and is widely used in Australia and internationally. It can be applied to simulate biophysical process in farming system, and where there is interest in the economic or ecological outcomes of management practices in the face of climate risk (Keating *et al.*, 2003). The model incorporates a wide variety of crops, pasture, and soil processes. APSIM has been used in some studies including crop management (Muchow & Keating, 1997), land use studies (Meinke & Hammer, 1995), evaluating intercropping of crops (Carberry *et al.*, 1996), climate risks and impacts (Keating & Meinke, 1997), and the impacts of climate change on Cassava yield in Fiji (Wairuru *et al.*, 2012).

CROPSYST

CROPSYST is a multi-year, multi-crop, daily time step cropping system simulation model, which is an effective environmental and agricultural tool to simulate the effect of climate, soil, and management inputs on cropping systems in both the environment and crop productivity (Stockle *et al.*, 2003). CROPSYST have been applied to perform risk and economic analyses of scenarios involving different cropping systems, management options, soil and climatic conditions. It has also been used in several studies to simulate cereals yield and biomass productions in response to nitrogen and water treatments at different locations (Stockle *et al.*, 1997; Stockle *et al.*, 1994).

AQUACROP

Aqua Crop is a crop water productivity model developed by land and water division of FAO. This crop model simulates yield response to water of herbaceous crops, and is particularly suitable for conditions where water is a key limiting factor in crop production. Aqua Crop attempts to balance accuracy, simplicity and robustness (Raes *et al.*, 2009). It simulates future climate scenarios analyses, crop sequence, crop productivity and yield related to water.

Decision Support System for Agrotechnology Transfer (Dssat Model)

Rational for using DSSAT Model

For this study DSSAT has been used to evaluate the impacts of climate change (temperature, rainfall and carbon dioxide) on taro production in Mankon, Bamenda. This crop model was chosen since it already contains the Taro model, unlike other crop models such as APSIM where the Taro model is still under development.

DSSAT Overview

DSSAT is a computer-based program which contains crop simulation models that incorporate soil, crop management and weather data, and can simulate the growth and development of crops overtime (Hoogenboom *et al.*, 2010). The growth, development and yield of a crop simulated by crop simulation models are a function of soil-plant- atmosphere dynamics. DSSAT crop model have been applied within over 100 countries worldwide, either on farm or at regional level, and have been widely used by researchers, educators, consultants, extension agents, farmers, and policy and decision makers (Hoogenboom *et al*, 2018). The release of version 4.5 of DSSAT contains 28 different crops under cereals (6), legumes (7), oil crop (1), vegetables (5), fibre (1), forage (2), sugar/energy (1), fruit crop (1) and root crops (4). The model simulates a function on a daily basis and it incorporates the effect of soil, crop phenotype, weather and management options, and allows the users to ask ***what if*** questions when carrying out virtual simulation experiments on a desktop computer in only a matter of minutes, but which would take much of an agronomist's time if conducted as real experiment (Hoogenboom *et al.*, 2018). There are three main components in DSSAT *(figuren 1 . 5)*: (a) the main driver program which controls the sequence of simulations; (b) the land unit module that manages simulations affecting land; (c) primary modules which mainly functions with the weather, soil, soil-plant-atmosphere, plant growth interface and management components. According to Hoogenboom *et al*., (2018); Jones *et al*., (2033) on a single land unit these components described will be simulated overtime with soil and plants as a result of the interaction of weather and management inputs.

DSSAT Minimum datasets

The minimum dataset refers to the minimum set of data that is required by the model to run and validate output like daily site weather data, site soil data, and crop management data from the experiment.

Soil data

Soil information required by the model includes, soil surface information (soil taxonomy, surface slope, soil colour, permeability, drainage class) and soil profile characteristics for each horizon, soil texture (sand, silt and clay), stones especially for surface layer, 1/3 bulk density, organic carbon, pH in water, aluminium saturation, and information on abundance of roots (Hoogenboom

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et al, 2018; Jones *et al*., 2010).

The soil in the research site, the Bamenda area, was left to fallow for some time. It was a reddish-brown clay laterite (ferrallitic) soil. There is little recent information about the soil in the experimental site. However, some data for the soil type and general location of the chosen sites was available from Quantine (1982) and Marie *et al*, (2002). The soil physical and chemical properties of the general site of the A horizon (0-20 cm) were as follows, Organic matter (%) 5.41, Clay (%) 47.80, Silt (%) 30.30, Fine sand (%) 7.58, Course Sand (%) 8.96, Organic Carbon (%) 2.82, N (%) 0.32, C/N 8.9 and Exchangeable cations (me%) such as Calcium 17.70, Magnesium 3.45, Potassium 1.22 and Sodium (NA). This soil composition was concocted to be at a moderate fertility so as to make sure that any disparity in yield during harvest would solely be due to climate variability.

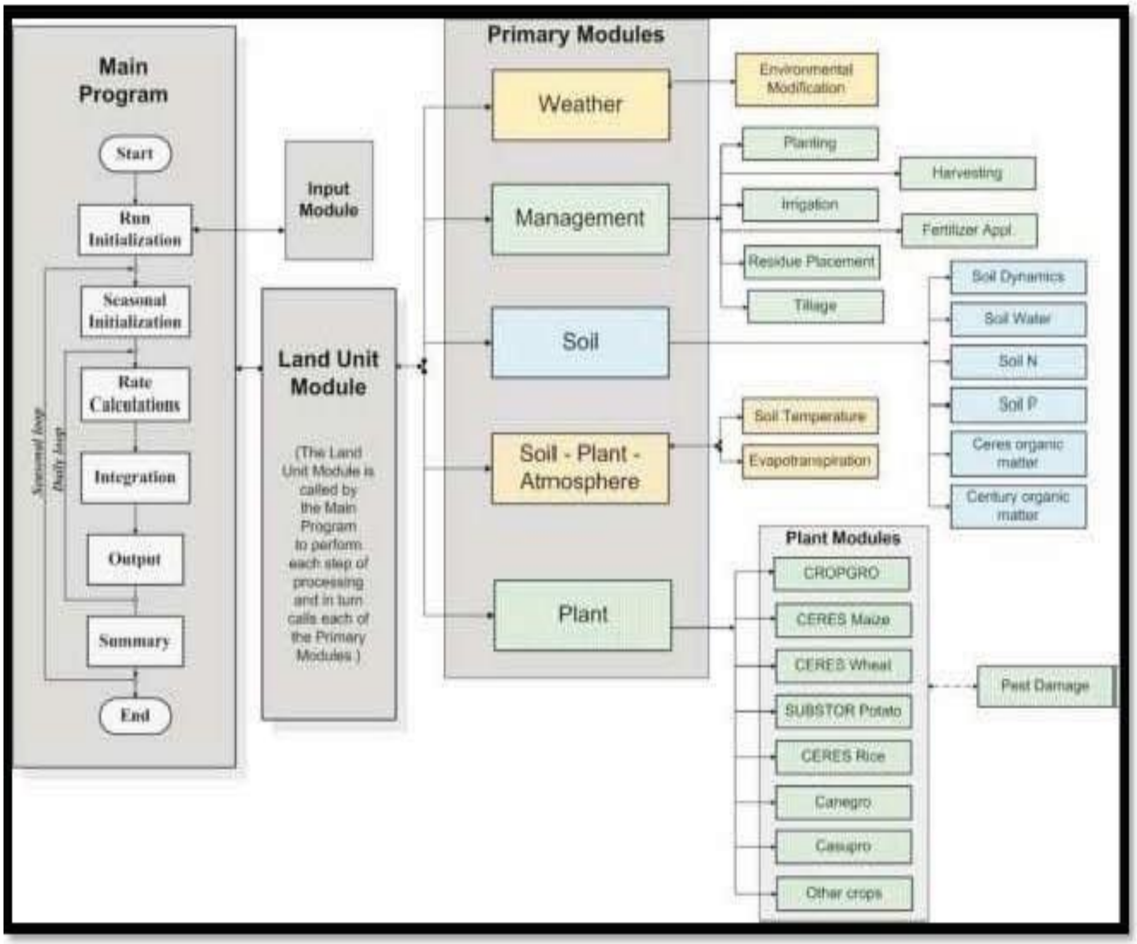

Table 1.4 shows soil characteristic data from the site

Depth	BD	Air dry	LL15	DUL	SAT	CLL
(cm)	*(g/cc)*	*(mm/mm)*	*(mm/mm)*	*(mm/mm)*	*(mm/mm)*	*(mm/mm)*
0-15	0.86	0.113	0.227	0.529	0.627	0.227
15-30	0.84	0.189	0.270	0.556	0.632	0.312
30-60	0.86	0.254	0.254	0.512	0.626	0.371
60-90	0.78	0.243	0.243	0.525	0.656	0.365
90-120	0.85	0.284	0.284	0.593	0.628	0.420
120-150	0.89	0.319	0.319	0.591	0.616	0.430
150-180	0.82	0.271	0.271	0.551	0.642	0.401

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	NH_4 N mg/kg		$N0_3$ N mg/kg
Layers		**Layers**	
cm	**Average**	**cm**	**Average**
0 - 15	2.75	**0 - 15**	3.00
15 - 30	0.85	**15 - 30**	5.50
30 - 60	0.78	**30 - 60**	9.00
60 - 90	0.33	**60 - 90**	7.00
90-120	0.33	**90-120**	5.50
120-150	0.33	**120-150**	3.50
150-180	0.33	**150-180**	3.00

Table 1.5 shows ammonium and nitrate distribution between different layers of the soil

According to Hoogenboom *et al*., (1985) soil characteristics which are needed to run the model include, albedo of soil surface, soil surface run off, first stage soil evaporation, water permeability, and drainage profile.

The DSSAT SBuild tool can automatically calculate the lower limit; drain upper limit and saturation of each layer of soil. In this study the lower and upper drain limits and saturation of the 0-20 cm profile were calculate automatically in DSSAT SBuild tool from chemical properties available from the secondary source.

Colocasia Esculenta Yield Simulation

The application of crop models to study the impacts of climate change has been widely used around the world. The variability in the climate and especially weather extremes is one of the main concerns of scientists. The increasing concentration of carbon dioxide, rising temperatures and rainfall may affect crop production since crop production is highly dependent on variation in weather (P Leo, 2016). Thus, any changes in our climate will have a major effect on crop growth and yield. In addition, it is important to understand the effects of climate change to help guide farmers as they make crop management decisions (Oteng-Darko, 2012).

I analyzed two scenarios:

The first was that of simulated pre-climate change conditions in a well sun-lit room where 300 colocasia bulbs were planted and allowed to grow with regular watering.

The second, that of unaltered (present day) Mankon, Mendankwe and Nkwen weather conditions with the exact same number of colocasia bulbs planted in the soil on a few farms in the aforementioned areas of the town.

1st Scenario: Colocasia Growth in the Presence of a Relatively Low Amount of Atmospheric CO2 and Relatively Lower Ambient Temperatures (pre-climate change conditions)

The experiment was conducted with two local recommended cultivars of *taro* (*Colocasia esculenta).* L. Schott, named Sakius and Tarapatan. One, a conical-shaped dry land corm which matures about 6 – 7 months after cultivation. It has white and purple colours of corm flesh with excellent eating quality. Sakius has a dry matter content of 44.3 %. Tarapatan cultivar is also a dry land taro that matures around 6 to 8 months after planting and has an elliptical corm shape with white colour corm flesh. It is of excellent eating quality, with dry matter content of 41.7 %. This experiment consisted of a total of 300 pots; individual pot dimensions were of 40 cm length x 40 cm width. The potting soil was dug up and sieved before filling the pots. After filling, the pots were transported to the experimental site. Planting material of the two cultivars (Sakius and Tarapatan) were harvested from a field in the Mankon area and transported to the experimental site several days before planting. The planting material were taken from the main plants and consisted of the apical portion of the corm 30 cm of the petiole above the corm. The corms were cut a few centimetres below the petioles. The planting materials were roughly of the same sizes and weighed approximately 300g. The pots were arranged in 1m x 1m spacing. Prior to planting the pots were watered to keep the soil moist and make planting easier. The planting holes were made using a stick in the pots to a depth of 30 cm and were planted by hand, and all plants were planted on the same day. Plants were watered to minimize any water stress and 30 were watered until the surface of the pot was filled with water. During dry days watering was done twice a day: in the morning and evening, using a watering can or watering hose. Plants were not watered during the rainy season. Planting material used for the experiment were pest and disease free. Throughout the growing period, insect and pest control practices were employed, and there was no significant occurrence of weed, insect pest or disease problems. Weeding was done by hand every two weeks after planting. The growth variables leaf area, plant height and sucker emergence were measured weekly. Leaf area was measured by multiplying leaf length and width of each leaf. The plant height was measured from the base of the pot to the longest petiole leaf end. Destructive harvests were done at 50, 100 and 150 days of planting (DAP). At each harvest, fresh weights of tubers roots, petioles and leaf were taken. Sucker and leave number were also counted and recorded at each harvest.

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Other crop management data or parameters collected which are required by the model are, planting date, emergence date, planting method, planting distribution, plant population at seeding plants per metre^2, plant population at emergence plant per metre^2, row spacing, planting density, row direction in degrees from north and planting depth. Three nitrogen levels were used in this study: 0 N kg/ha act as control, 100 N kg/ha as optimum rate and 200 N kg/ha as maximum rate.

The three levels of nitrogen used in this study were as follows:

Table 1.6: Nitrogen levels used in study

Treatment	Application per pot	Application per hectare	2 application
0 kg/ha N	0 g of N	0 kg/ha	**0 kg/ha N**
100 kg/ha N	3.6 g of N	36 kg/ha of N	**72 kg/ha of N**
200 kg/ha N	7.2 g of N	72 kg/ha of N	**144 kg/ha of N**

Sulphate of ammonia (46 % of N) was broadcasted around the plants in each pot. Two split applications of equal amounts were applied first during planting and second 6 weeks after planting.

2nd Scenario: Colocasia Growth in present (‘climate change’) times

Here, plot size of 15m^2 was selected around the Mankon area. The plot contained 16 plants partitioned equally between Sakius and Tarapatan, and spaced in rows 1 metre apart. Four inner plants within each plot were sampled for data collection. These plants were left to be influenced by the natural weather conditions of the area.

Pre-Climate Change Simulation

Crop simulation model such as DSSAT have been used in a broad range of conditions worldwide by researchers for different purposes such as an aid to nitrogen fertilization management (Gabrielle and Kengni, 1996; Gabrielle *et al*., 1998; Zalud *et al*., 2001), irrigation management (Ben nouna *et al*., 2000; Castrignano *et al*., 1998), crop management (Hunkar, 1994; Ruiz-Nogueria *et al*., 2001), precise farming (Booltink and Verhagen, 1997; Booltink *et al*., 2001), yield forecasting (Landau et al., 1998; Saarikko, 2000), sustainability (Hoffman and Ritchie, 1993) and climate change (Iglesias *et al.,* 2000; Semenov *et al*., 1996).

The application of crop models to study the subtler conditions of pre- industrial revolution climate times has been widely used around the world. The variability in climate and especially weather extremes is one of the main objects of scientists’ fascination. The much lower concentration levels of carbon dioxide, lower temperature and ‘balanced’ rainfall positively impacted crop production since crop production is highly dependent on variation in weather, making any changes in our climate to have a major effect on crop growth and yield. In addition, it is important to be cognizant of pre-climate change conditions in order to better understand the effects of climate change, so as to help guide farmers to make crop management decisions (Oteng-Darko, 2012).

Pre-climate change conditions were modelled after a model was calibrated using the Bamenda Area’s specific weather data, soil physical and chemical information, and crop management data. Model calibration mainly involved the modification of some model parameters such that the simulated model fitted the observed data. Since simulated values, in reality, do not exactly comply with the observed data, minor adjustments were made to ensure that the calibrated model closely represented a real situation.

After the model was calibrated using the ambient or current year data of the experiment, past climate conditions based on African Climate Change Adaptation Program (ACCAP) retrospection or historical analysis (such as for carbon dioxide, temperature and Rainfall, using climate modelling) were accessed for the years 1750 through to 1840. Business as Usual (BAU) scenarios were inputted into the model and run under each of these scenarios to see how pre-climate change impacted and will impact crop production. In DSSAT model, the environmental modification menu allowed me to set or change weather conditions for crop simulation; it allowed me to modify up to eight different environmental variables for simulation. These variables were: Day length (hour); Solar radiation (MJ m-2 day-1); Maximum daily temperature (°C); Minimum daily temperature (°C); Precipitation (mm); (6) CO2 (ppm); (7) Humidity (%); and (8) Wind speed (km d-1). Equally, the adjustment box allowed me to enter values for adjusting daily values of the variable while the factor pull down list provided three menu options which are *add*, *multiply* or *replace*. For example, if I wanted to change the CO_2 value, I could on the adjustment cell, and the type of adjustment would then be specified using the menu items in the factor pull down list.

To guarantee the effectiveness of the replication of pre-climate change CO_2 conditions in my simulations, note was taken of atmospheric CO_2 concentration specifically as before the industrial revolution. Atmospheric CO_2 levels then were approximately 280 parts per million (ppm), so special care was taken to set CO_2 concentration to this baseline level. Ice core data is what has always been referenced over the centuries when establishing the timeline and fluctuations in CO_2 levels. I used the EPICA Dome

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C ice core data, as it known to provide reliable information about atmospheric CO_2 concentrations as trapped in ice over thousands of years. Using ESM which allowed for the input of my specific CO_2 level, I set the CO_2 concentration to the base level of 280 ppm for the above-specified time frames, being sure to maintain the assumption of natural variability, without miscellaneous anthropogenic influences. In order to visualize and analyze the data, I used Python software.

The replication of temperature change to realize lower pre-climate change temperatures, especially of those around the above-specified years, involved a multi-step process including data collection, modeling, and analysis. Historical temperature reconstructions suggested that global average temperatures were about 0.5^0C – 1^0C cooler then than today. I accessed proxy data from tree rings, ice core, and historical records for more insight into the climate conditions of those years. An ESM was set to reflect pre-industrial temperature levels during the period of 1750 to 1840. Python was used for data analysis and visualization.

Colocasia Esculenta Harvest Procedure

During harvest, the data plants from each treatment were pulled up; leaves were counted and removed and the remnants of the plants were washed, air dried to remove excess moisture, and then dissected into petioles, corms and roots. Fresh weights (grams) were taken for each sample. The samples were then placed inside separated labelled paper bags for oven drying. Prior to oven drying, the samples were pre-dried out in the sun and on an air drier to reduce the water content of the plant. After pre-drying, they were removed and placed inside the oven for drying at 60°C for 24 hours. The dry weight (in grams) was collected once the weights were constant.

Input of climate data into WeatherMan tool

Climate data collected were firstly formatted in excel spread sheet, then it was imported into the DSSAT WeatherMan tool. DSSAT-CSM has the advantage being able to calculate missing data that were not available in the weather data (daily maximum or minimum temperature, daily rainfall and solar radiation). Missing data has become a challenging issue for modellers in developing countries especially in sub-Saharan Africa (Hoogenboom *et al*, 2010).

Table 1.7: Sample of the climate raw data at VARTC formatted using weatherman tool function in an excel spread sheet.

Lat: 5.9631^{0}N; Longitude:10.1591^{0}E; Elevation 1,500masl					
Research site: Mankon					
Mon	**Day**	**Rainfall (mm)**	**axTemp (°C)**	**Min Temp (°C)**	**Radiation (MJ/m2)**
1	1	6.1	31.5	23.6	28.48
1	2	0	31.2	23	28.48
1	3	7.9	31.5	22.6	28.51
1	4	0	31	23	28.35
1	5	9.9	31.5	22.9	28.6
1	6	23.9	31.25	21.95	28.63
1	7	0	31	21	28.57
1	8	3	29.5	21.5	28.18

Input soil data into soil Build File (SBuild)

The soil information obtained from past soil studies by Quantine (1982) and Melteras *et al*, (2002) were manually inputted into the Soil Build file (SBuild) in DSSAT SUBSTOR Aroid Model. They were entered by creating a new profile of 0 – 20 cm depth with their physical and chemical characteristics provided.

DSSAT SUBSTOR Taro model Calibration

AFile (Average File)

The AFile used was based on the averages of the *harvest three data* (final harvest) at 175 days after planting. It was used to create the measured data for simulation comparison. The data was entered into an excel spread sheet and imported into DSSAT SUBSTOR taro model under the experimental data tool. The information entered into AFile were as follows, TRNO – treatment number, UYAH – tuber fresh weight, UWAH– tuber dry weight, HDAT- harvest date (Julian Date format), SWAH- stem weight at harvest (kg/ha).

TFile (Time Series File)

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The average of all the three destructive harvests at 50, 113 and 175 DAP was taken into consideration when creating TFile or time series file. TFile were formatted in an excel file before they were imported into the experimental data tool inside the DSSAT SUBSTOR Taro model. The information entered into the TFile were as follows, TRNO – treatment number, Date- for each harvest time in Julian date format, UWAD- tuber dry weight (kg/ha), UYAD-Tuber fresh weight (t/ha), LWAD- leaf dry weight (kg/ha), SWAD- stem dry weight (kg/ha), Leaf area and CHTD- plant height canopy.

Calibration of genetic co-efficient of cultivars of taro.

Since the two local cultivars of taro (Sakius and Tarapatan) used in the experiment are not in the DSSAT crops database, they were required to be calibrated into the model. The genetic coefficients were adjusted manually utilizing the experimental data information on development days, corm/tuber/grain initiation time, and the model was made to precisely conform to the days of maturity and yields assessed during the experiment. Steps involved were as follows:

Firstly, a sensitivity analysis was applied to recognize which cultivar inside DSSAT had the most similarity to the experimental cultivars, Sakius and Tarapatan, regarding maturity days, corm/tuber/grain start time and yield. It is important to note that when running sensitivity analysis, the information for soil, climate and crop management will mirror those of the research site, but for the used cultivars which will contrast. The sensitivity analysis was performed for all the taro cultivars in DSSAT database. The Overview and Evaluate OUT records were used to recognize and select which existing cultivars were intently similar to the experimental cultivars Sakius and Tarapatan.

Secondly, of the most suited or appropriate cultivars chosen for each taro cultivar, genetic coefficients were adjusted. Before adjustment, the genetic coefficients of the closely- matching cultivar was copied and pasted in the genetic file of the taro crops and the local cultivar name was given. Next the genetic coefficient numbers or values under coded coefficients were controlled by either increasing or decreasing the values. The Overview OUT Files were utilized to distinguish and look at these variables. Every time the genetic coefficient qualities were controlled, the model was run.

Table 1.8 The information required to run DSSAT SUBSTOR Taro model for calibration

Variable	Information
Cultivar	Sakius & Tarapatan
Starting date	15th July
Planting date	16th July
Planting method	Dry seed
Planting distribution	Rows
Row spacing	100 cm
Plant population	4
Planting depth	30 cm
N- fertilizer (Urea)	0, 72 and 144 N kg/ha

Table 1.9 Calibrated genetic coefficients for the two cultivars of taro

		Genetic Coefficient calibrated					
ultivar type	**A. Best suited Cultivar** **B. Local Varieties**	**P1**	**P3**	**P5**	**G2**	**G3**	**G4**
Colocasia esculenta	A. Tausala Samoa	1200	1000	700	1.00	1.00	1.00
	B. Sakius	700	580	720	2.00	1.80	3.00
	A. Tausala Samoa	1200	1000		1.00	1.00	1.00
	B. Tarapatan	700	580		2.25	2.40	3.00

Simulating and evaluating the impacts of climate change

Climate retrospection for future climate projections for Bamenda.

The African Climate Change Adaptation Program (ACCAP) climate change future scenarios for the Bamenda area were used in

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DSSAT to simulate the impacts of pre-climate change on taro growth at the research site. The coupled model inter-comparison project3 (CMIP3) global climate output for the years 1750, 1800 and 1840 in the ACCAP projections were used to simulate the impacts of climate change. There were three projections utilized by ACCAP in particular B1 (low), A1B (medium) and A2 (high) future gas (carbon dioxide) outflows situations. In this study the A2 (high) situation was utilized as a part of an endeavour to see what might be the reaction of the two cultivars under this high scenario. Carbon dioxide, rainfall and minimum and maximum temperature for the year 1750, 1800 and 1840 were used for simulation.

Simulation and treatments

Simulation details were created using the XBUILD tool in DSSAT. The projections were included in the environmental modification component in DSSAT. There were three level of simulation. **Level 1** is the Potential Crop Yield where the defining factors affecting crop yield at this level are, Radiation, Temperature, Crop characteristics and Carbon dioxide. **Level 2** is the Attainable Crop Yield with limiting factors water, nitrogen and phosphorus. And lastly, **level 3** is the Actual Crop Yield where the reducing factors affecting yield were, Pests, Diseases Weeds, Pollutants and other calamities. In this study the term *ambient* refers to the current year or time period for the experiment, today's climatic conditions, when the data for crop management and weather files were collected and simulated. The *ambient* attainable simulations were run to see the attainable yield and growth of the crop for the following scenarios 1, 2, 3 and 4 listed below:

Ambient attainable production for Sakius and Tarapatan, where there is considerable water and nitrogen were turn on in the simulation options.

Climate historical analysis (retrospection) for cultivars Sakius and Tarapatan where;

Table 1.10: Climate historical analysis for Bamenda for 1750, 1800 and 1840

Year of retrospection	Retrospections
1750	Ambient vs 25% (300mm) decrease in rainfall Ambient vs 2^0 decrease in temperature Ambient vs 170 ppm decrease in CO_2
1800	Ambient vs 25% (300mm) decrease in rainfall Ambient vs 2^0 decrease in temperature Ambient vs 170 ppm decrease in CO_2
1840	Ambient vs 25% (300mm) decrease in rainfall Ambient vs 2^0 decrease in temperature Ambient vs 170 ppm decrease in CO_2

Climate retrospection for Sakius with combinations for the year 1750 (25% decrease in rainfall, 2°C decrease in temperature and 170 ppm decrease in carbon dioxide); 1850 (25% decrease in rainfall, 2°C decrease in temperature and 170 ppm decrease in carbon dioxide); 1840 (25% decrease in rainfall, 2°C decrease in temperature and 170 ppm decrease in carbon dioxide).

Climate retrospection for Tarapatan with combinations for the year 1750 (25% decrease in rainfall, 2°C decrease in temperature and 170 ppm decrease in carbon dioxide); 1850 (25% decrease in rainfall, 2°C decrease in temperature and 170 ppm decrease in carbon dioxide); 1840 (25% decrease in rainfall, 2°C decrease in temperature and 170 ppm decrease in carbon dioxide).

When simulations were run the following files were used for analysis overview: Output file (Overview. OUT), PlantGro Output files (PlantGro. OUT) and Evaluated Output file (Evaluate. OUT). These files were used to analyse and determine the impacts of the past climate scenarios on growth and yield of Sakius and Tarapatan. In DSSAT, the Output files contain both the View and plot function. The View function provides written summary and tabulates results while the plot function offers graphical representation of the simulation analysis in terms of time series or scatter plots. However, the output of graphics was then exported to Microsoft excel whereby the graphs were easily named and analyzed.

Results:

1^{st} Scenario Plant Height

Plant height Heights of the two cultivars responded well as the Nitrogen (N) levels increased and generally followed the same growth patterns. Significant differences in plant height were seen between the three nitrogen levels. An analysis overtime also showed a highly significant difference in plant height between measurement times. However, no real differences were detected in plant height between the two cultivars.

The application of nitrogen significantly increased plant height in the cultivar tarapatan from week 10 to 24, but beyond 100 kg/ha of nitrogen it did not show any real increase. In the cultivar Sakius height increased as the level of nitrogen applied increased from 100 (67.79 cm) to 200 (71.90 cm) kg/ha and plant height was only significant from week 6 to 24 at 100 kg/ha of nitrogen when compared with heights of plants at 0 kg/ha of nitrogen and it was not significant beyond 100 kg/ha of nitrogen. Sakius had the higher average height achieved at nitrogen level of 200 (71.90 cm) kg/ha compared to Tarapatan but the height difference being

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insignificant. In this work plant height responded positively to nitrogen fertilization and maximum plant height was achieved at the vegetative phase of the crop which confirm results by Kumar et al, (2007) and Mare (2006) who found plant height, leaf number and leaf area reached maximum at 120 days after planting (DAP) under pre-climate change conditions.

These results also agree with Manrique (1995) and Mare (2009) that different cultivars respond differently to nitrogen fertilization.

This proves that colocacia esculenta would have been prevalent in and around the Bamenda area before climate change effects began setting in, and that soil plays a little, almost non-existent role in its progressive disappearance.

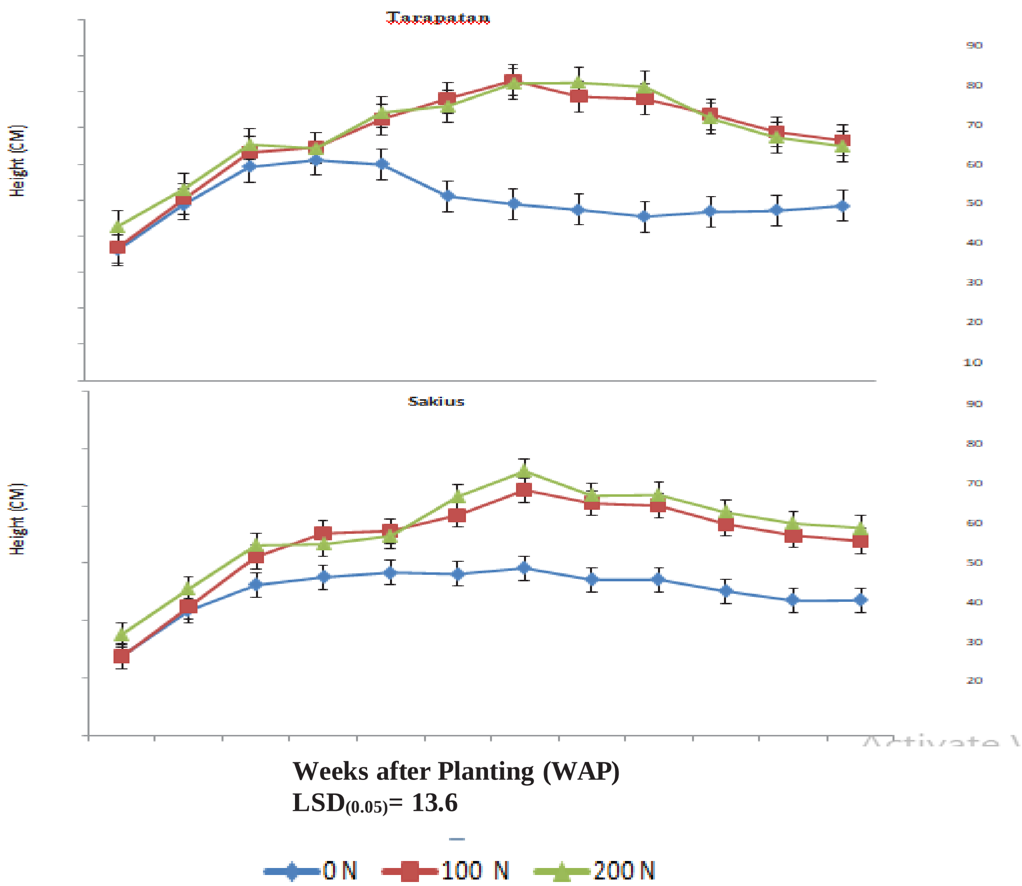

Figure 1.6: Heights of the two cultivars of taro, Sakius and Tarapatan at different levels of N. The magnitude of differences increased with time.

1st Scenario Leaf Number at Harvest Time

There were significant differences in leaf number between the two cultivars. Real differences in leaf number were also seen between harvest times as expected. However, there were no significant differences observed between the three nitrogen levels.

Leaf number varied at harvest times and generally Sakius showed significantly higher leaf numbers at each harvest, 50 DAP (5.6), 113 DAP (6.9) and harvest three (175 DAP (5.3)) compared to Tarapatan at 50 DAP (4.5), 113 DAP (5.6) and 175 DAP (4.4). Leaf number between the two cultivars were significantly different at harvest one (50DAP) and harvest two (113 DAP) at 200 N kg/ha. In both cultivars leaf numbers increase from harvest one (50 DAP) to harvest two (113 DAP) then decrease significantly in the last harvest (175 DAP).

In this study, leaf numbers were not influenced by nitrogen application. The result obtained from this study confirmed work done by Prasad (1998), where two cultivar leaf numbers were not influenced by the application of fertilizer. Highest leaf number was achieved at harvest two (113 DAP) at 200 (6.9) kg/ha nitrogen for both cultivars when they were at their vegetative stages of growth. This is supported by Mare (2006), Igbokwe (1984) and Tumuhimbise et al., where highest leaf number were achieved at the vegetative phase of growth at 120 DAP, 112 DAP and 113 DAP respectively. Silva et al, (2008) also found the vegetative growth stage to co-inside with an increase in number of leaves. At maximum canopy Tarapatan had 5 fully expanded leaves which are supported by Manrique, (1995) where he recorded at maximum canopy, taro plants having about 4 to 5 fully expanded leaves. However, the cultivar Sakius at maximum canopy had about 6 Leaves at 113 DAP. This differences between cultivars is supported by (Manrique, 1995) where he found different cultivars responded differently to nitrogen fertilization and Jacobs and Clark, (1993) where greater leaf numbers were recorded in improved cultivars than indigenous cultivars with leaf numbers being 150% greater under high nitrogen fertilization.

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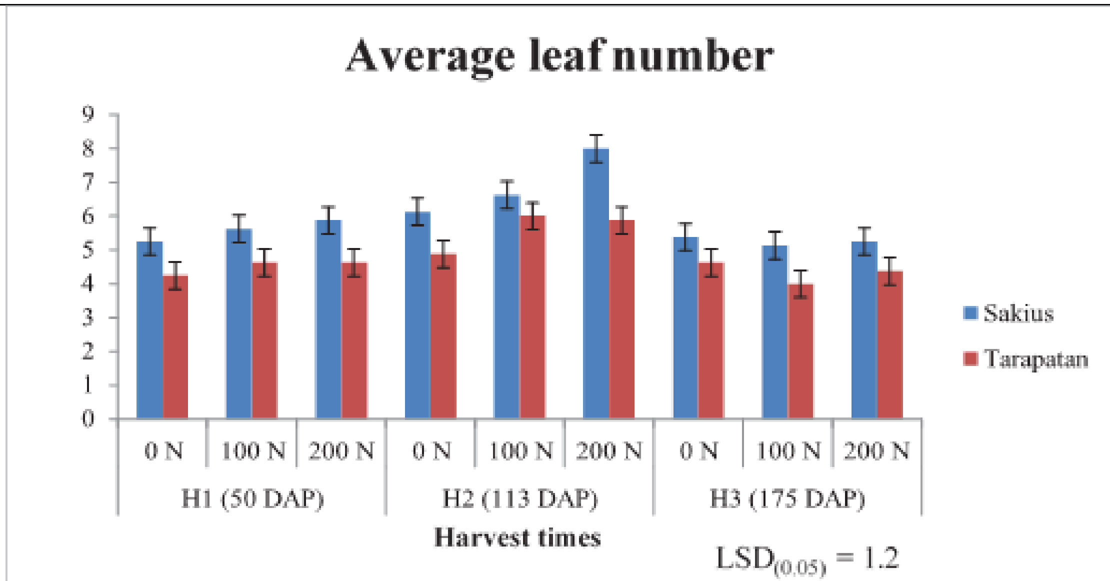


Figure 1.7: Effects of N levels and time on leaf number of the two cultivars Sakius and Tarapatan at different harvest times, the magnitude increased with time.

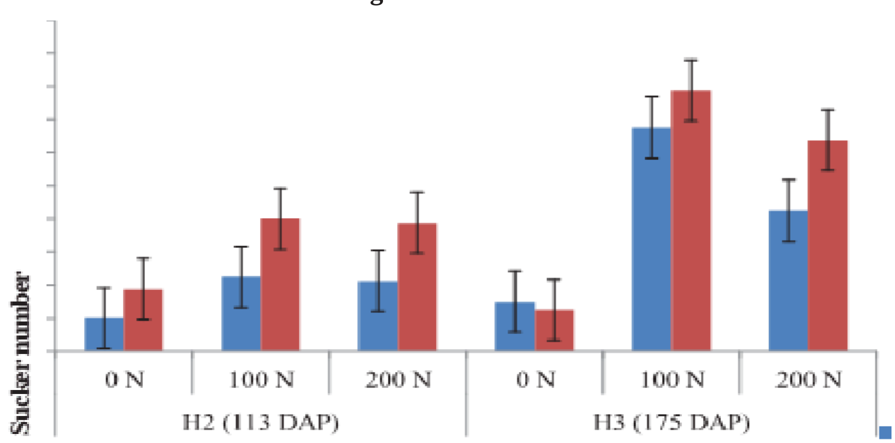
Leaf number decreased from harvest two (113 DAP) to harvest three (175 DAP) and is explain by Prasad (1998), as attributed to premature senescence of old leaves and may also be due to high evapotranspiration and low rainfall, causing a water deficit. However, plants in this work were watered ad Librium.

1st Scenario Sucker Number

There was a significant effect of time as indicated by harvests on the sucker production of the two cultivars. The nitrogen levels also showed significant effects on the suckers. The interaction of nitrogen levels and harvest were also significant. Conversely, no real differences were detected between the two cultivars.

There were no suckers observed during the first harvest (50 DAP). There was, however, an increase in sucker production in both cultivars at 100 and 200 kg/ha of nitrogen from harvest two (113 DAP) to three (175 DAP). The application of nitrogen did not affect sucker in the cultivar Sakius at harvest 2 (113 DAP) but significantly increased sucker production in Tarapatan. However, no real increase in sucker numbers was found beyond 100 kg/ha of nitrogen. In harvest three (175 DAP) application of 100 kg/ha of nitrogen again significantly increased sucker production in both cultivars, but was reduced when 200 kg/ha of nitrogen was applied. This result is supported by Manrique (1995) with his work on taro where applying 100 kg/ha of nitrogen increased taro sucker numbers. Generally, sucker numbers in this study increased at harvest three (175 DAP) which was the stage of corm bulking and towards maturation of the mother plant. Goenaga (1995) explained that during this stage as the plant matures, the partitioning ratio decreases significantly for leaves, petioles and roots, changed little in corms, and increase significantly in cormels of suckers.

Average of sucker number



Sakius

Harvest times LSD$_{(0.05)}$= 3.9

Figure 1.8 Effects of N levels and time on sucker numbers of the two cultivars during harvest two (113 DAP) and harvest three (175 DAP)

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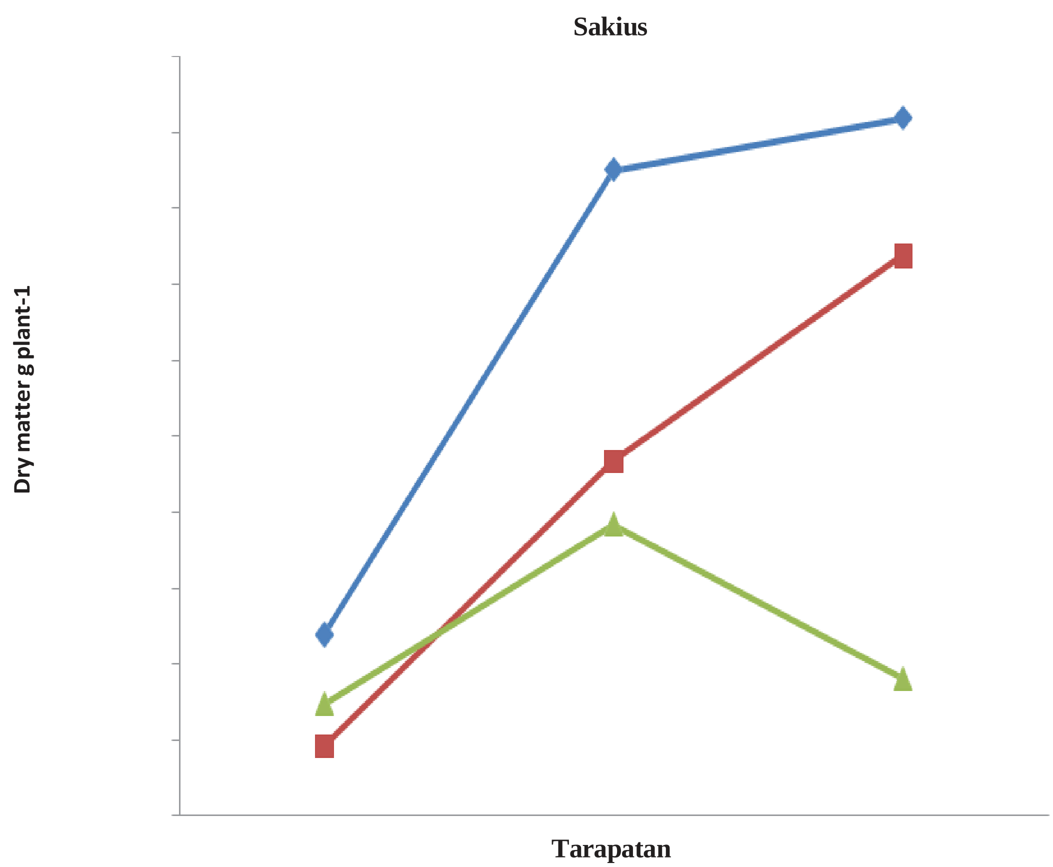
Scenario two results for plant height, leaf number and sucker number showed these to be generally lower than those of scenario one. The warming climate propounded the effects in the distortions in the proportions of soil nitrogen, carbon dioxide and nitrogen. The main reason for the low level of soil nitrogen was the chocking effect of the excessive carbon dioxide on the nitrogen-fixing bacteria. The increased amount of soil carbon dioxide which is the direct result of the Bamenda's warming trend, has encouraged both aerobic and anaerobic bacterial effect. These soil microbial decomposition activities have led to the exchange of soil oxygen with carbon dioxide. And since colocasia depend to a large extent on soil nitrogen, its depletion in the soil has culminated in its progressive disappearance – not its overexploitation.

1st Scenario Total Plant Biomass

The two cultivars' total biomass increased with time (figure 1.9) with nitrogen levels (figure 1.10). The cultivar Sakius in harvest one (50 DAP) had an above ground biomass DM of 72.9 g, which was 1.5 times higher than the below ground biomass of 45.9 g; and in harvest two (113 DAP) the above ground biomass (191 g) was 1.2 times less than the below ground biomass (233.3 g). At harvest three, below ground biomass (368.3 g) was 4 times higher than the above ground biomass (90.2 g). On the other hand, cultivar Tarapatan's above ground biomass (69 g) was 1.5 times greater than the below ground biomass (45.2 g) at harvest one (50 DAP), while at harvest two (113 DAP) the below ground biomass (215.7 g) increased and is 1.2 times higher than that of the above ground biomass (184.2 g). It was just like with harvest three (175 DAP) where below ground biomass (281.6 g) was 3.6 times higher compared to the above ground biomass (80.1 g). The results show above ground biomass declining over harvests and below ground total biomass increasing. Above ground biomass of the two cultivars was at optimum at harvest two since at that time the plants reached their vegetative phase where there was an increase in plant height, attainment of maximum leaf area and leaf number; and at harvest three it declines significantly due to a decrease in leaf number, leaf area, plant height and an increase in corm dry matter. Thus, results obtained from this study support findings from Sivan, 1982; Tumuhimbise *et al*., 2007; Lebot, 2009; Onwueme, 1999; Sing *et al*., 1998; and Manrique, 1995.

The nitrogen level of 200 kg/ha has the highest below and above ground biomass, where Sakius was 415.6 g while Tarapatan was 334.8 g. At nitrogen levels of 0 kg/ha the two cultivars' biomass showed a reduction in above ground biomass. Cultivar Sakius' below ground biomass (160.4 g) was 2.4 times higher than the above ground biomass (65.7 g), just like in nitrogen levels of 100 kg/ha (233.5 g) which was 1.8 times greater and at 200 kg/ha. The below ground biomass (253.5 g) was 1.6 times higher than that of above ground biomass (162.1 g). Tarapatan at 0 kg/ha had a below ground biomass (153.8 g) which was 2.4 times greater than the above ground biomass (64.7 g). Also at 100 kg/ha, its below ground biomass (192.2 g) was 1.5 times greater and 1.4 times greater in 200 kg/ha of N.

Average plant biomass at different harvest times



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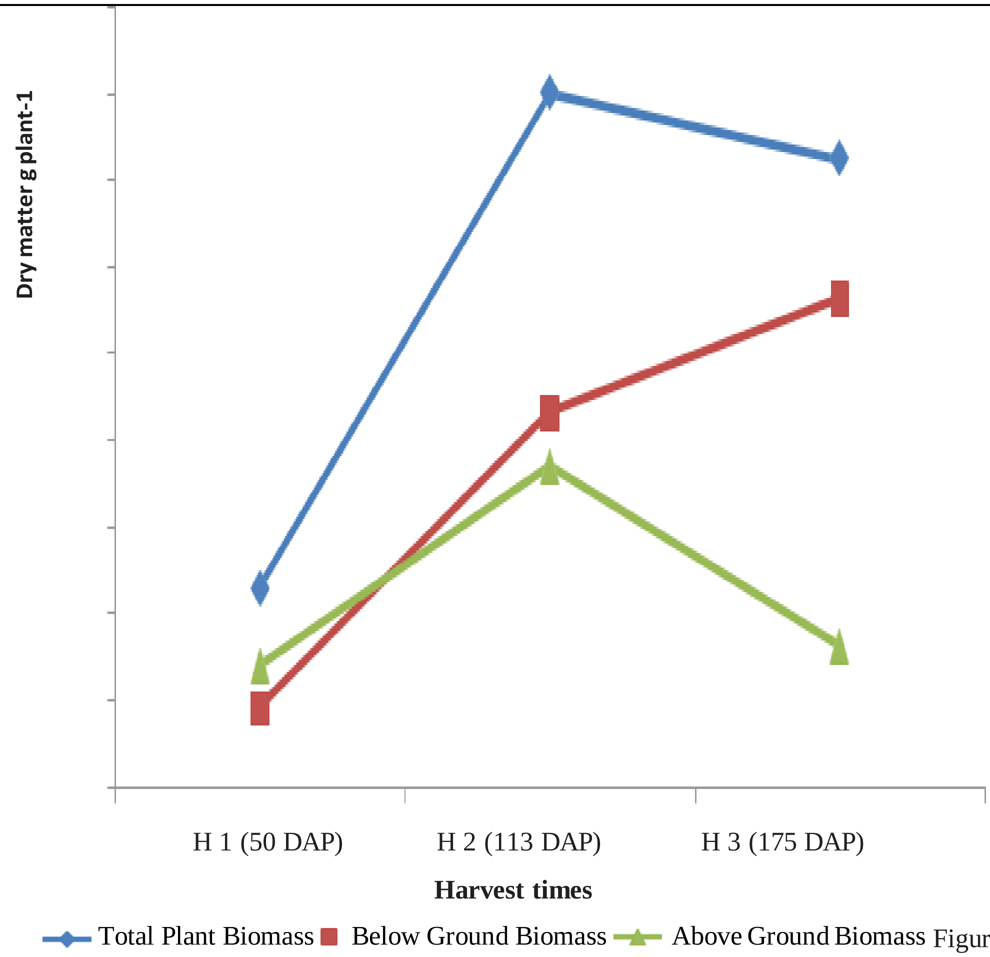
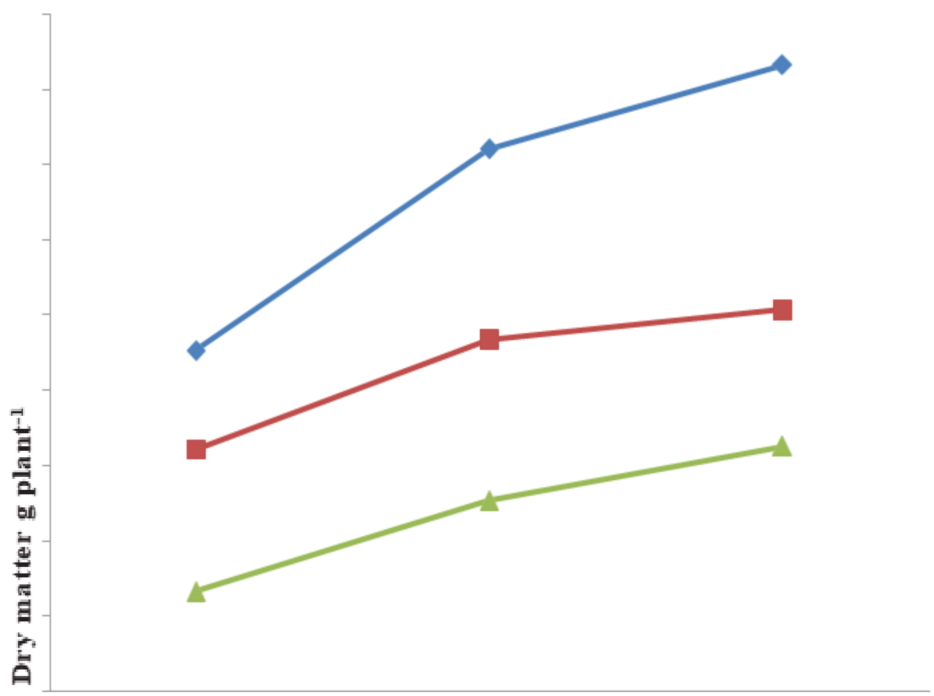


Figure 1.9: Average biomass yields of the two cultivars as influence by time.

Average plant biomass of the two cultivars at different nitrogen levels

Sakius



Tarapatan

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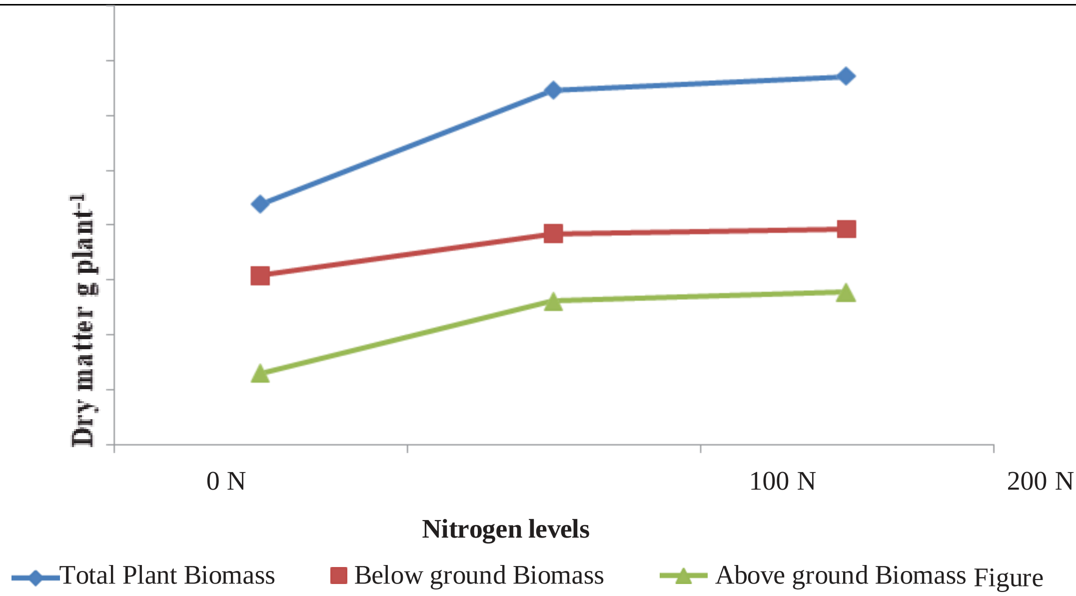


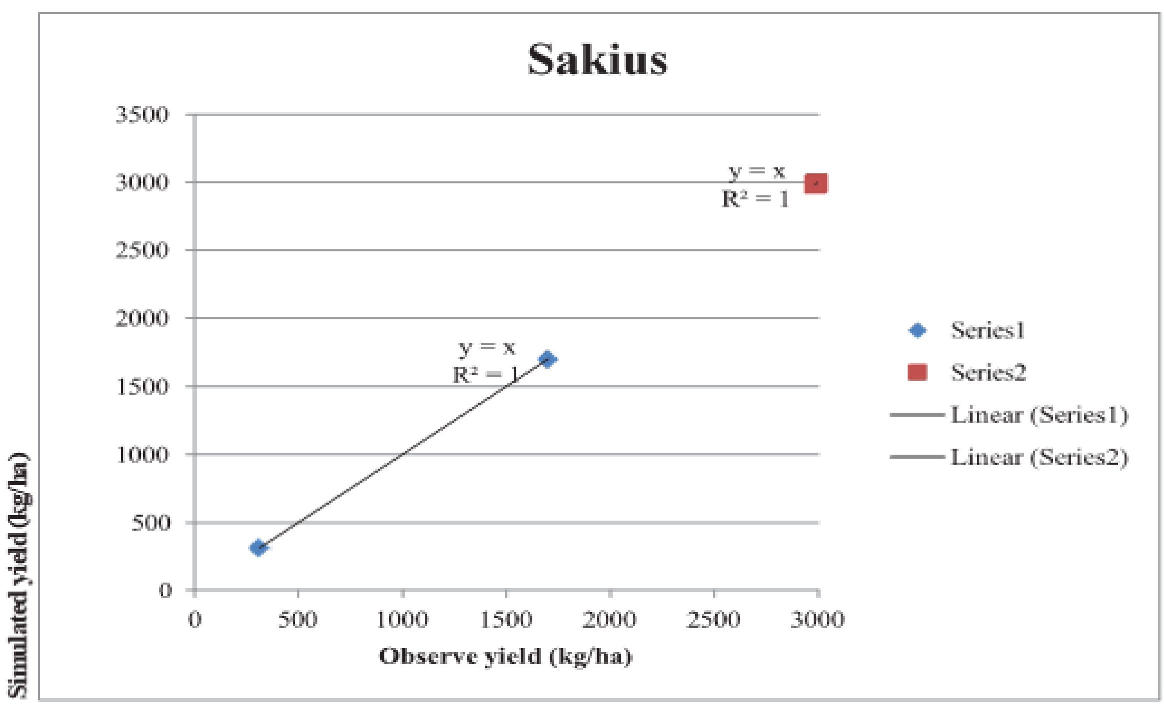
Figure 1.10: Average biomass yields of the two cultivars as influence by nitrogen levels

DSSAT Simulation Analysis

The use of DSSAT was to simulate the growth and development of the two cultivars (Tarapatan and Sakius) to three Nitrogen fertilizer levels under Cameroon climate conditions where the soil, climate and crop management data were used. The simulation was carried out for both cultivars using the SUBSTOR- Aroid taro model in DSSAT. The two Taro cultivars were considered as recommended under t h e list of Taro at the research site and were calibrated using the soil, weather and crop management. However only nitrogen levels of 0 and 100 kg/ha were used in the simulation analysis, since applying nitrogen beyond 100 kg/ha does not have any significant effect in increasing corm yield.

Linear regression analysis was performed after calibration of the two cultivars for tuber yield at the two nitrogen levels. However, the model shows to be very sensitive to nitrogen. At 100 kg/ha of nitrogen the model shows to be in good agreement with the simulated and observed values.

The straight line represents the linear function which relates the observed and simulated corm yield. Linear regression analysis helps in evaluating the model performance, and thus provides information on the slope and coefficient of determination (R^2), which in turn provides information on how well the model simulated values agree with the observed values.



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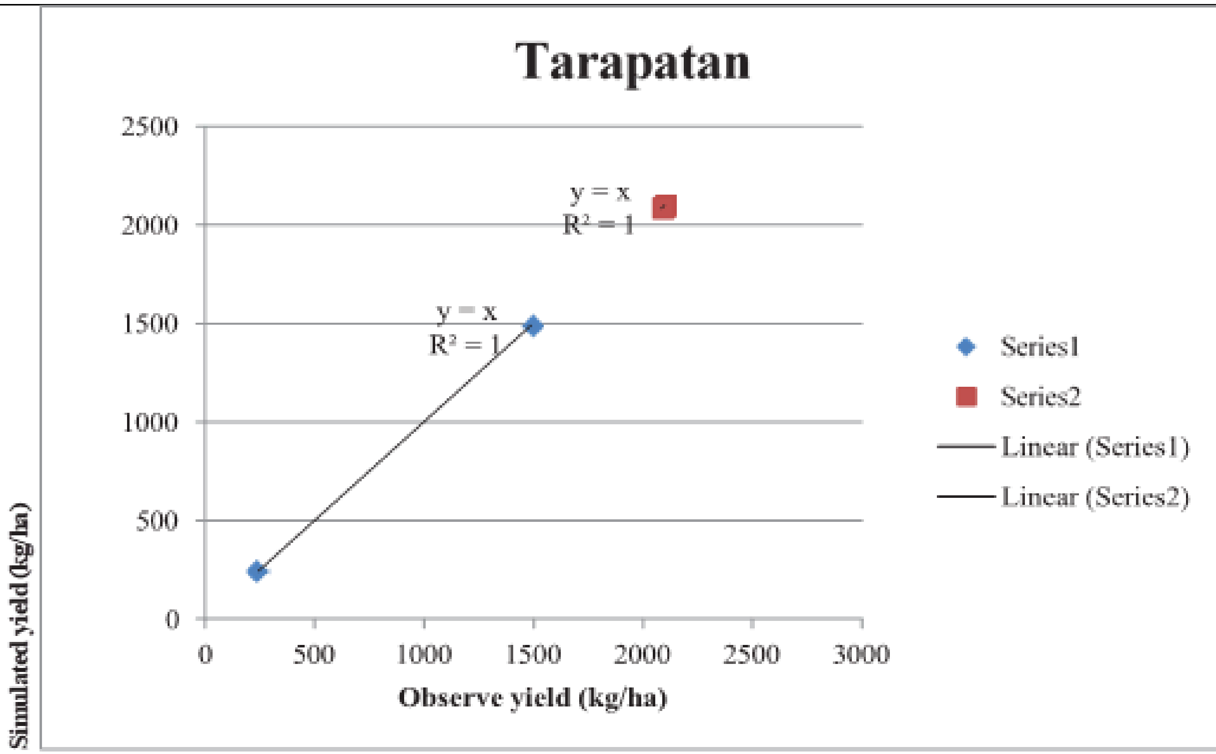

Figure 1.11 shows the evaluation of the two cultivars yield at VARTC under the two N levels (0 and 100 kg/ha). Cultivars Sakius R^2 for N level 0 kg/ha (blue is 1 and 100 kg/ha was also 1 likewise for Tarapatan

Ambient attainable production for Sakius and Tarapatan growth and yield.

Table 1.13 appended below shows the development phases of Sakius and Tarapatan as simulated by the DSSAT SUBSTOR-Aroid taro model. Despite the different genetic make-up, they are more or less the same in growth and development phases as simulated by the model.

Table 1.14 below is showing the measured attainable yield and simulated yield for the two cultivars of colocasia esculenta under Bamenda climate conditions where water and nitrogen are considered, since they are important components for growth and corm production of colocasia esculenta. The model is calibrated using the observed corm yield. When the calibrated DSSAT SUBSTOR – taro model is run to simulate the growth and yield of colocasia esculenta with the two levels of nitrogen (0 and 100 kg/ha) at the research sites, results showed that the DSSAT SUBSTOR taro model was sensitive to nitrogen fertilization.

The cultivar Sakius at 0 kg/ha of nitrogen proved that the DSSAT model underestimated the simulated yield (315 kg/ha) by 82% which indicates that the predicted value of yield was lower than the measured value (1700 kg/ha) with a relative difference of 1385 kg/ha. At 100 kg/ha of nitrogen the DSSAT model also underestimated the simulated yield (2985 kg/ha) with a relative difference of 9 kg/ha. This indicated that the DSSAT model underestimated the observed yield by 0.3%.

The cultivar Tarapatan at 0 kg/ha of nitrogen proved that the model underestimated the simulated yield (243 kg/ha) by 84% lower compared to the observed yield (1488 kg/ha) with a yield difference of 1254 kg/ha. At 100 kg/ha of nitrogen the model overestimated the simulated yield by 0.6 % (2097 kg/ha) respectively, with a relative difference of 12 kg/ha. The results indicated that when no nitrogen application was used in colocasia esculenta production, yield was reduced by about 84%, as assumed by the DSSAT model.

Growth phases of the two cultivars of taro Sakius and Tarapatan taken from the simulation overview

Crop growth stage	Sakius (DAP)	Tarapatan (DAP)
Establishment phase	49	49
Rapid vegetative phase	85	85
End corm	172	172
Maturity	175	175

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The two cultivars were morphologically different from each other but the ways they behave are more or less the same despite the different genetic makeup.

Showing the measured and simulated yield of the two cultivars, Sakius and Tarapatan under ambient (current) condition at the Bamenda research site (Mankon).

Cultivar	N levels (kg/ha)	easured yield (kg/ha)	mulated yield (kg/ha)	Difference (kg/ha)	Relative Difference (%)
Sakius	0	1700	315	1385	82
	100	2994	2985	9	0.3
Tarapatan	0	1488	243	1254	84
	100	2085	2097	12	0.6

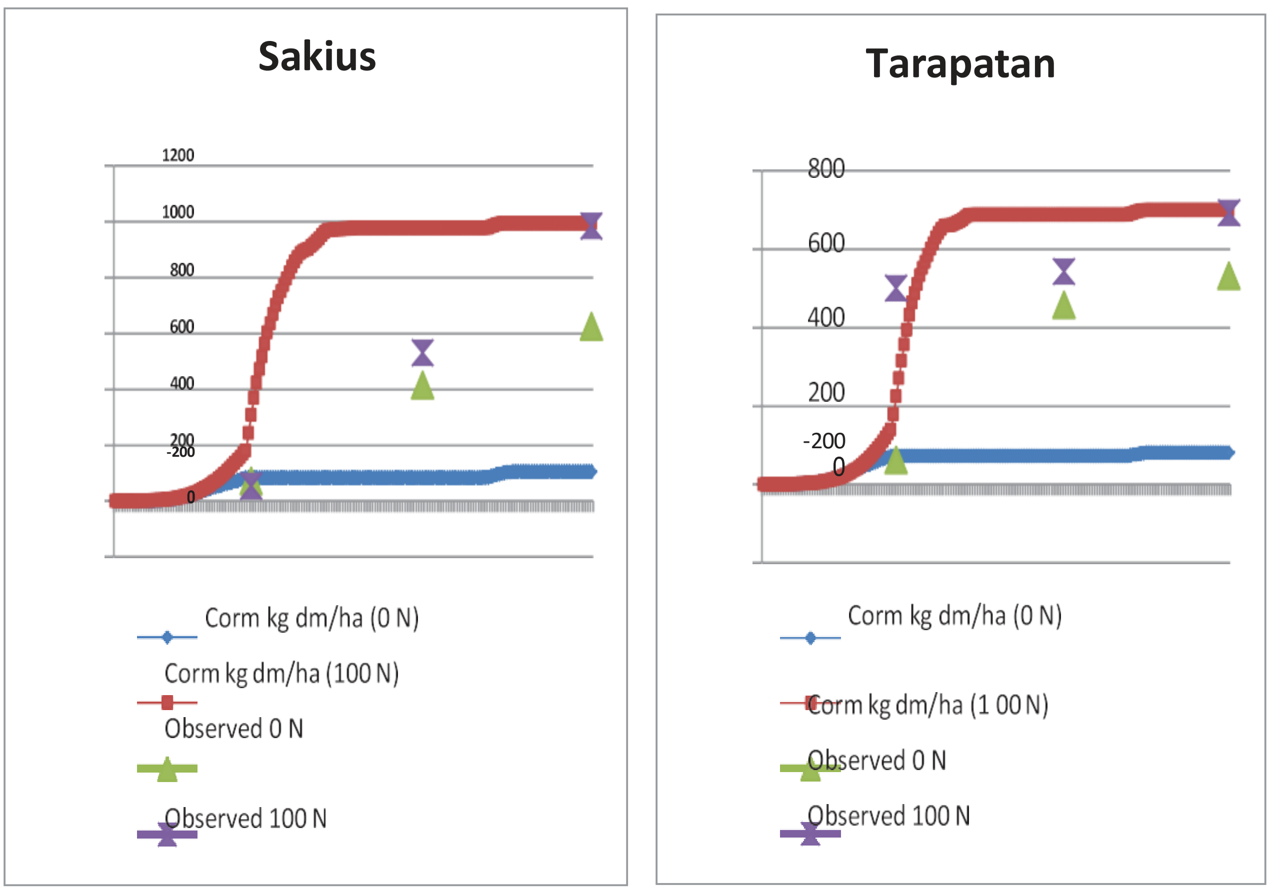

Figure 1.12:Shows the observed (doted) and simulated yield (line) (DM) for the two cultivars, Tarapatan and Sakius**.**

Relationship between Nitrogen application and Leaching due to precipitation at the research site

Figure 1.14 below is showing the relationship between nitrogen application and leaching in the soil as affected by precipitation. At 100 kg/ha of nitrogen there were two applications which totaled up to 72 kg/ha. Fertilization was on the 1st and 2nd days after planting (DAP) and again on 36 DAP. As shown on the graph of the interval days between 26 to 71, there was an increase in nitrogen leaching despite nitrogen application. This is due to the increase in precipitation occurrence during that period of time. The maximum nitrogen leached at 0 kg/ha was 15.5 mm, and at 100 kg/ha it was 36.4 mm. As nitrogen levels increased, so did nitrogen leaching also increase in the soil.

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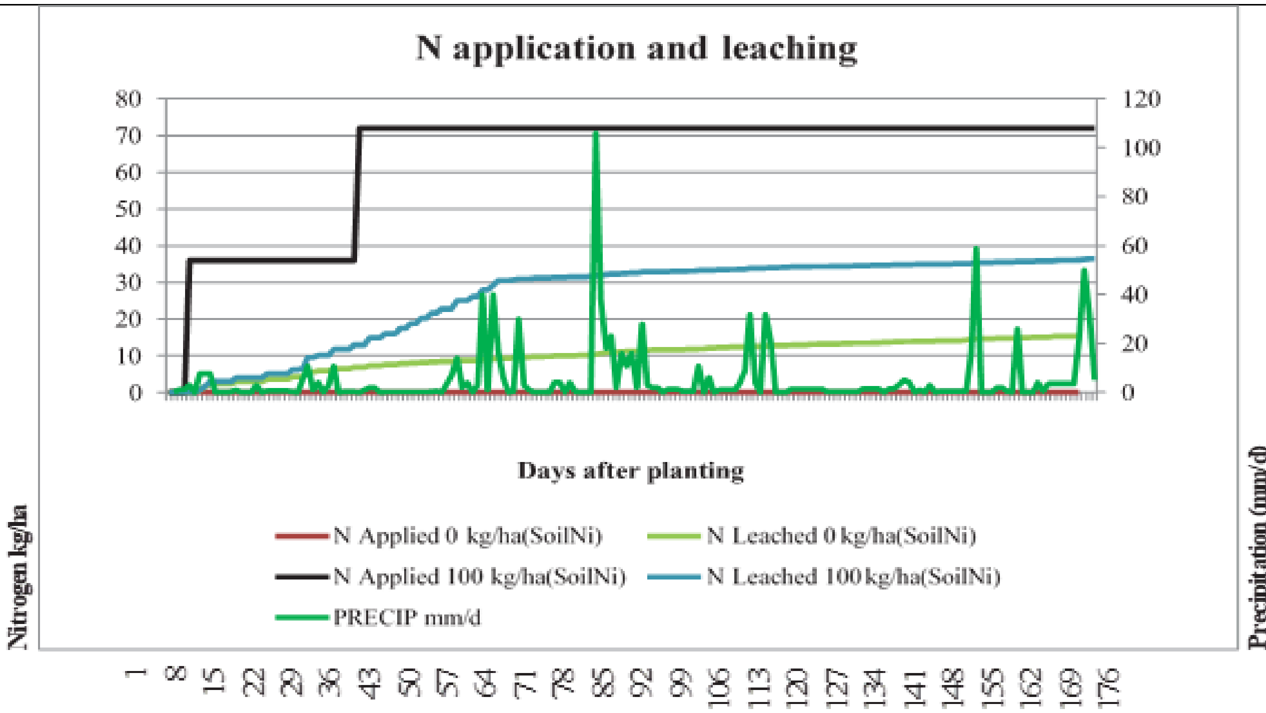

Figure 1.13 Impacts of rainfall on nitrogen applications and leaching in Mankon

Crop growth relationship to water and nitrogen stress

Table 1.14 below was extracted from the ambient analysis of the two cultivars and shows the relationship between crop growth and water and nitrogen stress occurrence at the research site soil. Fertilizer application as previously mentioned was first done two days after planting and then 36 days after planting. However as assumed by the DSSAT model, fertilizer was applied when the plants did not need much of it, since these were the times when corm bulking had not yet begun; so most of the fertilizers were transported to the above ground components of the plants, such as the leaves and petioles. However, both cultivars began to be nitrogen-stressed as soon as the corm started developing. During the establishment stage at 49 days after planting as assumed by the DSSAT model, both cultivars faced nitrogen stress where Sakius at 0 kg/ha of nitrogen was (0.34) and 0.13 at 100 nitrogen kg/ha while Tarapatan was 0.34 at 0 kg/ha of nitrogen and 0.05 at 100 kg/ha of nitrogen. There also was water stress at 100 kg/ha (0.01) for Sakius and 0.02 for Tarapatan.

As both cultivars neared their rapid vegetative stage, nitrogen stress increased rapidly. This indicates the absolute necessity of nitrogen in the soil by the plants, since at this stage suckers may form. Thus, the two cultivars needed extra nitrogen or nutrient in the soil. But since it was a pot trial there was no additional application of nitrogen. However, if the trial was out in the field, weeding, slashing of grasses can supply extra nitrogen or nutrients to the plant. Nitrogen stress at this stage for Sakius was 0.84 and 0.74 at 0 and 100 kg/ha nitrogen respectively, while for Tarapatan was 0.83 and0.73 at 0 and 100 kg/ha of nitrogen correspondingly. From the rapid vegetative stage, towards the end, corm nitrogen stress was highest compared to the other stages of growth as assumed by DSSAT model. At this stage corm bulking and suckers were getting bigger, indicating that more nutrient or nitrogen is needed to sustain the growth of colocasia esculenta.

Overall nitrogen stress seems to appear as the corm begins to develop, especially during the establishment stage and further towards the end, just before maturity. Notably nitrogen stress was high at 0 N kg/ha and decreased as the level of nitrogen application increased. Thus, it is important to apply fertilizer at the right time when the plants are in need of nutrient in the event to sustain their growth and encourage corm production. Finally, because the trial was rain- fed, there was less water stress during the growth of the two cultivars as assumed by the DSSAT-SUBSTOR - Aroid taro model.

Table 1.14: Relationship between crop growth with nitrogen and water stress for Sakius and Tarapatan

Sakius

		0 kg/ha N		100 kg/ha N	
Crop growth		**Stress**		**Stress**	
Date	**Age stage**	**water**	**Nitrogen**	**water**	**Nitrogen**
15-Jul	0 start sim	0	0	0	0

INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
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16-Jul	0 planting	0	0	0	0
17-Jul	1 Root form	0	0	0	0
18-Jul	21st lf egg	0	0	0	0
03-Sep	49 Establish	0	0.34	0.01	0.13
09-Oct	85 Rapid Veg	0	0.84	0	0.74
04-Jan	172 End corm	0	0.75	0	0.86
07-Jan	175 Maturity	0	0.33	0	0.33
07-Jan	175 Harvest	0	0	0	0

Tarapatan

0 kg/ha N				**100 kg/ha N**	
Crop growth		**Stress**		**Stress**	
Date	**Age stage**	**water**	**Nitrogen**	**water**	**Nitrogen**
15-Jul	0 start sim	0	0	0	0
16-Jul	0 planting	0	0	0	0
17-Jul	1 Root form	0	0	0	0
18-Jul	2 1st lf emg	0	0	0	0
03-Sep	49 Establish	0	0.34	0.02	0.05
09-Oct	85 Rapid Veg	0	0.83	0	0.73
04-Jan	172 End corm	0	0.75	0	0.85
07-Jan	175 Maturity	0	0.33	0	0.33
07-Jan	175 Harvest	0	0	0	0

Future Climate Change Projection Scenarios For Taro Growth And Yield

Ambient attainable versus projected attainable for rainfall, temperature and Carbon dioxide for the year 2030

The projections were run separately for each climate variable and to see how each of the climate variables affect growth and yield of the two cultivars of colocasia esculenta.

2030: Ambient versus increase of 1% in rainfall

2030: Ambient versus increase of 1°C minimum and maximum temperature

2030: Ambient versus increase of 451 ppm in carbon dioxide

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Table 1.15 shows the corm yield production under ambient attainable yield and projected yield scenarios for 2030 where each of the climate variables (rainfall, temperature and carbon dioxide) were run separately for each of the two cultivars with the three nitrogen levels (0 and 100 kg/ha).

At the research site (Bamenda), when there was an increase of 1% rainfall (*table 1.15* (A)) while other climate variables are constant, a decrease in yield was projected in both cultivars of colocasia esculenta at 0 and 100 kg/ha of nitrogen. The yield of Sakius at 0 nitrogen kg/ha (1700 kg/ha) decreased by a difference of 1403 kg/ha with a relative percentage difference of 83%, and at 100 kg/ha of nitrogen the yield (2979 kg/ha) decreased with a difference of 15 kg/ha and a percentage difference of 0.5%. The cultivar Tarapatan's yield at 0 nitrogen kg/ha (1488 kg/ha) and 100 nitrogen kg/ha (2085 kg/ha) decreased by 1254 kg/ha and 36 kg/ha respectively, which indicates that an increase of 1% rainfall would reduce yield of that cultivar grown with 100 of nitrogen kg/ha by 2% and 84% without the use of nitrogen fertilization. The margin between the ambient attainable yield and simulated yield of the two cultivars at 0 of nitrogen kg/ha might be due to the sensitivity of the model to nitrogen fertilization. The increase of rainfall by 1% does not affect the maturity date of the two cultivars.

An increase of 1°C minimum and maximum temperature while other climate variables are constant also shows a decrease in yield (*table 1.15* (B)) by 2030 in the Bamenda area. Temperature seems to affect growth stages and reduce yield of colocasia esculenta. When no fertilizer was applied, the cultivar Sakius' yield (1700 kg/ha) decreased by a difference of 1388 kg/ha with a relative percentage difference of 82%; at 100 of nitrogen kg/ha yield (2994 kg/ha) it decreased by a difference of 738 kg/ha with a percentage difference of 25 %, as assumed by the model. Tarapatan, on the other hand at 0 and 100 kg/ha of nitrogen, had its yield decline by a difference of 1254 kg/ha and 654 kg/ha respectively. It indicates that a 1°C increase in temperature will affect the yield of Tarapatan at the two nitrogen levels by 84% and 31% correspondingly. In addition, as assumed by the model, a 1°C increase in maximum and minimum temperature also affect the growth period of the two cultivars by shortening the maturity date down to 167 days for cultivar Sakius and 166 for cultivar Tarapatan. This also affect the other growth stages of the two cultivars where both cultivars' establishment stage was reduced by 3 days (46 DAP) and rapid vegetative phase reduced by 5 days (80 DAP), while end corm reduced by 8 days (164 DAP) for Sakius and 9 days for Tarapatan.

In addition, an increase in carbon dioxide (451ppm) in 2030 increased yield (*table 1.15* (C)) when nitrogen fertilization was used in colocasia esculenta production. In cultivar Sakius, the yield increased by a difference of 255 kg/ha with a percentage difference of 8.5% in 100 N kg/ha, while in Tarapatan, the yield increased by 13% at 100 N kg/ha. When no fertilizer was applied as assumed by the model, the yield for both Sakius and Tarapatan at the research site declined by 82% and 84% respectively. Increasing carbon dioxide does not have any effect on the rate of development of colocasia esculenta (to maturity) based on this study, as is supported by Craufurd and Wheeler, (2009).

Overall the results indicate that when rainfall increases by 1% it does not increase crop yield. A temperature increases by 1°C reduces yield of the two cultivars significantly and affect the growth of the two cultivars by encouraging early maturity; temperature, thus, seems to negatively affect the rate of development of the crop (Craufurd and Wheeler, 2009). In addition, an increase in CO_2 concentration (451 ppm), coupled with the use of nitrogen fertilization will increase of colocasia esculenta yield at the research site in 2030.

Showing the projected change of yield and growth of the two cultivars, Sakius (S) and Tarapatan (T) as affected by the future climate change in the year 2030.

A							
ltiva r	**N levels (kg/ha)**	**Ambient attainable (measured) yield (kg/ha)**	**Projecte d yield (kg/ha) 2030**	**Differenc e (kg/ha)**	**Relative Difference (%)**	**Attainabl e maturity (DAP)**	**Projecte d maturit y (DAP)**
S	0	1700	297	1403	83	175	175
	100	2994	2979	15	0.5		
T	0	1488	234	1254	84	175	175
	100	2085	2049	36	2		
B							
S	0	1700	312	1388	82	175	167
	100	2994	2256	738	25		
	0	1488	234	1254	84		

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T	100	2085	1431	654	31	175	166
C							
S	0	1700	306	1394	82	175	175
	100	2994	**3249**	**255**	**8.5**		
T	0	1488	240	1248	84	175	175
	100	2085	**2406**	**321**	**13**		

Ambient attainable versus projected attainable for rainfall, temperature and Carbon dioxide for the year 2055

The projections are run separately for each climate variable, and to see how each of the climate variables affects growth and yield of the two cultivars of taro

2055: Ambient versus increase of 3% in rainfall

2055: Ambient versus increase of 1.5°C minimum and maximum in temperature

2055: Ambient versus increase of 531 ppm in carbon dioxide

Table 1.16 shows the corm yield production under ambient attainable yield and projected yield scenarios for 2055 where each of the climate variables (rainfall, temperature and carbon dioxide) were run separately for the two cultivars with the two nitrogen levels (0 and 100 N kg/ha).

With an increase of 3% in rainfall in 2055 while other climate variables are constant, projected yield decline is predicted by the DSSAT model in 0 and 100 N kg/ha of the two cultivars (*table 1.16* (A)). Increase in rainfall by 3% in 2055 does not affect the crop stages to maturity, and therefore as rainfall increases the model assume that it will not affect the maturity date of the two cultivars at the research site.

Increase of temperature in 2055 by 1.5 °C will reduce projected yield of the two cultivars (*table 1.16* (B)) in spite of whether or not nitrogen fertilization is applied in the production. The increase of temperature by 1.5°C will also affect the growth stages of colocasia esculenta and shorten the maturity period to 11 days earlier (164 DAP) for cultivar Sakius and 12 days (163) for Tarapatan. As assumed by the model, the establishment phase of both cultivars was reduced to 4 days earlier (45 DAP); and the rapid vegetative phase was reduced to 7 days earlier (78 DAP). The cultivar Sakius' end corm was reduced by 11 days earlier (161 DAP), and its maturity and harvest were also 11 days earlier (164 DAP). On the other hand, Tarapatan's end corm was reduced by 12 days earlier (160 DAP) and maturity with harvest time was also 12 days earlier (163 DAP).

At the research site, an increase in carbon dioxide (531 ppm) in 2055 will increase the projected yield of the two cultivars (*table 1.16* (C)) at 100 N kg/ha respectively. Sakius' yield at 100 N kg/ha increased by 17% compared to the attainable yield. Tarapatan's yield also increases by 21% at 100 N kg/ha compared to the attainable yield. When no fertilizer was applied the model projected a decrease in yield for both cultivars.

In general, the results indicated that in 2055 at the research site, an increase in rainfall of 3% decreased yield of colocasia esculenta for both cultivars. Temperature increase of 1.5°C encourages early maturity in colocasia escuenta and so reduced yield significantly. The increasing CO_2 concentration (531 ppm), coupled with the use of nitrogen fertilizer will still increase yield of colocasia esculenta in 2055.

Showing the projected change of growth and yield of the two cultivars, Sakius (S) and Tarapatan (T) as affected by the future climate change in the year 2055.

A							
ltiva r	**N levels (kg/ha)**	**Ambient attainable (measured) yield (kg/ha)**	**Projecte d yield (kg/ha) 2055**	**Differenc e (kg/ha)**	**Relative Difference (%)**	**Attainabl e maturity (DAP)**	**Projecte d maturit y (DAP)**
S	0	1700	297	1403	83	175	175
	100	2994	2961	33	1.1		
T	0	1488	234	1254	84	175	175
	100	2085	2043	42	2		

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B							
S	0	1700	318	1382	81	175	**164**
	100	2994	1827	1167	39		
T	0	1488	240	1248	84	175	**163**
	100	2085	1206	879	42		
C							
S	0	1700	327	1373	81	175	175
	100	2994	**3495**	**501**	**17**		
T	0	1488	252	1236	83	175	175

Ambient attainable versus projected attainable for rainfall, temperature and Carbon dioxide for the year 2090

The projections are run separately for each climate variable and to see how each of the climate variables affects growth and yield of the two cultivars of colocasia esculenta.

2090: Ambient versus increase of 8% in rainfall

2090: Ambient versus increase of 2.3°C min and 2.6 °C max in temperature

2090: Ambient versus increase of 771 ppm in carbon dioxide

Table 1.17 shows the corm yield production under ambient attainable yield and projected yield scenarios for 2090, where each of the following climate variables (rainfall, temperature and carbon dioxide) were run separately for the two cultivars with the two nitrogen levels (0 and 100N kg/ha).

At the research site in 2090 when rainfall (*table 1.17* (A)) was increased by 8%, the projected yield as assumed by the model was predicted to decline for both cultivars; it was greatest when no nitrogen was applied in colocasia esculenta production.

In addition, the increase of 2.3°C minimum and 2.6°C maximum temperature in 2090 will decrease yield of both cultivars despite increasing nitrogen fertilization in the production of the two cultivars (*table 1.17* (B)). The increase in temperature also affects the growth stages of the two cultivars. Both cultivars' establishment and rapid vegetative stage decreased by 6 and 10 days earlier respectively. The cultivar Sakius' end corm growth stage was reduced by 16 days earlier (156 DAP); reduced too, were both its maturity (159 DAP) and harvest (159 DAP). Tarapatan's end corm growth stage was shortened by 17 days earlier (155 DAP); reduced too, were both its maturity (158 DAP) and harvest (158 DAP).

Carbon dioxide projection (771 ppm) for the year 2090 was projected to increase taro yield when increasing nitrogen fertilization. At 100 N kg/ha, yield increased by 38% for cultivar Sakius, while Tarapatan's yield increased by 33% compared to the attainable yield (*table 1.17* (C)). When no fertilizer was applied the model predicted a decline in yield.

Generally, the 2090 projections for the individual climate variables indicate that when rainfall increase by 8%, it decreases yield for the two cultivars. A temperature increase of about 2.3°C minimum and 2.6°C maximum, reduces yield of the two cultivars either with or without the use of nitrogen fertilization, and enables early maturity in taro production. Therefore, increasing temperature may accelerate the rate of $C0_2$ production, resulting in less than optimal conditions for plant growth. When temperature exceeds the optimal level for biological processes, crop often respond negatively with decline in growth and yield. According to Khanal, (2009) and Rosegrant *et al*. (2008), heat stress might affect the whole physiological development, maturation and overall yield of the crop. However, the increase of CO_2 concentrations (771 ppm) increased yield of the two cultivars significantly when 100 N kg/ha was added at the research site.

Showing the projected change of growth and yield of the two cultivars, Sakius (S) and Tarapatan (T) as affected by the future climate change in the year 2090.

ltiva r	N levels (kg/ha)	Ambient attainable (measured) yield (kg/ha)	Projecte d yield (kg/ha) 2090	Differenc e (kg/ha)	Relative Difference (%)	Attainabl e maturity (DAP)	Projecte d maturit y (DAP)

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S	0	1700	297	1403	83	175	175
	100	2994	2919	75	2.5		
T	0	1488	234	1254	84	175	175
	100	2085	2070	15	0.7		
B							
S	0	1700	318	1382	81	175	159
	100	2994	1452	1542	52		
T	0	1488	237	1251	84	175	158
	100	2085	861	1224	59		
C							
S	0	1700	369	1331	81	175	175
	100	2994	**4137**	**1143**	**38**		
T	0	1488	303	1185	80	175	175
	100	2085	**3099**	**1014**	**33**		

III. Conclusion and Recommendations:

This research was conducted to access the effect of three nitrogen levels on the growth and development Colocasia esculenta and by using an existing crop model to examine the differences between the observed and simulated outcomes, and propose options to improve the simulation outputs. It has also furthered compared simulation outputs for current and future climate projections for individual and combinations of the climate variables, and to see how each and the combination of the climate variables has affected growth, development and yield of Colocasia esculenta around the Bamenda area in the North West Region of Cameroon. The research was carried out around the Mankon, Mendankwe, and Nkwen areas. The experiment has shown that the nitrogen treatments have a statistically significant impact on plant height, leaf area, corm fresh weight, corm dry weight, roots, petiole and leaves dry weight, as well as leaf and sucker numbers under pre-climate change and post-climate change conditions. In this study the lower nitrogen conditions of the post-climate change condition resulted in the lowest tuber weights, shortest average plant heights, smaller leaf area and least suckering. The highest nitrogen treatment under the pre-climate change condition resulted in the highest tuber weight, largest average plant heights and most suckering. However, the application of 100 kg/ha of nitrogen under pre-climate change conditions has proven to increase growth and yield of Colocasia esculenta. Dry matter distribution of the above ground partitioning in the two cultivars in this study has followed a similar pattern as total dry matter, except for differences in magnitude of time and nitrogen levels. For both cultivars dry matter partitioning is at optimum at the second harvest and decrease during the third harvest as the plants become mature. Petioles accumulate more partitioning of dry matter compared to leaf at all harvest and nitrogen levels. The below ground dry matter distribution of the two cultivars followed the same pattern except for differences in time and nitrogen levels.

This research has provided critical insights into the effects of climate change on the growth of Colocasia esculenta, commonly known as taro, in the Bamenda area of the North West region of Cameroon. The findings reveal a troubling trend: as climatic conditions continue to shift, the productivity and viability of this essential crop are facing significant challenges. This study not only highlights the vulnerability of Colocasia esculenta to changing environmental factors but also emphasizes the urgent need for adaptive strategies to ensure its sustainable cultivation.

The novelty of this work lies in its localized focus on the Bamenda area, a region that presents unique climatic and ecological conditions. While previous studies have often examined climate change impacts on agriculture at a broader scale, they have overlooked the specific challenges faced by local farming communities. By concentrating on Colocasia esculenta, we have filled a crucial gap in the literature, providing detailed insights into how climate variables—such as temperature changes, altered precipitation patterns, and increased frequency of extreme weather events—directly affect the growth and yield of this important crop. This research contributes to a growing body of knowledge advocating for a more nuanced understanding of climate impacts on agriculture, particularly in regions heavily reliant on subsistence farming.

The significance of this work extends beyond academic discourse; it carries practical implications for farmers, policymakers, and agricultural stakeholders in the North West region of Cameroon. Understanding the detrimental effects of climate change on Colocasia esculenta can inform targeted interventions aimed at mitigating these impacts. One promising strategy is to promote the cultivation of this crop at higher altitudes, such as in Akum and Santa. These areas, characterized by generally lower temperatures, have a unique microclimate where the coolness has been moderated to create conditions that are conducive

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for Colocasia esculenta growth. By shifting cultivation practices to these higher altitudes, farmers may find a more stable environment for this crop, enhancing food security and economic resilience amid climate variability.

Looking forward, future research should focus on several key areas to build upon these findings. First, conducting longitudinal studies that monitor the long-term effects of climate change on Colocasia esculenta growth and yield across various altitudes in the Bamenda region will be essential. This will help determine optimal cultivation practices tailored to the specific climatic conditions of each area. Additionally, exploring agronomic practices that could enhance the resilience of this crop—such as improved irrigation techniques, soil management strategies, and pest control measures—will be critical for sustaining its production.

Moreover, engaging local farmers in participatory research initiatives can help tailor interventions to meet their specific needs and enhance their adaptive capacity. By involving farmers in the research process, we can ensure that the solutions developed are practical, culturally appropriate, and economically viable.

Barriers to Implementing Altitude-Based Cultivation of Colocasia esculenta in Bamenda, Cameroon

The cultivation of Colocasia esculenta, commonly known as taro, is an essential agricultural practice in Bamenda, Cameroon, where it plays a crucial role in local diets and economies. As climate change continues to pose significant threats to agricultural productivity, exploring altitude-based cultivation has emerged as a potential strategy to adapt to these challenges. However, implementing this approach is fraught with barriers that must be addressed to ensure its success. Below, I discuss two primary barriers: land tenure issues and infrastructural challenges, both of which are particularly pertinent in the context of Bamenda.

Land Tenure Issues

Land tenure refers to the legal framework governing land ownership and use, which significantly influences agricultural practices. In Bamenda, as in many regions of Cameroon, land tenure is characterized by a mix of formal and informal systems, often leading to insecurity and disputes that can hinder the adoption of altitude-based cultivation.

Insecure Land Rights

One of the most pressing issues regarding land tenure in Bamenda is the insecurity of land rights. Many farmers operate on land that is not formally documented or registered, leading to uncertainty about ownership. This lack of formal recognition can discourage farmers from investing in long-term agricultural practices, such as altitude-based cultivation, due to fears of eviction or loss of access to land. In a region where traditional land use practices are prevalent, the absence of clear land titles can create conflicts among community members, further complicating efforts to implement new agricultural strategies.

Fragmentation of Land Holdings

Land fragmentation is another significant barrier to altitude-based cultivation in Bamenda. Many farmers own small, scattered plots that may not be conducive to large-scale agricultural practices. This fragmentation can limit the ability to adopt altitude-based techniques that require larger contiguous areas for effective implementation. Additionally, the division of land among heirs over generations often results in smaller and less viable plots, making it challenging for farmers to achieve economies of scale necessary for successful taro cultivation.

Cultural and Social Dynamics

Cultural factors also play a critical role in land tenure issues in Bamenda. Traditional practices and social norms surrounding land ownership can impede the adoption of altitude-based cultivation. For instance, women in many communities often face barriers to accessing land due to cultural norms that prioritize male ownership. This gender disparity can limit the involvement of women in agricultural innovation and decision-making processes, further exacerbating challenges related to land tenure and hindering the overall effectiveness of altitude-based cultivation initiatives.

Infrastructural Challenges

Infrastructural challenges represent another significant barrier to implementing altitude-based cultivation of Colocasia esculenta in Bamenda. Effective agricultural practices rely on adequate infrastructure to support production, transportation, and market access.

Transportation and Accessibility

Bamenda is characterized by its hilly terrain, which can pose significant challenges for transportation. Many farming areas are located in remote or elevated regions that lack proper road infrastructure. Poor accessibility can make it difficult for farmers to transport their produce to markets, leading to post-harvest losses and diminished profitability. Additionally, the lack of reliable transportation can hinder the delivery of agricultural inputs such as seeds, fertilizers, and tools necessary for successful cultivation. Without improved transportation networks, the potential benefits of altitude-based cultivation may remain unrealized.

Irrigation Systems

Colocasia esculenta thrives in wet environments, making effective irrigation systems essential for its cultivation, especially in

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regions experiencing irregular rainfall patterns due to climate change. In Bamenda, many farmers rely on rain-fed agriculture, which can be inadequate during periods of drought or inconsistent rainfall. The absence of established irrigation infrastructure can limit water availability for altitude-based cultivation, making it challenging for farmers to maintain optimal growing conditions for taro. Investments in irrigation systems are crucial for enabling farmers to adopt altitude-based practices effectively.

Access to Technology and Resources

The successful implementation of altitude-based cultivation often requires access to modern agricultural technologies and practices, including pest management strategies, soil fertility improvement techniques, and climate-resilient crop varieties. However, farmers in Bamenda may have limited access to these resources due to infrastructural deficits, lack of extension services, or insufficient investment in agricultural research and development. Bridging this gap is essential for empowering farmers to adopt altitude-based practices effectively and sustainably.

Implementing altitude-based cultivation of Colocasia esculenta in Bamenda presents a promising opportunity for adapting to climate change impacts on agriculture; however, several barriers must be addressed to ensure its success. Land tenure issues—characterized by insecure land rights, fragmentation of holdings, and cultural dynamics—pose significant challenges that can deter investment in new agricultural practices. Additionally, infrastructural challenges related to transportation, irrigation systems, and access to technology further complicate the transition to altitude-based cultivation.

To overcome these barriers, stakeholders must engage local communities in discussions about land rights and tenure security while promoting equitable access to land for all members of society. Investments in rural infrastructure—particularly transportation networks and irrigation systems—are essential for facilitating access to markets and resources necessary for successful cultivation. Furthermore, enhancing agricultural extension services and promoting research into climate-resilient farming techniques will empower farmers in Bamenda to adapt effectively to changing environmental conditions.

By addressing these barriers comprehensively, stakeholders can create an enabling environment for the successful implementation of altitude-based cultivation of Colocasia esculenta in Bamenda, ultimately contributing to food security and resilience in the face of climate change.

Recommendations for local farmers and agricultural planners around Mankon, Nkwen and Mendankwe

It is crucial for local farmers around the Bamenda area to diversify their crops. By reducing their reliance on taro and exploring alternative crops such as ‘achu banana’ and ‘poyo’ (a locally-cultivated species of plantain), they can improve food security for the individual ménages and create additional income sources. This diversification not only mitigates risks associated with climate variability but also promotes a more balanced agricultural ecosystem.

In addition to diversifying crops, farmers in and around Mankon, Nkwen and Mendankwe should consider planting climate-resilient varieties of colocasia esculenta that can withstand changes in temperature and rainfall patterns. This adaptation can help ensure consistent yields despite the unpredictable impacts of climate change. Moreover, implementing improved agricultural practices is essential. Sustainable techniques such as crop rotation (especially in Mankon with abundant land), intercropping, and organic farming can enhance soil health and resilience, ultimately leading to better productivity.

Water management is another critical area where farmers can make significant improvements. Adopting efficient irrigation methods, such as drip irrigation and rainwater harvesting, can help optimize water usage and reduce dependency on unpredictable rainfall. Furthermore, soil conservation methods like mulching, cover cropping, and terracing can prevent erosion and maintain soil fertility, which is vital for sustaining agricultural productivity in the long term.

Agricultural planners, on the other hand, must take an integrated approach to land use planning that considers the impacts of climate change on agricultural zones. This holistic perspective is essential for creating sustainable agricultural systems that can withstand environmental challenges.

Establishing systems for data collection and monitoring is vital for understanding the effects of climate change on yields and farmer experiences. By gathering and analyzing this information, planners can make informed decisions that benefit the agricultural community. Promoting agroecological practices that enhance biodiversity and reduce chemical dependency should also be a priority for agricultural planners.

Finally, collaboration with research institutions like IRAD in Bambili, can foster partnerships that drive the development of innovative solutions tailored to local challenges.

In conclusion, while climate change poses significant challenges to the cultivation of Colocasia esculenta in Bamenda, there are viable opportunities for adaptation that can safeguard this crucial crop. Promoting higher altitude cultivation and investing in further research and community engagement are essential steps toward a more sustainable agricultural future. By focusing on these strategies, we can work to preserve Colocasia esculenta while supporting the livelihoods of those who depend on it, ultimately fostering resilience in the face of climate change.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue IV, April 2025

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