



## Application of mixture experiment in optimizing Cabbage (*Brassica Oleracea L.*) yield using varied organic manure sources, in Turbo – Uasin Gishu County, Kenya

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### Abstract

The basis for this research was to determine the optimum yield performance of Cabbage as influenced by four varied types of manures: Chicken, Pig, Goat and used Tealeaves. The primary goal was to develop the best organic fertilizer or mixture proportion that would maximize crop yield. Utilizing right quantities of manure would ultimately lead to small-scale farmers having optimal yields and hence fetching increased profits. The {4,4} Simplex-Lattice Design was employed considering either the single-component or combination of two manure at a time at different proportions. The final average weight of the crop was analyzed using R Software. Second-Order regression models were plotted with intercepts set to zero. The model aided plotting of the contour plot. This is essential in establishing recommended proportions of manure in their pure or binary blends that offer optimal operating conditions. Different combinations of manures adding to unity were tested. Results were comparably different because selected manures had different nutrient components in them. The study concluded that Pig manure was the best single component that yielded maximally with an average weight of 2.93 and 2.86 Kg in the overall model and reduced model, respectively. For the binary blends, a combination of Chicken and Pig manure gave highest output, 1.16 Kg, with 0.6 and 0.7 working conditions, respectively. These findings are recommended for adoption by farmers to boost yields. This would increase income and ultimately help in eradicating poverty, which is a menace to the economic growth of our country.

**Keywords:** Best organic manure, Optimum yield, Regression model, Simplex-Lattice Design, Working condition

### INTRODUCTION

Cabbage is a type of vegetable that widely used worldwide; consumed as either food or for medicinal purposes or sold for income. They are suited to various climatic zones of the world, ranging from cold to warm conditions depending on the variety. It's a first-rate source of vitamin C and contains several mineral contents such as potassium, calcium, magnesium and traces of zinc used by crops in their ionic form. It grows well by using inorganic fertilizers but because these fertilizers are generally not accepted in the world markets, hence use of organic fertilizers in growing such is highly recommended. Additionally, they have minimal side effects on the soil properties.

In recent years, consumption of this particular vegetable has risen immensely with the increase in world population. Nevertheless, its productivity per unit area remains quite low in the third-world as compared to developed countries (Anon, 2006). Among the various factors involved, nutrient supply is an imperative input for realizing higher cabbage yield and its nutrient content.

Cabbage farming is a reliable business that someone can venture into and fetch good profits at the end of production period, which is approximately shillings 50,000 per acre. However, decisions such as land size, variety and or type of cabbage, soil type, land terrain, season to plant and availability of market have to be made before the actual production commencement. Of key and significant impact is the market, this shows that market research ought to be explored earlier before actual planting is done.

Different varieties of cabbage do well under different climatic conditions thus variety choice is essential. Varieties differ in shape, colour, number of days to maturity, textures, yields and resistance to pests and diseases. It can be



grown in diverse soil types but to realize good profits, the soil should be well-drained, moisture retentive loamy soil that is well supplied with proportionate humus. The soil pH should range from 6.0 to 7.5.

Manure play important roles that benefit both plants and environment. They supplement the plant with required nutrients to boost growth, hence affecting quality and quantity as depicted by yield differences. Usually manure is applied at the time of planting though others are applied as top dress. This research intended to test effects of selected manures singly (purely) and/or in mixture form. Nutrient composition that respective manure was having were manifested by the overall yield production after the study.

Animal wastes', usually fecal droppings and urine, and plants' rotten matter have several nutrients including; nitrogen, potassium, calcium, phosphorus, sulphur, etc. at varied levels. These nutrients are absorbed and adsorbed by plants in ionic form with the aid of roots and used up to synthesize sustaining nutrients. Crops need these supplements to boost their yields. (BARI,2015).

A mixture experiment is an experiment which entails mingling of different proportions of two or more components to come up with an entirely different composition of a final product. Subsequently, several theoretical and practical problems are allied to the investigation of the mixture ingredients of  $m$  factors, assumed to impact the response through proportions in which they are unified (Cornell 1990). Several examples of application of mixture experiments have been done in different lines of disciplines provided that the factors under test can be blended. This was first done by (Scheffe, 1963).

Mixture and mixing are common terms in an extensive range of applications both in research and in theoretical talking. It usually involves in amalgamation of two or more ingredients with an intention of having a different component at the culmination. The final component is assumed to affect the variable of interest (the response). For instance, in making tea; water, milk, tea leaves and sugar should be mixed proportionately so that the response of interest, which is a sense of taste, should be attained (Cornell, 2002). In a mixture experiment, total amount of mixture is usually fixed and components are varied but must always sum to unity. (Bondari, 2005).

## METHODOLOGY

In the general mixture technique, response of interest is usually assumed to depend on ingredients under test in the mixture and not amount of mixture. In this research, amount of manure mixture (either single component or combination) was fixed to 48g per seedling per experimental point. (Bari, 2015). If this a forementioned condition is not considered, it will lead to erroneous conclusions since manure will add yields significantly. All proportions i.e., manure under study must sum to unity.

### Useful equation in the mixture experiment

In a mixture experiment with  $q$  components and  $N$  design points, just like normal canonical polynomials, the first-order (Linear) and Second-order (Quadratic) polynomial models are given as below:

Linear: 
$$\hat{Y}(x) = \sum_{i=1}^q b_i x_i + \varepsilon.$$
 (1)

Quadratic: 
$$\hat{Y}(x) = \sum_{i=1}^q b_i x_i + \sum_{i=1}^q \sum_{i \neq j=2}^q b_{ij} x_i x_j + \varepsilon.$$
 (2)

Coefficient of the resultant fitted polynomial of the mixture experiment is treated as the normal regression coefficient.  $\beta_i$ ,  $i = 1, 2, 3, \dots, q$  is taken as the effect of the  $i^{\text{th}}$  component in its pure blend and  $\beta_{ij}$  is taken as the combined effect of  $i^{\text{th}}$  and  $j^{\text{th}}$  components in their binary blend. If the sign of either  $\beta_i$  or  $\beta_{ij}$  is positive, then the components in  $i$  and  $ij$  in their joint effect are synergistic. On the other hand, if the sign of either  $\beta_i$  or  $\beta_{ij}$  is negative, they show antagonistic behavior. (Upendra, *et al.* 2017)

### The Slope of the Response Surface along the Component Axes

With the aid of Scheffe polynomial, the rate at which the mixture surface changes are depicted along the component axes. This will help in visualizing what happens when the mixture in both their pure and mixture form behaves to the overall result. This gives us hints on the shape and surfaces and their approach to optimality. Commonly used second-degree Scheffe polynomial in the  $q$  component is given as;



$$\hat{y}(x) = b_0 + \sum_{i=1}^n b_i X_i + \sum_{i=1}^n b_{ij} X_i X_j + \dots \quad (3)$$

For the mixture experiment the intercept values are not considered and equation 3 reduces to equation 4.

$$\hat{y}(x) = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{14} X_1 X_4 + b_{23} X_2 X_3 + b_{24} X_2 X_4 + b_{34} X_3 X_4 \quad (4)$$

Fitting slope with  $q \geq 4$  is usually cumbersome in the software. Since this research considers four components simultaneously and their mixtures, one of the components was fixed at a given interval of interest based on a certain criterion of choice. The interval of fixing one of the components to aid in visualizing the remaining is subject to the range  $0 \leq X_j \leq 1 - X_j$ .

**Materials**

The following supplies were necessary for this research; cabbage seeds, the four-selected manure under study, planting farm tools and equipment, stationery, land for planting and water. Certified seeds were sourced from Kenya Seed Company Ltd, Eldoret Depot. For the sake of research purposes, only one variety of cabbage (Flora F1) was planted. Four types of manures to be tested in this research were obtained from farmers who have animals that secrete them. Because they were readily available, they were either obtained free of charge or bought depending on mutual agreement between the farmer and researcher. However, used tea leaves were obtained from different hotels within Eldoret town.

For vibrant growth of the crop and for quality heads of cabbage to be realized, water is very essential. Selected site for planting the crop was a place where there was plenty supply of water for irrigation purposes. A borehole was in the nearby place that eased the watering process hence ensuring that the crop investigated was well irrigated throughout the study period. During the rainy seasons, watering was not of the essence.

Farm tools and equipment needed for research were sourced from home and those missing were bought to aid in implementation process. Stationery, in particular a book, pencils, lamination materials and others that were necessary for implementation of the study and data collection were bought too. Among crucial stationery were labels that show proportion of manure that was used in every plot and or every experimental point. These labels were typed, printed and laminated to avoid being torn easily.

**Labour**

Labour was provided by members of the immediate local community who have experience in all the processes of land preparation which includes tilling, soil sifting, levelling, making plots and holes where the seedlings are to be planted. These practices were undertaken under the keen supervision of researcher so that experimental layout procedures were well adhered to. Extension officer, horticulturist, was contacted and was answerable for supervisory on when and how to do several routine management practices of cabbage planting.

**NB:** All the routine practices were done on the same day and using similar methods/types to avoid other effects that may come up due to variations.

**Design**

The experiment was carried out in  $\{4 \times 4\}$  Simplex Lattice Design which is termed an ideal four-factor mixture experiment design (Chirchir, 2024). It had 35 experimental points as shown in Table 1.

**Table 1.** Layout of experimental points in  $\{4 \times 4\}$  Simplex-Lattice Design

Experimental Points	$\{4 \times 4\}$ design Components				Observed Response
	X1	X2	X3	X4	
1	1	0	0	0	Y1
2	0	1	0	0	Y2
3	0	0	1	0	Y3
4	0	0	0	1	Y4
5	0.25	0.75	0	0	Y12
6	0.25	0	0.75	0	Y13
7	0.25	0	0	0.75	Y14



8	0	0.25	0.75	0	Y23
9	0	0.25	0	0.75	Y24
10	0	0	0.25	0.75	Y34
11	0.75	0.25	0	0	Y12*
12	0.75	0	0.25	0	Y13*
13	0.75	0	0	0.25	Y14*
14	0	0.75	0.25	0	Y23*
15	0	0.75	0	0.25	Y24*
16	0	0	0.75	0.25	Y34*
17	0.5	0.5	0	0	Y12**
18	0.5	0	0.5	0	Y13**
19	0.5	0	0	0.5	Y14**
20	0	0.5	0.5	0	Y23**
21	0	0.5	0	0.5	Y24**
22	0	0	0.5	0.5	Y34**
23	0.25	0.25	0.5	0	Y123
24	0.25	0.25	0	0.5	Y124
25	0.25	0	0.25	0.5	Y134
26	0.25	0.5	0.25	0	Y123*
27	0.25	0.5	0	0.25	Y124*
28	0.25	0	0.5	0.25	Y134*
29	0	0.25	0.25	0.5	Y234
30	0	0.25	0.5	0.25	Y234*
31	0.5	0.25	0.25	0	Y123**
32	0.5	0.25	0	0.25	Y124**
33	0.5	0	0.25	0.25	Y134**
34	0	0.5	0.25	0.25	Y234**
35	0.25	0.25	0.25	0.25	Y1234

\*Implies the second time yield of a particular set of manure is mixed at a given proportion different from the first case while \*\* is its third appearance.

### Location

The experimentation was conducted at Murgusi Village, Murgusi sub-Location, Ngenyile Location, Nyenyile Ward, Turbo sub-County of Uasin Gishu County, Kenya. It is located approximately 37 km from Eldoret Town on the way to Uganda. The soil type is loamy and area is conducive for planting majorly all types of cereals, legumes, several fruit trees and horticultural crops. The place is located on gently undulating slopes, hence not waterlogged.

### Assumptions

The following assumptions were observed throughout the experimental period. They include:

- i. The amount of water irrigated/ rains in each plot was similar,
- ii. The seedling grew at an equal interval,
- iii. Site soil type is similar in all aspects i.e., texture, nutrient content, water retention ability and color,
- iv. Weather and sunshine shall remain constant and will affect all the seedlings simultaneously, and
- v. All the data collected at the end of the experimentation were distributed normally with a minute minimum error term difference.

### Implementation of the Research

To implement this research on the optimization of cabbage yields by using mixture methodology approach, the following were done to ensure the objectives of the study were realized. Proper and realistic procedures were followed to reduce errors and hence increase precision.

#### Step 1: Acquisition of manure and preparation

Manures were assembled, placed in separate black polythene bags and buried for 14 days to decompose. Decomposition is crucial because it releases the humus component of the manures. This was to help seedlings to easily absorb the nutritive components. After the elapse of 14 days, the manures were removed and dried under



the sun to maintain the moisture content in all the manures to be constant. This content was to be maintained at 60% in all four types of manures. Moisture content was done by taking the samples to a laboratory to be tested.

**Step 2: Measurement and mixing**

Depending on the given experimental point that was considered one by one, measurement was done proportionately. Measurement of the manures was done using a digital weighing machine. The manures were then mixed by hand to make a mixture of 1.5kg. The mixtures are then labelled clearly and distinctively, and then be kept safely. Measurement of 48g was measured and packed in small envelopes. These were the ones used in planting i.e., in every seedling position within a given plot.

**Step 3: Preparing seed nursery**

The seed nursery bed was prepared measuring 1M by 2M. The soil was heaped above the normal earth's surface level. The hardpans were removed and the soil was made to be soft. Levelling was done to ensure that there was an even growth of the seedlings after shooting. The site for the nursery bed was secure, well aerated and there was free penetration of the sun rays. These conditions will enable the seeds to shoot faster and grow in a healthy form.

**Step 4: Spacing and making planting holes**

The spacing for planting was measured accurately at a spacing of 60cm by 60cm i.e., from seedling to seedling is 60cm and from one row to another is also 60cm apart. Holes were then made that were about 4 inches deep. Manures were then placed in these holes and painstakingly mixed with the topsoil in readiness for plantation. Transplanting was done in one day to reduce any errors that may result due to sparing planting date.

**Step 5: Routine management practices**

All the necessary routine management for the production was adhered to as directed by the horticulturist at the right time that was deemed best to be done. Such practices include weeding, controlling pests and insects that might damage the crop under investigation and securing the area. All such practices were done in a single day.

**Step 6: Harvesting, weighing and recording**

Harvesting was done in a single day by hand and the resultants' heads of cabbage were weighed using the digital weighing machine and the results, weight in Kg, were recorded accurately. The whole crop was weighed from the very base of it to the entire shoot without interfering with its withered leaves. Data obtained were then used for analysis and to help in drawing relevant statistical conclusions.

**RESULTS AND DISCUSSION**

**General descriptive statistics**

**Table 2. Plot number, coded variables, manure source and final average weight of cabbage**

Plot	Coded Variables`				Manure Source				Average weight of cabbage (kg)
	X1	X2	X3	X4	Chicken manure (g)	Pig manure (g)	Goat manure (g)	Used Tealeaves manure (g)	
P1	1	0	0	0	48	0	0	0	2.5634
P2	0	1	0	0	0	48	0	0	3.0881
P3	0	0	1	0	0	0	48	0	2.2397
P4	0	0	0	1	0	0	0	48	0.8622
P5	0.25	0.75	0	0	12	36	0	0	0.1428
P6	0.25	0	0.75	0	12	0	36	0	2.9803
P7	0.25	0	0	0.75	12	0	0	36	0.8796



P8	0	0.25	0.75	0	0	12	36	0	2.0938
P9	0	0.25	0	0.75	0	12	0	36	1.1811
P10	0	0	0.25	0.75	0	0	12	36	0.8135
P11	0.75	0.25	0	0	36	12	0	0	2.6904
P12	0.75	0	0.25	0	36	0	12	0	1.9971
P13	0.75	0	0	0.25	36	0	0	12	2.441
P14	0	0.75	0.25	0	0	36	12	0	2.4919
P15	0	0.75	0	0.25	0	36	0	12	1.8322
P16	0	0	0.75	0.25	0	0	36	12	1.7416
P17	0.5	0.5	0	0	24	24	0	0	2.9122
P18	0.5	0	0.5	0	24	0	24	0	1.9711
P19	0.5	0	0	0.5	24	0	0	24	1.4717
P20	0	0.5	0.5	0	0	24	24	0	2.5081
P21	0	0.5	0	0.5	0	24	0	24	1.5792
P22	0	0	0.5	0.5	0	0	24	24	1.2871
P23	0.25	0.25	0.5	0	12	12	24	0	2.2272
P24	0.25	0.25	0	0.5	12	12	0	24	2.2927
P25	0.25	0	0.25	0.5	12	0	12	24	2.0304
P26	0.25	0.5	0.25	0	12	24	12	0	2.7882
P27	0.25	0.5	0	0.25	12	24	0	12	2.1197
P28	0.25	0	0.5	0.25	12	0	24	12	2.0222
P29	0	0.25	0.25	0.5	0	12	12	12	1.3373
P30	0	0.25	0.5	0.25	0	12	24	12	2.4851
P31	0.5	0.25	0.25	0	24	12	12	0	2.8488
P32	0.5	0.25	0	0.25	24	12	0	12	2.4219
P33	0.5	0	0.25	0.25	24	0	12	12	1.8822
P34	0	0.5	0.25	0.25	0	24	12	12	2.0975
P35	0.25	0.25	0.25	0.25	12	12	12	12	2.1909

Table 2 shows the plot number, coded variables, actual variable proportions and the final average weight records for the crop. They were entered in MicroSoft Excel Application and exported to R software for data analysis. With the help of the installed mixexp package: Library(mixexp), models were fitted as shown below:

**Boxplot of Average Weight of Cabbage (In Kg)**

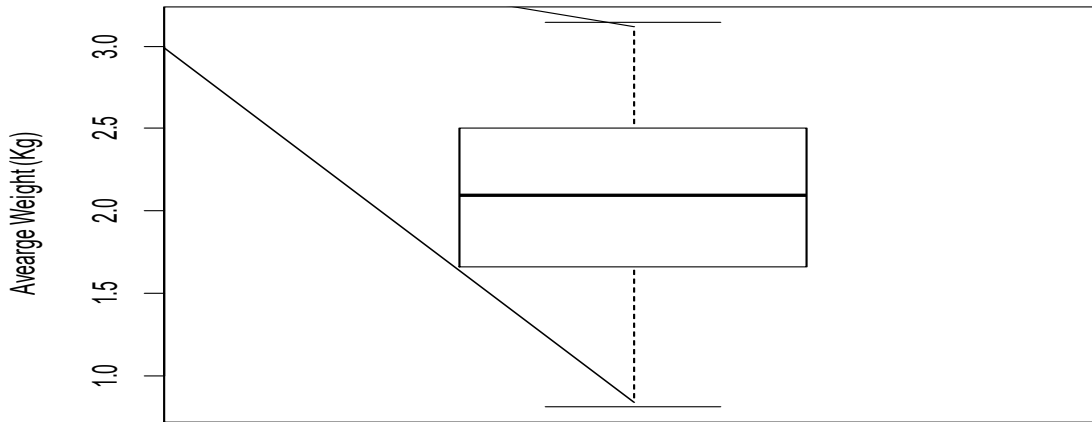


Figure 1. Boxplot of the average weight of cabbage (kg).

Considering Figure 1, it can be deduced that the average of the means of cabbage production as affected by the manures stands at approximately 2.1 kilograms. The lower quartile values were 1.65 kg and with upper quartile average figure of 2.5 Kg. The entire average weight was spread between 0.4 kg and 3.2 Kg.

**Visual test of the Data**

**Histogram of Average weight of Cabbage (in Kg)**

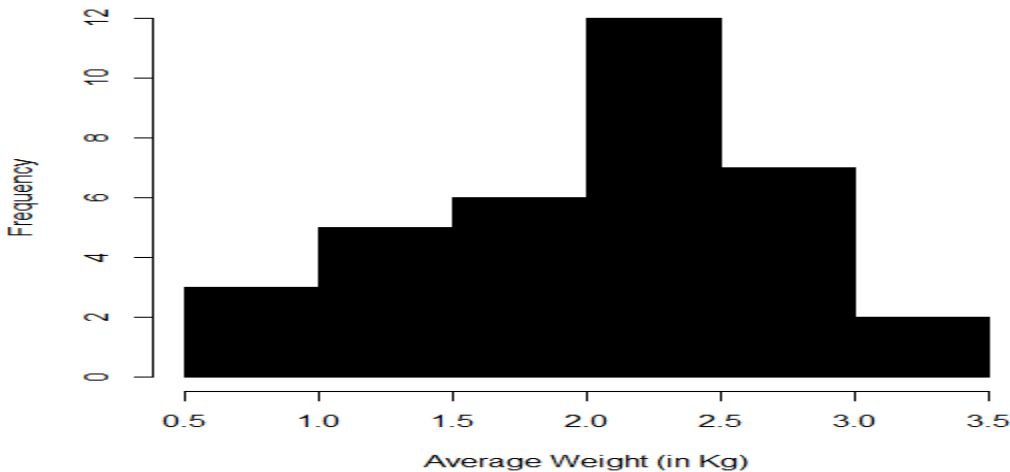


Figure 2. Histogram of the average weight of cabbage

From the above histogram of average weight of cabbage (kg), it is evident that majority of the crop weighed between 2.0 to 2.5 kilograms. For effectiveness of the manures as far as their effect is concerned, the weight should have been above 3 kilograms in each plot.

Only two (2) plots registered the high weight that is of much concern in the study. On the other hand, three (3) plots recorded an average weight of less than 1 kilogram showing that such manure or the proportion of manure present in those plots had the least effect on the production of the crop.

**Regression for mixture: Average weight of cabbage (kg) versus chicken manure, pig manure, goat manure and used tealeaves manure.**

The final weight collected upon measuring the weight of each head of cabbage in the 35 different plots was well recorded. The data were entered in Microsoft Excel Computer Application and saved as comma-separated values (.csv). The data were later on exported to R Software for analysis purposes. The model was fitted using the installed mixexp package: library(mixexp). Regression model is meant to show the relationship between the response of interest (the final average weight of cabbage) as affected by different proportions of manure, at different plots. The effects of the mixture components on the final weight of the crop are shown in Table 3.

Table 3. Table showing model fit for the final data

Variable	Coefficients Estimate	Standard Error	T-value	P- value	Significance level
X1	2.4551	0.24722	9.931	3.69E-10	***
X2	2.92675	0.24722	11.839	9.60E-12	***
X3	2.32556	0.24722	9.407	1.09E-09	***
X4	0.63954	0.24722	2.587	0.0159	*
X1X2	1.16088	1.00703	1.153	0.2599	
X1X3	-0.24141	1.00703	-0.24	0.8125	
X1X4	0.40072	1.00703	0.398	0.6941	
X2X3	-0.57667	1.00703	-0.573	0.572	
X2X4	-1.20671	1.00703	-1.198	0.242	
X3X4	0.06404	1.00703	0.064	0.9498	

Table 3 shows estimated regression coefficients. It can be seen clearly that the pure components X1, X2, X3 and X4 were significant as shown by the respective *p* – values at a 5% significance level.

The fitted model would be of the form below:

$$\hat{Y}(x) = 2.4551X1 + 2.92675X2 + 2.32556X3 + 0.63954X4 + 1.16088X1X2 - 0.24141X1X3 + 0.40072X1X4 - 0.57667X2X3 - 1.20671X2X4 + 0.06404X3X4. \tag{5}$$

The fitted model indicated a representation of the final weight of cabbage as achieved from the different mixture proportions of the manures under consideration. Hence, the following conclusions were arrived at based on the greatness of the parameter estimates from the equation:

$b1 = 2.4551, b2 = 2.92675, b3 = 2.32556$  and  $b4 = 0.63954$   
 i.e.,  $b2 > b1 > b3 > b4$

This shows that as far as the single-component mixture is concerned, the parameter estimates for component 2 (pig manure), 2.92675 kg, gave the highest final weight followed by component 1 (chicken manure), 2.4551 kg. Thirdly, component 3 (goat manure), 2.32556 kg, and finally component 4 (used tea leaves manure), 0.63954 kg, as shown above. Concluding that, pig manure will be the most effective single-component manure in maximizing cabbage production. If pig manure cannot be found, chicken manure will be the most probable for consideration followed by goat manure and last used tea leaves.

It further showed that all the pure mixtures had a synergistic effect on the final weight of the crop hence significant as a forementioned.

For the two components, the following has that,

$b12 = 1.16088, b13 = - 0.24141, b14 = 0.40072, b23 = - 0.57667, b24 = - 1.20671$  and  $b34 = 0.06404$  as values of the binary coefficient estimates, respectively. It shows that  $b12 > b14 > b34 > 0$ . That is, the positive interaction coefficients of blending chicken manure and pig manure, chicken manure and used tea leaves together with that of goat manure and used tea leaves manure are smaller than their coefficient, which indicates that combining these manures will not have a substantial impact on the yield beside the fact that they have a synergistic effect. On the other hand,  $b24 < b23 < b13 < 0$ . The negative interaction coefficient of pig manure/used tea leaves manure,



pig/goat manure and chicken/goat manure indicate no significance and antagonism towards each other. Implying that such components when mixed do not augment cabbage yield.

Therefore, in recommending single-component manure for the production of cabbage, then pig manure (Component X2) would be the best to use. As for the binary blends, the combination of component X1 (Chicken manure) and component X2 (Pig manure) is to be considered the best as compared to the other combinations. Furthermore, from the above output, the coefficient of determination,  $R^2$ , of 0.9855 (98.55%) and an adjusted  $R^2$  of 0.9798 (97.98%). This shows that the model could explain a greater variation of data. It further implies a good fit for the data.

Table 4. The Analysis of Variance (ANOVA) for cabbage yield (Kg) in mixture proportions.

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	F value	P value	Significance
X1	1	83.801	83.801	881.4412	< 2.2e-16	***
X2	1	53.282	53.282	560.4323	< 2.2e-16	***
X3	1	23.262	23.262	244.6769	2.03E-14	***
X4	1	1.276	1.276	13.426	0.001167	**
X1X2	1	0.199	0.199	2.0902	0.160665	
X1X3	1	0.01	0.01	0.1027	0.751256	
X1X4	1	0.029	0.029	0.3064	0.584833	
X2X3	1	0.017	0.017	0.177	0.677582	
X2X4	1	0.143	0.143	1.5032	0.23161	
X3X4	1	0.000	0.000	0.004	0.949797	
Residuals	25	2.377	0.095			
Total	35	164.396				

The Analysis of Variance results for the final weight of the crop under study is summarized as shown in Table 4. The probability values for the pure blends showed statistical significance as compared to the interaction terms. Furthermore, it could not be concluded wholly that there was a statistical significance between the terms and the response. As a result, this affected and implied the need for a model reduction so that only significant terms are considered.

**Model Reduction of Average Weight of Cabbage.**

Table 5. Table showing the model reduction for the crop.

Variable	Coefficient Estimates	Standard Error	T- Value	P- Value	Significance Level
X1	2.6301	0.1474	17.839	< 2e-16	***
X2	2.8589	0.1474	19.391	< 2e-16	***
X3	2.2413	0.1474	15.202	6.43E-16	***
X4	0.5568	0.1474	3.776	0.00068	***

The output above gives a significant model in equation 6.

$$\hat{Y}(X) = 2.6301X1 + 2.8589X2 + 2.2413X3 + 0.5568X4 \tag{6}$$

Generally, if coefficient estimates all have positive sign, then there is proof of the ability of the variables to increase the overall response of interest while a negative sign indicates an ability to decrease the response. Secondly, the model had all its terms being significant as shown by their respective P- values, all of them being

less than a 5% level of significance; hence, an indication of significant linear model fit. It was the recommended model for the final average weight of cabbage, given the varying proportions of the four manure components. The coefficient of determination,  $R^2$ , gave 0.9831 (98.31%) with an adjusted  $R^2$  of 0.9809 (98.09%) and an F-statistic of 451.4 on 4 and 31 Degrees of freedom (DF). This is an assurance that the model had a good fit to the data. The model could explain a greater variation of the data.

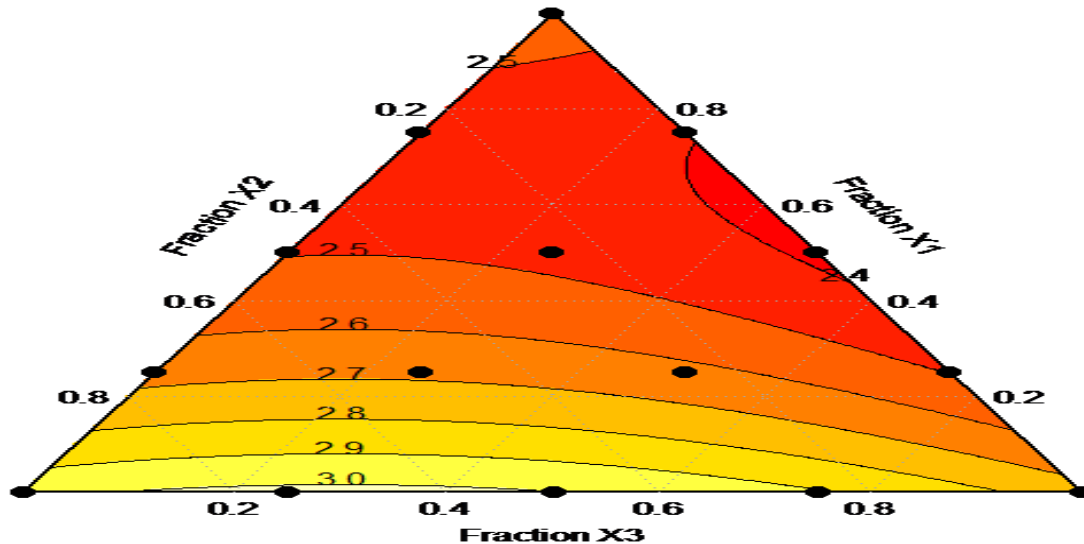


Figure 3. Contour plot for the final weight of the crop to the blend proportion of lead manure.

To get a graphical representation, a contour plot was plotted in Figure 3 to show how the fitted final weight values relate to the selected manures and mixture proportions based on the model of the equation. Component 4,  $X_4$  was equated to zero (0) because it gave out least impact on the final yield of the crop. The mixture triangular contour plots plotted illustrated the relationship between the final weights of the cabbage and the amounts of components  $X_1$ ,  $X_2$  and  $X_3$ . The highest final weight of 3 kg was obtained by 0.6 of component  $X_1$  (Chicken manure) and 0.7 of component  $X_2$  (Pig manure). This shows that as far as mixture proportions of manures are concerned, the above proportion would yield maximally.

### CONCLUSION

Mixture experiments and their analysis are widely applicable to a wide range of agricultural field experiments such as feed trials, intercropping and feed formulation among others.

The  $\{4 \times 4\}$  SLD was applied in the maximization of cabbage (*Brassica oleracea*) considering four selected manures from chicken, pigs, goats and used tea leaves. It had 35 experimental points and hence 35 different types of mixture proportions resulting in 35 plots. Out of the 35 plots, 4 were single-component (pure), 18 were double-component (binary), 12 were triple-component (ternary) and only one was a quadruple-component (all the four in equal proportions). All manures in their respective proportions were mixed accordingly and labelled distinctively and so were the plots.

The results of analysing the mixture experiment data, upon obtaining the yield at the finale of the study, led to coming up with models labelled Equation 5 and 6 i.e., the overall model and the reduced model respectively. They were evaluated further based on the coefficient of determination,  $R^2$ , of 0.9855 (98.55%) and 0.9831 (98.31%), and adjusted  $R^2$  of 0.9798 (97.98%) and 0.9809 (98.09%) in that order. These implied that the models explained a greater variation of the data and hence a good fit.

In the model, the varied proportions of nutrients present in the manures demonstrated that in pure blends, component  $X_2$  (Pig manure) gave the highest final average weight. On the other hand, a second-order mixture regression proved effective in finding a synergistic effect on the binary blend of component  $X_1$  (Chicken manure) and component  $X_2$  (pig manure) on maximizing cabbage yields as compared to the other mixture combinations, which had either a lower positive value or showed an antagonistic effect. This implies that production of this crop



can rise by blending these two manures. The contour plots also showed crucial information for establishing desirable working conditions as far as the four components and the highest final weight of the crop are concerned.

## RECOMMENDATIONS

- The plotted model is recommended to cabbage farmers, both small scale and large scale. Farmers who wish to venture into such farming of the crop are to be informed of these new findings so that they can apply and in return fetch good profits.
- The study would also recommend that it would be of great importance to apply a mixture experiment in the optimization of cabbage using five (5) or more organic manure to see if a much better model would be achieved. This is because there are several other types of organic manure such as cow manure, sheep manure, turkey manure and green manure among others that need to be tested as far as their effects on the growth of the crop are concerned. This is done to compare and contrast their response with what is obtained in this research work and hence reinforce it.
- The study suggests that research could be done on the maximization of other horticultural crops such as kale, spinach, pepper, Cole, etc. using a mixture experiment as an optimization tool.
- The study also suggests that maximization of cabbage (*Brassica oleracea*) yield in a different location such as the Central region of Kenya, where the crop is highly grown, be done using the same manure type and the same design for comparison purposes.

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