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Effect of Different Mulching Materials on Residual Moisture Content Conservation and Yield of Brown Beans (*Phaseolus vulgaris*) in Minna, Nigeria

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Abstract

The study examined the impact of mulching on the growth, yield, and moisture content of Brown Beans during the 2021 growing season at Diamond Global Academy school farm in Minna, Niger State. The experiment was conducted in a randomized complete block design with four replications. The treatments included no mulching, Dry maize straw mulch, black polythene mulch, and white polythene mulch. Blocking was used to prevent fertility and slope variations among treatments. The total seasonal water requirement was estimated at 258.48 mm. The results showed that white plastic mulch resulted in the highest average fresh pod yield of 3753.1 g/m^2, while the control plot had a minimum yield of 2844.4 g/m^2. The marketable yield was significantly affected by mulch application. The highest quality was observed in white plastic mulch (3528 g/m^2), while dry maize straw mulches did not show any significant difference. The study concluded that polythene may be a preferable mulch for increasing quality and brown bean production by conserving soil profile moisture.

Subject Areas

Agricultural Science

Keywords

Beans, Climate, Mulch, Soil, Straw

1. Introduction

Global warming, caused by human activities, has distorted agricultural practices, leading to significant losses in non-irrigated rain-fed farming regions due to water scarcity and inadequate irrigation facilities [1]. As the land frontier shrinks, improvements in land productivity are needed to increase agricultural production [2]. However, the degrading land resource base is crucial for sustainable development, including oil, food, health, peace and stability, and poverty eradication [3] [4].

Savannahs, a mixture of grass and woodland ecosystems, are characterized by erratic and variable rainfall, resulting in significant reductions in agricultural production and crop failure [5] [6]. Effective water resource management is essential to prevent or reduce the threat of complete crop failure and promote food security [7]. The efficient use of water is at the heart of sustainable development, as it is the common denominator of all global problems, including oil, food, health, peace and stability, and poverty eradication [8] [9].

In agriculture, soil moisture content (SMC) is critical to crop growth and productivity [9] [10]. Mulching, which involves spreading various covering materials on the surface of the soil to minimize moisture losses and weed population, can enhance crop yield [11] [12]. Mulches can reduce water runoff, improve soil infiltration capacity, restrain weed population via shading, and act as an obstacle in evapotranspiration [12] [13]. They manipulate soil heat flux and affect soil temperature, reducing evaporation from the land surface and retaining soil water content as much as possible [14].

Mulch cover also suppresses weed infestation in the crop field [14]. Synthetic materials have altered mulching methods and benefits over the last 60 years [15], such as polythene mulches, which are impermeable to water, preventing direct evaporation of moisture from the soil and limiting water losses and soil erosion over the surface. This plays a positive role in water conservation and helps control temperature fluctuations, improving the soil's physical and chemical condition [11] [16].

Brown beans, a crucial leguminous crop in African socioeconomic farming systems, have enormous potential for addressing food insecurity, income generation, and regional poverty alleviation [17]. Despite its high nutritional content, brown bean growers face challenges such as water shortage, which can be addressed through effective conservation practices like mulching. This study aims to assess the effect of different mulching materials on residual soil moisture conservation and their effects on the yield of brown beans in Minna, Nigeria.

2. Materials and Method

2.1. Description of the Study Area

The experimental site is situated at Minna (9˚34'N and 6˚29'E) in Niger State, Nigeria. The climate of the study area exhibits the characteristics of a tropical wet and dry savannah climate. This has a pronounced dry season in the low-sun months, no cold season, and the wet season is in the high-sun months with an average temperature of 27˚C. The total annual Precipitation is 1209.7 mm. While the mean annual relative humidity is 80%, there are 2672 hours of sunshine per year, making about 7.5 h/day. The upland soils under the basement complex formation around Minna are generally deep, weakly to moderately structured sand to sandy clay with gravelly and concretionary layers in the upper or beneath the surface layers [18] [19].

2.2. Experimental Treatment and Design

The study aimed to investigate crop weather using three approaches: physiological, statistical, and simulations. The physiological approach was used to generate data on brown bean yield in Minna, using an experiment on farmland from August to November 2022. The experimental area was 100 m^2 with 16 plots, each with 2 m by 2 m area (**Figure 1**). Cultural practices were performed manually, and the beds were levelled, smoothed, and loosened uniformly. Planting was done on August 1, 2022, and the plots received all prevalent practices among local farmers. Harvesting was done by hand-picking between November 20 and 25, 2022. The experiment had 16 plots with treatments (T). No irrigation was given to the plots during the cultivation period, instead, weeding was done 30 days after planting (DAP) to maintain weed-free conditions and minimize disturbances to the mulches. This approach was necessary to reduce errors due to fertility and gradient differences.

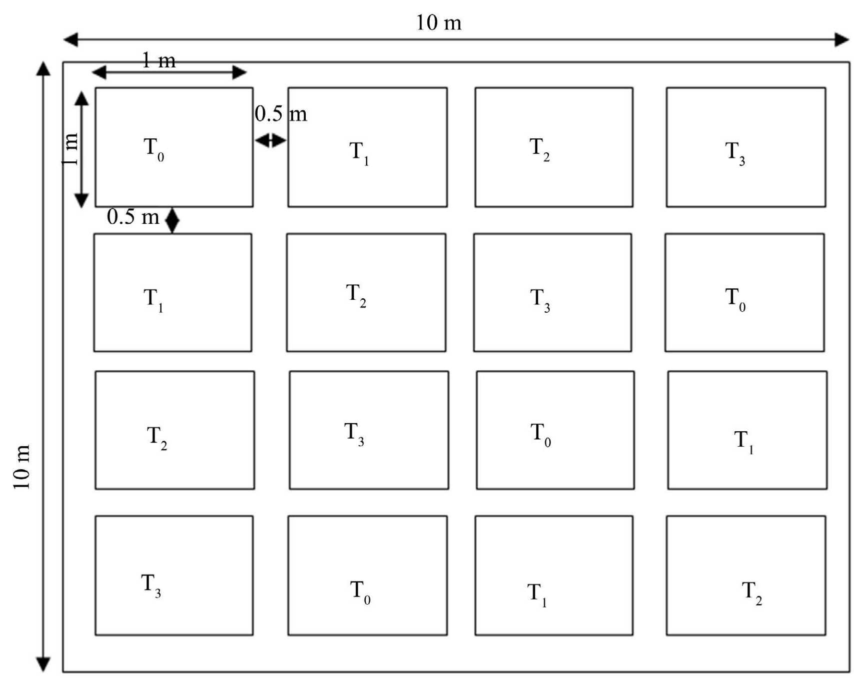

Figure 1. Layout of the experimental plots[1].

[1]Where T_0 is the control (no mulch was applied), T_1 is the dry maize straw mulch, T_2 is the black polythene mulch of 0.05 mm thickness and T_3 is the transparent polythene mulch of 0.05 mm thickness.

2.3. Data Collection

The experiment involved collecting secondary and primary data on climatic and crop parameters, soil properties, infiltration rate, soil moisture content, yield, and yield components, and weather elements [20] like temperatures, rainfall, wind speed, relative humidity, and sunshine duration from a meteorological station.

2.4. Soil Moisture Content (SMC)

Soil samples were collected using an auger to cover the crop's root zone, placed between plant rows. Each sample is placed in a polythene bag to prevent evaporation loss and recorded in a laboratory. The soil moisture content will be calculated using Equation (1).

$$\text{SMC} = \frac{W_1 - W_2}{W_1} \times 100\% \quad (1)$$

W_1 is the weight of soil before drying, the weight properly maintained with air-tight polyethene packets, and W_2 represents the weight of soil after oven drying until constant weight at 80˚C ± 2˚C.

2.5. Growth Components

The growth rate will be measured weekly until 12 weeks after planting (WAP) using the thread and meter rule, and the leaf area index (LAI) will be computed monthly using Kumar *et al.*'s [21] method, considering factors like fruit number, length, harvesting period, dry fruit weight, and total dry weight.

2.6. Yield Components

The study recorded yield data from plants harvested at physiological maturity, with pods turned brown and slightly dried. Seeds were collected and weighed, preserved in polyethene bags. Key yield components included pod length, dry weight, harvested period, total dry, day to flowering, day to physiological maturity, plant height, fresh pod weight, marketable and unmarketable pod weight, total yield, and water use efficiency.

2.7. Statistical Analysis

The study utilized Minitab statistical software for statistical analyses, employing ANOVA, CV, and LSD tests to verify the statistical significance of treatments' differences. ANOVA was used to verify significant differences, CV to check variation within treatments, and LSD to identify treatments with statistically different means. CV values ranging from 15 to 35 indicated moderate to high variation.

3. Results and Discussion

3.1. Climate of the Study Area

Climate is a crucial factor affecting human life, including agriculture. It varies across regions, making it essential to understand these variations for informed decisions and developing climate change mitigation and adaptation strategies. Climate data from the Nigerian Meteorological Agency (NIMET) station in Minna, Niger State, shows a sinusoidal pattern of rainfall over 35 years. The volume of rainfall increases gradually over decades, with a 38% increment in 1994 compared to 1984. The duration of rainfall also changes over time, with 7 months of data in 1984 reducing to 1994. The data for 2022, the crop's planting year, is presented in **Figure 2** while **Table 1** presents the weather condition of the study area.

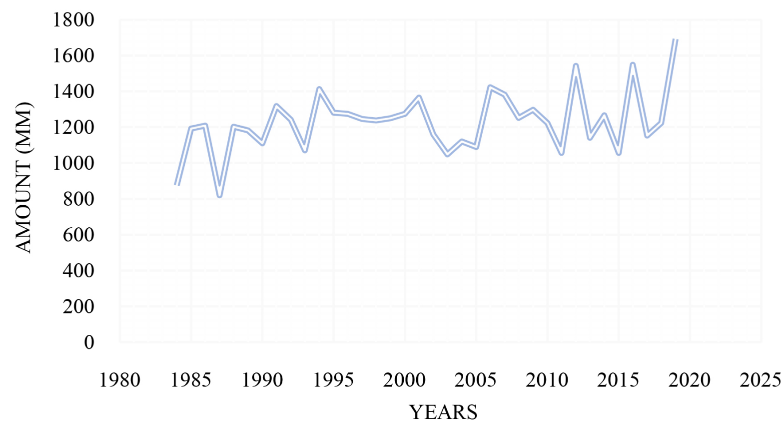

Figure 2. Annual rainfall pattern of Minna for between the years 1980 to 2019.

Table 1. Weather data for the study area.

Month	Rainfall (mm)	Temperature (˚C)		Relative humidity (%)	Wind spread (km/day)	Sunshine (hrs)
		Minimum	maximum			
January	1.40	20.40	34.70	18	12	8.40
February	5.40	22.80	36.80	33	13	8.60
March	11.90	24.50	37.10	33	9	8.30
April	60.90	24.80	35.70	79	7	7.60
May	135.90	23.70	32.80	78	6	7.70
June	174.50	22.30	30.70	75	5	7.10
July	206.60	22.10	29.10	73	4	4.60
August	271.90	21.80	28.80	72	3	3.60
September	239.90	21.60	30.00	73	5	5.50
October	100.00	21.50	32.00	70	6	8.30
November	1.20	19.40	34.40	37	7	9.20
December	-	-	-	-	-	-
Total	1209.60	244.90	362.10	641.00	77	78.90
Average	110.00	22.30	32.90	58.30	7	7.20

The study area experiences an average annual rainfall of 110.0 mm, with the highest rainfall occurring in August and September. The lowest rainfall occurs in December and January, with almost no rainfall. The region's precipitation patterns are influenced by the Inter tropical Convergence Zone (ITCZ) and the West African Monsoon. The growing season (August to November) receives the most rainfall, which steadily decreases until the last month. The experiment recorded 613 mm of rain from August to November 2022, which is within the required amount for brown bean cultivation.

The study analysed the temperature data for Minna from 2006 to 2019, revealing high temperatures with an average annual temperature of 27˚C. The highest temperatures were recorded in March to May, reaching 38˚C, and the lowest in December and January, dropping to 16˚C (Table 1). The dry season experienced higher temperatures than the wet season, as rain cools the atmosphere and lowers the temperature. The research region's mean maximum and minimum temperatures were 32.9˚C and 22.3˚C, respectively. These temperatures were within the average requirement for brown beans, indicating a high air temperature range that provides the necessary energy for water vaporization.

Relative humidity (RH) values were highest in 2009 and lowest in 2011 (Figure 3), with the highest values being 74% in 2009 and 54% in 2011. The most significant humidity was 79% in April, and the average relative humidity was 63% from August to November. High atmospheric humidity indicates significant evaporative air demand at the experiment site, which depends on the energy available to evaporate water. Variations in energy availability, particularly solar radiation and temperature, directly affected evapotranspiration rates, supporting the notion that evapotranspiration depends on the energy available for water vaporization.

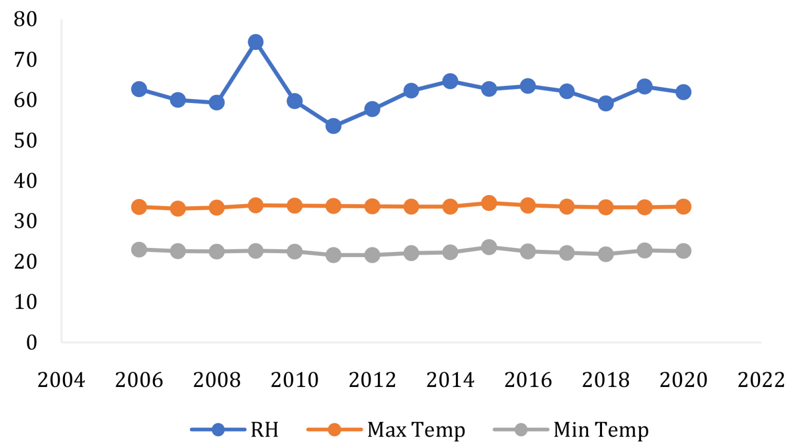

Figure 3. Climatic data collected from NIMET between the years 2006 to 2020.

The study area in Minna experiences two main winds: the north-east trade wind and the southwest monsoon wind. The north-east trade wind brings dry and dusty air from the Sahara Desert, while the southwest monsoon wind brings moist and humid air from the Atlantic Ocean. The strength and direction of the wind are influenced by local topography and pressure gradient force. Wind speed affects evapotranspiration (ET), which often occurs due to high solar radiation and intermittent evapotranspiration loss. Zhang *et al.*, [22] found a positive linear relationship between wind speed and ET, with higher wind speeds resulting in higher ET rates. A similar relationship was observed in a wheat field in Australia.

3.2. Soil Properties

Physical Properties

Soil residual moisture content significantly influences soil physical properties such as bulk density, porosity, and permeability. As soil residual moisture content increases, bulk density increases due to pore space being filled with residual moisture, which improves soil porosity and permeability.

Soil samples from the experimental site showed Sandy Clay loam and Clay loam textures across depths of 0 - 30 cm and 30 - 60 cm, respectively [18] [19]. These soil types are ideal for producing brown beans due to their ability to grow on various soil types. The results for bulk density, total accessible water (TAW), field capacity (FC), and permanent wilting point (PWP) for depths of 0 - 30 cm and 30 - 60 cm are shown in **Table 2**.

Table 2. Soil Physical properties for the study area.

Soil parameters	Soil depth		
	0 - 30 cm	30 - 60 cm	Average
Sand (%)	47	44	45.50
Silt (%)	19	28	23.50
Clay (%)	34	28	31.00
Class (Soil texture)	Sandy clay loam	Clay loam	Sandy Clay loam
Bulk density (gm/cm^3)	1.32	1.35	1.33
FC (V/V %)	31.00	34.00	32.50
PWP (V/V %)	18.00	22.00	20.00
TAW (mm/m)	120	130	125

Note: BD = bulk density, FC = field capacity, PWP = permanent wilting point and TAW = total available water content.

Bulk density is defined as the mass of a unit volume of dry soil (105˚C), reflecting the total soil porosity. Low bulk density values indicate a porous soil condition, while high bulk density values indicate poorer root growth, reduced aeration, and undesirable changes in hydrologic function. Field capacities ranged from 31% to 34% on a volume basis [19], and the difference between FC and

PWP is closely correlated with the total accessible water (TAW).

Using mulch, organic amendments, and/or irrigation methods can reduce soil bulk density and hydraulic conductivity while increasing total porosity, drainable pores, and available water in the soil.

Chemical Properties

Soil residual moisture content significantly impacts soil chemical properties, including nutrient availability and pH. Nutrients are crucial for plant growth, and increased soil moisture can enhance microbial activity and mineralization, making nutrients more accessible for plant uptake. Soil pH, another essential chemical property, can be influenced by soil residual moisture content. In the research location, soil pH increased slightly with depth, from 5.85 to 6.2, indicating a basic soil. Beans can grow in soil with a pH range of 5.5 to 6.5, making this soil suitable for bean growth. The soil's saturated extract electrical conductivity was 0.017 and 0.016 ds/m, indicating low soil salinity and minimal impact of salt on the crop.

Biological Properties

Soil residual moisture content impacts soil biological properties, including microbial activity and plant growth. Increased moisture leads to improved nutrient availability and favourable conditions for microbial growth, affecting plant growth and productivity through nutrient cycling and symbiotic relationships. Soil residual moisture also influences root growth and water uptake. The organic matter content of soil varies from 3.15 to 2.79 (See Table 3).

Table 3. Chemical and biological properties of the soil for the study area.

Soil parameters	Soil depth		
	0 - 30 cm	30 - 60 cm	Average
Sand (%)	47	44	45.5
Silt (%)	19	28	23.5
Clay (%)	34	28	31
Class (Soil texture)	Sandy clay loam	Clay loam	Sandy Clay loam
Bulk density (gm/cm^3)	1.32	1.35	1.33
FC (V/V %)	31	34	32.5
PWP (V/V %)	18	22	20
TAW (mm/m)	120	130	125

Note: ECE = electrical conductivity; OM = organic matter.

3.3. Effect of Mulch on Soil Residual Moisture Conservation at Different Crop Stages

Soil residual moisture is crucial for plant growth and yield, and any deficiency or excess can negatively impact plant growth. This study used mulching to conserve soil residual moisture, which was measured for various soil depths and crop growth stages. The ability of a crop to convert solar energy into economic growth depends on the size and efficiency of its leaf canopy, which is influenced by factors such as temperature, solar radiation levels, water and nutrient supply, crop type, cultivar, and age. Eze *et al.*, [23] emphasize the importance of effective agricultural management practices that maximize the uptake and utilization of limited residual moisture supply from rainfall for sustainable soil productivity and improved crop growth and yield (**Table 4**).

Table 4. Effect of mulch application on volumetric residual moisture content (%) at different growth stages and soil depths.

Initial growth stage						
Depth (cm)	T0	T1	T2	T3	CV (%)	LSD (0.05%)
0 - 30	28.78	29.75	30.2	29.85	2.05	1.35
30 - 60	29.51	30.12	30.65	30.48	1.66	1.07
Development stage						
Depth (cm)	T0	T1	T2	T3	CV (%)	LSD (0.05%)
0 - 30	28.77	29.46	30.31	29.8	2.19	2.83
30 - 60	29.45	30.06	30.53	30.31	12.18	3.23
Mid-stage						
Depth (cm)	T0	T1	T2	T3	CV (%)	LSD (0.05%)
0 - 30	20.95	23.74	24.79	25.19	8.07	2.18
30 - 60	22.65	27.75	27.78	28.89	10.34	3.01
Final stage						
Depth (cm)	T0	T1	T2	T3	CV (%)	LSD (0.05%)
0 - 30	21.33	22.18	22.9	22.97	3.44	2.46
30 - 60	23.18	23.38	26.37	26.36	7.19	3.04

Soil Residual moisture at the initial stage

The initial stage of plant growth, where seedlings emerge from the soil, is highly susceptible to residual moisture stress, leading to stunted growth and reduced yield [24]. Mulching effectively reduces this stress. The application of clear polythene mulch significantly impacted residual moisture content at both soil depths, with a p-value of 0.05. The plot covered with clear polythene had the most excellent volumetric residual moisture content, measuring 22.97% and 26.37% at depths of 0 - 30 cm and 30 - 60 cm, respectively (**Table 4**). There were no discernible differences between the black and clear polythene mulches. Similarly, there were no significant differences between the maize straw mulch and control at the early development stage when organic mulches were compared to un-mulched plots. Polythene mulches help retain residual moisture throughout the early stages of brown bean development. Studies have shown that polythene mulches retain more residual moisture than other mulched treatments. Similarly, rice straw mulch at the beginning of maize growth increased soil residual moisture content by 12.5% and improved seedling emergence by 23%.

Soil Residual moisture at the Development Stage

Mandal *et al.*, [25] found that mulching is effective in enhancing soil residual moisture conservation during the development stage of plant growth. The study found that the control plot had the lowest residual moisture levels (20.95% and 22.65%), while the polyethylene mulched plot had the most significant residual moisture contents (25.19% and 28.89%) as presented in **Table 4**. The polyethylene mulches can reduce evaporation loss, effectively retaining residual moisture at both soil depths, and making it accessible to satisfy the crop's water needs during the developing period. Similarly, Goudarzi *et al.*, [26] found that applying wheat straw mulch at the development stage of barley growth increased soil residual moisture content by 8.6% and improved plant height, shoot dry weight, and grain yield. Ibrahim *et al.*, [27] found that using sugarcane bagasse mulch at the development stage of tomato growth increased soil residual moisture content by 18.6% and improved plant height, stem diameter, and leaf area.

Soil residual moisture at the mid-season stage

Research indicates that mulching can significantly improve soil residual moisture retention during the middle phase of plant growth, which is crucial for proper fruit maturation. Clear polythene mulch showed a maximum residual moisture conservation rate of 27.80% at 0 - 30 cm and 30.11% at 30 - 60 cm, with increments of 27.18% and 26.77% compared to control plots. This suggests that polythene mulches effectively reduce evapotranspiration from plots by increasing residual moisture in the soil profile during the middle stage of growth. Studies have shown that applying sawdust mulch during the middle stage of apple growth increased soil residual moisture levels by 12.5%, leading to improved fruit yield, weight, (**Table 4**), and size. Similarly, using pomegranate peel mulch during the middle stage of strawberry growth increased soil residual moisture levels by 14.7%, resulting in improved fruit yield, weight, and total soluble solids.

Soil residual moisture at the late season stage

The final stage of plant growth, characterized by fruit maturation and leaf senescence, requires sufficient residual moisture for optimal fruit quality. Mulching is an effective technique to improve soil residual moisture retention during this critical stage. However, no discernible difference was found between mulch treatments in terms of residual moisture conservation. Transparent polyethylene showed slightly greater residual moisture content than an un-mulched plot, despite no discernible impact. High humidity and cloudiness may have decreased evapotranspiration, and some plots' soil residual moisture levels were almost at their field capacity late in the growing season. Studies have shown that maize stover mulch can enhance soil residual moisture content by 14.3% during the final stage of okra growth, resulting in improved fruit yield, weight, and total soluble solids. Wheat straw mulch can also increase soil residual moisture content by 10.5% during the final stage of saffron growth.

3.4. Effects of Mulch on Reproductive Growth of Brown Bean

Days to flowering

The study found a significant difference in days to flowering due to different mulch application treatments. Plots mulched with white plastic took longer to reach 50% flowering, while plots without mulch took the shortest time (54 days). Control plots flowered six days earlier than those mulched with white plastic. Plots mulched with dry maize straw were also affected by day-to-flower (57.37) than unmulched plots as observed in Table 5. This could be because plants under residual moisture stress complete their life cycle earlier than those under normal or high soil residual moisture conditions, ensuring species perpetuation. Plants matured more early under residual moisture stress than under favourable conditions, indicating that plants delay flowering to distribute more biomass to vegetative growth. Mulch application extended flowering days, possibly due to residual moisture harvested in the soil favouring vegetative growth.

Table 5. Effects of mulch on reproductive growth of brown bean.

Mulch Type	Days to flowering	Days to physiological maturing	Plant Height (cm)
Control (T_0)	54.00d	64.50c	14.64d
Dry Maize Straw (T_1)	57.38bc	67.75b	21.00bc
White plastic (T_2)	60.00a	71.25a	27.52a
Black plastic (T_3)	59.50ab	70.00ab	25.00ab
LSD (0.05)	2.24	3.1	4.22
CV (%)	2.54	2.95	12.83

Days to physiological maturity

The study found that mulch application significantly influences the time it takes for plants to reach physiological maturity. Brown bean plants mulched with white plastic took 71.25 days longer to reach maturity, while those without mulch took 64.5 days (Table 5). The study also found a 7-day difference between white plastic mulched and un-mulched plots. Dry maize straw mulched plants had a slower maturity period of about 3 days, with a significant difference.

Plant height

The application of mulch significantly impacted plant height, with the shortest plants (14.63 cm) obtained from plots without mulch and taller plants (27.52 cm) from plots with white plastic mulch (Table 5). This finding is consistent with previous studies in common beans, brown beans, and faba beans. Residual moisture stress during vegetative and generative stages decreased plant height, possibly due to the soil residual moisture conserved by mulch. Plant height had a linear correlation with soil residual moisture availability, and the capacity of the mulch to conserve soil residual moisture is attributed to these effects.

3.5. Effects of Mulch on Growth Parameters of Brown Bean

Number of pods per plant (NP)

Mulch treatment significantly impacts the average number of pods per plant, with controlled plots producing the fewest pods (12.25). White plastic mulched plots produce the most pods per plant (16.65). Implementing better residual moisture conservation techniques resulted in a 36% increase compared to the control plots (Table 6). Residual moisture deficiency can lead to inadequate fruit setting, and factors such as flower shedding and fertilization failure can cause reductions. The highest reduction of pods per plant occurs during the flowering stage, as confirmed by Mederski [28]. Recent research by Kumar *et al.*, [29] found that residual moisture stress during the flowering and pod formation stage resulted in a smaller number of pods per plant in green gram. Rahman *et al.*, [30] reported a significant reduction in pods per soybean plant when exposed to residual moisture stress during the flowering stage. However, exposure to reproductive structure, residual moisture stress, physiological and biochemical processes could lead to unfavourable conditions for pod formation and ultimately reduce pod number per plant.

Table 6. Effect of mulch on the growth parameters.

Mulch Type	Number of pods per plant (NP)	Pod length (cm)	Pod dry weight (gm)	Harvest period	Total dry matter
Control (T_0)	12.25d	9.04c	0.33c	7.00c	6.63c
Dry Maize Straw (T_1)	14.32bc	10.04b	0.55b	9.00b	9.30b
White plastic (T_2)	16.65a	11.00a	0.7675a	12.00a	12.00a
Black plastic (T_3)	16.03a	10.70b	0.7625a	14.00a	11.30a
LSD (0.05)	1.68	6.06	0.18	3.03	2.38
CV (%)	7.58	0.94	20.7	18.16	16.07

Pod length

The study found that white plastic mulched plots had the highest pod length (11.00 cm), while un-mulched plots had the lowest (0.94 cm) as presented in Table 6. No significant differences were found between dry maize straw mulch and control plots. The analysis of variance showed significant differences in pod length due to different mulch types. Plastic mulches generally play a more significant role in plant cell division and fruit enlarging due to residual moisture availability, turgor pressure, and photosynthesis rate.

Pod dry weight (PDW)

The study found that the maximum single pod dry weight was observed on a plot mulched by white polythene (0.7675 g), while the minimum was observed on the plot without mulch (0.33 g). Organic mulch (dry maize straw) significantly affected pod dry weight (PDW), with an increased weight of 66.6% compared to control plots (Table 6). This could be due to residual moisture in the soil interrupting physiological and biochemical processes, leading to restrictions on carbohydrate metabolism and biochemical changes in pods. This is due to reduced acid invert activity, resulting in a lower hexose-to-sucrose ratio, inhibiting cell division in ovules and pod walls. This weakens the strength of attracting photosynthates from source organs, resulting in lower availability of photosynthates in source leaves and decreased carbohydrates being distributed into the pods. This may have impaired the capacity of developing pods to use incoming sucrose, retarding expansion growth.

Harvesting period

The harvesting period for un-mulched and black plastic mulch ranges from 7 to 14 days, with a 7-day difference between control and white plastic (Table 6). This could be due to favourable soil residual moisture conditions, which encourage more pod development in highly moistened plots. However, stressed or un-mulched plots result in pod abortion, resulting in a short harvesting period. Organic mulch, such as dry maize straw mulch, has no significant difference from unmulched plots due to no residual moisture variation. Significant differences were observed among different mulch applications for the pod harvesting period at $p < 0.01$.

Total dry matter

The study found a significant difference in total dry weight per plant between different mulch applications. White plastic mulch increased total dry matter by 81.13% compared to control plots (Table 6). This could be due to evapotranspiration, reduced transpiration and photosynthesis rates, and reduced biomass accumulation. Organic mulch, such as dry maize straw, affected total dry matter more than un-mulched plots due to residual moisture conservation in the soil profile. The increase in plant dry matter under optimal soil residual moisture could be attributed to water-induced changes in specific metabolic processes of plant cells. High soil residual moisture reduces stomatal closure, opening pathways for water, carbon dioxide, and oxygen exchange, leading to an increased photosynthetic rate. This increases vegetative growth, such as plant height, leaf area, and lateral shoot number. The increase in leaf area, light interception, and photosynthesis leads to increased fresh and dry weights, which positively respond to increasing residual moisture conservation practices.

3.6. Effects of Mulch on Yield Parameter of Brown Bean

Average fresh pod weight per plant

Mulching significantly impacts the average fresh pod weight per plant, with transparent polythene plots having a mean average fresh pod weight of 15.01 g/sq·m, compared to 11.37 g/sq·m in an un-mulched plot. This decrease in soil residual moisture leads to reduced water absorption by roots, resulting in decreased leaf area, cell size, and intercellular volume. This decrease in fruit residual moisture accumulation and weight is expected during residual moisture stress, as it decreases photosynthesis, tissue water potential, and the flux of photosynthetic supply from source leaves to the pods. The analysis of variance results showed a statistical difference between fresh pod weight from dry maize straw mulched and control plots, while the differences between black and transparent polythene mulched plots were not significant due to the non-availability of residual moisture.

Marketable yield

The study found that different mulch types significantly impacted marketable brown bean yields. Transparent polythene mulches yielded the highest mean yield (35.28 tonnes/hectare), while un-mulched plots had the lowest yield (24.39 tonnes/hectare) as presented in Table 7. No significant difference was found between transparent and black polythene mulches. The results suggest that mulch helps prevent crop pod contact with the ground, reducing soil rot and maintaining product cleanliness.

Table 7. Mean value of fresh pod weight, marketable, unmarketable, and total yield.

Mulch Type	Fresh pod weight (t/ha)	Marketable yield (t/ha)	Unmarketable yield (t/ha)	Total yield (t/ha)
Control (T_0)	0.11d	24.39c	4.20a	28.44d
Dry Maize Straw (T_1)	0.13bc	28.82b	3.23bc	33.00bc
White plastic (T_2)	0.15a	35.28a	2.16d	37.53a
Black plastic (T_3)	0.14ab	33.49a	2.85cd	35.62ab
LSD (0.05)	1.2	293.5	87.57	299.78
CV (%)	5.89	6.39	17.36	5.89

Unmarketable Yield

Mulching significantly impacts the yield and quality of crops, including beans. A study found that the highest unmarketable yield was obtained from un-mulched plots, while the lowest was observed from plots applied with transparent polythene. This finding is similar to a 2015 study by McIntosh *et al.*, [31] which found that using maize stover and cattle manure mulch significantly reduced the unmarketable yield of common beans in Zimbabwe. Similarly, Dia *et al.*, [32] found that using maize stover and dry grass mulch significantly reduced the unmarketable yield of bush beans in Zambia. The study also found that mulching improved soil residual moisture and nutrient retention, contributing to increased bean yield and quality. Overall, mulching is a beneficial method for improving the yield and quality of various crops, including beans.

Total Yield

Soil residual moisture plays a crucial role in determining bean yield. A study by Wang *et al.*, [33] [34] found that moderate soil residual moisture content (around 60% field capacity) is optimal for bean growth and yield. Excessive soil residual moisture (above 80% field capacity) reduces yield due to decreased root respiration and increased disease incidence. Inadequate soil residual moisture (below 40% field capacity) reduces yield due to decreased plant growth and nutrient uptake.

A significant difference was observed among different mulch applications for total pod yield. The highest total pod yield (37.53 tonnes/hectare) was recorded from plots mulched with transparent polythene, followed by the black (35.62 tonnes/hectare). Fine polythene mulch, black polythene mulch, and dry maize straw mulch increased total fruit yields by 32%, 25%, and 16%, respectively (**Table 7**), compared to un-mulched treatments.

A study by Zhou *et al.*, [35] found that moderate soil residual moisture content (about 70% field capacity) was optimal for bean growth and yield. Excess soil residual moisture (above 90% field capacity) reduced yield due to decreased soil aeration and increased disease incidence. Inadequate soil residual moisture (below 50% field capacity) reduced yield due to decreased nutrient uptake and plant growth.

Another study by Zhang *et al.*, [22] found that soil residual moisture content significantly affected bean yield. The optimal soil residual moisture content for obtaining the highest yield was determined to be 60% of field capacity.

4. Conclusion

The study found that inorganic mulch, specifically polythene mulch, was more effective in conserving residual moisture in brown beans than organic mulch. Polythene mulch conserved water by 16.4%, 17.3%, 27.14%, and 4.2% (0 - 30 cm) and 22.88%, 25.55%, 25.77%, and 4.4% (30 - 60 cm) compared to the control at four growth stages. However, the difference was insignificant at any soil depth, as transparent polythene absorbs less solar radiation, resulting in less evaporation. Dry maize straw also conserved residual moisture by 5.57%, 12.54%, 13.19%, and 1.75% (0 - 30 cm) and 9.7%, 14.98%, 15.24%, and 2.58% (30 - 60 cm) at four growth stages. The yield components measurement showed that brown bean yield from polythene mulch was higher (37.531 g/sq·m) than control plots (28.444 g/sq·m) total yield increment by 32%. The study concluded that mulching had a significant effect on soil residual moisture conservation and agronomic parameters, with white polythene mulch having the highest soil water content. The best material for the study area was transparent polyethylene.

Conflicts of Interest

The authors declare no conflicts of interest.

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