ACTA TECHNICA CORVINIENSIS
– Bulletin of Engineering
Tome X [2017]
Fascicule 1 [January – March]
ISSN: 2067 – 3809

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PREDICTING AMARANTH YIELD (Amaranthus Hypochondriacus) CULTIVATED ON A NON-COHESIVE SOIL

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Abstract: Amaranth hypochondraicus is an uncommon amaranth in West Africa highly characterized with his multifunctional values which ranges from its good edible leaves, ornamental purpose and to its highly nutritious and medicinal seeds. This study was aimed at predicting yields obtained from an experimental farm using irrigation water as a single factor at four different levels. The levels of factor imposed include: applying 60%, 70%, 80% and 90% of the water needed to bring soil moisture content to field capacity. The site used in the study was designed to provide for maximum water control as much as possible. The plot framing was used to demarcate the study site into sixteen different plots of 1 m^2 each with four replicates designed with Latin Square Experimental Design. A total crop yield of 33.6 kg was obtained for all the plots. Plots treated with 90% water needed to bring soil moisture to field capacity recorded yield of 11.6 kg (representing 34.52% of total yield), plots with 80% water treatment yielded 9.3 kg (27.68%), plots with 70% water treatment recorded 7.2 kg (21.43%) and those treated with 60% water yielded 5.5 kg (16.37%). The results showed that higher yield is obtainable at higher water application. Using Design Expert to analyze the yields from the field, the predicted yields which correlate with the actual yields from the field was obtained. Significant differences existed between the yields obtained. The predicted and actual yield models gave ranges of R-square values with the highest value of 0.86 obtained plots treated with 90% water needed to bring soil moisture to field capacity. R-square values of 0.64, 0.61 and 0.47 were obtained for plots treated with 80%, 70% and 60% water needed to bring soil moisture to field capacity. The study shows that Amaranthus hypochodraicus is better predicted with minimum water stress of the field capacity.

Keywords: Amaranthus hypochondriacus, yield, field capacity and water stress

INTRODUCTION

The challenge for agricultural practices to increase food production to obtain food security still persists after 45 years of the Green Revolution (Hobbs, 2007 and Prabhu, 2012). The first Millennium Development goal is to reduce hunger and poverty by 2015 (Dixon et al.,2006). The demand for food is increasing, not only because of the growing population, but also to provide more nutritious food with high protein quality and nutraceutical compounds. Amaranth (Amaranthus hypochondriacus) (Prince of Wales) is a crop naturally resistant to water deficit and is a good source of protein; the seeds have high amounts of protein containing essential amino acid such as lysine, methionine and squalene, an important precursor for all steroids (He et al., 2002, Barba et al; 2009, Garcia-Gonzalez, et al; 2009, Achigan-Dako, et al; 2014). Since the beginning of the 1980s, amaranth has been rediscovered and several reports have tried to promote it as a basic crop (Kauffman, 1992). In addition to nutritional characteristics, amaranth plants have agronomic features identifying it as an alternative crop where cereals and vegetables cannot be grown (dry soils, high altitudes and high temperatures) (Omamiet al., 2006). In general, the selection of promising genotype in a breeding program is based on various criteria, with the most important being final crop yield quality (Kozaket al., 2008).Dietary intake of vegetables is low in Africa compared to the world's average. This situation is worsened by low water availability for vegetable production especially in the dry season. Amaranth can be grown in the different agro-ecologies of Nigeria is a dual purpose crop with edible leaves and seeds rich in essential nutrients, minerals and proteins

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(Olufolajiet al., 2010). There is dearth of knowledge about water requirements of amaranth especially as it relates to varietal water use efficiencies (Liu and Stutzel 2004; Quereshi et al; 2012). Amaranth varieties differ in morphology, physiological structures, root system and days to maturity. These differences could be responsible for the ability of one variety to use irrigation water more optimally than the other (Olufolaji and Tayo 1989). This study was therefore conducted to predict the optimum yield that can be obtained under different water stress situations.

METHODOLOGY

The Study Site and Land Preparation

This study site (Fig 1)is located at University of Ilorin main campus, Ilorin, Kwara State, Nigeria. The institution is situated at Ilorin South Local Government Area, Ilorin, Nigeria which lies on the latitude 8^0 30^1 N and longitude 4^0 35^1 E at an elevation of about 340 m above the sea level (Ejieji and Adeniran, 2009). Ilorin, the capital city of Kwara State is in Southern Guinea Savannah Ecological Zone of Nigreria with an annual rainfall of about 1300 mm. Plot framing was done immediately after the field has been irrigated to field capacity and the sample for the determination of field capacity has been taking from the field. Framing was done to minimize inter-seepage of irrigation water from one plot to the other thereby minimizes experimental error due to treatment (irrigation water).. The plank frame is 25mm x 100 mm (i.e. 1” x 4”) plank. The frame is then fully forced to the ground.

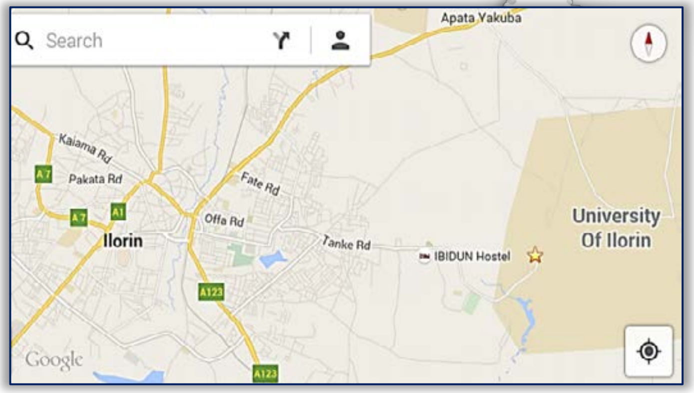

Figure 1: Ilorin Metropolis indicating University of Ilorin, Kwara State, Nigeria. *Source: Google search GPS*

Experimental Design

The experimental field was designed using Latin Square Design (LSD) with four (4) blocks of four replicates applying the principle of rational mechanism. Moreover, the principle of local control is adequately accommodated.

Sieve Analysis for Determination of Soil Cohesiveness

The sieve analysis (Table 1) conducted shows that the field soil is non-cohesive since the proportion of the clay content is negligible.

Table 1: Soil sieve analysis

Sieve Size	weight retain (g)	% retained	% passing
2	330	14.52	85.48
1.7	260	11.44	74.03
1.4	257	11.31	62.72
0.3	710	31.25	31.47
0.15	400	17.61	13.86
0.075	280	12.32	1.54
< 0.075	35	1.54	0.00

Determination of Moisture Content at Field Capacity

The field was irrigated till the soil was saturated and then allowed to drain for about 72 hours. At this point, the field was assumed to be at field capacity (Michael, 2008). A graduated sampler of 4.4 cm diameter and about 55 cm long was carefully driven through the soil to take sample randomly in the experimental field to a depth of 40 cm (covering the effective root depth zone of amaranth which is about 30-40 cm). The sample was cut into five (5) layers which represent 8 cm profile each. Each profile mass was determined and recorded separately as m_1(wet mass). The samples were placed in the oven at temperature of 105 ^{0}C for 24 hours. The oven dried mass were determined and simultaneously as m_2. The moisture content at field capacity was determined as:

$$mc_{fP} = \frac{m_2 - m_1}{m_1} \times 100\ (\%) \qquad (1)$$

$$\rho_b = \frac{m_d}{V_s} \qquad (2)$$

where $m_d = m_2$ and $V_s = \frac{\pi\phi^2}{4}$

$$\rho_b = 4\left(\frac{m_3 - m_1}{\pi d^2 h}\right) \qquad (3)$$

where ρ_b = bulk density of soil (g/cm^3), h = height of sampler, m_1= mass of wet sample, m_2 = mass of dry oven dry sample, where ρ_b = bulk density of soil (g/cm^3), ϕ = diameter of sampler, V_s = volume of sampler

Available Water(AW)

$$AW = \frac{D\rho_b}{\rho_w}\left(\frac{FC - WP}{100}\right), cm \qquad (4)$$

For this study, the moisture content at field capacity (FC) = M_{cf}

$$AW = \frac{D\rho_b}{\rho_w}\left(\frac{M_{cf} - WP}{100}\right), cm \qquad (5)$$

where: ρ_w = density of water, D = soil profile depth

$$WP = \frac{FC}{F} = \frac{M_{cf}}{F} \qquad (6)$$

where:

WP is moisture content at wilting point and F is a factor ranging from 2.0 – 2.4

The factor F depends on the percentage of silt content in the soil. Since the soil is made up of 85.48 % mainly sand (70.08%) and silt (15.4%) which gave ratio 1:4.5 silt to clay, F of 2.1 was adopted. For this research, WP was calculated to be 12.04%.

Analytical Modeling of Irrigation Management

From Figure 2,

$$AW = D\frac{\rho_b}{\rho_w}\left(\frac{FC-PWP}{100}\right), cm \qquad (7)$$

$$d = D\frac{\rho_b}{\rho_w}\left(\frac{FC-m_c}{100}\right) = X\%TAW \qquad (8)$$

$$FC = D\frac{\rho_b}{\rho_w}\theta_v, cm \qquad (9)$$

where θ_v is the volumetric FC (%).

Table 4 gives the soil data from the experimental farm taking into consideration the equations 3.7 and 3.9 at D = 35 cm (an approximate of root depth zone of amaranth).

Table 4: Soil moisture data

Soil moisture	Value
ρ_b	1.355g/cm^3
FC (25.3%)	11.999 cm
PWP (12.04%)	5.710 cm
TAW	6.289 cm

Net volume of water required for irrigation per plot, V_n

$$V_n = I_d \times A \qquad (10)$$

where A = area of the plot, For this study, A =1 m^2

Actual volume of water required for irrigation per plot

$$V_{actual} = (I_d + Losses - Gain)A \qquad (11)$$

$$Losses = ET \qquad (12)$$

$$Gain = ER + S \qquad (13)$$

where: ER = effective rainfall. This can be obtained from the installed raingauge. S = carry over soil moisture in the root zone which is an equivalent of the instantaneous moisture depth in the root zone. ET = evapotranspiration

Mathematically,

$$S = Dm_c\frac{\rho_b}{\rho_w} \qquad (14)$$

Water losses have been reduced to ET only because the soil has been significantly drain therefore subsequent drainage is negligible.

Equation 11 could be rewritten as given in eqn 15

$$V_{actual} = (I_d + ET - ER - S)A \qquad (15)$$

where: V_{actual} is the actual volume of irrigation water required per plot.

Models for the Average Evapotranspiration and Irrigation Interval

Average evapotranspiration (ET) was obtained by subjecting the soil at field capacity to normal atmospheric conditions and thereby determine the soil moisture content to the assigned root zone by taking sample randomly in at least four points of the experimental field. This experiment was done for at least 7 days by randomizing the portion of the field from which the sample was taken. Average daily changes in moisture content were obtained as analyzed in Table 5. The daily results for the moisture content as it changes with evapotranspiration is given in Table 6 while Table 7 shows the computed daily moisture fluctuation in the experimental field.

Average daily ET

The model for the average daily ET is given in eqn (16)

$$ET = D\frac{\rho_b}{\rho_w}\sum_1^N\frac{\Delta m_c}{N},\ N \neq 0\ (cm) \qquad (16)$$

Average daily change in moisture content

The model for the average daily change in moisture content (S) is given in equation (17)

$$S = D\frac{\rho_b}{\rho_w}\sum_1^N\frac{m_c}{N},\ N \neq 0\ (cm) \qquad (17)$$

Table 5: Daily change in moisture content

Day	Moisture content, m_c (%)	Δm_c (%)
1	m_{c1}	FC - m_{c1}
2	m_{c2}	m_{c1} - m_{c2}
3	m_{c3}	m_{c2} - m_{c3}
4	m_{c4}	m_{c3} - m_{c4}
5	m_{c5}	m_{c4} - m_{c5}
6	m_{c6}	m_{c5} - m_{c6}
7	m_{c7}	m_{c6} - m_{c7}

Table 6: Moisture content as it changes with evapotranspiration

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
19.52941	26.19757	21.42623	15.51843	18.94045	19.77863	15.21053
24.17009	18.6328	13.88376	15.01813	17.89559	16.83545	13.89855
19.9103	15.6724	21.61145	15.71328	16.97857	18.41935	12.3536
19.92371	18.57409	24.80854	18.08946	17.79751	16.59328	18.02191
24.75423	20.43652	20.39208	25.69545	22.61252	14.85455	20.08153
19.40966	21.08277	18.53065	15.0448	16.69656	16.61056	14.88135
24.56603	19.1812	15.72103	15.14658	18.24947	17.35238	16.89479
30.49977	17.82752	15.44887	16.76808	14.77242	17.79825	15.52352
26.19686	19.72206	21.56738	20.65447	13.18516	16.76271	15.1047
22.64384	22.06304	20.21851	24.88199	19.70063	16.29061	17.26649
23.16039	19.939	19.36085	18.25307	17.68289	17.12958	15.9237

Table 7: Computed Moisture Content Fluctuation in the Soil

Day	Moisture content, m_c (%)	Δm_c (%)
1	23.16039	2.13961
2	19.939	3.22139
3	19.36085	0.57815
4	18.25307	1.10778
5	17.68289	0.57018
6	17.12958	0.55331
7	15.9237	1.20588
Average	18.7785	1.339471

ET = 0.635 cm/day

Irrigation Interval

The empirical model computed for irrigation interval is given in equation (18)

$$I_v = \frac{d}{\left(\frac{\sum_1^N \Delta m_c}{KN}\right)} \quad \text{(days)} \qquad (18)$$

where: K is a crop factor, N = no of days, Δm_c is the daily change in soil moisture, d is depth of water required to bring the soil to field capacity and I_v is the irrigation interval.

Since the average moisture content next day after irrigation is 18.78% (8.906 cm), while the field capacity is 25.30% (11.999 cm), then water needed to bring the soil to FC is the difference between FC and S which is equivalent to 6.52% (3.093 cm). At 60% SMD (i.e. 60% of 3.093 cm) it gives 1.8558 cm. For this research, actual S the difference between I_d and 1.8558 (i.e. 3.093 – 1.856) which is equivalent to 1.237 cm.Since d is 3.77 cm and the average moisture loss per day ET is 1.339% (0.635 cm), therefore, for this study, irrigation interval was divided into two (2) phases: vegetative phase 2-7 WAP and the maturity phase 7-9 WAP. Table 8 give the summary of the determination of irrigation interval for each phase while Table 9 summarize the net actual volume of irrigation water required per plot in the absence of rainfall.

Table 8: Determination of Irrigation Interval

Phase	K	ET (cm/day)	d (cm)	I_v (day)
Vegetative phase (2-7 WAP)	0.7	0.635	3.77	8
Maturity phase (7-9 WAP)	1.0	0.635	3.77	5

Table 9: Net and Actual volume of irrigation water required per plot

Level	I_d of d	I_d (cm)	ET	S	V_n (litres)	V_{actual} (litres)
1	I_d = 60% of d	2.26	0.635	1.237	22.6	16.6
2	I_d = 70% of d	2.64	0.635	1.237	26.4	20.4
3	I_d = 80% of d	3.02	0.635	1.237	30.2	24.2
4	I_d = 90% of d	3.39	0.635	1.237	33.9	28.0

For this study, irrigation interval of 4 days (vegetative phase) and 2-3 days (maturity phase) was adopted using half of the actual volume of water required for irrigation for every plot.

Development of growth equation

The yields obtained from the conduct of the field experiment in relation to their various treatments could be used to model the growth equation of the amaranth through their graphical relationship. It is certain that the yield would do best at certain soil moisture which is in fraction of field capacity or water required to bring the soil to field capacity. The linear relationship between the yield and the treatment is in form of equation (19)

$$Y = f(A,B,C,D,E) = kX \qquad (19)$$

where: Y = yield (treatment effect);A, B, C, D are treatments (water application in percentage of field capacity or of water required to bring soil to filed capacity).

The growth model (in terms of yield) was developed using: regression analysis and design expert.

Regression Analysis and Modeling

Regression model is of form of eqn 20

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon \qquad (20)$$

where: y is the response variable (yield, kg) that you wish to predict β_0, β_1, $\cdots\beta_k$ are parameters with unknown values; x_1, x_2, $\cdots$ x_k are independent variables (water application,%)

The random error $\varepsilon$was assumed to have a normal distribution probability distribution with mean equal to zero and variance equal to σ^2 and that they are mutually independent.For this study, Regression Calculator was adopted for the experiment analysis and modeling. This was so because it iseasy-to-use statistical software for regression analysis. It does not require any programming or some sort of command.It also provides advanced modelling tools such as variable selection and transformation.

Design Expert and Optimization

Design expert was used to optimize the yields obtained from the study. It is an automatic system that uses combined, mixture, response surface and factorial design. For this study, Factorial Design of Experiments (DOE) was adopted because it accommodates to a large extent all engineering experimental design provided that the factor for the design does not exceed twelve. Factorial design expert was used to analyze individual yield per plant and obtain predicted optimized yields.

Validation of Results

Validation of results was done by adopting polynomial function model (mathematical and graphical) by comparing the actual measurement with the optimized predicted measurements for all levels of factor (60%, 70%, 80% and 90% of the field capacity respectively). Graphical analysis of the optimized predicted measurements and actual measurements were determined for every level of factor.R^2 for every level of factor were obtained and compared with measured values.

RESULTS AND DISCUSSION

Results of the Amaranth Yield at Different Levels of Water Application

Figure 2 summarized the yield of Amaranthus hypochondraicus of each plots using random treatment effect of water application in percentage of the field capacity. The water applications in percentage of field capacity are indicated by the symbols as described by the key. Table 10 shows yield per plant from the experimental farm. It shows that the yields at: 60% of the field capacity ranges from 1.2 kg – 1.5 kg, 70% of the field capacity ranges from 1.7 kg to 1.9 kg, 80% of the field capacity ranges from 2.1 kg – 2.5 kg while 90% of the field capacity ranges from 2.5 kg to 3.3 kg.

The study shows that as the moisture content increases the R-square value increases, that is, the R-square value increases as crop water stress reduces. This show that the yield of the study crop, Amaranthus hypochondraicus is better predicted as moisture content approaches that at field capacity. The R-squares values show that Amaranthus hypochondraicus is highly sensitive to water stress.

Design Expert Optimization

Using design expert optimization, the response in yields per plant in relative to each standard order, block and run is summarized in Table11. An average of ten yields were selected randomly from the field and classified into ten classes namely Yield 1, Yield 2, Yield 3, ..., Yield 10. The selected measurements were analyzed as shown in the results in Tables 11 and 12.

ResultsValidation

The predicted results as evaluated by design expert optimization were compared with the actual results from field. It was found that the various observations with their relative levels of factor were so close in magnitude (Tables 11 and 12).

When the predicted and actual results were graphically analyzed through polynomial function model the R-square obtained showed that there is significant difference between the efficiency of various levels of water application in relation to the yield obtained.

Figs 2 to 5 shows that at the water stress of 60, 70, 80 and 90%of the field capacity, R-square was found to be 0.4688 (46.88%), 0.6077 (60.77%), 0.6409 (64.09%) and 0.8628 (86.28%) respectively. This infered that higher yield is achievable at higher moisture contents.

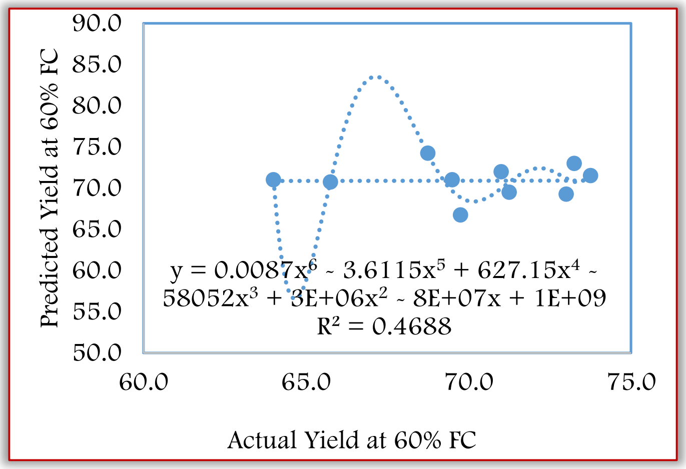

Figure 2. Predicted Yield vs Actual Yield (at 60% moisture content of the field capacity

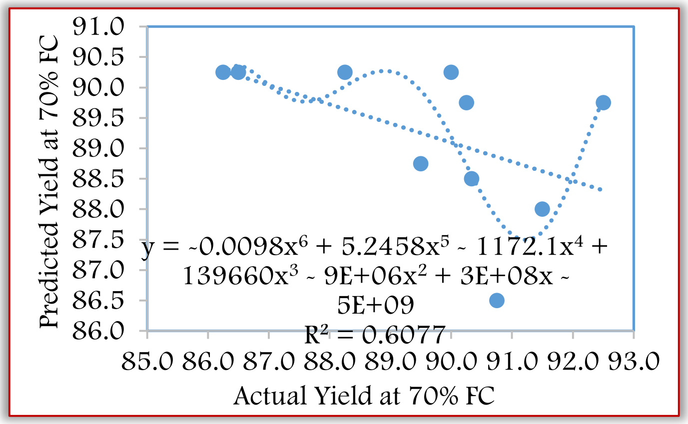

Figure 3. Predicted Yield vs Actual Yield (at 70% moisture content of the field capacity)

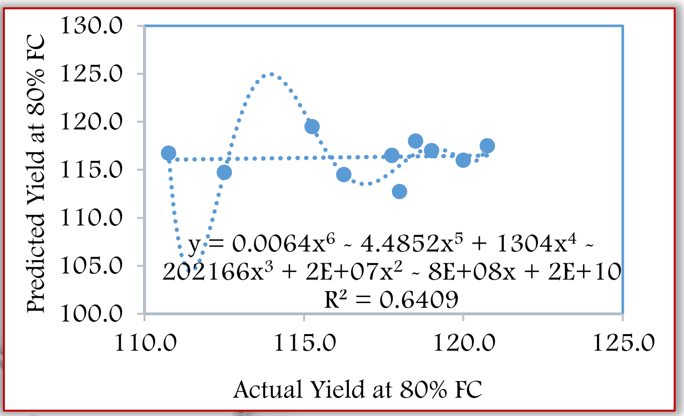

Figure 4. Predicted Yield vs Actual Yield (at 80% moisture content of the field capacity)

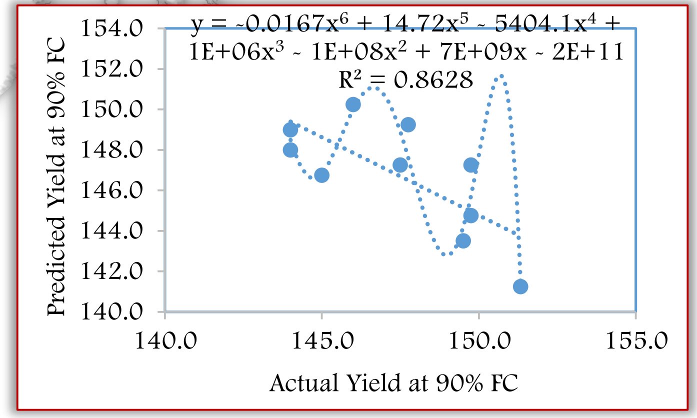

Figure 5: Predicted Yield vs Actual Yield (at 90% moisture content of the field capacity)

Table 11: Predicted Measurement at Various Degree of the field capacity

Response	Predicted (g)			
	60% FC	70% FC	80% FC	90% FC
Yield 1	73.0	88.0	119.5	143.5
Yield 2	70.8	89.8	117.5	149.3
Yield 3	71.5	90.3	117.0	150.3
Yield 4	69.3	89.8	116.0	149.0
Yield 5	69.5	86.5	118.0	146.8
Yield 6	71.0	90.3	116.8	144.8
Yield 7	74.3	90.3	114.8	148.0
Yield 8	66.8	88.8	114.5	147.3
Yield 9	72.0	90.3	116.5	147.3
Yield 10	71.0	88.5	112.8	141.3
Average	70.9	89.2	116.3	146.7

Table 12: Actual Measurement at Various Degree of the field capacity

Response	Actual (g)			
	60% FC	70% FC	80% FC	90% FC
Yield 1	73.3	91.5	115.3	149.5
Yield 2	65.8	90.3	120.8	147.8
Yield 3	73.8	86.5	119.0	146.0
Yield 4	73.0	92.5	120.0	144.0
Yield 5	71.3	90.8	118.5	145.0
Yield 6	69.5	86.3	110.8	149.8
Yield 7	68.8	88.3	112.5	144.0
Yield 8	69.8	89.5	116.3	149.8
Yield 9	71.0	90.0	117.8	147.5
Yield 10	64.0	90.3	118.0	151.3
Average	70.0	89.6	116.9	147.5

CONCLUSION

This study shows that the accuracy of predicting the yield of Amaranthus hypochondraicus increased as the moisture content increases, the highest is obtained when there is no water stress, that at 100% of the field capacity. Optimization of measurements from the experimental farm indicates maximum yields at the maximum field capacity which goes in agreement with the actual measurement after validation.The field water regulation of the amaranth for maximum yield is best done at possible maximum field capacity. It is therefore recommended that the moisture content be maintained at the field capacity in other to obtain maximum yield for every amaranth planted on a non-cohesive soil.

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ISSN:2067-3809

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