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Article

Modelling of Cowpea Growth Phases Under the Impact of Water Stress Using Regression Analysis

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Abstract: Cowpea, *Vigna unguiculata* (L.) also known as southern peas is a yearly grown legume that is native from Africa but now are widely cultivated around the world, particularly in South-east Asia, Latin America, and Southern United States. Moreover, the crop can endure excessive heat but is also susceptible to frost. Cowpea are profitable for the agricultural industry and are often utilized as a supplement nutrition for both human and animals. As a result, it serves as a significant low-cost source of premium plant protein across many poor households. Moreover, the crop is widely used as a green mature and as a cover crop. Furthermore, the cowpea thrives in a wide range of soil types and soil conditions. The crop's capacity to withstand drought is a special trait for coping with the severe environmental challenges caused by global warming. However, due to a prolonged lack of rain during the rainy season, South African agriculture is subject to severe edaphic and climatic challenges, including water stress and insufficient soil nutrients. Consequently, this work focuses on analyzing cowpea's growth phases by proposing novel regression models under the impact of water stress for local farmers to optimally map out cultivation over the period of drought without imperiling their yields. The proposed regression models predict the cowpea's growth at various periods of water stress including vegetative to maturity, flower to maturity and excellent water through the season. At each period of water stress, regression models of the leaf area and shoot dry weight are developed. The various growth phases of the cowpeas were studied under three-pot test conditions. The results suggest that water stress at initial growth phases decreased the shoot dry weight (SDW), and leaf area (LA) of studied cowpeas. Growth analysis of cowpeas species cultivated in pure stands for the distinctive periods showed that the leaf area was the most explanatory variable in the SDW of cowpea at the initial growth phase. The correlation coefficient of the LA and SDW of cowpeas produced by the proposed models at vegetative to maturity, flower to maturity and excellent water through the season are 0.957 and 0.983, 0.963 and 0.980, 0.957 and 0.976

Keywords: South Africa; Cowpeas; water stress.

1. Introduction

Cowpea *Vigna unguiculata* (L.) is the fourth most essential oil seed producer and the fifteenth most important and widely cultivated grain crop in the world [1,2]. The primary reason cowpea is grown is because they are significant sources of plant protein and energy for both human and animal nutrition, making them an essential plant in the global food security. cowpea is also notable for its capacity to fix atmospheric nitrogen, utilizing part of it for its own development and growth while returning some of it into the soil for the interest of the following crop in rotation with it. Cowpea have a protein value of 23-25%, which is usually equivalent to dry beans 15-24%, chickpeas 20-25%, lentils 9-15%, and spotted sugar beans 9.8%. Despite its capacity to support food security and its potential to solve starvation of the enormous increasing population which is predicted will be 50 billions by 2050, cowpea is ignored and neglected in many countries. Cowpea is sown in Southern African countries for its grain, pods, and leaves. However, it makes a good source of feed for livestock and is

essential to agricultural schemes for crop output and exportation. It improves the of soil in the agricultural system by making up for the loss of nitrogen received by cereals. cowpea repairs about 70 and 344 kg per hectare of nitrogen yearly by biological means. Unfortunately, due to poor agronomic systems and insufficient soil fertility farmers are unable to do this. It is a potential food source and foraging species in a conventional tropical lowland climate since it is a drought-resistant and warm-season crop.

There are 6.2 million metric tons of cowpea produced yearly on an approximate 14.5 million ha of cultivated land worldwide. Global cowpea production increased by 7% yearly on average over the last four decades, with annual area growth of 4.5% and productivity growth of 1.9%, with elongated contributing of 60%. Over 80% of African supply is concentrated in West Africa, which also accounts for over 84% of the world's total production of cowpeas. Although cowpea development has been effective across so many countries and in the key producing regions, very little is documented about its productivity, yield, storage, distribution, significance, and use. Cowpea yields have consistently lagged behind global standards and have regularly not reached their full potential. Inadequate information and inconsistent performance are signs that small-scale farming predominates in the production of cowpea. The inaccessibility to advanced technologies, such as improved varieties and the crop and pest management strategies that go along with them, inputs like fertilizers (both mineral and biofertilizers), seeds of improved varieties, and inadequate input and output market access limit the production and productivity of cowpea. In view of their excellent ability in utilizing soil water, they can tolerate drought stress and recover quickly throughout the vegetative development phase by re-watering. Competition is a continuous process that is influenced by the number of resources obtained by various species as well as their ability in utilizing those resources for biomass. Competition might well be influenced by rates of growth and other aspects of plant density and function. Understanding the factors that influence crop, weed development, and competition interaction could contribute to the emergence of production strategies that optimize crop development by reducing weed competition. Mpumalanga's yearly rainfall is unusually low, and severe agricultural water shortages. Additionally, in moderate areas, soil water is the major limiting factor.

Interestingly, cowpea is a summer-grown plant that grows together in the field in various areas of the country. Cowpea is largely-known for its ability to tolerate water scarcity. A typical example of Cowpeas in South African soil is demonstrated in Figure 1.



Figure 1. Cowpeas in South African soil.

The seeds generally yielded in South Africa are illustrated in Figure 2.



Figure 2. Common Cowpeas seeds in South Africa.

As a result, the current study was conducted to determine cowpea growth and performance under different water strain treatments and the growth, survival and development of cowpea cultivated separately or in combination for various periods.

2. Materials and Methods

2.1. Description of the Study

Various activities were carried out during the course of this study, such as site selection, soil sample prior to planting for detailed characterization, field trial setup, and subsequent follow-up tasks. From March to June 2021, three-pot tests were conducted on a farm-based in Mpumalanga has a yearly average temperature of 28 °C, with a sandy loam soil, and receives about 667 mm of rain annual, (25.4365°S, 30.9818°E), one in a greenhouse environment and the other two in the outdoors. A 30.7 % of silt soil, clay loam soil with 57.6% clay, 12% sand by weight, organic matter composition [2.03 % (w/w)], a 12.25 % (w/v) of CaCO₃, phosphorous (0.025 mg g⁻¹) with a pH of 8.3 was used as well. However, the Lowveld Agricultural Corporation contributed to the cowpea seeds.

2.2. Description of Experimental Design and Layout

At the trial sites previously mentioned in the description site, five (5) cowpea varieties were planted using a randomized complete block design (RCDB) with three replications. The experimental units were three-row plots that were 5 m long, 0.75 m wide, and had an intra-row spacing of 0.30 m, resulting in a population density of 44,444 plants/ha at a density of one plant per stand. Three to four seeds were sown per hill, however they had to be thinned to two plants after three weeks before seedling emergence. 10 kg of lime ammonium nitrate (LAN) will be administered per hectare in order to encourage great root growth and remove any potential confounding effects of nitrogen deficit. From late vegetative growth until pod physiological maturity, regular 80 ml/15L application of the broad-spectrum insecticide karate will be made to combat weeds and insects.

2.3. Experiment: Effect of Water Stress on Growth of Cowpea Grown in Pure Stands

The purpose of this experiment was to understand how various levels of water strain affected the development of cowpeas. Containers with a width of 25 cm and a depth of 22 cm were occupied with uniformly mixed field soil. Seed sowing was done on March 25, 2021 in all containers and further thinned after three weeks to one plant seedling to reduce competition like sunlight, moisture, and nutrients. However, the same spatial configuration was maintained for mutually samples from

various treatments. Seedlings were propagated in an untreated greenhouse with an average day/night temperature of 30/21° C.

Experiments were set up in a randomized complete block design (RCDB), including three water stress treatments as plots treated, all of which were replicated four times. Seedlings were immersed in water as a standard treatment. Interestingly, stress that occurred during the vegetative phase persisted during blooming, and there was no water stress. Moisture was controlled in stress applications till the tensiometer confirmed 65% and the plants began to show wilting signs, after which water was given to the soil surface. The practice of drying and re-watering proceeded till the crop fully developed. Furthermore, plants in the treated stress condition were irrigated daily with an equal quantity of water.

Each crop variety height, leaf number, and length were recorded, as well as the number of branches, and age-related number of leaves, beginning 26 days following emergence and continuing throughout harvesting. Temperature at the greenhouse was maintained on a daily bases. Prior to crop harvest, data on growth characteristics, such as leaf length, plant height, number of branches, chlorophyll content index, and the number of trifoliate leaves per plant, were collected on a two weeks interval. Data on the pod mass, total plants per pod, pod length, seed yield, seeds per pod, mass fodder, and haulm weight were also collected during the harvest.

On June 15, 2021, all plants in each container were acquired by cautiously uprooting dry cowpea plants, and trembling the collected plants to eradicate freely adhered soils to the roots. Collected samples were transported in a disinfected brown envelop to the Biology Laboratory in an cooler box. Gathered samples were kept at -20°C until further analysis.

2.4. Statistical Analysis

The analysis of variance (ANOVA) system were used to analyze all of the acquired data. The generalized linear mixed model was used to analyze greenhouse data (growth and yield) (GLMM). The least significant difference (LSD) at a 5% probability level was used to determine whether there is a significant difference between the treatment means.

3. Results

This section presents results on cowpeas growth at various phases of water stresses. The results indicate regression models developed for various periods of water stress including vegetative to maturity, flower to maturity and excellent water through the season. At each period of water stress, regression models of the leaf area and shoot dry weight are developed. The growth phase of cowpeas at the vegetative to maturity period is observed in the next subsection. The LA and SDW of the cowpea are observed and regression models are developed.

3.1. Vegetative to Maturity Period

Leaf Area (LA)

Cowpea dry shoot weight decreased at a modest rate up to a concentration of 8 seedlings per container whenever water stress occurred earlier in the vegetative phase and remained unchanged afterwards. Shoot dry weight dropped dramatically with concentration whenever water stress began at flowering and there was no water pressure as a result of a reduction in leaf surface relative productivity growth. Furthermore, extended miserable water stress gives rise to the strength of intraspecific competition. Cowpea leaf length and breadth and leaf surface had a linear correlation that was independent of moisture stress and seedling frequency. The experimental data of the leaf area measured over 14 weeks is presented in Figure 3.

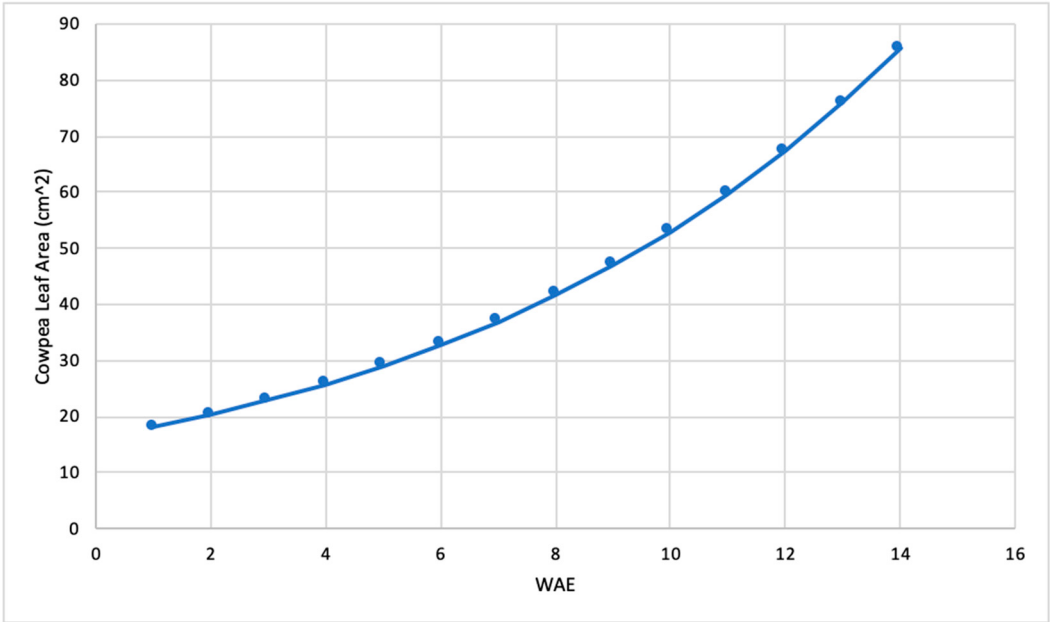


Figure 3. Experimental data of the leaf area measured over 14 weeks.

3.2. NB: Week After Emergence (WAE)

Cowpea pod and seed production were influenced by both low moisture and compaction stresses. When contrasted to water stress that began at the plant developmental and blooming stages, capsule dry weight improved about 5.5 and 1.76 times, whereas the amount of seeds/plant improved by 7 and 4 times, accordingly. Seed frequency was inversely associated with cowpea capsule dry mass and quantity of seeds per plant. At low plant rates, the inequalities in moisture stress impact were higher. The proposed regression model for the LA under the vegetative to maturity period is tabulated in Table 1.

Table 1. Regression summary for the Cowpea Leaf Area.

Regression	Stats						
Multiple R	0.978						
R Square	0.957						
Adjusted	0.953						
Standard Er.	4.667						
ANOVA	df	ss	MS	f	Significance f		
Regression	1	5794.586	5794.586	266	1.487E-09		
Residual	12	261.411	21,784				
Total	13	6056					
	Coefficients	Standard Err	t stat	P-value	Upper95%	Lower95,0%	Upper95,0%
Intercept	6.156	2.635	2.336	0.038	0.415	11.896	11.896
WAE	5.047	0.309	16.309	1.487E-09	5.721	4.372	5.721

The correlation coefficient is observed to be 0.957, signifying a significant correlation between the practical data and the predicted values. Consequently, the p-value is observed to be less than 0.05 (0.038) which implies that the data is statistically significant. It specifies convincing substantiation in

contradiction to the null hypothesis, given that there is less than a 5% probability the null is correct. Therefore, for the Cowpea Leaf Area, the null hypothesis is rejected.

The line fit plot for the Cowpea leaf area of the proposed model is demonstrated in Figure 4.

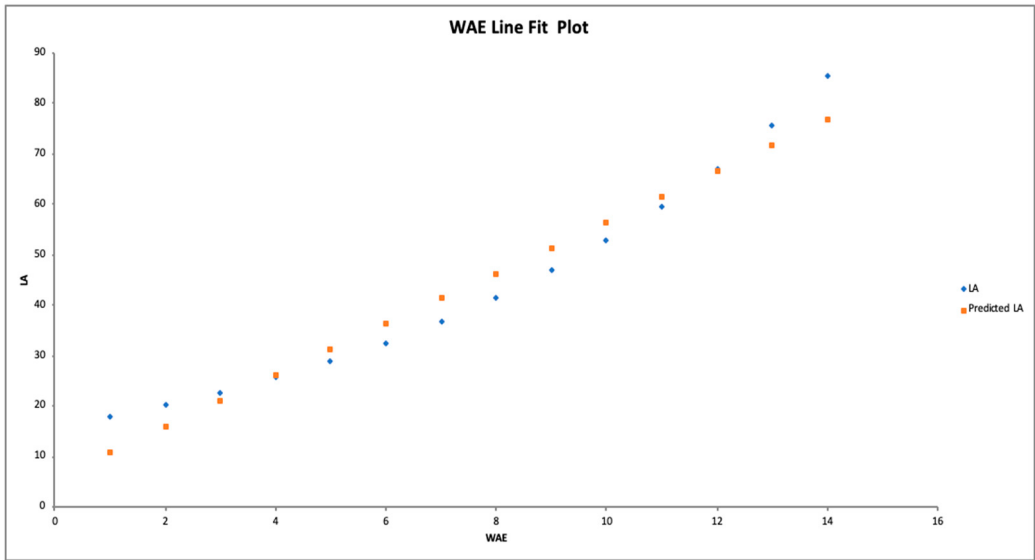


Figure 4. Line fit plot of Cowpea leaf area.

As observed, the line fit plot for the Cowpea leaf area under the Vegetative to Maturity period yields good results with a strong correlation of 0.957 between the actual Cowpea leaf area and the predicted values over the 14 weeks period.

Shoot Dry Weight

The experimental data of the shoot Dry Weight under the Vegetative to Maturity period measured over 14 weeks is presented in Figure 5.

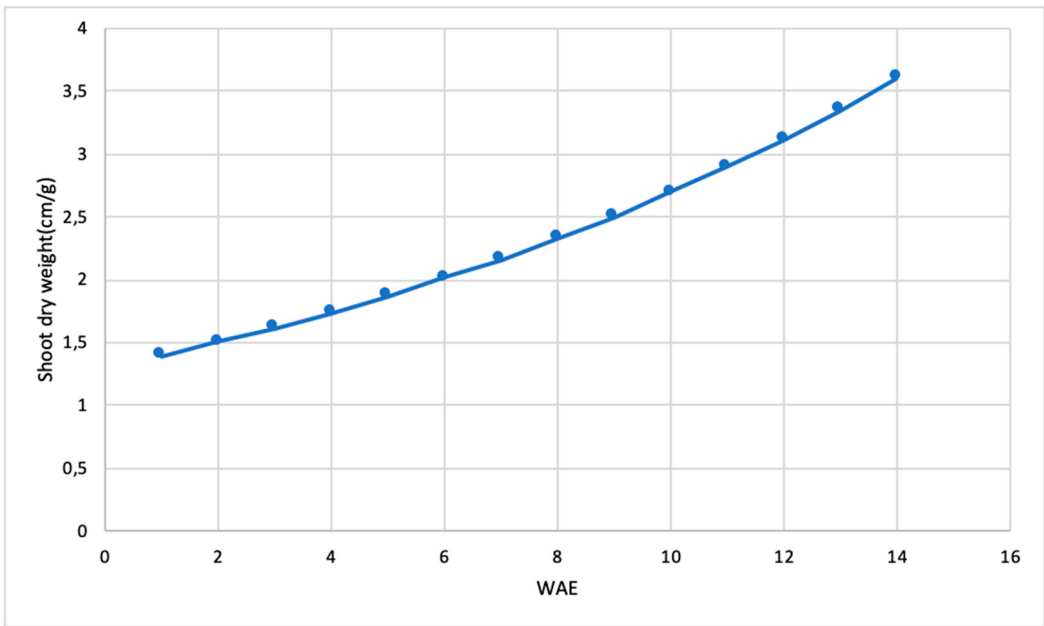


Figure 5. Experimental data of the SDW measured over 14 weeks.

The proposed regression model for the SDW under the vegetative to maturity period is tabulated in Table 2.

Table 2. Regression summary for the Cowpea SDW.

<i>Regression</i>	<i>Stats</i>						
Multiple R	0.992						
R Square	0.983						
Adjusted	0.982						
Standard Er	0.095						
<i>ANOVA</i>	<i>df</i>	<i>ss</i>	<i>MS</i>	<i>f</i>	<i>Significance f</i>		
Regression	1	6.417	6,417	709	4.,82E-12		
Residual	12	0.0109	0.00905				
Total	13	6.526					
	<i>Coefficients</i>	<i>Standard Err</i>	<i>t stat</i>	<i>P-value</i>	<i>Upper95%</i>	<i>Lower95,0%</i>	<i>Upper95,0%</i>
Intercept	1.081	0.054	20.133	1.29E-10	1.198	0.964	1.198
WAE	0.,168	0.0063	2.82E-12	0.15421	0.182	0.154	0.182

The correlation coefficient is observed to be 0.983, signifying a significant correlation between the practical data and the predicted values. Consequently, the p-value is observed to be less than 0.05 (1.29E-10) which implies that the data is statistically significant. It specifies convincing substantiation in contradiction to the null hypothesis, given that there is less than a 5% probability the null is correct. Therefore, for the Cowpea SDW, the null hypothesis is rejected.

The line fit plot for Cowpea SDW of the proposed model is demonstrated in Figure 6.

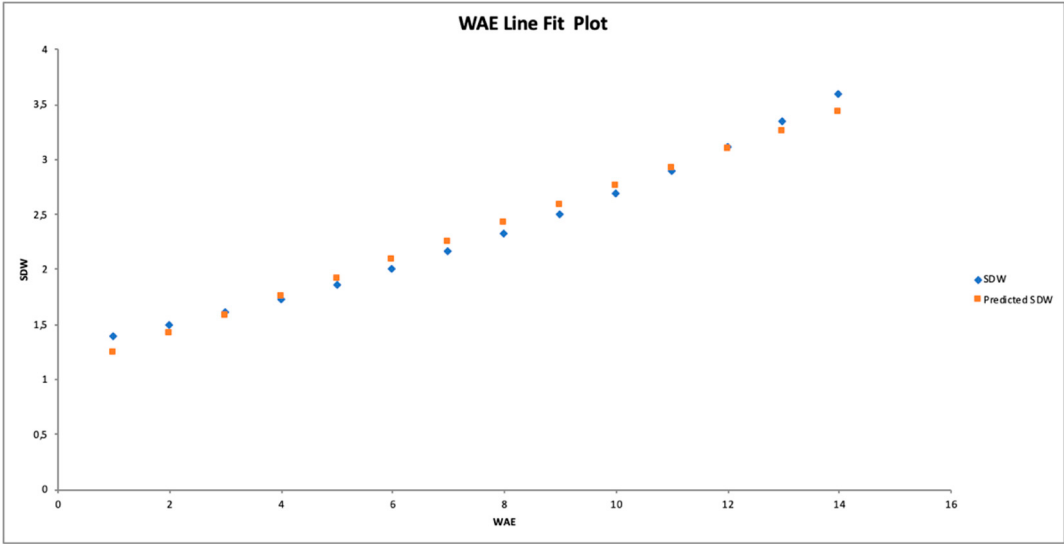


Figure 6. Line fit plot of Cowpea SDW.

As observed, the line fit plot for Cowpea SDW under the Vegetative to Maturity period yields good results with a strong correlation of 0.983 between the actual Cowpea SDW and the predicted values over the 14 weeks period.

3.3. Flower to Maturity Period

3.3.1. Leaf Area

The experimental data of the Cowpea LA under Flower to maturity period measured over 14 weeks is presented in Figure 7.

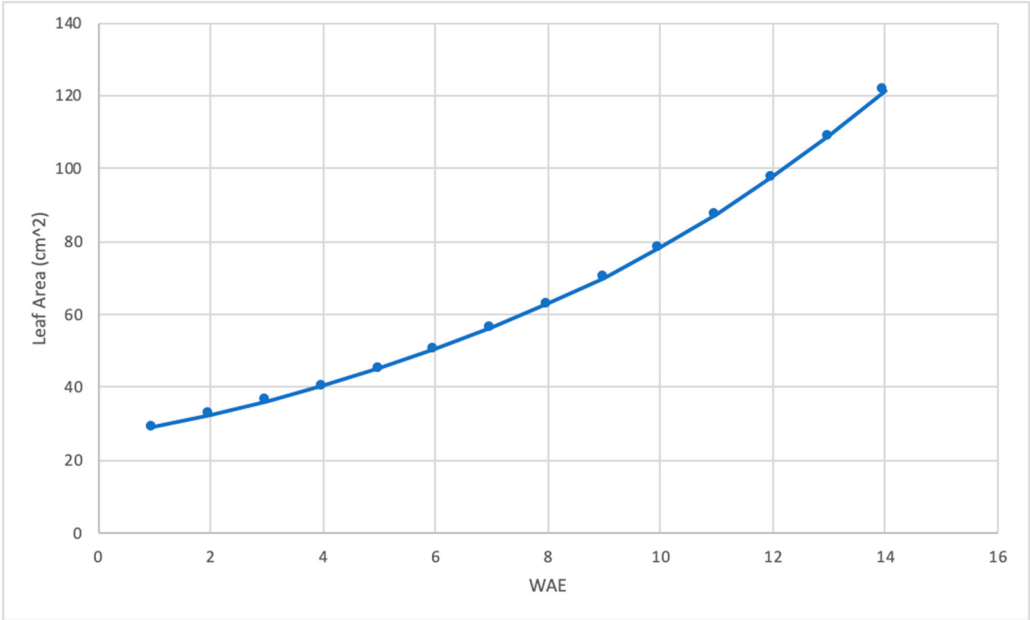


Figure 7. Experimental data of the leaf area measured over 14 weeks.

The proposed regression model for the LA under Flower to maturity period is tabulated in Table 3.

Table 3. Regression summary for the Cowpea Leaf Area.

Regression	Stats						
Multiple R	0.982						
R Square	0.963						
Adjusted	0.96						
Standard Er	5.884						
ANOVA	Df	ss	MS	f	Significance f		
Regression	1	10924.8	10924.78	315.5	5.5462E-10		
Residual	12	415.51	34.6				
Total	13	11340.3					
	Coefficients	Standard Err	t stat	P-value	Upper95%	Lower95,0%	Upper95,0%
Intercept	13.48	3.32	4.06	0,038	20.72	6.25	20.7
WAE	6.93	0.39	17.76	5.5462E-10	7.78	6.08	7.797

The correlation coefficient is observed to be 0.963, signifying a significant correlation between the practical data and the predicted values. Consequently, the p-value is observed to be less than 0.05 (0,038) which implies that the data is statistically significant. It specifies convincing substantiation in contradiction to the null hypothesis, given that there is less than a 5% probability the null is correct. Therefore, for the Cowpea Leaf Area, the null hypothesis is rejected.

The line fit plot for the Cowpea leaf area of the proposed model is demonstrated in Figure 8.

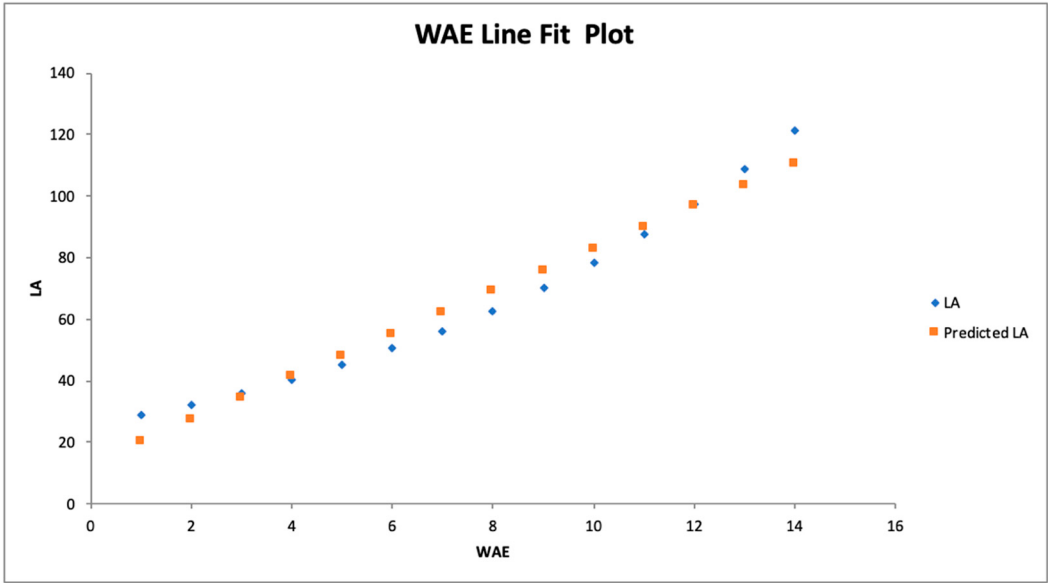


Figure 8. Line fit plot of Cowpea leaf area.

As observed, the line fit plot for the Cowpea leaf area under Flower to maturity period yields good results with a strong correlation of 0.963 between the actual Cowpea leaf area and the predicted values over the 14 weeks period.

3.3.2. Shoot Dry Weight

The experimental data of the Cowpea SDW under the Flower to maturity period measured over 14 weeks is presented in Figure 9.

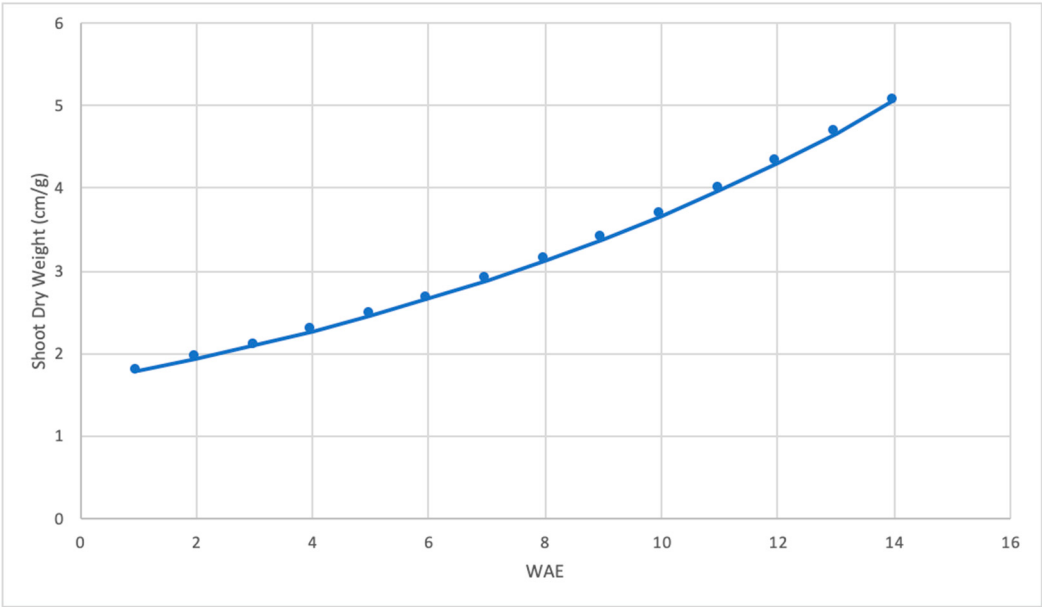


Figure 9. Experimental data of the SDW measured over 14 weeks.

The proposed regression model for the SDW under Flower to maturity period is tabulated in Table 4.

Table 4. Regression summary for the Cowpea SDW.

Regression	Stats						
Multiple R	0.99						
R Square	0.98						
Adjusted	0.978						
Standard Er	0.154						
ANOVA	df	ss	MS	f	Significance f		
Regression	1	13.977	13.98	591.5	1.406E-11		
Residual	12	028352705	0.026				
Total	13	14.26					
	Coefficients	Standard Err	t stat	P-value	Upper95%	Lower95,0%	Upper95,0%
Intercept	1.304	0.087	15.03	3.81E-09	1.115	1.115	1.493
WAE	5.047	0.309	16.31	1.49E-09	0.270	0.226	0.270

The correlation coefficient is observed to be 0.98, signifying a significant correlation between the practical data and the predicted values. Consequently, the p-value is observed to be less than 0.05 (3.81E-09) which implies that the data is statistically significant. It specifies convincing substantiation in contradiction to the null hypothesis, given that there is less than a 5% probability the null is correct. Therefore, for the Cowpea SDW, the null hypothesis is rejected.

The line fit plot for Cowpea SDW of the proposed model is demonstrated in Figure 10.

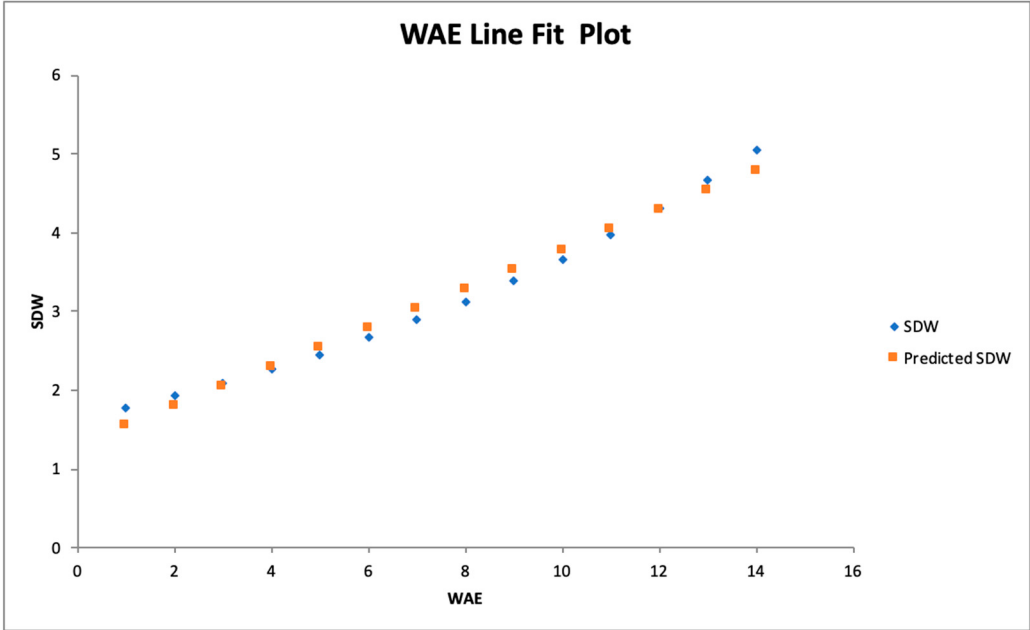


Figure 10. Line fit plot of Cowpea SDW.

As observed, the line fit plot for Cowpea SDW under Flower to maturity period yields good results with a strong correlation of 0.98 between the actual SDW and the predicted values over the 14 weeks period.

3.4. Excellent Watering Through the Season

3.4.1. Leaf Area

The experimental data of the Cowpea LA under Excellent watering through the season measured over 14 weeks is presented in Figure 11.

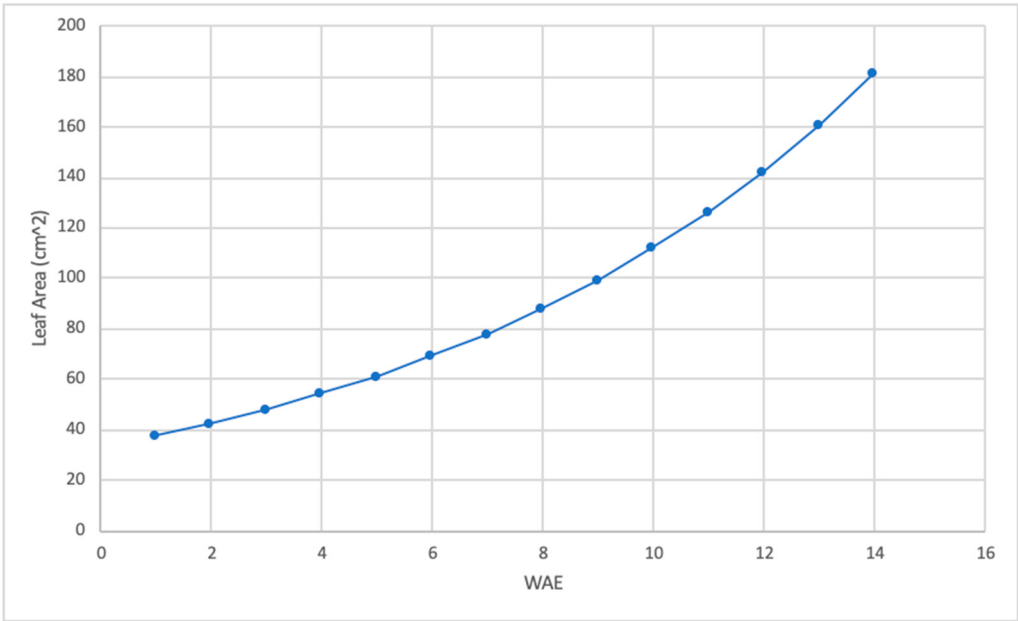


Figure 11. Experimental data of the leaf area measured over 14 weeks.

The proposed regression model for the LA under Excellent watering through the season is tabulated in Table 5.

Table 5. Regression summary for the Cowpea Leaf Area.

Regression	Stats						
Multiple R	0.978						
R Square	0.957						
Adjusted	0.953						
Standard Er	9.880						
ANOVA	df	ss	MS	f	Significance f		
Regression	1	25969.5	25969.5	266	1.487E-09		
Residual	12	1171.6	97.63				
Total	13	14.26					
	Coefficients	Standard Err	t stat	P-value	Upper 95%	Lower95 %	Upper 95%
Intercept	13.03	5.578	0.038	0.879	25.185	0.879	25.185
WAE	10.68	0.655	1.487E-09	9.257	12.111	9.257	12.111

The correlation coefficient is observed to be 0.98, signifying a significant correlation between the practical data and the predicted values. Consequently, the p-value is observed to be less than 0.05 (0.957) which implies that the data is statistically significant. It specifies convincing substantiation in contradiction to the null hypothesis, given that there is less than a 5% probability the null is correct. Therefore, for the Cowpea Leaf Area, the null hypothesis fails to reject.

The line fit plot for the Cowpea leaf area of the proposed model is demonstrated in Figure 12.

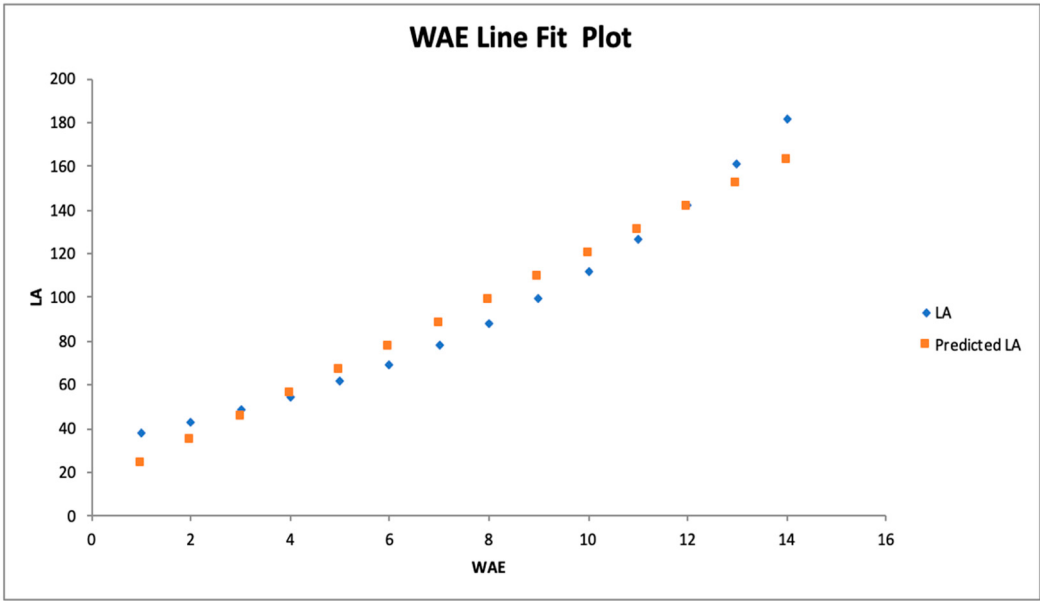


Figure 12. Line fit plot of Cowpea leaf area.

As observed, the line fit plot for the Cowpea leaf area under excellent watering through the season yields good results with a strong correlation of 0.957 between the actual leaf area and the predicted values over the 14 weeks period.

3.4.2. Shoot Dry Weight

The experimental data of the Cowpea SDW under Excellent watering through the season measured over 14 weeks is presented in Figure 13.

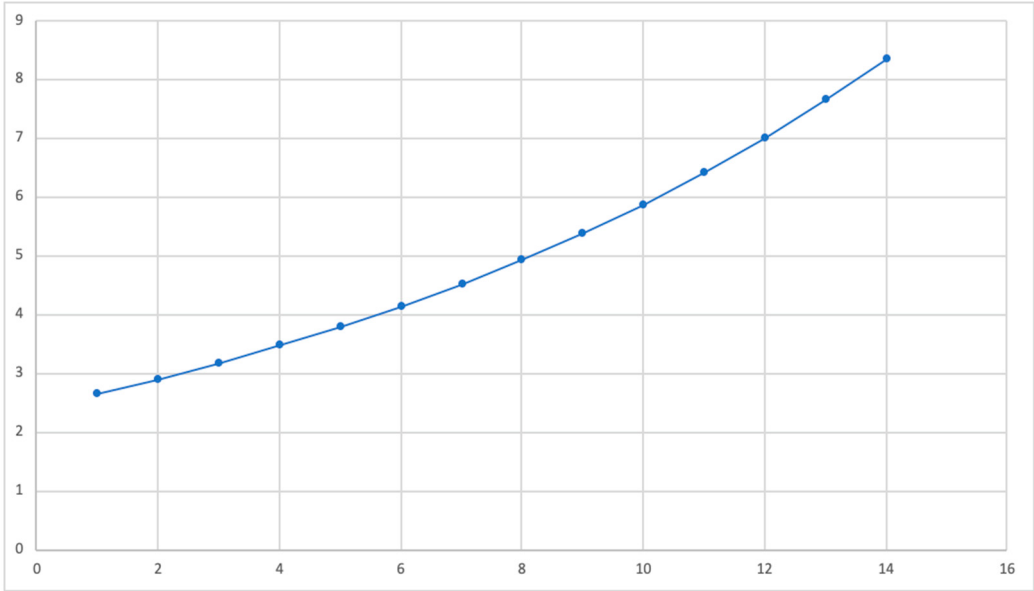


Figure 13. Experimental data of the SDW measured over 14 weeks.

The proposed regression model for the SDW under Excellent watering through the season is tabulated in Table 6.

Table 6. Regression summary for the Cowpea SDW.

Regression	Stats						
Multiple R	0.988						
R Square	0.976						
Adjusted	0.974						
Standard Er.	0.293						
ANOVA	df	ss	MS	f	Significance f		
Regression	1	42.136	42.1358	489.852	4.2603E-11		
Residual	12	1.032	0.086				
Total	13	43.168					
	Coefficients	Standard Err	t stat	P-value	Upper95%	Lower95,0%	Upper95,0%
Intercept	1.786	0.166	10.786	31.57E-07	1.425	1.413	2.153
WAE	0.4303	0.019	22.133	4.26E-11	0.388	0.442	0.423

The correlation coefficient is observed to be 0.976, signifying a significant correlation between the practical data and the predicted values. Consequently, the p-value is observed to be less than 0.05 (31.57E-07) which implies that the data is statistically significant. It specifies convincing substantiation in contradiction to the null hypothesis, given that there is less than a 5% probability the null is correct. Therefore, for the Cowpea Leaf Area, the null hypothesis is rejected.

4. Conclusions

In this work, a focus was drawn on analyzing cowpea's growth phases by proposing regression analysis under the impact of water stresses to facilitate South Africa's local farmers in optimally mapping their cultivation schedule over the period of drought without imperiling their yields. The proposed regression models predict the cowpea's growth at various periods of water stress including vegetative to maturity, flower to maturity and excellent water through the season. At each period of water stress, regression models of the leaf area and shoot dry weight are developed. The various growth phases of the cowpeas were studied under three-pot test conditions. The results suggest that water stress at initial growth phases decreased the shoot dry weight (SDW), and leaf area (LA) of studied cowpeas. Growth analysis of cowpeas species cultivated in pure stands for the distinctive periods showed that the leaf area was the most explanatory variable in the SDW of cowpea at the initial growth phase. The correlation coefficient of the LA and SDW of cowpeas produced by the proposed models at vegetative to maturity, flower to maturity and excellent water through the season are 0.957 and 0.983, 0.963 and 0.980, 0.957 and 0.976

The study further revealed that water stress abridged growth and implementation of Cowpeas and adversely effects the generative organ. Additionally, the detrimental effect of water stresses augmented with plant densities.

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