# MAIZE-KIDNEY BEAN INTERCROP AND ITS EFFECTS ON SOME SOIL PROPERTIES IN BENIN CITY, NIGERIA.

**BY**

**Elizabeth Chinwendu UNEKE (Miss)**

**AGR2004424**

**DEPARTMENT OF SOIL SCIENCE AND LAND MANAGEMENT**

**FACULTY OF AGRICULTURE**

**UNIVERSITY OF BENIN**

**OCTOBER, 2025**

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**PROJECT SUBMITTED TO THE DEPARTMENT OF SOIL SCIENCE AND LAND MANAGEMENT, FACULTY OF AGRICULTURE, UNIVERSITY OF BENIN. IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE BACHELOR OF AGRICULTURE (B. AGRIC) IN SOIL SCIENCE.**

**OCTOBER, 2025**

# CERTIFICATION

This is to certify that this Project work was carried out by Elizabeth Chinwendu UNEKE with Matriculation Number AGR2004424 of the Department of Soil Science, Faculty of Agriculture, University of Benin City, Nigeria.

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| __________________________ | ____________________ |
| **Dr. E.O. Airueghian**<br>**Project Supervisor** | **Date** |
| _______________________ | _____________________ |
| **Dr. (Mrs) V.I.O. Edosa**<br>**Head of Department** | **Date** |

# DEDICATION

This project work is dedicated to God Almighty, for the gift of the Holy Spirit, wisdom, love, strength, grace and mercy that has carried me through every stages.

I also dedicate it to my family, whose love, encouragement, and continual support have been my greatest motivation.

To everyone who believed in me, supported me, and inspired me along the way, this achievement is truly shared with you.

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# ABSTRACT

The experiment was carried out at the experimental site of Faculty of Agriculture, University of Benin, Benin City, to determine the effect of maize kidney bean intercrop on some properties. The experiment was laid out in a randomized complete block design (RCBD), with three (3) levels of same treatment and replicated three (3) times. The treatment levels are sole kidney bean, sole maize and maize-kidney bean intercrop. Soil parameters determined include; pH, Total Nitrogen, Total organic carbon (TOC), Available phosphorus, Potassium, Calcium, Magnesium, Exchangeable Acidity, Base saturation, Soil textural classes (sand, silt and clay), these were analyzed before sowing and after harvest. Plant nutrient concentrations, growth parameters, and yield components were also measured. Results showed that intercropping significantly improved soil fertility, with higher pH (5.56), TOC (12.30 g/kg), and TN (0.73 g/kg) compared to sole maize. Intercropping enhanced nitrogen, phosphorus, potassium, and magnesium concentrations in kidney bean tissues, while maize showed reduced nutrient concentrations under intercropping, indicating differential nutrient uptake between the two crops. Agronomic performance of kidney bean improved under intercropping, with higher stem girth, vine length, and number of leaves, while maize yield was reduced slightly. The yield of kidney bean was not affected by intercropping at 5% level of significance while the yield of maize was significantly ($p < 0.05$) reduced from 7.23t/ha to 6.45t/ha. In conclusion maize-kidney bean intercropping enhances soil fertility, improves nutrient uptake, and improve yield.

# CHAPTER ONE

# INTRODUCTION

Intercropping is an age-long agricultural practice in which two or more crops are grown together on the same field. Although traditional, this farming system remains relevant in modern agriculture because it plays a vital role in enhancing food security, improving soil fertility, conserving soil, and increasing the efficient use of available resources (Lithourgidis *et al*., 2011). Compared with sole cropping, intercropping enables farmers to maximize land productivity, diversify yields, and reduce risks linked to climate variability and unstable markets (Brooker *et al*., 2015). This is particularly significant in smallholder farming systems, where the consequences of crop failure can be severe (Li *et al*., 2023).

Ecologically, intercropping improves the microclimate and soil environment by providing better ground cover, which reduces water loss through evaporation, suppresses weed growth, and minimizes soil erosion (Agegnehu *et al*., 2006). Furthermore, the combination of crops with different rooting systems enhances nutrient use efficiency. Shallow-rooted crops absorb nutrients from the topsoil, while deep-rooted crops utilize nutrients from deeper layers (Brooker *et al*., 2015).

In addition, legume-based intercrops have the ability to fix atmospheric nitrogen, thereby improving soil fertility and reducing the dependence on synthetic fertilizers (Yu *et al*., 2015; Li *et al*., 2023).

ln Benin City and other regions of southern Nigeria, maize (*Zea mays* L.) is widely cultivated as a staple cereal crop due to its utilization for food, animal feed, and use as raw material in industries. Kidney bean (Phaseolus vulgaris L.), on the other hand, is an essential legume crop valued for its high protein content and its role in improving soil fertility through biological nitrogen fixation (Peoples *et al*., 2009). When cultivated together, maize and kidney bean intercrops can complement each other by enhancing nutrient use efficiency, optimizing canopy architecture, and utilizing different rooting depths (Lithourgidis *et al*., 2011).

## Aim and objectives

The aim of this study is to determine the effects of maize-kidney bean intercropping on soil properties and agronomic performance of both crops in Benin city.

Specific objectives are to determine the;

1. effects of maize-kidney beans intercrop on soil chemical and physical properties
2. growth and yield performance of maize and kidney bean under monoculture and intercropping
3. nutrient concentration of the grains of maize and kidney bean

# CHAPTER TWO

# 2.0 LITERATURE REVIEW

## 2.1 Maize

Maize (*Zea mays* L.), also called corn, is one of the most important cereal crops globally, originally domesticated in southern Mexico (Matsuoka *et al*., 2022). The plant consists of tassels (male inflorescences) and ears (female inflorescences), which produce kernels after fertilization. Taxonomically, maize belongs to the Kingdom Plantae, Order *Poales*, and Family *Poaceae*.

Currently, maize is cultivated worldwide as a staple food, feed, and industrial raw material. It has surpassed wheat and rice in global production, with more than 1.2 billion tonnes harvested in 2022 (FAO, 2023). Beyond human consumption as food (e.g., maize flour, porridge, tortillas), maize plays a crucial role in livestock feeding, biofuel (ethanol) production, and industrial applications (Shiferaw *et al*., 2021). Six primary maize types exist dent, flint, pod, flour, sweet, and popcorn each adapted for specific uses (O'Neill *et al*., 2020). Sweet corn, rich in sugars, is cultivated for fresh consumption, while field maize is primarily grown for feed, starch, oil, and ethanol production.

The United States, China, and Brazil dominate global production, though sub-Saharan Africa remains highly dependent on maize for food security (Shiferaw *et al*., 2021). Genetically modified (GM) varieties now contribute significantly to production, especially in the Americas, where traits such as pest resistance and herbicide tolerance enhance yields and reduce losses (Brookes and Barfoot, 2023).

### Taxonomy

Maize (*Zea mays* L.), commonly known as corn, belongs to the kingdom Plantae**,** which comprises all green plants. Within this kingdom, it falls under the division *Tracheophyta* (vascular plants) and the class *Liliopsida* (monocotyledons). It is classified under the order *Poales*, family *Poaceae* (the grass family), subfamily *Panicoideae*, and tribe *Andropogoneae*. The genus *Zea* includes both cultivated maize and its wild relatives, collectively known as teosintes (Doebley *et al*., 2006; NCBI, 2024).

Kingdom**:** Plantae
Division**:** *Tracheophyta* (Magnoliophyta in older systems)
Class**:** *Liliopsida* (Monocots)
Order**:** *Poales*
Family**:** *Poaceae*
Subfamily**:** *Panicoideae*
Tribe**:** *Andropogoneae*
Genus**:** *Zea*
Species**:** *Zea mays* L.

The genus *Zea* consists of several species, but *Zea mays* L. is the most economically important, being the primary domesticated form cultivated globally for food, feed, and industrial uses. Other species within the genus, commonly referred to as teosintes**,** are native to Mexico and Central America and represent the wild progenitors of modern maize (Matsuoka *et al*., 2002; Sánchez-González *et al*., 2018).

Maize has a diploid chromosome number of 2n = 20**,** a characteristic feature distinguishing it from some of its wild relatives.

The tribe *Andropogoneae* encompasses both Old World and New World groups. Old World genera include *Coix* (2n = 10 or 20), *Chionachne* (2n = 20), *Sclerachne* (2n = 20), *Trilobachne* (2n = 20), and *Polytoca* (2n = 20), whereas the New World group comprises *Zea* and *Tripsacum* (Biology of Maize, 2011; NCBI, 2024).

## 2.2 Cultural Practices

Maize is a warm-season crop that requires sufficient soil moisture, especially during critical growth stages like tasseling and silking. As a C4 plant, it exhibits higher water-use efficiency than many C3 crops (Hatfield and Dold, 2019). It thrives best when planted in spring under temperate climates, although tropical regions allow multiple growing cycles annually.

Drought stress during reproductive stages remains a major constraint to yield, often causing incomplete pollination and kernel abortion (Daryanto *et al.*, 2020). Farmers employ diverse practices including irrigation, mulching, and the use of drought-tolerant hybrids to mitigate stress. In Africa, where maize production under rainfed conditions is vulnerable, the adoption of improved agronomic practices such as timely planting, intercropping, and conservation agriculture has been shown to improve resilience (Tesfaye *et al.*, 2021).

## 2.3 Climatic and Soil Requirements

Maize requires abundant sunlight and warm temperatures, with optimal growth at 25–30°C (CIMMYT, 2020). Growth ceases below 10°C, while prolonged exposure above 35°C impairs pollination and accelerates water loss, leading to crop failure (Lobell *et al.*, 2020).

Annual rainfall requirements range between 750–1,200mm, well distributed throughout the growing period. However, uneven rainfall patterns and droughts in sub-Saharan Africa increasingly threaten yields (Nyakudya *et al.*, 2021). Maize performs best on fertile, well-drained sandy loam soils with a pH of 5.5–7.0, though new varieties show greater adaptability to acidic and low-fertility soils (Worku *et al.*, 2022).

## 2.4 Maize Types and Their Uses

Maize (*Zea mays* L.) is classified into several kernel types based on endosperm texture, starch composition, and genetic traits, with each type having distinct food, feed, or industrial uses (Salvador-Reyes and Castro-Álvarez, 2021).

**1. Flint maize**: Kernels are predominantly hard and vitreous with only a small soft center. Flint types are common in Latin America and Europe, valued for food products such as hominy, porridges, and cornmeal. Their hard pericarp also provides resistance to pests and spoilage, making them suitable for storage (Bage, 2022).

**2. Dent maize:** This is the most widely cultivated maize type worldwide, especially in the United States. It has a combination of hard endosperm on the sides and soft starch in the center. During drying, the soft starch at the crown contracts, forming a dent. Dent maize is primarily used for livestock feed, ethanol production, and industrial starches, but also serves in food processing (IJFANS, 2022; ScienceDirect Topics, 2024).

**3. Floury (soft) maize**: Characterized by a predominantly soft endosperm, it is easy to grind and is primarily cultivated in the Andean region. The floury texture makes it well-suited for traditional foods such as tortillas, breads, and porridges (Mertz *et al*., 2012; National Center for Biotechnology Information [NCBI], 2014).

**4. Waxy maize**: This type contains almost 100% amylopectin in its starch, compared with the typical 70% amylopectin and 30% amylose. Waxy maize is important for food industries requiring thickening agents, adhesives, and gels, and is widely used in East Asia and specialty food industries (IJFANS, 2022).

**5. Popcorn:** Pop maize kernels have a hard pericarp with optimal internal moisture (~13–14%), which causes them to expand explosively when heated. Although grown on a smaller scale compared to dent or flint maize, popcorn is consumed globally as a snack and is a growing niche crop with breeding focused on expansion volume and flavor (University of California Agriculture and Natural Resources [UC ANR], 2023).

**6. Sweet maize (sweet corn):** Genetic mutations (e.g., *su1*, *sh2*, *se*) prevent the rapid conversion of sugars into starch, giving kernels a high sugar content at the milk stage.

Sweet corn is harvested fresh (18–20 days after pollination) and consumed boiled, roasted, canned, or frozen. Its rapid post-harvest sugar conversion limits storage and transport (UC ANR, 2023).

Recent studies highlight that endosperm composition not only determines kernel hardness and culinary properties but also influences milling efficiency, nutritional quality, and industrial suitability (Salvador-Reyes and Castro-Álvarez, 2021; Sharma *et al*., 2025).

## Nutrient Requirements

Commercial maize production, whether for grain or silage, demands substantial inputs of macro and micronutrients primarily nitrogen (N), phosphorus (P), and potassium (K) (Grant and Bailey, 2019).The importance of secondary and micronutrients (e.g., zinc, molybdenum) is also increasingly recognized, especially in soils that are deficient or have adverse chemical properties.

Seedlings are particularly sensitive to high fertilizer concentrations. Starter fertilizer should therefore be placed to the side (5 cm) of the seed at planting to avoid seed burn and ensure optimal early growth (Rees *et al*., 2021).

In many tropical maize-growing regions, soil acidity and associated aluminum toxicity pose serious constraints on root development, limiting nutrient uptake and water absorption (Fageria and Baligar, 2020).

### Nitrogen (N)

Under optimal moisture and temperature regimes, nitrogen is often the most limiting nutrient to maize yield (Fageria and Baligar, 2020; Oikeh *et al*., 2022).

It is critical for chlorophyll formation and efficient capture of solar radiation, hence influencing biomass accumulation and grain yield (Lobell *et al*., 2019).

Deficiency symptoms include yellowing of lower leaves (chlorosis), delayed flowering, reduced kernel set, and overall stunting (Grant and Bailey, 2019).

Maize absorbs nitrogen in both ammonium (NH4+) and nitrate (NO3) forms, although nitrate typically predominates in well-aerated soils due to microbial nitrification (Fageria and Baligar, 2020).

Urea remains a commonly used nitrogen source and can be applied via topdressing or through fertigation, provided losses via volatilization or leaching are managed (Oikeh *et al*., 2022).

**Phosphorus (P)**

Phosphorus is central to energy transfer processes in plants (e.g., ATP, ADP) and is essential for root development and early growth stages (Anju *et al*., 2021).

P deficiency often curbs leaf area index (LAI), reducing the capacity for photosynthesis and thus limiting biomass and grain yield (Zheng *et al*., 2023).

Symptoms include stunted growth, delayed maturity, purpling or reddening of leaves, poorly developed root systems, and reduced ear size (Grant and Bailey, 2019).

**Potassium (K)**

Potassium plays multiple physiological roles: enzyme activation, regulation of stomatal opening and closing, water relations, and assimilate transport (Han *et al*., 2021).

Maize used for silage has especially high K needs, because large biomass production increases demand for K (Oikeh *et al*., 2022).

Deficiency typically manifests first in older leaves, which exhibit yellowing and necrosis along the margins; poor ear filling; and increased susceptibility to lodging (Grant and Bailey, 2019).

**Micronutrients**

### Zinc (Zn)

Zinc deficiency is common in calcareous, alkaline, or high-phosphorus soils, and in highly weathered tropical soils (Alloway, 2021).

Symptoms include interveinal chlorosis, light striping on leaves, stunted shoots, and reduced grain or kernel size (Han *et al*., 2021).

### Molybdenum (Mo)

Acidic soils often lack available Mo, which is required for nitrogen metabolism and enzyme function (especially nitrate reductase) (Fageria and Baligar, 2020).

Typical deficiency symptoms are yellowing of leaf tips, stunting, and, in severe cases, plant failure to thrive (Han *et al*., 2021).

## 2.4 Harvesting

Depending on the variety and purpose, maize matures within 90–120 days after planting. Green maize (sweet corn) is harvested at the milk stage for fresh consumption, whereas field maize is harvested after full physiological maturity when grain moisture declines to 18–20% (FAO, 2023). Mechanical harvesting is common in large-scale systems, while manual methods dominate in smallholder farming systems across Africa and Asia (Tesfaye *et al*., 2021).

### Commercial Uses

Maize (*Zea mays* L.) ranks among the oldest domesticated cereals and continues to be one of the highest yielding crops globally. Modern average yields exceed 5–6 tonnes per hectare in many productive regions, reflecting improvements in varieties, management, and inputs (Erenstein, *et al*., 2022).

Maize has a versatile array of uses:

**Food Consumption:** It can be eaten at various growth stages from baby corn to mature grain. In many parts of sub-Saharan Africa and Latin America, maize remains a staple food crop, consumed as whole grain, meal, grits, or in fermented and lava-cooked forms (nixtamalization), depending on local culture and processing traditions (Erenstein *et al*., 2022).

**Animal Feed:** Globally, a large fraction of maize produced is used for feed. In developed countries, this can represent up to 70–80% of total maize production being allocated to livestock feed, either as whole grain, silage, or processed feed fractions. In the tropics, this proportion is somewhat lower but still significant (Erenstein *et al*., 2022; Zhang *et al*., 2025).

**Silage and Green Chop**: Particularly where maize is used for fodder, whole-plant maize is ensiled or used as green chop to ensure high biomass and feed value (Zhang, *et al* ,2025).

**Industrial Uses and Processing**: Maize is processed to extract starch, oil, protein fractions, and fibre. The starch is used for food products (such as sweeteners, corn syrup, baking supplies), industrial applications (paper, adhesives, bio-plastics), and in ethanol production for fuel (Erenstein *et al*., 2022; Zhang *et al*., 2025). Oil extracted from maize germ is utilized in cooking oils, margarine, and as carriers for fat-soluble vitamins; protein and fibre by-products are often used in animal feeds.

**Market Trends and Trade**: The global maize market is expanding rapidly, driven by increasing demand for animal feed, industrial starch, biofuels, and rising consumption in urbanising populations. According to recent market-analysis reports, the maize market was valued at roughly USD 148-150 billion in 2024 and is projected to grow significantly (Erenstein *et al*., 2022, Market Data Forecast, 2025

*Whole-plant maize silage* is receiving renewed attention, particularly in livestock nutrition studies, for its contribution to feed quality, animal performance, and resource efficiency. A recent review highlights improvements in harvesting, storage, and nutritional retention in silage systems (Zhang, *et al*., 2025).

Global trends in trade and production show maize increasingly dominating agricultural systems not just for food but feed and industrial uses especially in developing countries, which are both major producers and consumers (Erenstein *et al*. 2022

## 2.5 Pests and Diseases

### 2.5.1 Insect Pests

Maize is highly susceptible to insect pests that cause severe yield losses. Notable pests include fall armyworm (*Spodoptera frugiperda*), stem borers (*Busseola fusca, Chilo partellus*), maize weevil (*Sitophilus zeamais*), and rootworms (*Diabrotica spp*.). Fall armyworm, first reported in Africa in 2016, remains the most destructive, reducing maize yields by up to 50% if unmanaged (Harrison *et al*., 2019; Goergen *et al*., 2020).

The development of genetically modified (Bt) maize, which expresses Bacillus thuringiensis toxins, has provided effective control against lepidopteran pests in several regions, though pest resistance and regulatory restrictions remain concerns (Brookes and Barfoot, 2023).

### 2.5.2 Diseases

Maize diseases include fungi, bacteria, and viruses. Major fungal diseases are grey leaf spot (*Cercospora zeae-maydis*), northern corn leaf blight (*Exserohilum turcicum*), and ear rots caused by Aspergillus and Fusarium spp., which also contaminate grains with harmful mycotoxins (Ostry *et al*., 2015; Cotty and Jaime-Garcia, 2021). Viral diseases such as maize streak virus and maize lethal necrosis are widespread in Africa, while bacterial wilt (*Pantoea stewartii*) affects temperate regions (Awata *et al*., 2022).

Integrated pest management (IPM) approaches, combining resistant varieties, crop rotation, timely planting, and judicious pesticide use, remain the most sustainable strategy (FAO, 2023).

**Weeds and Maize: Competition, Impact, and Management**

Though maize (*Zea mays*) is a robust, tall crop, it is especially vulnerable to weed competition in its early growth stages. The wide spacing between rows, often used in conventional maize plantings, allows sunlight and resources to reach the soil surface, favoring weed germination and proliferation (Sharma *et al.,* 2022,Nedeljković *et al*., 2025); Uncontrolled weeds during this period can significantly reduce yield by competing for moisture, nutrients, and light, particularly nitrogen; studies in maize have shown that weeds may deprive the crop of substantial nitrogen amounts if left unchecked (Sharma *et al.,* 2022, Farm Progress, 2025)

Weed species composition in maize fields is diverse, including many annual grasses (e.g., *Echinochloa colona*, *Eleusine indica*, *Pennisetum*, *Digitaria*, *Brachiaria*) and broadleaf weeds (e.g., *Tribulus terrestris*, *Senna obtusifolia*, *Cyperus rotundus*, *Portulaca* spp.). Parasitic weeds like *Striga* spp. also pose serious threats in cereal-growing zones, especially under low fertility and marginal soil conditions (Ugljić *et al*., 2025;)

The timing of weed removal is critically important. Recent empirical work indicates that failure to control weeds early can lead to yield reductions ranging from 4% to as high as 76%, depending on weed species, density, and environmental conditions (Nedeljković *et al*., 2025). Critical weed removal periods (CWRPs) often occur when maize has developed 3–5 leaves; weed control beyond this window is increasingly difficult and less profitable (Nedeljković *et al*., 2025).

**Weed Management Strategies**

Modern weed control in maize typically follows an integrated weed management (IWM) framework that combines cultural, mechanical, chemical, and biological methods. Recent reviews emphasize the importance of diversified strategies to mitigate herbicide resistance and environmental impacts (Sharma *et al* 2022, Paul *et al*., 2023)

Key practices include:

**Cultural practices:** Crop rotation, use of cover crops, narrow rows or strip/relay intercropping to increase early canopy closure and suppress weeds by shading the soil surface (Ali *et al*., 2024; Leskovšek *et al*., 2025).

**Mechanical control**: Pre-plant tillage or cultivation, inter-row cultivation during early growth, and site-specific weeding. For example, reduced chemical input by combining mechanical and chemical control has shown efficacy in maintaining maize yield while lowering herbicide use (Fang *et al*., 2022).

**Chemical control**: Use of pre-emergence herbicides (applied before weeds or maize emerge) and post-emergence herbicides. Combinations of herbicides with different modes of action deliver broader spectrum control and help delay resistance (Begović *et al*., 2023). Herbicides like mesotrione, terbuthylazine, dicamba (among others) are used in recent trials under various agro-ecological conditions (Begović *et al*., 2023).

**Precision agriculture / technological innovations**: Advances in remote sensing, and robotic spot spraying are emerging tools that allow more accurate and targeted weed control, reducing herbicide use and environmental impact (Sap- kota *et al*., 2022; Parven *et al*., 2025).

**Biological control**: There is increasing interest in bioherbicides, including fungal agents, especially in regions affected by parasitic weeds such as *Striga*, which are challenging with conventional herbicides (Reuters, 2024).

## 2.6 Kidney Bean (Phaseolus vulgaris L.)

Kidney bean is a highly nutritious legume widely grown across tropical and subtropical regions. It is a vital source of protein, fiber, vitamins, and bioactive compounds, often serving as a meat substitute (Beebe *et al*., 2014; Messina, 2022). The crop occurs in multiple varieties (red, white, light-speckled, and red-speckled), differing in color, size, and nutritional profile.

Kidney bean cultivation systems vary, ranging from monoculture to intercropping with cereals like maize. In sub-Saharan Africa, beans are frequently intercropped with maize due to their ability to fix atmospheric nitrogen, thereby improving soil fertility (Wortmann *et al*., 2022). However, productivity is constrained by drought, heat stress, low soil fertility, and diseases such as angular leaf spot, anthracnose, and root rots (Porch *et al*., 2013). Breeding programs are now targeting heat- and drought-tolerant varieties to improve resilience under climate change (Beebe *et al*., 2014; Rao *et al*., 2021).

### Types of Kidney Beans

Kidney beans (*Phaseolus vulgaris L.*), also known as “sweet beans” in Nigeria, occur in several varieties that differ in seed coat color, size, shape, flavor, and nutritional composition. The major types include:

Red kidney beans (Rajma) – widely consumed in South Asia and Latin America, rich in iron and protein.

White kidney beans (Cannellini**,** also known as “lobia” in India) – commonly used in Mediterranean diets, with a milder taste.

Light-speckled kidney beans – characterized by cream-colored seed coats with reddish streaks.

Red-speckled kidney beans – bright red with mottled patterns, often used in African cuisines.

Although all belong to the same botanical species, their culinary uses and nutritional profiles vary due to genetic and environmental factors (Murube *et al*., 2021, Mehak ,2022)

## Taxonomy

Kingdom: Plantae
Phylum: *Tracheophyta*
Class: *Magnoliopsida* (Angiospermae)
Subclass: Eudicots
Order: *Fabales*
Family: *Fabaceae*
Subfamily: *Faboideae*
Genus: *Phaseolus*
Species: *P. vulgaris* L.
Botanical name: *Phaseolus vulgaris*

## Cultivation and Management Practices

Common bean (*P. vulgaris*) is cultivated either as sole crops, in mixed plantings of different landraces, or intercropped with cereals (maize, sorghum), root crops (sweet potatoes, cassava), and cash crops (cotton, coffee). Farmers, especially in developing regions, often exchange seed landraces, maintaining significant genetic diversity (Wortmann, 2006).

## Cropping Systems and Seasons

In regions with bimodal rainfall, two bean crops per year are feasible, whereas in unimodal rainfall areas, only one planting is common (Beebe *et al.*, 2014; Assefa *et al.*, 2022).

Vegetable beans (snap beans) are often grown as monocrops due to their short growth cycle (60–70 days), while dry beans are commonly rotated with cereals or tubers (Singh and Schwartz, 2010).

### Planting and Spacing

Seeding rates vary between 150,000–400,000 seeds/ha, depending on whether beans are sole-cropped or intercropped (Wortmann, 2006).

Bush types are usually planted at higher densities (30–90cm × 15–30cm), while pole types are planted on hills (30–120cm apart, 3–6 plants per hill) (Liebenberg, 2009).

In mechanized systems, rows are spaced 75–90cm apart to facilitate weeding and harvesting (Beebe *et al.*, 2014; CIAT, 2020).

### Soil and Fertility Management

Beans thrive in well-drained soils with a minimum germination temperature of 12°C and optimal growth at 22–30°C (Wortmann, 2006).

Though legumes fix atmospheric nitrogen, *P. vulgaris* is relatively inefficient, and supplemental nitrogen may be applied in commercial systems (Hungria and Mendes, 2015).

Low phosphorus remains a key yield-limiting factor in tropical soils (Beebe *et al.*, 2014; Kamfwa *et al.*, 2019).

### Crop Protection and Stress Tolerance

Weed control is critical during the early growth stages, particularly in determinate varieties (Liebenberg, 2009).

Heat and drought stress are increasing constraints, and breeding programs now explore genes from tepary bean (*P. acutifolius*) for improved resilience (Porch *et al.*, 2013; Rao *et al.*, 2020; CIAT, 2022).

Climate variability exacerbates yield instability, making stress-tolerant and early-maturing varieties essential in Sub-Saharan Africa and Latin America (Assefa *et al.*, 2022).

### Harvest and Post-harvest Management

Snap beans are harvested 7–8 weeks after sowing, while dry beans are harvested once pods turn yellow and seeds mature (Wortmann, 2006).

Harvest typically occurs when seed moisture is 15–16%, with drying to 11–12% recommended for safe storage. Delayed harvest can lead to shattering, seed cracking, or post-harvest defects like "bin burn" (Liebenberg, 2009; CIAT, 2020).

Smallholder farmers often hand-harvest, while large-scale systems use mechanized threshing.

### Yield Gaps

Yields in developing countries average 0.6–1.2t/ha compared to 2.5–3.0t/ha in mechanized systems (Beebe *et al.*, 2014; Assefa *et al.*, 2022).

Major constraints include low soil fertility, pests, diseases, and abiotic stress. Investment in improved cultivars, fertilizer use, and irrigation is key to bridging this gap (Rao *et al.*, 2020).

## 2.7 Intercropping

Intercropping is a multiple-cropping practice in which two or more crops are cultivated simultaneously on the same field. It aims to optimize land use efficiency and exploit ecological complementarities between crops, thereby producing a higher combined yield compared to sole cropping (Lithourgidis *et al.*, 2011). By capitalizing on ecological principles such as niche differentiation, resource partitioning, and facilitation, intercropping enhances overall productivity and stability while promoting sustainability in cropping systems (Bybee-Finley and Ryan, 2018; Raseduzzaman and Jensen, 2017).

## Types of Intercropping

Different intercropping systems are practiced worldwide depending on farmer preferences, ecological conditions, and the targeted functions of the cropping system. They include

### 1. **Row intercropping**

Row intercropping involves growing two or more crops in distinct rows within the same field. This method allows easier crop management, facilitates mechanization, and optimizes resource capture such as light, water, and nutrients (Varma *et al.*, 2017; Brooker *et al.*, 2015).

### 2. Mixed Intercropping

In mixed intercropping, crops are grown together without a defined row arrangement. This is common among smallholder farmers where land is limited and risk minimization is crucial. Grass–legume mixtures in pastures are classic examples, enhancing both forage yield and soil fertility (Von Cossel *et al.*, 2019; Gulwa *et al.*, 2017).

### 3. Strip Intercropping

Strip intercropping entails growing crops in alternating strips wide enough for independent cultivation but close enough for interaction. It improves light interception, enhances soil conservation, and reduces erosion on sloping lands (Yang *et al.*, 2015; Tanveer *et al.*, 2022).

### 4. Relay Intercropping

Relay intercropping involves planting a second crop into a standing crop before the first one is harvested, ensuring partial overlap of growth cycles. It is particularly suitable in areas with short growing seasons or limited soil moisture, allowing more efficient use of time and resources (Balde *et al.*, 2011; Saha *et al.*, 2020).

## Benefits of Intercropping

### 1. Nutrient Cycling and Soil Fertility

Legume–cereal intercropping remains one of the most effective strategies for improving soil fertility. Legumes fix atmospheric nitrogen via rhizobia, thereby reducing reliance on synthetic fertilizers and improving the nutrient budget for companion crops (Dahmardeh *et al.*, 2010; Jensen *et al.*, 2020). Meta-analyses suggest that global adoption of cereal–legume intercropping could reduce nitrogen fertilizer use by up to 25%, lowering costs and greenhouse gas emissions (Jensen *et al.*, 2020; Xu *et al.*, 2020).

### 2. Space and Resource Use Efficiency

Intercropping enhances land equivalent ratio (LER), meaning less land is needed to produce the same yield compared to monocultures (Li *et al.*, 2020). Differences in canopy structure and root architecture allow intercrops to utilize solar radiation, soil water, and nutrients more effectively. For example, maize–peanut systems achieve up to 40–45% higher combined yields than monocultures due to complementary light and nutrient capture (Awal *et al.*, 2006; Zhou *et al.*, 2019).

### 3. Water Use Efficiency and Climate Resilience

Intercrops reduce soil evaporation, improve infiltration, and maintain higher soil moisture due to larger canopy cover and diverse root systems (Morugán-Coronado *et al.*, 2020). Increased soil organic matter from intercrop residues further enhances water-holding capacity, helping farmers adapt to drought and erratic rainfall (Tamburini *et al*., 2020; Yin *et al*., 2020).

### 4. Weed, Pest, and Disease Suppression

Diverse intercrops limit available niches for weeds and create unfavorable microclimates for pests and pathogens. Reduced reliance on herbicides and pesticides is common in legume–cereal intercrops, contributing to agroecological intensification (Verret *et al*., 2017; Zhou *et al*., 2019).

### 5. Yield Stability and Risk Reduction

Intercropping systems buffer against environmental variability by diversifying production. If one crop fails due to pests, drought, or disease, the other can still contribute to yield and income, thereby reducing risk (Martin-Guay *et al*., 2018; Loreau *et al*., 2021). This insurance function is particularly critical for small holder farmers in regions facing climate extremes. Recent studies emphasize the role of intercropping in sustainable intensification and climate-smart agriculture. Advances in functional trait analysis, ecological modeling, and precision agriculture are improving crop pairing strategies for maximum complementarity (Brooker *et al*., 2021; Duchene *et al*., 2020). Furthermore, research is highlighting how intercropping can contribute to carbon sequestration, biodiversity conservation, and reduction of nutrient losses, making it a cornerstone of agroecological transitions (Tamburini *et al*., 2020; Wezel *et al*., 2024

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Study Area

### 3.1.1 Location

The experiment was carried out in the Experimental Field of Faculty of Agriculture, University of Benin, Benin City. The area lies between latitude 06° 24′ 02.2″ and 06° 24′ 03.4″ North and longitude 005° 37′ 35.9″ and 005° 37′ 36.8″ East. University of Benin is located in Benin City, Edo State, South-South, Nigeria. The site lies within Nigeria's lowland tropical rainforest belt, which features two clearly defined seasons a dry period roughly from November to March and a wet period from April to October. In this zone, mean annual rainfall typically exceeds 2,000mm and mean annual temperature averages around 27°C (Nigerian Meteorological Agency [NiMet], 2020; World Bank Climate Change Knowledge Portal, 2024)

The soils are classified as Ultisols, derived from the *recent coastal plain sands* (locally referred to as the Benin Formation). These soils tend to be well-weathered, with low base saturation and moderate to low fertility, requiring management for sustained crop productivity. Prior to planting, the major weed species present in the experimental field included *Panicum maximum*, *Sporobolus pyramidalis*, and *Mimosa pudica*.

## 3.2 Planting Materials

Oba 80™ hybrid maize seeds were obtained from farmer shop in Benin City while red kidney bean seeds, was bought from New Benin Market in Benin City.

## 3.3 Planting operation

The seeds were planted at the specified seed rate of 3 seeds per hole.

## 3.4 Cultural Practices

Maize and kidney bean were planted as monocrops using a spacing of 90cm between rows and 70cm within rows, while kidney bean was planted at the middle of the spaces between rows, in intercrop. The crops were planted on plots measuring 4.5m × 2.8m at the rate of three seeds per hole which was later thinned to two plants per hole while missing stands were replanted. Weeding was done with hoe, while at harvest, grains were picked for estimation of yield parameters (number and weight of fruit per plant, yield per plot and total yield per plot).

## 3.5 Crop Combinations

The crop combinations are: sole maize, sole kidney bean, maize + kidney bean

## 3.6 Post planting operation

Weeding was carried out manually using hoes at regular interval to control weed pressure.

## 3.7 Experimental Design

This experiment was carried out as a Randomized Complete Block Design (RCBD) with three replicates

**Figure 1. Experimental Layout**

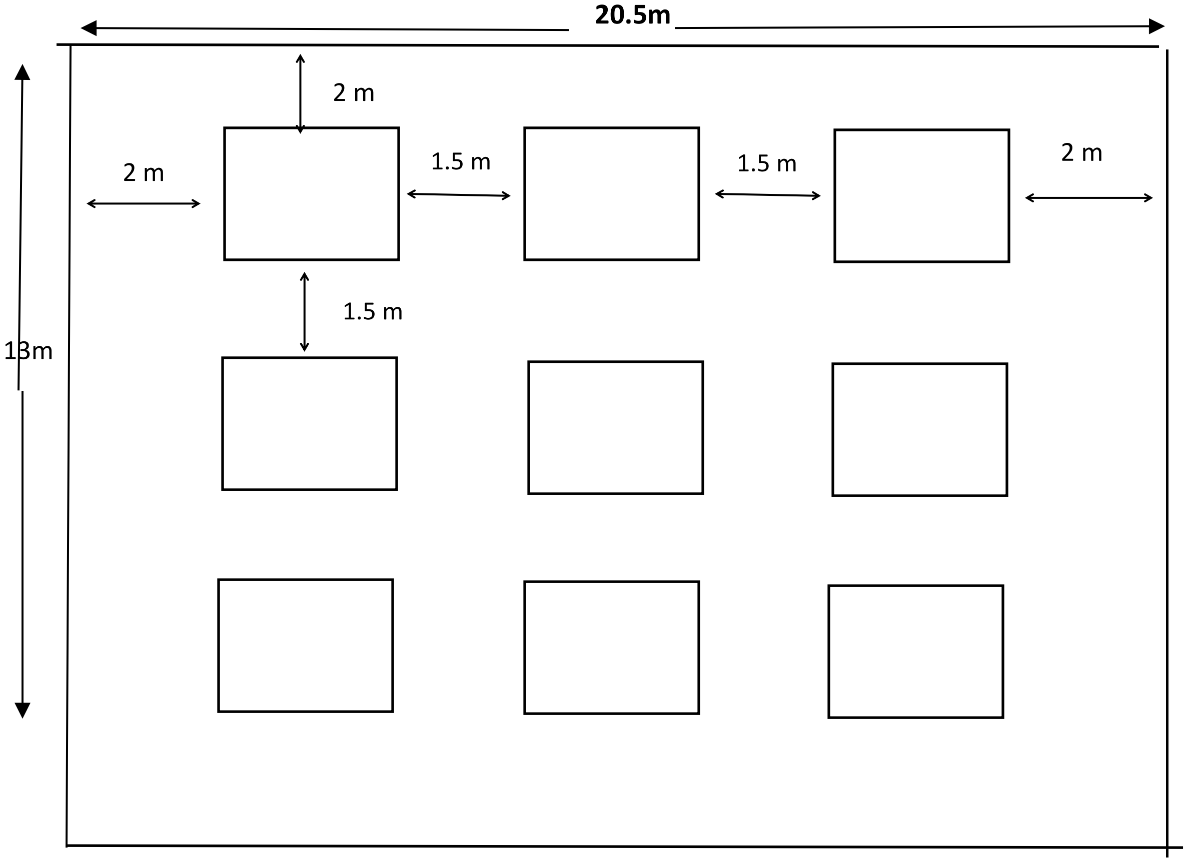

**Figure 2. Crop Arrangement**

| | | | | | | |
|---|---|---|---|---|---|---|
| O | KO | KO | KO | KO | KO | KO |
| O | KO | KO | KO | KO | KO | KO |
| O | KO | KO | KO | KO | KO | KO |
| O | KO | KO | KO | KO | KO | KO |
| O | KO | KO | KO | KO | KO | KO |

**Plots with kidney bean in intercrop. (Where K = kidney bean and O = maize)**

### 3.8 Variables Measured

Plant Height/Vine Length (cm): The plant height of maize and vine length of kidney bean, from base to tip were measured at 50% flowering, using a tape and the means were determined and recorded.

Number of Leaves: The number of leaves at 50% flowering stage was counted and mean determined and recorded.

Stem Girth (cm): The circumference of stems at collar level at 50% flowering was measured using a tape and recorded.

Fresh Grain Weight (g): The weight of fresh grains (ear of maize and pods of kidney bean) per plot was taken and made equivalent of a hectare.

Seed weight (g): the weight of 100 seeds was measured and average weight of seeds was calculated.

Nutrient Concentration (%): the shoots of crops were analyzed for nutrient content and values obtained were recorded.

Land Equivalent Ratio (LER): was determined by Wiley and mead (1980)

$$LER = \frac{MA}{SA} + \frac{MB}{SB} = LA + LB$$

Where; MA+MB=Yields of crop A and B in intercrop

SA+SB =Yields of crops A and B in monoculture

LA+ LB =Equivalent Area for crop A and B

### 3.9 Soil Analysis

Soil samples from the experimental field were taken before and after the experiment at depth of 0–15cm, air-dried, crushed and passed through 2mm sieve for physical and chemical analysis. Organic matter content was removed with hydrogen peroxide and dispersion done with sodium hexametaphosphate (IITA, 1979).

**Particle size determination**

The particle size distribution was determined by the hydrometer method (Bouyoucos, 1951) as modified by Gee and Bauder (1986).

Fifty grams(g)of air-dried soil was weighed into shaking bottles and 20ml of 10% calgon solution (sodium hexameta phosphate) was added to soil. Then 50ml distilled water was added and shaken for 1 hour on a reciprocal shaker. The sample was transferred quantitatively into 100ml measuring cylinder and made up to mark with distilled water. The first reading was taken when the cylinder was dropped on the platform within 40 seconds, the percentage silt + clay was determined with in the 40 seconds.

The second reading was taken after 2 hours. The percentage clay was determined after 2 hours.

Then:

$$\textbf{Percentage of Clay} = \frac{R_{(2hrs)}}{\text{Weight of soil sample (g)}} \times 100$$

$$\textbf{Percentage of Silt + Clay} = \frac{R_{(40s)}}{\text{Weight of soil sample}} \times 100$$

**Percentage of Silt = (Silt + Clay) – (Clay)**

**Percentage of Sand = 100 - (Silt + Clay)**

**pH**

The pH of the air-dried soil was determined using a glass electrode pH meter at ratio 1:1 and (20g soil to 20ml distilled water) and in 1N KCl solution at a ratio of 1:2 soil to water suspension according to Mclean, (1982) method.

Twenty grams (g) of air-dried soil was weighed into 100ml beaker, 20ml of distilled water was added and the mixture was stirred intermittently for 30 minutes with a stirring rod. The pH meter was standardized with buffer pH 4.0 and 9.0, before the pH of the soil was taken. The reading was taken by dipping the electrode into the liquid part of the mixture and the reading recorded.

**Organic Carbon Content**

This was determined by the chromic acid wet oxidation procedure of Walkley and Black as described by (Black 1965).

One-gram(g) air-dried soil was weighed into 250ml conical flask, 10ml of 1N potassium heptaoxodichromate (vi) $K_2Cr_2O_7$ solution was added using a 10ml pipette and the flask gently swirled to effect proper mixing. Thereafter, 20ml of concentrated tetraoxosulphate (vi) acid $H_2SO_4$ was added violently but carefully to avoid dissipation of heat of the reaction and to enhance complete oxidation, after 30 minutes, 100ml of distilled water was added with 100ml measuring cylinder followed by 6 drops of ferroine indicator. The content of the flask was titrated with 0.5N iron (ii) tetraxosulphate (vi) pentahydrate solution ($FeSO_4.5H_2O$) the colour changed from dirty brown to a wine color. A blank titration was carried out (without soil samples). Thus, organic carbon is calculated as;

$$\textbf{Organic carbon} = \frac{\textbf{(Bml - Tml)} \times \textbf{1.33} \times \textbf{0.03f} \times \textbf{N}}{\textbf{Weight of soil sample}} \times \frac{\textbf{100}}{1}$$

Where Bml = titre value of blank

Tml = titration value

N = normality of $FeSO_4$ Solution

### Exchangeable Base (K, Ca, Mg and Na) determination

Calcium and magnesium were determined volumetrically by the EDTA titration procedure described by Black (1965).

Ten grams (g) of air cried soil was weighed into shaking bottle. 70ml of 1N ammonium acetate solution of pH 7 was added with 100ml measuring cylinder to extract the exchangeable bases. The bottle was covered tightly and shaken for 1 hour on reciprocal shaker thereafter, the soil suspension was filtered through Whatman No 42-filter paper into 100ml volumetric flask and residue washed into three 10ml aliquots of 1N ammonium acetate of pH 7 solutions.

A volume of 25ml aliquot of the filtrate was withdrawn with pipette into 250ml conical flask, 20ml of concentrated ammonia solution was added followed by 6 drops of eriochrome blank T indicator, the content of the flask was titrated with 0.01ml of disodium salt of ethylenediaminetera acetic acid (EDTA) solution and the colour change was sky blue colour as end point.

Potassium and sodium were determined from the filtrate by flame photometry as described by Black (1965).

### Exchangeable Acidity Determination

Ten grams (g) soil sample was shaken with 100ml 1N KCl for 1 hour on a reciprocal shaker and thereafter filtered through Whatman No 1 filter paper. aliquot of the filtrate was pipetted into a 250ml conical flask and titrated to a permanent pink end point using 0.01N NaOH and 4 drops of phenolphthalein indicator. Results were expressed as cmolkg$^{-1}$.

Calculation:

$$\mathbf{Meg/100g} = \frac{\mathbf{N \times V \times 100}}{\mathbf{2.5}}$$

Where: N = Normality

V = Litre Volume

2.5 = Weight of soil in aliquot meg/100 = cmolkg$^{-1}$.

**Available Phosphorus Determination**

The available phosphorus in the soil samples was determined using Bray and Kurtz (1945) solution. Here a 5g soil sample that passed through 2 mm sieve was weighed into a shaking bottle in duplicate. 35ml of Bray and Kurtz (1945) No. 1 solution was added into the shaking bottle and suspension was shaken for 1 minute. The suspension was then filtered through Whatman-42 filter paper. The phosphorus content of the filtrate was determined using the colorimetric molybdenum blue procedure of Riley and Murphy (1992). The phosphorus content of aliquot was extrapolated from a standard curve prepared alongside the samples.

**Total Nitrogen**

One gram(g) of finely ground soil sample was weighed into a Micro–Kjedahl flask followed by 1.33g of catalyst mixture. Few drops of distilled water were added to moisten the soil/catalyst mixture. 10ml concentrated $H_2SO_4$ was added and the flask was heated in a fume cupboard until digestion was completed and the digest had become clear or slightly green in colour. The flask was cooled slightly and the content diluted to about 50ml with distilled water. The digest was filtered through Whatman No. 42 filter paper into 100ml volumetric residue and filter paper several times with aliquot of distilled water.

The nitrogen in the filtrate was determined by the alkaline phenate procedure of Fiore and O Brien (1962). A set of standards were prepared and the nitrogen content used for the extrapolation of nitrogen content of the samples.

## 3.8 Plant Analysis

At harvest, 30% of crops were randomly selected from each plot and oven dried for forty–eight hours at 75°C. The plants were ground to powder and placed in Muffle furnace for about forty-eight hours at 450°C to completely turn samples into ashes. Ashes were treated with both 0.1M HCl and 1 M HCl and filtered (A.O.A.C., 1990). The filtrates were used for determination of P, K, Ca and Mg.

P was determined by the molybdenum–blue colorimetric procedure of Murphy and Riley, (1962).

K was determined using flame photometer while Ca and Mg content will be determined volumetrically by EDTA titration procedure (Black, 1965).

The N content was determined by Micro–Kjedahl digestion method (Bremner, 1996).

## 3.9 Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) using GenStat version 12(2012) and standard error of mean (SEM) was used to separate the means at 5% level of probability.

# CHAPTER FOUR

## 4.0 RESULT AND DISCUSSION

### 4.1 Soil pH

The results in Table 1 indicate that the soil pH before sowing was 5.45 and after cultivation, it decreased slightly to 5.23 in the sole kidney bean plot but increased to 5.46 and 5.56 in the sole maize and maize + kidney bean intercrop plots, respectively. According to the soil reaction ratings by Chude *et al*. (2011), all plots fall within the strongly acidic category.

This level of acidity is typical of many soils in southern Nigeria and other humid tropical regions, where high rainfall promotes leaching of basic cations such as $Ca^{2+}$ and $Mg^{2+}$ (Atofarati, 2021; Ehigiator *et al*., 2015). Similar observations were reported by Nwite (2022), who found that tropical ferruginous soils often maintain pH values between 5.0 and 5.8 even after crop cultivation. The minor variations in pH among treatments suggest that short-term intercropping did not significantly alter soil acidity. These results align with findings that soil pH changes gradually and is influenced more by long-term management practices such as liming, organic matter additions, and fertilizer type (Onwuka *et al*., 2016; Uwiragiye *et al*., 2023).

### 4.1.2 Total Organic Carbon (TOC)

The value of total organic carbon was 14.20g/kg and under sole kidney bean was 13.70g/kg and the sole kidney bean plots significantly higher than the 11.50g/kg and 12.30/kg recorded respectively in the sole maize plot and kidney bean + maize intercrop plot.

**Table 1: Particle Size Distribution and Chemical Properties of Soil**

| Crop mixture | pH | | | | Exchangeable Bases | | | | Exch. Acidity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1:1) | TOC | TN | Av. P | K | Ca | Mg | Na | H | Al | ECEC | BS | Sand | Silt | Clay | TC |
| | in water | (g/kg) | | (mg/kg) | | | | (cmol/kg) | | | | (%) | | (g/kg) | | |
| Before sowing | 5.45$^{b}$ | 14.20$^{a}$ | 0.63$^{b}$ | 12.41$^{a}$ | 0.20$^{a}$ | 0.54$^{a}$ | 0.39$^{a}$ | 0.18$^{c}$ | 0.89$^{b}$ | 0.33$^{a}$ | 2.53$^{a}$ | 51.78$^{a}$ | 856.66 | 79.34 | 64.00 | LS |
| Sole kidney bean | 5.23$^{c}$ | 13.70$^{a}$ | 0.80$^{a}$ | 12.04$^{a}$ | 0.19$^{ab}$ | 0.46$^{b}$ | 0.29$^{b}$ | 0.24$^{a}$ | 0.97$^{ab}$ | 0.25$^{b}$ | 2.40$^{ab}$ | 49.17$^{ab}$ | 868.67 | 68.33 | 63.00 | LS |
| Sole maize | 5.46$^{b}$ | 11.50$^{b}$ | 0.54$^{b}$ | 11.78$^{a}$ | 0.19$^{ab}$ | 0.42$^{c}$ | 0.32$^{b}$ | 0.21$^{b}$ | 1.02$^{ab}$ | 0.30$^{ab}$ | 2.46$^{ab}$ | 46.34$^{ab}$ | 862.00 | 72.67 | 65.33 | LS |
| Kidney bean + maize | 5.56$^{a}$ | 12.30$^{b}$ | 0.73$^{ab}$ | 11.56$^{a}$ | 0.18$^{b}$ | 0.39$^{c}$ | 0.25$^{c}$ | 0.19$^{c}$ | 1.14$^{a}$ | 0.23$^{b}$ | 2.38$^{b}$ | 42.44$^{b}$ | 867.33 | 70.33 | 62.34 | LS |
| SEM | 0.175 | 1.013 | 0.157 | 1.054 | 0.0265 | 0.044 | 0.035 | 0.013 | 0.216 | 0.075 | 0.13 | 9.26 | | | | |
| CV (%) | 5.7 | 4.8 | 9.8 | 7.6 | 8.4 | 7.9 | 12.0 | 10.3 | 17.9 | 19.3 | 7.3 | 9.2 | | | | |

Means with same alphabet(s) in the same column are not significantly different ($P \leq 0.05$)
Where TC = Textural Class, SEM = Standard Error of Mean, CV = coefficient of variation, LS = Loamy Sand

### 4.1.3 Total Nitrogen (TN)

According to Table 1, total nitrogen (TN) decreased from 0.63g/kg before planting to 0.54 g/kg in the sole maize plot. In contrast, TN increased to 0.80 g/kg in the sole kidney bean plot and to 0.73g/kg in the intercrop plot. The increases in plots with kidney bean may result from biological nitrogen fixation by the kidney bean Goyal *et al*., 2021; Ladha *et al*., 2022 also reported increased TN contents in plots after the harvest of legumes.

The TN contents of the sole kidney beans plot 0.80g/kg was significantly ($p<0.05$) higher than those recorded in the soil before sowing (0.63g/kg) and sole maize (0.54g/kg)

### 4.1.4 Available Phosphorus

The available phosphorus (P) content of the soil after the experiment decreased in all treatments compared to the initial level of 12.4mgkg$^{-1}$. The maize–kidney bean intercrop recorded the lowest available P (11.56mgkg$^{-1}$), followed by sole maize (11.78mgkg$^{-1}$) and sole kidney bean (12.04mgkg$^{-1}$). Although these reductions were not statistically significant ($p < 0.05$), they indicate a general depletion trend due to crop uptake.

This result agrees with reports that phosphorus availability often declines after cultivation because of plant uptake, soil fixation, and leaching in acidic tropical soils (Chude *et al*., 2011; Ehigiator *et al*., 2015).

### 4.1.5 Exchangeable Potassium (K)

Exchangeable K in the soil declined after cultivation across all treatments compared to the initial concentration of 0.20cmol/kg. The maize-kidney bean intercrop recorded 0.18cmolkg$^{1}$, followed by sole maize (0.19cmolkg$^{1}$) and sole kidney bean (0.19cmolkg$^{1}$). Only the sole kidney bean plot + maize intercrop differed significantly ($p < 0.05$) from the control.

The general reduction in K suggests nutrient removal by crop and possible leaching, which is common in high-rainfall regions (Singh *et al*., 2020). This observation agrees with Osakue *et al*. (2023), who reported declining exchangeable K in maize-based systems in southern Nigeria. Similarly, Batista *et al*. (2020) found that K depletion is typical in maize–legume systems when crop removal exceeds nutrient return through residues.

### 4.1.6 Exchangeable Calcium (Ca)

The exchangeable Ca content decreased from 0.54cmolkg$^{-1}$ before planting to 0.42cmolkg$^{-1}$ in the sole maize plot and 0.39cmolkg$^{1}$ in the intercrop. The Ca level was recorded in the maize–kidney bean intercrop, The Ca content of the soil before sowing is significantly higher than the content recorded in the other plots at 5% level of probability

This decline may result from Ca uptake by plants and leaching losses under humid tropical conditions. Adedokun *et al*. (2024) and Law-Ogbomo *et al*. (2021) reported similar findings where legumes enhanced nutrient uptake (K, Ca, Fe, and Zn) in intercropped systems, potentially depleting exchangeable Ca in the short term. Continuous cropping without liming or residue return can aggravate Ca loss in acidic soils (Uwiragiye *et al*., 2023).

### 4.1.7 Exchangeable Magnesium (Mg) and Sodium (Na)

Both Mg and Na levels showed slight decreases after cultivation. Magnesium declined from 0.39cmolkg$^{-1}$ before planting to 0.25cmolkg$^{-1}$, while sodium dropped from 0.18cmolkg$^{-1}$ to 0.19cmolkg$^{-1}$. These changes were not statistically significant ($p \leq 0.05$), implying moderate nutrient uptake by crops.

This agrees with Singh *et al*. (2018), who reported reductions in exchangeable bases after cereal-legume intercropping due to nutrient absorption and leaching. In contrast, Nasr *et al*. (2024) found that maize-legume intercropping can enhance nutrient availability when sufficient organic matter and microbial activity improve cation exchange capacity.

### 4.1.8 Particle Size Distribution

The soil texture remained sandy throughout the experiment. Sand fraction increased slightly from 856.66gkg$^{1}$ (before planting) to 867.33gkg$^{1}$ in the maize–kidney bean intercrop plot. Silt content varied between 68.33gkg$^{1}$ (in the kidney bean plot) and 79.34gkg$^{1}$ (before planting), while clay content increased marginally from 64.00gkg$^{1}$ (before planting) to 65.33gkg$^{1}$ in the sole maize plot. Based on the USDA classification, the soil texture in all plots falls within the Loamy sand category.

Minor changes in texture fractions are common during cropping due to cultivation, root activity, and erosion processes (Omokaro *et al.*, 2023). Similar findings have been reported in tropical Alfisols of Nigeria by Ehigiator *et al.* (2015) and Omokaro *et al.* (2023).

### 2.1 Nitrogen Concentration in Grains

The nitrogen concentration in kidney bean grains was 3.00% under monoculture and 3.10% under intercropping; this increase in the intercropped plot was statistically significant ($p < 0.05$). In contrast, maize grain nitrogen contents were 1.85% in sole maize and 1.74% in the maize + bean intercrop, with the higher value in monoculture being significantly greater than that in the intercrop ($p < 0.05$). Some intercropping studies document lower grain nitrogen concentration in the maize vines was significantly lower under intercropping with kidney beans compared to maize grown in monoculture, likely due to shared competition or dilution effects (Jalloh *et al.*, 2024).

### 4.2 Phosphorus Concentration in Grains

For kidney bean, phosphorus content was 0.25% in monoculture and 0.28% under intercropping; the increase was not statistically significant. In maize, phosphorus was 0.16% in monoculture and 0.13% in the intercrop again, the difference was not significant. This pattern is consistent with intercropping research where the cereal often shows slight reduction or no change in P concentration due to interspecific interactions of uptake (Yimer *et al.*, 2025).

**Table 2. Nutrient Concentration of Vine of Kidney bean and Maize**

| | **Kidney bean** | | | **Maize** | | |
|---|---|---|---|---|---|---|
| | **Monoculture** | **Intercrop** | **LSD** | **Monoculture** | **Intercrop** | **SEM** |
| Nitrogen (%) | $3.00^{b}$ | $3.10^{a}$ | 0.0421 | $1.85^{a}$ | $1.74^{b}$ | 0.0418 |
| Phosphorus (%) | $0.25^{b}$ | $0.28^{a}$ | 0.0224 | $0.16^{a}$ | $0.13^{b}$ | 0.0201 |
| Potassium (%) | $0.77^{b}$ | $0.80^{a}$ | 0.0235 | $0.58^{a}$ | $0.53^{b}$ | 0.0240 |
| Calcium (%) | $0.60^{a}$ | $0.62^{a}$ | 0.0221 | $0.36^{a}$ | $0.32^{b}$ | 0.0237 |
| Magnesium (%) | $0.48^{b}$ | $0.50^{a}$ | 0.0192 | $0.30^{a}$ | $0.25^{b}$ | 0.0208 |

Means with same alphabets in same row are not significantly different at ($P \leq 0.05$)
Where: ns = not significant, SEM=Standard Error of Mean

### 4.2.3 Potassium Concentration in Grains

Kidney bean grains had potassium concentrations of 0.77% (monoculture) and 0.80% (intercrop), where the intercrop value was significantly lower ($p < 0.05$). In maize, K was 0.58% for monoculture versus 0.53% for intercropping, differences that were not statistically significant (Singh *et al*., 2018). Some studies similarly report that intercropped cereals show slight declines in K concentration, possibly due to competition or dilution effects

### 4.2.4 Calcium Concentration in Grains

Calcium in kidney bean grains was 0.60% in monoculture and 0.62% in the intercrop, with the intercrop value being significantly higher ($p < 0.05$). For maize, Ca content was 0.36% and 0.32%in both monoculture and intercropping, with no significant difference. Research on micronutrients in intercrops is less plentiful, but trends often show legumes maintaining or slightly increasing Ca due to their deeper root systems and nutrient mobilization (Jalloh *et al*., 2024).

## 4.3 Growth and Yield Parameters

### 4.3.1 Effect of Intercropping on Growth

Table 3 indicates that intercropping improved growth parameters in kidney bean: stem girth increased from 3.70cm to 4.10cm, leaves rose from 26 to 38, and vine length increased from 242cm to 264cm, though not all changes were statistically significant. This suggests that kidney bean was not adversely affected by intercropping. Conversely, maize growth declined: stem girth dropped from 7.40cm to 6.60cm, leaf number from 11 to 8, and plant height from 194.5cm to 165.3cm under intercropping, likely reflecting competition for resources between the component crops. Kidney bean exhibits increased vegetative growth

**Table 3. Growth and Yield Parameters of Kidney bean and Maize**

| | Kidney bean | | | Maize | | | SEM |
|---|---|---|---|---|---|---|---|
| | Monoculture | Intercrop | LSD | Monoculture | Intercrop | LSD | |
| Stem girth (cm) | $3.70^b$ | $4.10^a$ | 0.3521 | $7.40^a$ | $6.60^b$ | 0.5718 | |
| Number of leaves | $26^b$ | $38^a$ | 8.416 | $11^a$ | $8^a$ | ns | |
| Plant height/ vine length (cm) | $242.0^b$ | $264.0^a$ | 20.190 | $194.5^a$ | $165.3^b$ | 15.64 | |
| Weight of 100 grains (g) | $31.9^a$ | $32.8^a$ | ns | $29.5^a$ | $20.6^b$ | 6.854 | |
| Average weight of pod/ear (g) | $1.02^a$ | $1.04^a$ | ns | $137^a$ | $114.5^b$ | 9.351 | |
| Yield of fresh pod/ear (t/ha) | $0.70^a$ | $0.72^a$ | ns | $7.23^a$ | $6.45^b$ | 0.532 | 1.92 |

Means with same alphabets in same row are not significantly different at ($P \leq 0.05$)
Where: ns = not significant, SEM= Standard Error of Mean

due to complementary interactions, while maize suffers reductions in growth and yield due to competitive stress. Effective intercropping requires careful planning and management to maximize system productivity.

### 4.3.2 Effect of Intercropping on Yield

Under intercropping, kidney bean showed slight yield gains: 100-grain weight rose from 31.9g to 32.8g, and total yield increased from 0.70t/ha to 0.72t/ha. For maize, intercropping reduced yield; 100-grain weight fell from 29.5g (monoculture) to 20.6g (intercrop), and overall yield declined from 7.23t/ha to 6.45t/ha. These yield decreases in maize under intercropping are consistent with known trade-offs when interspecific competition intensifies, especially if nutrient or light resources are insufficient.

Intercropping kidney bean with maize results in maintained or slightly improved legume yield, but significantly reduced maize yield. The system demonstrates a classic legume–cereal trade-off, emphasizing the need for careful management to balance productivity goals.

These findings are in contrast with those of Oyelola *et al*. (2022), who reported that intercropping maize with kidney bean and pigeon pea resulted in significantly higher maize grain yields compared to sole cropping. However, in the present study, maize yield declined, which may be attributed to short-term competition effects rather than long-term fertility improvements. This is consistent with the observations of (Yang *et al*. 2024), who noted that intercropping systems can lead to yield reductions in the short term due to resource competition between crops. Conversely, long-term studies have shown that intercropping can enhance soil fertility and lead to sustained yield increases over time. For instance, a seven-year field trial by Ahmad *et al*. (2025) demonstrated that continuous maize/soybean intercropping outperformed maize monocropping across all year intervals, with maize yield increasing by 37%, 35%, and 58% over the first, third, and seventh-year intervals, respectively. This suggests that while short-term competition may reduce yields, intercropping can contribute to long-term productivity gains.

The LER is widely used in agronomic research to assess the benefits of crop combinations, optimize cropping patterns, and support sustainable intensification of agriculture. By demonstrating a higher LER, farmers and researchers can justify the adoption of intercropping practices to maximize output per unit area while maintaining soil health and biodiversity.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

This study assessed the influence of maize–kidney bean intercropping on soil properties and agronomic performance in Benin City. From the result, intercropping enhanced soil nitrogen due to the nitrogen-fixing ability of kidney bean, while slightly reducing available phosphorus, potassium, calcium, and magnesium, likely as a result of nutrient uptake and leaching under humid tropical conditions. The soil pH remained moderately acidic, consistent with the characteristics of ferruginous tropical soils, while the texture was dominated by Loamy sand.

Agronomically, kidney bean showed improved growth performance and grain nutrient content under intercropping, whereas the growth of maize slight reduce in height, stem girth, and yield, which may be attributed to short-term interspecific competition for nutrients, moisture, and light.

The results indicated that maize–kidney bean intercropping promotes efficient land use, enhances legume productivity, and contributes to soil nutrient cycling. The practice therefore appears to be a sustainable and climate-smart system that supports soil health, crop diversification, and long-term productivity.

## 5.2 RECOMMENDATIONS

Intercropping kidney bean with maize can improve soil nitrogen, enhance legume growth, and optimize land use, making it a viable system for farmers in Benin. Although maize yield may decline in the short term due to competition, careful management of spacing, nutrient supply, and variety selection can mitigate these effects. Incorporating legume residues and monitoring soil fertility will sustain productivity and soil health over time.

Adoption of this intercropping system, combined with proper agronomic practices, offers a sustainable approach to improving both crop yield and soil quality.

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