DYNAMICS OF WATER AND NUTRIENT USE, STRESS DEVELOPMENT AND YIELD OF *Corchorus olitorus Linn*.

BY

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ABSTRACT

The need to remove more water in agricultural production, without limiting crop growth and yield, has led to the development of crop models. This makes more water available for domestic and industrial uses. Studies on water and nutrient use efficiencies have been reported but there is dearth of precision agriculture information on *Corchorus olitorus*. The study was designed to investigate the effects of water and nutrient use on the growth and yield of *Corchorus olitorus*.

Field and greenhouse studies were conducted at the University of Ibadan. Plot size ($1m^2$) with three replications were used for planting *Corchorus olitorus* seeds at 30 cm x 10 cm with planting rate of 300,000 stands/ha. At greenhouse, 1 plant/pot containing 5 kg soil was used. Soil samples were collected at 0-30 cm depth for soil textural classification. Four irrigation treatments of 2, 4, 6, and 8 mm of water were applied at 2-day interval for 10 weeks coupled with NPK 15-15-15 fertilizer application at a rate of 100, 200, 300 and 400 kg/ha. Experimental design was split plot for field trial and completely randomised for greenhouse trial. Yield, Crop Growth Coefficient (K_c) for 8 weeks using field trial and CropWAT model, Actual Evapotranspiration (ET_a) and Growing Degree Days (GDD) were obtained using standard methods. Data on Water Use Efficiency (WUE), Fertilizer Use Efficiency (FUE) and Stress Tolerance Index (STI) were evaluated. Empirical crop growth models were developed. Data were analysed using ANOVA at $\alpha_{0.05}$.

Soil type was loamy sand. Yield (t/ha) at different irrigation treatments were 0.73±0.15 (2 mm), 1.27±0.12 (4 mm), 2.63±0.16 (6 mm), 3.53±0.57 (8 mm), and 1.33±0.21 (2 mm), 2.03±0.15 (4 mm), 4.23±0.50 (6 mm), 5.83±0.38 (8 mm) for field and greenhouse, respectively. Fertilizer application increased yield (t/ha) significantly to 0.93±0.11 (2 mm, 400 kg/ha), 1.47±0.12 (4 mm, 400 kg/ha), 2.97±0.45 (6 mm, 400 kg/ha), 5.07±0.35 (8 mm, 300 kg/ha), and 1.53±0.15 (2 mm, 400 kg/ha), 2.23±0.21 (4 mm, 200 kg/ha), 5.80±0.61 (6 mm, 400 kg/ha), 7.13±0.38 (8 mm, 100 kg/ha) for field and greenhouse, respectively. The K_c were 0.43, 0.44, 0.61, 0.81, 0.98, 0.89, 0.61, 0.61 for field trial compared to 0.44, 0.44, 0.57, 0.80, 0.92, 0.82, 0.67, 0.55 from CropWAT model. Cumulative weekly ET_a of 2, 4, 6, 8 mm were 55.79, 103.46, 152.74 and 182.98 mm, respectively. Cumulative GDD ranges were 1311.80-1374.10^{o}C (greenhouse) and 1316.35-1397.20^{o}C (field). The WUE ranges were 0.08-0.15 (field), 0.12-0.27 (greenhouse), with 8 mm, 100 kg/ha (greenhouse) and 8 mm, 200 kg/ha (field) being the optimum. The FUE ranges were 0.05-0.21 and 0.11-0.25 for field and greenhouse, respectively. The STI were 0.067-0.461 and 0.088-0.649 for field and greenhouse, respectively;

establishing water-stress impact on crop yield. At 8 mm irrigation treatment, fertilizer application of 100 and 300 kg/ha obtained maximum STI values for greenhouse and field trials, respectively. Empirical model to predict yield as affected by evapotranspiration was $y=28.263x^5-69.51x^4+65.037x^3-29.477x^2+7.1939x-0.0219$.

Irrigation treatments at 8mm had less water stress effect and improved yield. Water-stress, nutrient dynamics, crop growth and yield prediction model of *Corchorus olitorus* were established.

Keywords: *Corchorus Olitorus*, Crop growth model, Evapotranspiration, Stress tolerance index, Yield

Word count: 499

CERTIFICATION

I certify that this work was carried out by EHUMADU, CHIKODI NWOKOMA, in the Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Ibadan, Oyo State, Nigeria.

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DEDICATION

This project is dedicated to God Almighty, the source of my strength and life.

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CHAPTER ONE

INTRODUCTION

1.1 PREAMBLE

One of the major issues in the present century is global warming. Studies on global warming and its effect on climatic change are being pursued vigorously as a multi-disciplinary problem. Climate change will lead to an intensification of extremes of the global hydrological cycle and could have major impacts on water resources, affecting both ground and surface water supply for domestic and industrial uses, irrigation and in st ream ecosystems (Mimi and Jamous, 2010). The impacts of climate change on agricultural activities have been shown to be significant for low input farming systems in developing countries in Africa (Samia *et al.*, 2012). Crop production investigations are usually done using generally accepted research based standard agronomic procedure, where functions of crop production can be derived using statistical analysis without involving principles of physical or biological methods. Statistical analysis involving regression and correlation analysis have helped in providing a level of qualitative understanding which involves variables and possible interactions which occurred in cropping systems and proper understanding of agricultural science (Patricia *et al.*, 2012). Due to the over use of available water resources, it has become very important to define appropriate strategies for planning and management of irrigated farmland (Feng *et al.*, 2007). The crop response complexities to deficits water supply brought about the introduction of empirical functions as a suitable and practicable option in assessing response of yield to water (Steduto *et al.*, 2008). Introduction of models which can be empirical models, which makes use of daily average temperature to determine yield of a crop, to advanced or sophisticated models which try to describe the effect of growth substances on plant development (Franco and Mindi, 1993). Generally, crop simulation models used as support systems for decision making are normally site-specific (Priya and Shibasaki, 2000). However, information which are obtained using such type of analysis are usually site specific. The data observed using this method can only be acceptably applied in any other sites where crop management, climate, and soil parameters are similar to the results used in developing or determining the original functions. The application of crop yield models using regression in making decisions are limited. However, due to weather variations, more than 10 years is required in developing proper statistical relationships useful in agricultural decision making (Patricia *et al.*, 2012). Therefore, use of physics-based crop simulation models were preferred over the regression equations (Sarangi, 2012). There are different issues that agricultural researchers, policy makers with the desire to develop productive systems who want to improve agricultural production are faced with (Bruno *et al.*, 2013). Traditional methods of predicting crop yields throughout the growing season include models that assimilate climate, soils and other environmental data as response functions to describe development, photosynthesis, evapotranspiration and yield for a specific crop (Ijaz *et al.*, 2014). With the aid of a crop model, a more detailed analysis of the management decisions and the possible effects on final yield can be undertaken. It also should be acknowledged that uncertainty exists in the final yield estimate because of uncertainty in the input data and errors in the models. The first order uncertainty analysis to examine the effect of uncertainty in input data on the model outcome of a mechanistic decision support system. They reported large uncertainty, which was contributed mostly to the given variability in specific model parameters. Therefore, the model output must be critically assessed, which is mostly done based on regressions. The most commonly used criterion of model performance is the coefficient of determination (R^2), which is the ratio of the variance explained by the model to the total variance in the data. Many authors have concluded that R^2 is not a good means of comparison between models representing yield response (Simone *et al.*, 2012). The development of an acceptable forecast model, requires adequate input of variables used such as agricultural, technological, and meteorological variables. The meteorological variables should include temperature, soil moisture, rainfall, which significantly affect crop yields (Sawa and Ibrahim, 2011).

1.2 OBJECTIVES

The objectives of this study work are:

1. Determining the effect of the crop water, nutrient use and stress development on the growth and yield of *Corchorus olitorus*.

2. Develop a model to simulate the dynamics of crop water, nutrient use and stress development on the yield of *Corchorus olitorus*.

1.3 STATEMENT OF PROBLEM

Maximizing productivity has always been paramount to farmers. The need for accurate and optimum utilization of scarce water resources and cost-effective application method of inorganic fertilizer (NPK) in the cultivation of *Corchorus olitorus* for maximum yield and to forecast plant output before cultivation have been a problem in modern day agriculture. Lack of adequate knowledge of plant physiology and morphology have led to excessive application of scarce water resources and inorganic fertilizer (NPK) which result to plants experiencing stresses. This avoidable situation has led to plant experiencing stunted growth and poor yield.

1.4 JUSTIFICATION

Innovation in the agricultural sector is needed to provide adequate information to farmers, policy makers and other decision makers on how to accomplish sustainable agriculture over the wide variations in climate and scare resources around the south-western part of Nigeria. In this direction, the adequate utilization of crop models in research is pertinent. The simulation of models for agriculture should be encouraged, particularly since computers and other electronic gadgets have become accessible to crop producers. This laudable initiative makes it possible for farmers to visualize growth stages, irrigation requirements and yield. Computer models operated from offices could facilitate irrigation water management, crop growth and yield by making frequent field visits and measurements less essential.

1.5 SCOPE OF WORK

This study was limited to the determination of the effect of crop water, nutrient use on the yield considering specific growth parameters. Five irrigation treatments of 0, 2, 4, 6, and 8 mm of water were applied at 2-day interval for 10 weeks and application of fertilizer (NPK 15-15-15) at a rate of 0kg/ha, 100kg/ha, 200kg/ha, 300kg/ha and 400kg/ha in each of the plots respectively in the Department of Crop Protection and Environmental Biology, University of Ibadan, South Western part of Nigeria. The experiment was carried out in the field using a split plot experimental design, and a randomised complete design in a greenhouse. This study was limited to developing statistical models to simulate crop water dynamics, nutrient use, and yield of *Corchorus olitorus*. This model did not consider the effect of pest, insect and diseases.

1.6 CONTRIBUTION TO KNOWLEDGE

The models developed help in visualising plant growth and development under certain conditions using mathematical equations which would otherwise take months in field conditions. This is an instructive tool that should be used for teaching, research and decision making.

The actual and cumulative crop evapo-transpiration, growing degree days using mathematical models from sowing to harvest and crop coefficient of *Corchorus olitorus* were determined

The potential evapo-transpiration, crop water requirement, yield reduction due to drought stress at different irrigation regimes were ascertained, and development of irrigation schedules using CROPWAT model.

The authenticity of chlorophyll content, leaf reflectance and leaf water content and stress tolerance index as a veritable factor for identifying water stressed vegetables were established.

The determination and evaluation of fertilizer-yield relationships by applying the knowledge of evapotranspiration-yield response factor equation were established for easy understanding and predictions using developed fertilizer-yield models.

CHAPTER TWO

LITERATURE REVIEW

2.1 WHAT IS CROP MODELING

It can be defined as the use of equations or sets of equations to represent the behaviour of a system. In effect crop models are computer programmes that mimic the growth and development of crops. Model simulates or imitates the behaviour of a real crop by predicting the growth of its components, such as leaves, roots, stems and grains. Thus, a crop growth simulation model not only predicts the final state of crop production or harvestable yield, but also contains quantitative information about major processes involved in the growth and development of the crop (Patricia *et al.*, 2012). Crop simulation model is a representation of a simplified crop production system, and it consists of nonlinear mathematical equations and logic to provide a systematic analysis of the crop production system (William *et al.*, 1996). A model is a schematic representation of the conception of a system or an act of mimicry or a set of equations, which represents the behaviour of a system. Also, a model is "a representation of an object, system or idea in some form other than that of the entity itself". Its purpose is usually to aid in explaining, understanding or improving performance of a system. A model is, by definition "a simplified version of a part of reality, not a one to one copy". This simplification makes models useful because it offers a comprehensive description of a problem situation (Murthy, 2003). Crop Simulation Models (CSM) are computerized representations of crop growth, development and yield, simulated through mathematical equations as functions of soil conditions, weather and management practices (Bruno *et al.*, 2013).

2.2 BRIEF HISTORY OF CROP MODELING

Crop growth models have been used since the 1970s. The first crop growth models were based on approaches of simulating industrial processes and developed some of the early crop growth models in a program called BACROS. The main aim of their modeling activities was to understand the underlying processes at the plant scale. While all models have achieved various degrees of success in application, they all have their weakness and fail under certain circumstances, wherefore authors of models should clarify the limitations of their models and ranges of applications (Simone *et al.*, 2012). According to Ruiz and Angel (2003), modeling has come into agriculture because of several reasons: More comprehension about the processes that take place at the soil water atmosphere continuum (SWAC), specialists from different fields come to work together, different and more efficient codes for obtaining the solutions of complex equations were introduced, amazing development of hardware and supporting software, large data banks coming from a lot of years of experimental laboratory and field work (mainly at the developed countries), desires to put together as much SWAC processes as possible to get a better comprehension of such a complex system.

Models are generally defined as simplification or abstraction of a real system. This is particularly the case for models of biological systems like crops, where the reality is composed of different components and interacting processes taking place at different organizational levels. Specifically, it can also be said to be a quantitative method or scheme that can be used for determining or predicting crop growth, development, and yield, given a set of genetic features and relevant environmental variables (Pasquale *et al.*, 2009). New scientific knowledge can be gained using crop models to explain physiological processes and can also be used to evaluate impact of agronomic practices on environment and income of farmers. Many crop models cannot account or explain important factors during crop growth such as diseases, tillage, diseases, weeds, phosphorus and insects (Bruno *et al.*, 2013).

2.3 AVAILABLE CROP MODELS

The ability of crop models to predict irrigation demand and yields reliably is a very big challenge (Charles *et al.*, 2012). There are different kinds of crop models available for research. However, different crop-growth models have been designed, based on physiological processes, and used for projects involving water management with different levels of success recorded (Soom *et al.*, 2011). The usage of crop models is important in taking an integrated approach in discovering solutions to complex challenges of crop management, soil and weather. According to Murthy (2003), ADEL, ALAMANC, WOFOST, CROPSYST, EPIC simulation models were used for predicting the growth and yield of maize crop. Models such as SORGF, SorModel, SORKAM, has ALMANAC model which are used for addressing specific tasks involving proper management of sorghum crop. CROPSYST, PmModels, CERES, are models used for studying pearl millet genotype suitability and simulation of yield worldwide. Similarly, the two common growth models used for cotton are GOSSYM and COTONS models. The PNUTGRO for groundnut, CHIKPGRO for chick pea, WTGROWS for wheat, SOYGRO for soybean, QSUN for sunflower. The APSIM, GROWIT are being used in crop rotation, crop sequence and simulation studies involving perennial crops. ClipCrop and CROPWAT models are used for simulating yield estimates, irrigation demand (Charles *et al.*, 2012). AquaCrop model, used for simulating yield-response to water (Bitri *et al.*, 2014). The ability crop yield models to predict the yield of a crop with response different deficit irrigation to reduce field expenses by collecting data is of great importance (Salami *et al.*, 2011). The precision of these models relies mainly on the precision and validity of the input data and in case of fine calibration; they can be employed to simulate various scenarios of irrigation management with no temporal or spatial limitations existing in field experiments (Khorsand *et al.*, 2014). Other uses, such as planning and policy analysis, can benefit from modeling as well. Efforts in crop simulation modeling, aimed primarily at the integration of physiological knowledge, were started in the late 1960s by several research groups; among them that of de Wit and co-worker (Pasquale *et al.*, 2009).

2.4 TYPES OF MODELS

According to Franco and Mindi (1993), models can be divided into two main types namely:

2.4.1 Descriptive Model

This type of model simulates the behaviour of the plant in a simple manner. In the model data obtained from experiments are used to develop mathematical equations which describe a system.

2.4.2 Explanatory Model

This model is an elaborate description of processes and mechanisms that occurs in a system. The individual processes and mechanisms are analysed, and equations formulated. Each process must be quantified in relation to environmental factors such as radiation and temperature, and to the crop status including leaf area, development stage and nitrogen content.

2.4.3 Classification of Models

According to Patricia *et al.* (2012), classification of models can be done considering the purpose for which it was designed namely:

2.4.3.1 Empirical or statistical models

These are models using direct descriptions of observed data which are usually presented as a regression equation containing one or more factors that are used in calculating final yield. According to Colunga *et al.* (2008), the initial set of models applied for large-scale yield simulations were statistical. Average yields from large areas for many years were regressed on time to reveal a general trend in crop yields.

2.4.3.2 Mechanistic models

This model can mimic relevant physical, chemical or biological processes and to describe how and why a response occurs. According to Bruno *et al.* (2013), the model uses fundamental mechanisms of plant and soil processes to simulate specific outcomes. Mechanistic models were initialled to simulate photosynthetic processes such as light interception, uptake and loss of CO_2, biomass partitioning.

2.4.3.3 Static and dynamic models

It does not contain time as a variable even if the end products of cropping systems are accumulated over time. In contrast dynamic models explicitly incorporate time as a variable and are first expressed as differential equations.

2.4.3.4 Deterministic models

This helps to make definite or proper predictions for variables such as crop yield or rainfall without considering any of the associated probability distribution, random elements involved or variance. Deterministic models help in estimating exact values of crop yield or possible dependent elements or variables. Deterministic models usually have defined coefficients (Murthy, 2003).

2.4.3.5 Stochastic models

When variation and uncertainty reach a high level, it becomes advisable to develop a stochastic model that gives an expected mean value as well as variance.

2.4.3.6 Simulation models

It is designed for imitating the behaviour of a system. These models contain aspects of data variabilities which are usually related to changes in soil and weather conditions that are integrated. According to Gommes (2010), this model attempts to stimulate the actual interactions between plants and their environment based on chemical, physical, physiological and anatomical data and principles.

2.4.3.7 Optimizing models

These models have the specific objective of devising the best option in terms of management inputs for practical operation of the system.

According to Murthy, (2003), models are classified into the following group namely; Statistical, Mechanistic, Deterministic, Stochastic, Dynamic, Static and Simulation Models where statistical model uses statistical techniques such as step-down regression, correlation.

According to Pasquale *et al.* (2009) depending on the purpose and objectives of the crop model, we can distinguish two main modeling approaches: scientific and engineering. The first mainly aims at improving our understanding of crop behaviour, its physiology, and its responses to environmental changes. The second attempts to provide sound management advice to farmers or predictions to policymakers. Scientific models are usually more mechanistic, based on theories and laws concerning the way the system functions, while engineering models are meant functional, due to a combination of acceptable theories and well established empirical relationships. The crop yield response at different water applications in controlled environment or field is cumbersome and costly to examine. Modelling can be used as an important tool in studying cum development of proper irrigation deficit strategies with the observed limitations. Models can be used for assessment of different factors affecting crop growth and yield to obtain optimal quantities for different irrigation regimes (Bitri *et al.*, 2014).

2.5 CROPWAT MODEL

This model is a decision support system that was developed by the Division of Land and Water Development, FAO with the aim of proper planning and management of irrigation. CROPWAT model is a practical tool developed to carryout standard calculations involving reference evapotranspiration, crop water requirements at different stages and crop irrigation requirements, and also to specifically determine the design and irrigation management schemes. It also allows for the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation (Marica, 2000). It uses penman-montieth method for calculating reference evapotranspiration (Yarahmadi, 2003). The Food and Agriculture Organization of the United Nations (FAO) has proposed using the Penman-Monteith method as the standard method for estimating reference evapotranspiration (ETo) (Husam, 2011). ET is the field level water parameter associated most directly with yield, the depth of applied irrigation water represents water purchased and is of greatest concern to planners (Reca *et al.*, 2000). The program (CROPWAT 8.0) uses the same Penman Monteith methodology as used in CROPWAT versions 5.7 and 7.0 and uses the same data such as the CLIMWAT climate and rainfall files (Clarke, 1998). The Cropwat model can appropriately estimate the yield reduction caused by water stress and climatic impacts which makes this model as a best tool for irrigation planning and management (Gohari, 2013). Models that adequately simulate the effects of water stress on yield can be valuable tools in irrigation management (Nazeer, 2009). CROPWAT model from FAO/UN (Food and Agricultural Organization of the United Nations) uses only three soil texture groups of clay, silt, and sand to calculate irrigation schedules (Cornejo, 2003).

2.6 CORCHORUS OLITORUS ("Ewedu")

Corchorus olitorus belongs to the family Tiliacea and it is called Jew's mallow or jute mallow in English and corete potagere in French respectively (Bamigboye, 2011). It is also known under various names such as long fruited jute, bush okra, Ewedu or Ooyo (Western Nigeria) and Lalo (Northern Nigeria). The plant has a height of 2–4 m, with only a few side branches. The leaves are alternate, simple, lanceolate, 5–15 cm long, with an acuminate tip and a finely serrated or lobed margin. The flowers are between 2–3 cm diameter and yellow, with five petals; the fruit is a many-seeded capsule. It thrives almost anywhere and can be grown year-round. *C. Olitorus* as leafy vegetable is accredited with possession of high nutritional values of essential nutrients like protein, calcium, phosphorous, iron and other important components such as vitamins A, B complex, C, fiber, carbohydrate, fat and a high calorific value. Despite the nutritional value and importance of *C. Olitorus* in Nigerian diet, little is known about the factors that are responsible for the optimum yield of the crop. Attempts should therefore be made to increase the yield (Sanni and Adesina, 2012). It requires an annual temperature ranging from 16 to 25 °C. The optimum temperature is 25 to 32 °C. Temperatures below 15°C are detrimental to the crop. It tolerates a pH ranging from 4.5 to 8.2. It cannot grow in the shade (DAFF, 2012). *Corchorus olitorius* leaves are rich in antioxidants, fatty acids, minerals, vitamins and mucilaginous polysaccharides, and have been used as traditional folk medicine (Yokoyama *et al*, 2014). *C. olitorius* are used are used to treat toothache in Kenya whereas in Nigeria concoction prepared from seeds are used as purgative (Nwangburuka *et al.*, 2012).

2.7 SINGLE, TWO AND THREE OR MORE FACTOR EXPERIMENT

This is an experiment where a single factor varies, and other factors remain constant. The result obtained from the experiment is usually criticised because other factors are maintained at a level. Two factor occurs where one factor is varied and the level of the other factor changes. The effect of two factors can only be ascertained if both factors are applied in the same experiment. This effect of a factor changes as the level of the other factor changes. Three or more factor occurs when there is rapid increase in the number of treatment and an increase in the frequency and form of interaction effects. The disadvantage of this type of experiment is that it is highly expensive, and the interaction effect is complex, but the information gained from this type of experiment is highly valuable (Gomez and Gomez, 1984).

2.8 EVAPORATION

The process whereby water is lost from the surface of a soil or wet vegetation is called evaporation. Evaporation is affected by climatic factors such as solar radiation, air temperature, air humidity and wind speed. The change of state of molecules of water from liquid to vapour requires energy. When soil surface is the evaporating surface, canopy shading and the amount of water available at the soil surface can be considered as factors affecting evaporation (Andreas and Karen, 2002). Evaporation is lowest at cold and humid atmospheric conditions while it is high at very high temperature i.e when pressure deficit is large.

Potential Evaporation: This type of evaporation occurs when the surface is well watered

Actual Evaporation: This type of evaporation occurs under a given amount of water i.e water available to the soil.

2.9 TRANSPIRATION

Transpiration can be defined as the loss of water in the form of water vapour from a plant. This can also be regarded as the evaporation of water from the plant surface. Water is taken by the root of the plant and transported to other parts of the plant through the xylem. Small pores situated in the leaves allow water to escape in the form of vapour. The amount of water used by plant for growth is less than 5% of the total amount of water absorbed by the plant. This water loss occurs to enable plants control stress conditions. Hydrogen bonding which occurs between water molecules makes it possible for evaporation to occur at the surface (Sterling, 2004). It is the the vaporization of liquid water in plant tissues and vapour removal to the atmosphere. The intercellular spaces which are in the leaf is where vaporization occurs, vapour exchange between the plant and atmosphere, is usually controlled by the pores of the stomatal. The stomata aperture depends on the wind, vapor pressure gradient and energy supply (Allen *et al.*, 2006)

2.10 EVAPOTRANSPIRATION

This is the rate at which water in the form of vapour would be removed from the surface of the soil or plant (Cornejo, 2003). Transpiration and evaporation occurs simultaneous and the processes cannot the distinguished easily. Water availability and a fraction of solar radiation reaching the surface of the soil are the main factors that affect evapotranspiration. An increase in the canopy of the plant, reduces the amount of solar radiation reaching the soil surface. When the plant is at its early stage, the sizes of the leaves are small as a result, evaporation mainly takes place. When the plant is fully matured the size of the leaves are large and evaporation is lowest while transpiration mainly occurs (Thorsten, 2006). It can also be referred to as the consumptive use of water. Evapotranspiration usually occur to avoid plant water stress. If ET is limited water stress will occur because water is not available to plants (Hajare *et al.*, 2008). ET occurs due to an energy gradient that occurs between water in the plants and soil, and the available water that occurs in the atmosphere. This process is influenced by meteorological factors of the area, such as radiation, wind speed, and by water available in the soil and on the surface of the plant (Bithell and Smith, 2011).

2.10.1 Reference Surface Potential Evapotranspiration

It can be said to be the amount of water used by a well-watered reference crop (Cornejo, 2003). This is the evapotranspiartion from surfaces with sufficient amount of water. Reference surface evapotranspiration was introduced to understand the evaporative demand of the atmosphere independently of crop type, crop development stage and management practices. As water is abundant at the evapotranspiring surface, soil factors do not affect evapotranspiration. Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from other surfaces can be related. It removes the need to define a separate evapotranspiration level for each crop and stage of growth (Andrea and Karen, 2002). According to Bos *et al.* (2002), the potential evapotranspiration, ET_p, can be regarded as the amount of irrigation water needed to attain the crops' potential evapotranspiration during a specific time, under a given cropping pattern.

2.10.2 Crop Evapotranspiration Under Standard Conditions

It is denoted as ET_c, it is the evapotranspiration from a healthy or disease-free, well-fertilized crop, grown in large fields under optimum soil water conditions and achieving full production under the given climatic conditions. The values of ET_c and CWR (Crop Water Requirements) are identical, whereby ET_c refers to the amount of water lost through evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss (Allen *et al.*, 2006).

2.10.3 Crop Evapotranspiration Under Non-Standard Conditions

It is the evapotranspiration from crops grown under management and environmental conditions that is different from the standard conditions. When crops are propagated in the field, the real crop evapotranspiration may be different from ET_c due to non-optimal conditions such as occurrence of pests and diseases, soil salinity, poor soil fertility and water logging (Andrea and Karen, 2002).

2.10.4 Crop Water Requirement

This is the amount of water required to compensate for the evapotranspiration loss from the cropped field. Although crop evapotranspiration and crop water requirement can be regarded as been identical, crop water requirement refers to the amount of water that needs to be applied during cultivation, while crop evapotranspiration refers to the amount of water that is lost through the pores of the leaves (Thorsten, 2006). The water depth required to replace the water loss through evapotranspiration of a crop which is healthy, growing in large fields under a good soil condition which include soil water and fertility, and attaining full production potential under certain growing environment (Andrea and Karen, 2002). According to FAO (2002), the water requirement of a crop depends on the following; The climate: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate. The major climatic factors that affect crop water requirement are sunshine, temperature, wind speed, humidity

The crops type: millet or sorghum require less amount of water compare to sugar cane or maize.

The growth stage of the crop; mature crops require more water than crops just planted or at the early stage of growth.

According to Demba (2014), factors affecting crop evapotranspiration include weather, crop characteristics, management and environmental factors.

According to Andrea and Karen (2002), factors like lack of pest and disease control, soil salinity, limited chemicals and fertilizers usage, poor land fertility, limited water availability at root zone, poor soil management, plant density and ground cover, kinds of irrigation system used and cultivation practices.

2.10.4.1 Field Methods of Estimating Crop Water Requirement

Crop water requirement can be estimated using several field methods namely; Lysimeter Experiment, Field Experiment, Soil Moisture Depletion Studies, Water Balance Method (Hajare *et al.*, 2008).

2.10.4.2 Lysimeter Method

According to Mohammed (2011), this is an artificial structure used for cultivation of crops where natural conditions are simulated. The structure is filled with soil sample in which crops can be grown to measure evapotranspiration. This method can be used to study the effect of climate on evapotranspiration. The soil structure in a lysimeter is usually disturbed thereby affecting the accuracy of using this method. Lysimeters can be categorized into three types namely:

2.10.4.2.1 Non-Weighing, Constant Water-Table Type

The data obtained from this method is reliable where water table is high and where the lysimeter has the same water table level inside and outside.

2.10.4.2.2 Non-Weighing Percolation Type

In this method the difference in water storage is calculated using sampling or neutron methods and also precipitation and percolation are measured. This method is usually used in areas of high rainfall.

2.10.4.2.3 Weighing Type

In this method soil water is determined either by weighing the structure with a mechanical scale or by supporting the lysimeter hydraulically. Hydraulically weighed lysimeters generally are not accurate for periods less than 24 hours.

2.10.4.2.4 Moisture Depletion Method

According to Odofin *et al.* (2011), this method can also be called field capacity method, where downward flow because of gravity stops after 1 to 3 days (for sands and clays respectively). Thermo-gravimetric (oven-drying) measurement of available soil moisture was determined twice within each 4-day irrigation cycle, using triplicate soil samples from various depths. The first soil sampling was done a day after each irrigation event, to allow soil moisture content of the soil to drop to field capacity and downward movement of water to cease, water losses that occur after field capacity can be regarded as evapotranspiration. The next soil sampling will occur on the 4th day after the previous irrigation event. The measurements will be repeated until the cropping period ends. Evapotranspiration can be determined from changes on soil moisture content using the equation below:

$$ET_c = \sum^{n}_{1} \ (M_1 - M_2)/100 \times A_i \times D_i \qquad \ldots\ldots\ldots\ldots\ 2.1$$

Where:

ET_c = Evapotranspiration from the root zone

M_1 = Gravimetric Water Content (%) at the time of first sampling

M_2 = Gravimetric Water Content (%) at the time of second sampling

A_i = Soil Bulk Density of the ith layer

D_i = Depth of the ith layer of the Soil

2.10.4.2.5 Soil Water Balance Method

According to Ketema and Leonard (2012), precipitation or water applied artificially (irrigation) which reaches a unit surface area of the soil which may infiltrate or flow through the soil surface as runoff. Water that passes through the soil surface may experience the following:

(i) Evaporate from the surface of the soil because of change in vapour pressure

(ii) Absorbed by the plant for growth or transpiration

(iii) Flows or moves downwards because of gravity (percolation)

(iv) Stored within the root zone

This method implies that the change in soil moisture content is the same as the amount of water added to the root zone i.e change in soil water content (ΔS) = Q1- Q2

$$ET_c = P + I + U - R - D - \Delta S \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2.2$$

Where;

ET_c = Evapotranspiration

P = Precipitation

I = Rainfall

U = Upward Capillary Rise in the Root Zone

R = Runoff

D = Deep Percolation Beyond the Root

ΔS = Change in Root Zone Soil Moisture Storage

2.11 ESTIMATING REFERENCE CROP EVAPOTRANSPIRATION (Et_o)

According to Praveen *et al.* (2011), meteorological data can be used in estimating ET_O using several empirical methods such as outlined below; Pan Method, Penman Method, Penman Monteith, Kimberly Penman, Priestly Taylor, Hargreaves, Samani Hagreaves, Blanney Criddle, The Thornthwaite Method, The Makkink Method, The Turc Method, The Jenson And Haise Method. According to Paul *et al* (2005), Penman Monteith equation is recommended by experts as the new FAO standard for calculating reference crop evapotranspiration.

2.12 ESTIMATING CROP EVAPOTRANSPIRATION OR CROP WATER REQUIREMENT UNDER STANDARD CONDITIONS

Calculations on evapotranspiration can be done both in a standard condition or nonstandard condition. Deviations from the standard environmental and management practices can be regarded as the nonstandard conditions. Examples of such deviations are water logging, poor soil fertility, salinity problems, pests, diseases, impenetrable soil horizon.

2.12.1 Crop Coefficient Method For Calculating Evapotranspiration

Evapotranspiration of a crop can be calculated by multiplying crop coefficient, Kc by the reference evapotranspiration, ET_o of that crop (Paul *et al.*, 2005).

2.12.2 Factors Affecting Crop Coefficient of a Crop

According to Allen *et al.* (2006), factors affecting crop coefficient of a crop include the following

2.12.2.1 Crop Type

The evapotranspiration from full grown, well-watered crops differs from ET_o because of changes in albedo, crop height, aerodynamic properties, and leaf and stomata properties. The close spacing's of plants and canopy height that are taller and roughness of many mature crops makes crops to have crop coefficient values which are greater than 1. Crop coefficient factor sometimes is 5-10% greater than the reference, this occurs at $K_c = 1.0$, also it can be 15-20% greater for crops like sugar cane, sorghum, maize that are tall. Crops that close their stomata at daylight like pineapples, have crop coefficient that are small. However, as radiation or sunlight increases the stomata opens for most species. The crop water losses can be determined from the number and position of the stomata and cuticula resistance to transfer of vapour. Kc values of crop species with stomata on the lower leaf side or large leaf resistance are usually small. This is why citrus and most deciduous fruit trees have smaller Kc values. Spacing and transpiration control with only 70% ground cover for mature trees, may lead to Kc values to be less than one, if cultivated without ground cover crops.

2.12.2.2 Climate

Crop coefficients and aerodynamic resistance of crops are altered by variations in wind, mostly for crops taller than the hypothetical grass reference. The effect of the difference in aerodynamic properties between crop and grass reference surface depend on crop type, crop height and climatic conditions. Aerodynamic properties are usually higher for crops compared to grass reference, K_c increases as relative humidity decreases and wind speed increases. Higher wind speed leads to greater Kc values. Under humid and calm wind conditions, Kc values depend less on aerodynamic components differences of ET_c and ET_o and the K_c values for full-cover crops not exceeding 1.0 by more than about 0.05. This is because full-cover agricultural crops and the reference crop of clipped grass both provide for nearly maximum absorption of shortwave radiation, which is the primary energy source for evaporation under humid and calm conditions. Generally, the albedos, are similar over a wide range of full cover agricultural crops, including the reference crop.

2.12.2.3 Soil Evaporation

Differences between evaporation occurring on the soil surface and transpiration on crop between the reference surface and crops in the field are integrated in the crop coefficient. The crop coefficient K_c at full-cover reflects mainly the differences in transpiration where soil evaporation has relatively small contribution. After irrigation or rainfall, evaporation effect occurs predominantly when the cultivated crop is small with very little ground cover. When such low-cover conditions occur, crop coefficient can be determined by the level of soil surface wetness. When soil is wet from rain or irrigation, evaporation from surface of the soil is considerable and the K_c value may exceed 1. However, when the surface of the soil is dry, evaporation is very low or restricted, and the crop coefficient will be small and can even be less than 0.1.

2.12.2.4 Crop Growth Stages

As the crop develops, the ground cover, crop height and the leaf area change. Due to differences in evapotranspiration during the various growth stages, the Kc for a given crop will vary over the growing period. The growing period can be divided into four distinct growth stages: initial, crop development, mid-season and late season.

2.12.2.4.1 Initial Stage

This covers the planting date to approximately 10% ground cover. The duration depends on the type of crop, variety of the crop variety, climate and the planting date. Then the ground surface is approximately 10% covered by green vegetation the initial period ends.

2.12.2.4.2 Crop Development Stage

This stage starts from 10% ground cover to effective full cover. The crop effective full cover starts at the beginning of flowering. In cases of row crops, where rows commonly interlock leaves like corn, sugar beets, beans and potatoes, effective cover is the time when some leaves of plants in adjacent rows begin to intermingle so that soil shading becomes nearly complete, or when intermingling does not occur and plants reach nearly full size. For some crops, especially those taller than 0.5 m, the average fraction of the ground surface covered by vegetation (fc) at the start of effective full cover is about 0.7-0.8. and shaded soil and leaves do not change significantly with further growth of the crop beyond fc 0.7 to 0.8. In dense grasses, effective full cover may occur at about 0.10-0.15 m height. For thin strands grass (dry rangeland), grass height may approach 0.3-0.5 m before effective full cover is reached. Forages that are densely planted like clover and alfalfa attain effective full cover within 0.3-0.4 m. When soil surface is dry, K_c = 0.5 which is about 25-40% of the ground surface covered by vegetation including transport of sensible heat from the surface of the soil into the vegetation. When K_c = 0.7, it is usually about

40-60% ground cover. However, K_c values varies, depending on crop type, frequency of wetting and if at full ground cover, more water is used by the crop than the reference crop.

2.12.2.4.3 Mid-Season Stage

This starts from effective full cover to the start of maturity. Maturity can be observed aging begins, yellowing or senescence of leaves, leaf drop, or fruits becoming brown. This stage has the highest duration both for perennials and many annuals, but usually short for vegetable crops. This stage has the maximum K_c value and the same for most of the growing and also cultural conditions. The reason for the difference of the reference value which is 1 and K_c mid is as a result of differences in height of the crop and resistance that occurs between grass reference surface, agricultural crop and weather conditions.

2.12.2.4.4 Late Season Stage

It starts from when crop is matured to time of harvest or full senescence. When crop harvest is done, the calculation involving K_c and ET_c ends. The crop dries out, experiencing leaf drop and reaches full senescence.

2.13 VARIATION REQUIREMENT

This can be defined as the amount of water to be applied to the soil through irrigation so as to guarantee that the soil attains its full water requirement. When the only source of water applied to the plant is through irrigation, the irrigation requirement is always greater than crop water requirement which allows inefficiencies in the system. If water is received from other sources such as rainfall, underground water, then irrigation requirement can be less than crop water requirement (Andreas and Karen, 2002). Irrigation requirement is one of the main parameters to be considered when planning, designing and operating irrigation and water systems. Irrigation requirement is essential in the formulation of policies for optimum allocation of water resources (Demba, 2014). According to Hajare *et al* (2008), the irrigation requirement (IRR) for crop production is the amount of water, in addition to rainfall, that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield.

2.13.1 Net Irrigation Requirement

According to Demba (2014), net irrigation requirement is the amount of irrigation water to be applied to the plant to replenish all evapotranspiration losses. This can be calculated using soil water balance equation which includes effective rainfall, stored soil water, crop evapotranspiration and leaching requirements.

$$I_{rnet} = ET_c - (Pe + Ge + Wb) + LR \qquad \ldots\ldots.2.3$$

Where:

I_{rnet} = Irrigation Net Requirement (mm)

ET_c = Crop Evapotranspiration (mm)

Pe = Effective Dependable Rainfall (mm)

Ge = Ground Water Contribution from Water Table (mm)

Wb = Water Stored in The Soil (mm)

LR = Leaching Requirement (mm)

2.14 SOIL, WATER PLANT RELATIONSHIP

Soil is a key criterion that needs to be understood before an irrigation schedule can be prepared. Soil contains organic and inorganic matters which cover the earth's surface. It contains living organisms, water, air and can also support the growing of vegetation. It also acts as a storehouse for nutrients, habitat for micro-organisms cum plant roots and stores water that will meet evapotranspiration of plants. It provides water, nutrients and serves as a platform for plant growth. It helps to determine how much water should be applied for plants to grow optimally. The physical and chemical properties of a soil determine the amount of water the soil can store for plant growth. This amount of water determines how long the plant can be sustained sufficiently between irrigation and/or rainfall events, the frequency of irrigation and the amount and rate to be applied. The soil plays a vital role in plant evapotranspiration and determines the irrigation system capacity needed for a desired crop yield. Grading of land, ploughing and other tillage practices can alter the soil properties within a profile. Infiltration and soil permeability rates can be affected by shallow tillage practices. Adequate on-site soil information should be obtained for irrigation planners to make proper recommendations (Andrea and Karen, 2002). Soil water availability is one of the main factors affecting plant growth. Consequently, plant cover influences soil water moisture and the evapotranspiration process (Silva *et al.*, 2015).

2.14.1 Soil Structure

This entails the way soil particles are arranged and organized in the soil. It also involves the way soil particles bind together in aggregates. The aggregation affects flow path of water, gases, solutes and pollutants. The soil structure affects plant growth and development through aeration, soil compaction, water relations and soil temperature. The structural development of the soil is influenced by the amount and type of clay, amount of organic and inorganic matter, presence of iron, aluminum oxides and vegetations and can also be destroyed by tillage, decrease in organic matter and irrigating land with high silt and salt concentration (SSC, 2000).

2.14.2 Soil Moisture and Water Retention

This is the amount of moisture or water contained in the soil at a time which could range from a zero i.e dry soil, to saturation depending on the porosity of the soil. Soil moisture can be determined in the laboratory or the field. Soil moisture content can be calculated using the volumetric or gravimetric methods. Improvement of soil moisture from 1 to 10g can occur when soil organic matter is increased by 1g (Emerson, 1995). Leaf area index and crop yield can be increased with soil moisture, but emergence of crops is negatively affected (Odjugo, 2008).

2.14.3 Soil Fertility Depletion

Soil fertility can be defined as the ability of a soil to maintain and provide essential nutrients during plant growth and development over a period. The soil serves as a base for nutrient supply to plants but inadequate supply of essential nutrients such as N and P are the major constraints affecting African agriculture (Mokwunye *et al*., 1996). It is important to note that with the knowledge of the rate of depletion of soil nutrient, if other factors affecting crop production are solved, crop yield in Africa will continue to decrease unless conscious effort are made to remedy soil fertility depletion. The rate of nutrient depletion is field specific, caused due to the manner such field are managed over a period (Sanchez and Leakey, 1997).

2.14.4 Soil Fertility Improvement

About 8 million tons of nutrients are lost by agricultural soil in Africa. Restoring the lost minerals absorbed by plants and agricultural produce is necessary to maintain the proper crop yield (Fleshman, 2006). The compensation for nutrient losses in agricultural soil because of crop cultivation, leaching with the use of inorganic fertilizer has been tested in Africa and increase in yield has been reported (Bationo *et al*, 2006). It is important to note that the cost of fertilizer is very high in Africa therefore the need for its cost-effective application becomes inevitable (Conwey and Toenniessen, 2003).

2.14.5 Fertilizer Use

Fertilizer application poses a strong limitation for peasant farmers in Africa compare to their counterparts in other parts of the world. This is because of favourable policies initiated by government of these countries such as fertilizers are produced massively at a subsidized rate, crop rice support programmers and investment in the provision of logistics and storage facilities (Sanchez and Leakey, 1997). In Africa approximately 1.38 million tons of fertilizer per year is applied for the propagation of crops, this is an average fertilizer consumption of 8.3 kg ha^{-1}. This value is the lowest and represents only 2% of worldwide demand (Morris *et al.,* 2007). The most important factors in crop production are fertilizer and water. The consideration of irrigation application and fertilizer usage by plant separately is not possible. Therefore, the production of functions that can be used to determine the effects of water and fertilizer use on the crop yield is paramount. The knowledge of the amount of water needed for optimum fertilizer uptake by plants is important. Hence, optimum crop production requires the effective usage of these factors. This requires a detailed understanding of plant growth and yield as a result of fertilizer and water usage under different conditions (Ertek, 2014).

2.15 GROWING DEGREE DAYS (HEAT UNIT)

According to Salama *et al.*, (2015) growing degree days (GDD) can also be referred to as the heat units which can be determined using the single sine curve during the growing season of a crop. It can also be calculated using a simple linear method which requires the daily minimum and maximum air temperatures of the study area, recorded from the local meteorological weather station. Heat units can be used in the prediction of the rate of phonological development of different plant species. Developmental rates of plant species increase approximately linearly as a function of air temperature; therefore, temperature changes will affect plant growth, when temperature is above lower threshold (T_U) or upper threshold temperature (T_L or T_{base}), plant growth and yield will be significantly affected. The upper threshold temperature can be set as 30 °C and lower threshold temperature (T_{base}), at 5 °C.

2.16 DYNAMICS THAT AFFECT PLANT GROWTH AND YIELD

The dynamics that affect crop growth and yield according to Marshal, (1988) are:

2.16.1 Water

This is the most important factor that affects the growth and yield of plants. Water deficit occurs when transpiration is greater than absorption. According to Decoteau (1998), yield of a crop is affected directly when water stress occurs at critical stages of growth. Permanent, irreparable damages occurs when moisture requirement are not attained when the phase is critical. The plant quality is diminished, or the plant yield is reduced.

2.16.2 Temperature

Plant growth processes require certain temperature to operate optimally (20^o C to 25^o C) while growth is reduced at high temperature (> 25^o C). Temperature affects the initiation of growth, water movement to root, permeability of the membrane on the root surface, opening of stomata (affecting photosynthesis). Mortality occurs when very low temperature occurs over a long period of time. Temperature is said to be the degree of coldness or hotness of a substance (Eagleman, 1985). Activities of enzymes and speed of chemical reactions increase with an increase in temperature. At a point, enzymatic reaction doubles with every 10^0C temperature increase but at excessively high temperatures, destruction of enzymes and other proteins occur (Mader, 1993)

2.16.3 Light

Light varies in intensity, duration and angle of inclination. Decreased light becomes a factor reducing growth when shading occurs; this reduces photosynthesis compared to respiration. Growth is inhibited when excessive respiration becomes a burden. Light captured by plant depends on leaf size, angle of display, age, physiological condition and pubescence. High leaf area index is important for sustaining growth rate. According to Abellanosa and Pava (1987), light is essential in producing chlorophyll which is used for photosynthesis, this is a process by which plants produce their food in the form of carbohydrate. Other plant processes that are enhanced or inhibited by this factor include stomatal movement, phototropism, translocation, mineral absorption and abscission.

2.16.4 Atmosphere

This contains gases like CO_2 (photosynthesis), O_2 (respiration) and N_2 which are essential for plant growth. According to Miller (2000), the oxygen and carbon dioxide in the air are important to plant physiology. Oxygen is essential in respiration which is the production of energy used in various growth and development processes. Carbon dioxide is a raw material used during photosynthesis for the manufacture of food. The air also contains other suspended particles of dust and chemical air pollutants such as carbon monoxide (CO), sulfur dioxide (SO_2), sulfur trioxide (SO_3), nitrogen oxides, methane (CH_4), propane, chlorofluorocarbons (CFCs), solid particles of dust, soot, asbestos and lead, ozone and many more which can be harmful to plants.

2.16.5 Nutrient

It is the major nutrient limiting plant growth. Nutrient deficiency results in reduced foliage production, modified vegetation composition, altered nutrient content of forage. Nitrogen increases vigor of leaves, height and seed stalks, seed production, number of roots and size of stem and leaves. Growth responses of plant vary with available soil moisture.

According to Jeff (2001), soil helps to hold the plant firmly to the ground. It contains the nutrients utilized for plant development. The pH (acidity or alkalinity) of the soil also affects the growth rate of plant. All plants do not have the same nutrient and pH requirement.

2.17 PROCESSESS THAT OCCUR DURING PLANT GROWTH

Growth is the process of filling space expansively with organic mass by cell division, expansion and elongation. It involves uptake of water, warmth, CO_2, minerals to produce food. This is possible due to photosynthesis. The food (carbohydrate; sugar, starch) is oxidized to maintain normal plant function and grow new tissues. This process is called respiration (Joke and Machteld, 2002). Stomata are the microscopic pores that occur on stems, leaves, flowers and fruits but not on aerial roots. The full opening of stomata is associated with slight decrease in turgor of epidermal cells. Stomata opening requires an increase in turgor of the plant guard cells. The stomata of Crassulacean Acid Metabolism plant behave in opposite manner i.e closed at day and open at night. Factors affecting stomata aperture include light, CO_2, humidity, temperature, tissue water status while guard cells are affected by water status, internal CO_2 concentration and growth regulators e.g Absissic acid (ABA), cytokinins, kinetin. Stomata opening and closing result from tugor differences between guard cells and the surrounding which is caused by K concentration (Theodore, 1973). The resistance to diffusion of vapor strongly depends on leaf area index (LAI), ground cover, soil moisture conditions and crop height. Due to differences in albedo, crop height, aerodynamic properties, and leaf and stomata properties, the evapo-transpiration from full grown, well-watered crops differs from ET_0pot (Thorsen, 2006). ABA is produced in the roots and leaves during water stress and transported by ATP binding cassette located in plasma membrane. We also have secondary signaling messenger that are for stomata closure such as Calcium, Hydrogen peroxide and nitrogen(II)oxide. If evaporation of water from the surface of the leaf (transpiration) is greater than the water supplied to the plant by the soil the stomata closes to avoid desiccation. This results in limited CO_2 absorption because of which assimilation declines. Therefore, growth rate during water shortage is smaller than the potential growth rate. Water deficit reduces the number of leaves per plant, leaf size and decrease soil water potential (Arve *et al.*, 2011). Proline accumulation is the first response of plant to water stress. Plant produces internal protective system during drought to avoid desiccation. These include ascorbate and carotenoids (Skakeel *et al.*, 2011). Experiments show that rate of photosynthesis affects carbohydrate status of leaf with consequence for crop yield (Tracy and Micheal, 2014). Plant susceptibility to stress is influenced by the stage of development (Robert *et al.*, 1996). Drought affects nearly all the plant growth processes; however, the stress response depends upon the intensity, rate, and duration of exposure and the stage of crop growth (Sikuku *et al.*, 2010). Another consequence of exposure to these stresses is the increase in root/shoot ratios (Cheng *et al.*, 2011). Two useful water plant indicators are leaf water potential and stomatal conductance, others are canopy temperature, trunk diameter, sap flow, leaf reflectance (albedo), chlorophyll fluorescence. Finally, vegetative growth indicator such as tissue expansion is the first to be affected when water stress occurs, easy to observe or measure, and tend to correlate well with crop yield (Pellegrino *et al.*, 2005). Leaf relative water content (RWC) is an important indicator of water status in plants; it reflects the balance between water supply to the leaf tissue and transpiration rate. However, physiological and agronomic definitions of drought tolerance differ distinctly; the first stipulates that under drought, tolerant plants remain viable and produce viable seeds, while the second requires sufficient plant growth to produce an economically significant yield (Dorota *et al*., 2016).

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

The study was conducted on an experimental plot at the Department of Crop Protection and Environmental Biology research farm and greenhouse, University of Ibadan, Ibadan, Oyo State, Nigeria. The annual rainfall ranges between 788m and 1884m while the mean monthly temperature is 26.6^{o}C. The experimental plot is located approximately on Longitude 3^{0}89' East of the Greenwich Meridian, and Latitude 7^{0}45' North of the Equator. The elevation of the study area is precisely 223.5m (± 12.0m) above sea level. *Corchorus olitorus* was planted both in the rainy season (May to September/October) and dry season (October to March/April).

3.2 LAND PREPARATION

The experimental plot was prepared by clearing and levelling the required area. The experimental plot was tilled to prepare it for planting. A seed bed was prepared; loose, well drained, deep enough, made good contact with the seed. The seed bed retained adequate moisture and was free of weed. The facilities e.g pipes, fittings, tanks, construction of platforms were installed for irrigation purposes. The surface irrigation method used was drip irrigation.

3.3 EXPERIMENTAL LAYOUT

The experimental plot was designed using a split plot method with two treatments and three replications. The blocks were assigned at random levels of treatment factors to avoid bias. The size of each vegetable bed was 1m x 1m, the spacing between replicates was 0.40m. The spacing of *Corchorus Olitorus* was 30cm x 10cm giving a plant population of 300,000 plants per hectare. The experiment was also carried out in a greenhouse using completely randomized design with three replications on a 5kg soil.

3.4 SOIL PHYSICAL ANALYSIS

The soil sample of the experimental plot was analysed to ascertain various parameters namely:

3.4.1 Determination of Initial Soil Water Content

Soil water content was determined using two methods. The first method was done in-situ using a soil moisture meter (Lutron PMS-714 made in Taiwan). The second method was carried out using the gravimetric method.

3.4.2 Soil Textural Class, Particle Size Distribution and Soil Classification

The soil type or soil textural class was classified using mechanical sieve analysis method.

3.4.2.1 Mechanical Sieve Analysis

The soil was oven dried and then all lumps are broken into small particle before they were passed through the sieves. After shaking the mass of soil retained in each sieve was weighed in a balance. The results are usually represented in terms of the percentage of the total weight of the soil that passed through the different sieves (Pennell, 2002).

3.4.2.2 Hydrometer Method

The Bouyoucos hydrometer method by Gee and Bauder (1986), was used to carry out the particle size analysis on the soil samples. Fifty gram of air-dried soil was weighed into a dispersion cup. Twenty millilitre of 25% sodium hexametaphosphate (calgon) was added as the dispersant. Three hundred and fifty millilitre of water was then added and the mixture was subjected to the mechanical stirrer for 10 minutes. After the process of stirring, the observed suspension was decanted into a sedimentation cylinder through a 210-micron sieve-funnel apparatus. The coarse sand fraction collected in the sieve was oven-dried in a moisture can at 105°C and weighed. The suspension in the sedimentation cylinder was made up to the 1 litre mark by adding distilled water. The temperature and density of the suspension were taken with the aid of a thermometer and the Bouyoucos hydrometer, respectively at 1 minute (silt and clay concentration) and 2 hours (clay concentration). Soil samples or particles ≤ 0.05 mm (silt and clay fractions), sedimentation method based on Stokes law was applied to ascertain particle size distribution. Soil particles settle as a result of gravity in aqueous solution attaining terminal velocities which was proportional to their masses and sizes. The amount of soil suspended after a given settling time was used to deduce particle size fractions.

3.4.2.3 Bulk Density

Bulk density was determined using a bulk density ring (core) to take soil samples. A cylindrical core of 7 cm diameter and 7 cm height was used to take soil samples for soil bulk density (ℓb) and determined as described by Grossman and Reinsh (2002). Samples were then oven dried at 105 °C for 24 hours, and the dried weight recorded. Bulk density was calculated by dividing the oven-dried soil mass by volume of the cylinder (Landon, 1991) as:

$$\ell b = (M_2 - M_1)/V \qquad \ldots\ldots\ldots\ldots \quad 3.1$$

where $V = \pi r^2 h$

Where:

ℓb = Bulk Density (g cm $^{-3}$)

M_2 = Mass of the Core Cylinder + Oven dried Soil

M_1 = Mass of empty Core Cylinder

V = Volume of Core Cylinder

r = Radius of the Cylinder

h = Height of Cylinder

3.4.2.4 Maximum Infiltration Rate Test

This is the rate at which moisture moves from the surface of the soil into the soil. This was calculated using a field method called the double ring infiltrometer method. A small ring was installed, centered inside a larger ring. The diameters of the rings were 12 and 24 inches. The sides of the infiltrometer rings were kept vertical, and undue disturbance of the soil surface from driving of the ring or from excessive trampling over the surface was avoided. The infiltrometer rings were driven 6 to 8 inches into the soil. An infiltration ring was driven by means of a driving cap, which was centered on the ring and on the edge of which was placed a heavy wood block; both rings were installed to the same depth. Some type of depth gage should be installed on the infiltrometer rings, to assist the investigator visually in maintaining a given water level (head). The water was at the proper depth when the point of the wire or hook barely made a small pimple on the surface of the water. A minimum water level of 1 inch and a maximum of 6 inches was maintained. A recording level gage may be installed on the supply tank to record the amount of water used for the test. To dissipate the force of the applied water and to prevent disturbance of the soil, the soil surface within the infiltrometer rings were covered with a splash guard (pieces of burlap or rubber sheet). The initial amount of water poured into the rings need not be measured, but any water added to maintain the desired depth of water, after the start of the timing interval, should be recorded. This process was followed for both rings in the double-ring infiltrometer. For comparison, infiltration rate is usually calculated for the outer as well as inner ring. The water level was maintained near the desired depth as possible. To prevent evaporation, the driving cap or some other type of covering was placed on the infiltrometer rings during the time intervals between water measurements. Upon completion of the infiltration test, the infiltrometer rings were removed from the soil by light hammering on the sides (Johnson, 1963).

3.4.2.5 Hydraulic Conductivity

This is a measure of the soils ability to transmit water. A cylindrical core of 7 cm diameter and 7 cm height was used to take soil samples. Soil samples were also taken to determine saturated hydraulic conductivity (K_s) in the laboratory using a constant head permeameter (Reynolds and Elrick, 2002). K_s was calculated as described by Hillel (2004). In this type of laboratory setup, the water supply at the inlet was adjusted in such a way that the difference of head between the inlet and the outlet remained constant during the test period. After a constant flow rate was established water was collected in a graduated flask for a known duration. The total volume of water collected may be expressed as

$$Q = Avt = A(Ki)t \qquad \ldots\ldots \qquad 3.2$$

Where:

Q = Volume of Water Collected

A = Area of Cross Section of the Soil Specimen

t = Duration of Water

Where $i = h/L$

Where L = Length of Specimen

Insert i into the equation

$$Q = A (K \times h/L)t$$

$$Q = AKht/L$$

$$K = QL/Aht$$

3.5 SOIL CHEMICAL COMPOSITION

3.5.1 Soil pH

This was determined in a 1:1 ratio mixture of soil and distilled water (Mclean, 1982). Ten gram of 2 mm sieved air-dried soil was weighed into a 50 ml beaker. Ten millilitre of distilled water was added and the mixture was stirred with a glass rod for 10 minutes. The soil pH was read by inserting a glass-electrode pH meter into the mixture.

3.5.2 Organic Carbon

The organic carbon content of the soil was determined using the Walkley-Black wet-oxidation method (Nelson and Sommers, 1982). A half gram of 0.5 mm sieved air-dried soil was weighed into a 250 ml conical flask and 10 ml of 1N $K_2Cr_2O_7$ was added to it. The mixture was swirled to mix. Twenty millilitre of concentrated H_2SO_4 was added rapidly to the mixture and this was allowed to cool. One hundred millilitre of distilled water was prepared without soil as the blank. Three drops of ferroin indicator was added to blank and sample, respectively before titrating with 0.5 N ferrous sulphate until it changed to a wine colour. The value for organic carbon was calculated as described below.

$$\% \text{ Org C} = \frac{(B-T) \times N \times 1.33 \times 0.003 \times 100}{W} \qquad \ldots\ldots\ldots\ldots\ldots 3.3$$

Where B = Blank titre value

N = Normality of ferrous sulphate

W = Weight of sample

% organic matter = % Org C x 1.724

T = initial titre value

3.5.3 Total Nitrogen

Total nitrogen was determined using the micro-kjeldahl digestion-distillation apparatus (Bremmer and Mulvaney, 1982). Half gram of 0.5 mm sieved soil was weighed into a 250ml conical flask. Five millilitre of concentrated sulphuric acid was added before swirling for 5 minutes and allowed to stand. One tablet of selenium was added as the catalyst. This was digested until a clear substance was attained. The clear substance in the beaker was rinsed and made up to 5 ml with distilled water. This was allowed to settle before pouring into the micro-kjedhal apparatus. It was distilled by adding 5 ml of boric acid and NaOH, respectively into the Erlenmeyer flask of the distillation apparatus. The nitrogen content in the distillate was determined by titrating with 0.01 M standard HCl until the colour changed at the end point from green to pink.

3.5.4 Available Phosphorus

Colorimetric determination of phosphorus in water and soil extracts using ascorbic acid molybdate blue method (Olsen and Sommers, 1982) was done by weighing 2 g of soil into a reaction cup. Five millilitre of Melich 3 was added before extracting through whatman filter paper. Five millilitre of Murphy and Riley colour reagent was added before the addition of 15 ml of distilled water. Phosphorus absorbance was read using the spectrophotometer.

3.5.5 Exchangeable Acidity

This was determined using the KCl extraction method. 2g of air-dry soil was weighed into a 150ml plastic bottle. 20 ml of 1 N KCl was added and shaken for an hour. This was later filtered through the whatman filter paper into a conical flask. Three drops of phenolphthalein indicator were added before titrating against 0.01 N NaOH until the colourless solution turned pink.

3.5.6 Exchangeable Bases

The exchangeable bases were extracted from 5 g of air-dried soil using 100 ml neutral ammonium acetate as the extractant (Rhodes, 1982). 5g of air-dried soil was weighed into a plastic bottle and 100 ml of neutral 1 M ammonium acetate was added. The mixture was mechanically shaken for 10 minutes and filtered through whatman filter paper into a 100ml volumetric flask. This was later made up to mark with acetate. Calcium and magnesium were determined from the extract by 0.01 M EDTA titration method, while sodium and potassium were determined using the flame photometer (Jackson, 1970).

3.5.7 Micronutrient Extraction

The hydrochloric acid procedure was used to determine the Fe, Cu, Mn, and Zn content, respectively in the soil (Rhoades, 1982a). 10g of soil was weighed into a plastic bottle and 100 ml of 0.1 M HCl was added before a stopper was inserted. This was shaking for 10 minutes and filtered through whatman filter paper No. 42. The nutrients were determined using the atomic absorption spectrometer (Adams *et al*., 1980).

3.5.8 Electrical Conductivity (ECe)

This indicates the amount of soluble salt ions in the soil. A conductivity cell (meter) that measures electrical resistivity of a 1: 5 soil water suspension and a pipette cell was used. 30ml standard 0.01MKCl solution was poured to a 50ml beaker and the temperature measured. The pipette cell was rinsed and filled with standard KCl solution or a dip cell was inserted into the solution. The temperature compensation dial was set at measured temperature and adjusted reading of the meter to 1.412mS/cm with cell constant dial. This is the specific conductivity of the standard 0.01MKCl solution at 25^0C. Measure the temperature of the extract and set temperature compensation dial at this temperature, the reading is automatically corrected to 25^0C. Pipette cell was filled with extract or dip cell inserted into extract and conductivity read (ISRC, 2002).

3.6 EXPERIMENT FOR MODEL PARAMETERIZATION

Crop simulation models are modern research technologies that are used by researchers to estimate the growth, development and yield of specific crops using several input parameters such as environmental factors and management strategies (Mavromatis *et al*, 2001). The mode of operation of the model is because of a range of component modules. The CROPWAT model is built with algorithms that express the correlation between plant growth processes (morphological development and water uptake) and environmental driving forces (e.g., daily temperature, photoperiod and available soil water). Generally, crop simulation models need some form of parameterization before they can be used in an area other than where they were originally made. Model parameterization involves modifying sensitive input parameters, within an acceptable range in an attempt to match model output, to measured data based on a predefined objective function (Fosu-Mensah, 2012).

3.6.1 Total Available Soil Moisture (TAW)

This refers to the capacity of a soil to hold or retain water available for plant use. After water is supplied through rainfall or irrigation, the soil drains due to gravity until field capacity is reached. Field capacity can be defined as the amount of water that a well-drained soil can hold against gravitational forces. Wilting point is the water content at which plants will permanently wilt.

$$TAW = 1000\ (FC - WP)\ Z_r \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where:

TAW = total available soil water in the root zone [mm],

FC = water content of the soil at field capacity [$m^3\ m^{-3}$],

WP = water content of the soil at wilting point [$m^3\ m^{-3}$],

Z_r = rooting depth [m].

3.6.2 Soil Moisture Retention

Soil moisture retention was determined in the laboratory using pressure plate apparatus following Dane and Hopmans (2002) procedures. Pressure was imposed by setting the matric suctions at 10kPa equivalent field capacity (FC). The moisture content of the soil was determined after there was no sign of water coming out of the pressure chamber. The core samples were transferred to chamber having higher matric suction while pressure was imposed at 1,500kPa. The samples were also weighed thereafter before transferring the samples to electric oven, setting the temperature at 105^oC. Each sample was oven-dried to a constant mass. Total available soil moisture was estimated as the difference between field capacity (FC) obtained at 10 kPa (–100 cm water) and permanent wilting point (PWP) at 1500 kPa (–15,000 cm water).

$$TASM = (\theta_{FC} - \theta_{PWP})/\rho_b \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3,5$$

Where:

TASM = Total Available Soil Moisture

θ = Gravimetric Moisture Content, (%)

ρ_b = Bulk Density at the required depth in g cm^{-3}.

3.6.3 Maximum Rooting Depth (Zr)

This is the deepest rooting depth attained by the crop under specific soil condition. The can be obtained using a meter rule.

3.6.4 Effective root depth

The upper portion of the root zone where plant get water. It is one half the maximum rooting depth.

3.6.5 Initial Soil Moisture Depletion (D_r)

This is a percentage of the total available moisture initial. It indicates the dryness of the soil at the start of irrigation. This is expressed as a depletion percentage from FC.

3.6.6 Soil Water Holding Capacity

It is determined by the amount of water held in the soil sample vs the dry weight of the sample. The amount of pressure applied in these different methods can be as low as 1/3 atmosphere of pressure (about 5 psi) up to 15 atmospheres of pressure (about 225 psi).

3.6.7 Available Soil Moisture

This was obtained from the CROPWAT model when parameters such as soil type, total available soil moisture, maximum infiltration rate, maximum rooting depth, initial soil moisture depletion are inserted using the equation below:

$$RAW = p\ TAW \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where:

RAW = readily available soil water in the root zone [mm],

p= average fraction (critical depletion fraction)

TAW= Total Available Soil Water

The factor p varies from 0.30 for shallow rooted plants at high rates of ET_c (> 8 mm d^{-1}) to 0.70 for deep rooted plants at low rates of ET_c (< 3 mm d^{-1}). A value of 0.50 for p is commonly used for many crops.

3.7 PLANTING

The viability of the seeds was first determined by pouring the seeds inside a bowl of water, the seeds that settle at the bottom of the water because of gravity are the viable ones while the seeds that float on the surface of water are not viable. Seed dormancy was be removed by pouring the seeds in a light bag or cloth and dipped into hot water for ten seconds and allowed to dry. Seeds were spread over the prepared land by throwing small quantities of the seeds into the air close to the surface of the prepared land. Broadcasting method was used for the propagation of *Corchorus olitorus*. Thinning of vegetable was done to reduce the number of seedlings per stand when planted in situ. The source of water for vegetable growing was from irrigation during the dry season while in the wet season, rainfall was the source of water.

3.8 WATER APPLICATION AND FERTILIZER APPLICATION

It is an important variable cost in vegetable production. Irrigation will be done on different plots at the rate of 2mm, 4mm, 6mm, 8mm and control (considering average daily ET_o of 4mm/day) while fertilizer of 0kg/ha, 100kg/ha, 200kg/ha, 300kg/ha, 400kg/ha was added to each of the irrigated plot respectively. *Corchorus olitorus* is mature for harvesting between 8 to 10 weeks of planting.

3.9 Potential Evapo-Transpiration

This is the amount of water lost through evaporation from the soil and transpiration from the crop. Reference surface evapotranspiration (ET_O) is a climatic parameter expressing the power of the atmosphere in reference to a standard surface; it was calculated using CROPWAT model. Potential Evapotranspiration (ET_C) is an excellently managed, well-watered fields that achieve full production under the given climatic conditions. ET_c can also occur as adjusted under nonstandard condition (nutrient deficit, saline soil, water deficit). This was measured using a Lysimeter.

3.9.1 Evapo-Transpiration Using Lysimeter

This is the amount of water required to compensate for the loss from the cropped field. It is equal or identical to crop water use. The amount of water lost is equal to the amount of water gained. The lysimeter was constructed with a cylindrical container measuring 20 cm internal diameter, 15 cm deep and wall thickness of 5 mm, with edges that can fit into the soil. The lysimeter was filled with soil sample by penetrating it into the soil profile, using light strokes. The lysimeter walls were lubricated with vegetable oil for the soil to be easily removed from the container. The lysimeter bottom was sealed to avoid escape of water through the bottom, this method was used to make sure that changes in mass, was experienced due to evaporation of water from the soil surface and plant (Evett et al., 1995).

Evapo-Transpiration of microlysimeter (ETa) in mm was calculated:

$$ETa = (\Delta MML / AML) + W \qquad \text{…………………} \ 3.7$$

ΔMML - microlysimeter variation of mass, kg;

AML – microlysimeter surface area, m^2

W – water applied, mm.

3.9.2 Crop Coefficient

Crop Coefficient (Kc) can be obtained by dividing crop evapo-transpiration (ET_c) by reference surface evapo-transpiration (ET_0). It varies with specific crop characteristics and only slightly to climate.

3.9.3 Water Stress Factor/Coefficient and Water Deficit

Water stress factor (Ks) is the ratio of real evapotranspiration (ET_{real}) to the potential evapo-transpiration (ET_c) while water deficit is ET_c - $ET_{real.}$

3.9.4 Yield Response Factor

Yield response factor (Ky) is the response of yield to water deficit and it varies with growth stages. The equation for obtaining Ky is:

$$Ky = (1-Ya/Ym) / (1-ETa/ETm) \quad \text{…………….. 3.8}$$

Where a and m represent actual and maximum respectively.

3.9.5 Fertilizer- Yield Response Factor

According to Ertek (2014), fertilizer- yield response factor (Kyf) is the response of yield to fertilizer deficit and it varies with growth stages. The equations for obtaining fertilizer yield response factor are:

$$Ky_N = (1-Ya/Ym) / (1-Nupa/Nupm) \quad \text{……………………3.9}$$

$$Ky_f = (1-Fa/Fm) / (1- ETa/ETm) \quad \text{……………………3.10}$$

$$K_{N\text{-}ET} = (1- Nupa/Nupm) / (1- ETa/ETm) \quad \text{…………………3.11}$$

Where; Ky_N = yield response with respect to nitrogen,

Ky_f = yield response with respect to fertilizer,

$K_{N\text{-}ET}$ = constant relating N (fertilizer) and ET,

F = fertilizer, up = uptake

3.10 METEOROLOGICAL HISTORY

Meteorological history such as temperature, humidity, wind speed, sunshine, radiation and precipitation prediction were recorded using an automatic weather station.

3.11 PLANT GROWTH PARAMETERS

The phenology of the crop was studied carefully to understand when temperature, moisture and day-length determine the timing of phase's i.e from sowing to maturity. Growth parameters at different stages such as initial (from sowing to 10% ground cover), development (from 10% to 70% ground cover), mid-season (flowering or yield formation), late season (ripening and harvest) was monitored and recording such as first and last planting dates, harvesting dates was carried out.

3.11.1 Yield

This is the weight of grain recovered from an area of crop, corrected to moisture content of 15%).

3.11.2 Number of Leaves Per Plant

Randomly five plants were selected, all the leaves were counted and the mean number of leaves per plant was obtained weekly after sowing.

3.11.3 Plant Height

Plants from each plot were randomly selected and tagged, plant height was measure from a point immediately above the soil surface to the top of the plant, and then the mean of height per plant was obtained in cm.

3.11.4 Stem Girth

Plants from each plot were taken and the diameter in the middle of the plant was measured using striping and a ruler and then the mean stem girth in cm were estimated weekly after sowing.

3.11.5 Number of Branches

From tagged plants the mean number of branches per plant was counted and the number recorded weekly after sowing for 10 weeks

3.11.6 Length and Width of Leaves

The width North South and East West were measured in cm with a metre rule and the longer part regarded as the length while the shorter part the width

3.11.7 Leaf Area

The leaf area of the plant was measured using an existing equation considering the leaf shape coefficient.

Leaf Area = Leaf shape coefficient x Leaf Length x Leaf Width ……………. 3.12

3.11.8 Leaf Relative Water Content (LRWC)

It is the appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit. LRWC is an appropriate estimate of plant water status in terms of cellular hydration under the possible effect of both leaf water potential and osmotic adjustment. The leaf relative water content was calculated using the fully expanded leaf after 10 weeks from each plant. The fresh weights were measured immediately after excision using an electronic balance, then put in test tubes containing distilled water. After 24 hours, turgid weights of leaves were obtained after cleaning. Dry weights were also obtained after oven drying the flag leaves at 85 ^oC for 48 hours. LRWC was calculated using the following equation:

$$LRWC=[(Fw-Dw)/(Tw-Dw)] \times 100 \qquad \ldots\ldots\ldots\ldots\ldots 3.13$$

or

$$LRWC= (LWC/MLWC) \times 100 \qquad \ldots\ldots\ldots\ldots\ldots 3.14$$

Where: Fw = Leaf fresh weight in grammes

Dw = Leaf dry weight in grammes

Tw = turgid weight in grammes

LWC= leaf water content in grammes

MLWC= maximum leaf water content in grammes (Cheng-Xu *et al*., 2011)

3.11.9 Biomass/Plant Water Content

This is the dry weight of above or below ground tissue/plot area. If the above-ground and below (plant) biomass was not separated in the field. Separate standing dead from standing live (green) above-ground (plant) biomass. Once the materials are separated, weigh each fraction in order to determine the fresh weight. Dry for 24-48 hours at 80^oC (constant weight), cooled in a desiccator jar, and reweighed (dry weight) (Brower, 1984).

Water Content = Fresh Weight – Dry Weight ……………3.15

3.11.10 Water Use Efficiency

This is the ratio of plant yield to total seasonal evapo-transpiration or net CO_2 assimilation to total water transpired.

3.11.11 Maximum Rooting Depth

This is the maximum length of the organ of a plant that typically lies below the surface of the soil.

3.11.12 Growth Index

According to Irmak *et al.* (2004), this can be used as a quantitative indicator of plant growth rate and compares the size of the plants grown under different systems. This is also a plant stress parameter. This can be calculated using the equation below

$$GI = H + ((WEW + WNS)/2))/2 \qquad \ldots\ldots\ldots\ldots\ldots 3.16$$

Where:

GI = Growth Index

H = Plant Height

WEW = Width of Plant East West

WNS = Width of Plant North South

3.11.13 Substrate Temperature

This can also be regarded as the soil temperature. The soil is the substance which the plant grows and lives in. The temperature of the soil was measured using a soil multimeter.

These data were used for generating parameters such as crop water requirement, crop irrigation requirement and reference evapotranspiration required to simulate the dynamics of crop water and yield using CROPWAT model. CROPWAT model was also used to estimate the yield reduction caused by water stress and climate

3.11.14 Growing Degree Days (Heat Unit)

This is calculated using minimum and maximum temperature and a temperature threshold (Tbase) of 5^{o}C with the formulae below;

$$GDD = ((Tmax + Tmin)/2) - T_{base} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.17$$

GDD = Growing degree days

Tmax = Maximum temperature

Tmin = Minimum temperature

T_{base} = Threshold temperature

3.11.15 The stress tolerance index

This is used for determining the resistance and sensitivity of a crop under water stress conditions (Fernandez, 1992).

$$STI=(Y_{Pi})(Y_{Si})/(Y_P)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.18$$

STI : Stress tolerance index

Y_{Pi} : yield in the surface without stress and adequate irrigation

Y_{Si} : yield in the stress surface which lacks adequate irrigation

Y_P: yields average without stress.

3.12 PROXIMATE ANALYSIS

3.12.1 Determination of Moisture Content

This was determined using standard method (AOAC, 2000). Samples of plant (2g) were weighed into moisture cans. The samples were dried to constant weight at a temperature of 105^{o}C. From the final weights, the replicate percentage moisture contents was determined using the formula below:

$$\%\text{ moisture content} = \frac{\text{initial weight of sample} - \text{final weight of the sample}}{Initial\ Weight\ of\ the\ sample} \times 100 \quad \ldots\ldots\ldots 3.19$$

3.12.2 Determination of Crude Protein

The crude protein content of plants samples was determined by Kjedahl method (AOAC, 2000). The sample (1g) was weighed into the Kjedahl flask, 12ml of concentrated H_2SO_4 was be added to the sample in the flask, with the addition of two tablets of catalyst. The flask was placed in the Kjedahl digester and heated until its content became clear and then cooled. This was transferred to the neutralization and distillation chamber of the Kjedahl apparatus, where it was neutralized and distilled with 40% NaOH solution for about four minutes. The distillate was titrated with standardized HCl (0.1N) using two to three drops of indicator until the blue grey end point was achieved.

$$\%\ \text{Kjedahl Nitrogen} = \frac{(\text{Vs} - \text{Vb}) \times \text{C} \times 1.4007}{\text{W}} \qquad \ldots\ldots\ldots\ldots 3.20$$

$$\%\ \text{Crude Protein} = \%\ \text{Kjedahl Nitrogen} \times \text{F} \qquad \ldots\ldots\ldots\ldots 3.21$$

Where;

Vs = titre value

Vb = titre value of the blank determination

C = Concentration of acid (0.1N HCl)

W = Weight of sample (grams)

F = factor to convert nitrogen to protein (6.25)

3.12.3 Determination of Crude Fat

The sample (2g) was weighed in a filter paper and dropped into a pre-dried extraction thimble, with porosity permitting a rapid flow of n-hexane. The n-hexane was poured into the dried boiling flask. The boiling flask, Soxhlet flask and condenser will be assembled followed by extraction which took place at a rate of 5 or 6 drops per second, condensation for about 4 hours by heating solvent in boiling flask. The fat content was determined using the formula shown below at the end of the extraction process (AOAC, 2000):

$$\% \text{ fat on dry weight basis} = \frac{Weight\ of\ fat\ in\ sample\ (g)}{Weight\ of\ dried\ sample\ (g)} \times 100 \qquad \ldots\ldots\ldots\ldots 3.22$$

3.12.4 Determination of Ash

Two grams of sample was weighed and put into a clean pre-dried and pre-weighed crucible. The crucible was placed in warm muffle furnace with the use of tongs. The sample was then ignited in the furnace at about 550^{o}C for about 4-6hours, after which it was turned off and the temperature allowed to drop to at least 250^{O}C before the furnace was carefully opened to avoid losing ash that may be fluffy. The crucible will be transferred to a desiccators using a safety tong and allowed to cool prior to weighing (AOAC, 2000). The ash content will be calculated as follows:

$$\% \text{ ash on dry basis} = \frac{\begin{array}{c}Weight\ after\ ashing - tare\\ weight\ of\ crucible\end{array}}{Original\ sample\ weight} \times 100 \qquad \ldots\ldots\ldots 3.23$$

3.12.5 Determination of Carbohydrate

Carbohydrate composition was determined in percentage as the difference from the other proximate composition: ash, moisture content, crude fat and crude protein (AOAC, 2000).

% carbohydrates = 100 – (% ash + % moisture content + % crude fat + % crude protein)…..3.24

3.12.6 Determination of Crude Fibre

According to AOAC (2000), a weighed crucible containing 1g of defatted sample was attached to the extraction unit (in Kjeldahl, D-40599; Behr Labor-Technik GmbH, Dusseldorf, Germany) and into this, 150 mL of hot 1.25% H_2SO_4 was added and digested for 30 minutes. The acid was drained, and sample washed with hot distilled water for 1½ hours. The crucible was removed and ovendried overnight at 105°C, cooled, weighed, and incinerated at 550°C in a muffle furnace (MF-1-02; PCSIR Labs, Lahore, Pakistan) overnight and reweighed after cooling. Percentage extracted fibre was calculated as:

$$\text{Crude fibre (\%)} = \frac{\text{Weight of digested sample-Weight of ashed sample}}{\text{Weight of samples}} \times 100\% \qquad \ldots\ldots 3.25$$

3.13 Evaluation Using Analysis of Variance (ANOVA)

Analysis of variance was performed to ascertain the performance and influence of each of the plant growth parameters from 2 weeks to 10 weeks at maturity. The ANOVA was carried out using SPSS software.

3.14 Evaluation of Multiple Regression Model

Prediction mathematical models were developed to predict plant growth parameters, water stress parameters and evapo-transpiration using multiple regression analysis which were done using Microsoft excel and MATLAB software

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 **WATER RETENTION CURVE**

Figure 4.1 shows the soil moisture retention of the soil sample from the study area. The loamy sand soils water holding capacity can be accessed from the forces binding the soil particles and porosity. The graph shows the relationship that occurs between volume water content Ɵ and matric potential Ψ of the soil sample. The results obtained from the matric potential at zero shows that the soil is saturated at 0.503, 0.515, 0.496 at 0-15cm depth, 0.333, 0.357, 0.34 at 15-30cm depth. However, as the matric potential Ψ move farther from the zero mark to 1500kpa, it approaches the soil wilting point. The volumetric water content Ɵ of the soil was observed to be 0.123, 0.132, 0.118 at 0-15cm soil depth, 0.081, 0.08, 0.086 at 15-30cm soil depth when the matric potential Ψ was at 1500kpa. The volumetric water content Ɵ of the soil at saturation was reduced by more than 70% for the soil to reach wilting point at matric potential Ψ of 1500kpa. This shows that less than 30% of the soil moisture is held back by the soil binding forces during wilting. The volumetric water content Ɵ of the soil at saturation reduced slightly (table 4.2) from 100kpa to 500kpa but reduced significantly by more than 50% from 500kpa to 1000kpa and reduced slightly from 1000kpa to 1500kpa (wilting point at matric potential Ψ).

Table 4.1: Average Soil Chemical and Physical Composition at Different Depth

Parameter	Depth (0-15)	Depth (15-30)
pH	6.5	6.36
Electrical Conductivity (E.C) US/cm	2180	2040
Organic Carbon (C) %	2.23	1.82
Nitrogen (N) %	0.21	0.19
Available Phosphorus (mg/kg)	25.03	15.76
Exchange Acidity cmol/kg	0.3	0.3
Calcium (Ca) cmol/kg	2.54	1.35
Magnesium (Mg) cmol/kg	0.4	0.2
Potassium (K) cmol/kg	0.26	0.15
Sodium (Na) cmol/kg	0.34	0.26
Manganese (Mn) mg/kg	204	247
Iron (Fe) mg/kg	182	144
Copper (Cu) mg/kg	6.2	2.34
Zinc (Zn) mg/kg	6.07	1.39
Clay %	11.94	11.94
Silt %	2.26	0.46
Sand %	85.8	87.6
Bulk Density (g/cm3)	1.54	1.56
Porosity %	0.43	0.41
Hydraulic Conductivity (cm/sec)	0.0019	0.0011
Infiltration Rate (cm/mins)	3.6	3.6

Table 4.2 Water Retention Curve of a Loamy Sand Soil

Description	Moisture					
	0kpa	10kpa	100kpa	500kpa	1000kpa	1500kpa
0-15	0.503	0.355	0.336	0.311	0.135	0.123
0-15	0.515	0.350	0.339	0.318	0.143	0.132
0-15	0.496	0.342	0.332	0.305	0.131	0.118
15-30	0.333	0.220	0.208	0.195	0.089	0.081
15-30	0.357	0.238	0.214	0.204	0.097	0.080
15-30	0.340	0.231	0.211	0.200	0.092	0.086

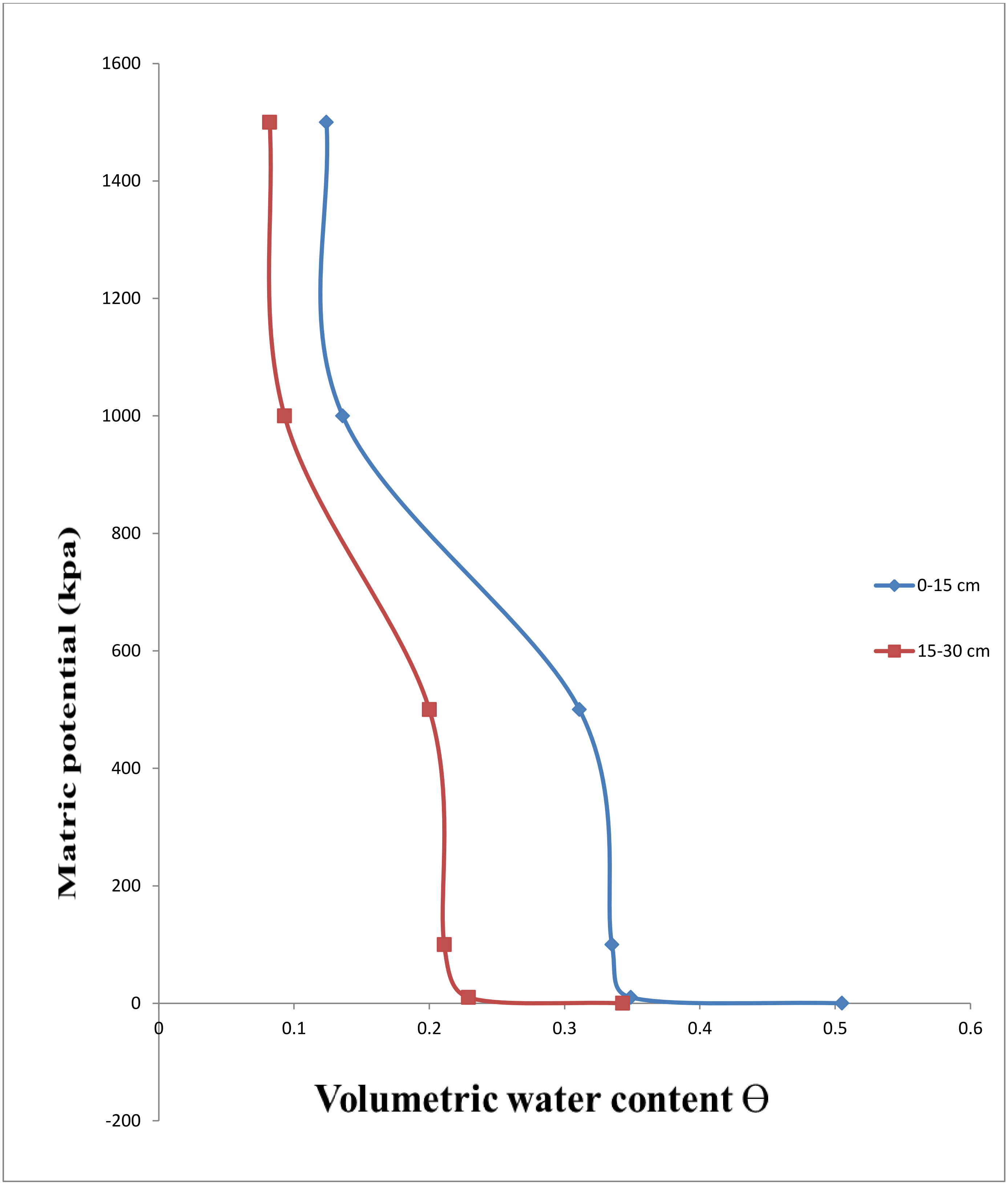


Figure 4.1: Water Retention Curve of the Loamy Sand Soil at The Study Area

4.2 PLANT GROWTH PARAMETER

4.2.1 Length of Leaves

Figure 4.2 and 4.3 present the leaf length of *Corchorus olitorus* as influenced by water and fertilizer treatment for field trials. At 2 weeks after sowing (2WAS), treatment (2ET), (2ET, 100kgNPK), (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean value of 1.53cm which was significantly higher than treatments (1/2ET), (1/2ET, 100kg NPK) and (1/2ET, 200kg NPK) which had a mean value of 1.44cm each. At 3WAS, treatment (1ET, 200kg NPK) recorded the highest mean value of 2.53cm which was significantly higher than treatments (2ET, 400kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK), (1ET, 300kg NPK), (1ET), (1/2ET, 400kg NPK), (1/2ET, 100kg NPK), (1/2ET, 200kg NPK) and (1/2ET) which had mean values within the range of 1.87-2.27cm. At 4WAS, treatment (3/2ET, 400kg NPK) recorded the highest mean value of 4.20cm which was significantly higher than (1ET) and all the treatments involving 1/2ET which had mean values ranging from 2.83-3.80cm. At 5WAS, treatment (2ET, 400kg NPK) recorded the highest mean value of 5.83cm which was significantly higher than all treatments of 1/2ET, 1ET, 3/2ET and (2ET, 0kg NPK) which had values within the range of 3.33-5.5cm. At 6WAS, treatments (1/2ET, 100kg NPK) and (1/2ET, 200kg NPK) recorded the lowest mean values of 3.43cm each while treatment (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean value of 6.0cm. At 7WAS, treatment (1/2ET) and (1/2ET, 100kg NPK) recorded the lowest mean value of 3.83cm while treatments (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest value of 6.55cm each however it was not significantly higher than other treatments of 2ET. At 8WAS, all treatments involving 2ET and (3/2ET, 400kg NPK) had the highest mean value of 6.50cm which was significantly higher than the rest treatment with the values ranging from 6.30-3.90cm. At 9WAS, treatments (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean values of 6.63cm while (1/2ET, 0kg NPK) and (1/2ET, 100kg NPK) recorded the lest value of 4.33cm each. At 10 WAS, treatments (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean values of 7.43cm although not significantly higher than treatment (2ET, 100kg NPK) with a mean value of 7.27cm however it was significantly higher than the other treatments with values ranging from 4.87-7.07cm.

Figure 4.3 and 4.4 present the leaf length of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (2ET, 400kg NPK) recorded the highest value of

1.77cm. This was significantly higher than treatment (1/2ET, 300kg NPK), (1/2ET, 200kg NPK), (1/2ET, 100kg NPK) which had mean values within the range of 1.40-1.43cm. At 3WAS, treatment (2ET), (3/2ET,400kg NPK), (3/2ET, 300kg NPK), (3/2ET, 100kg NPK) had the highest value of 3cm each which was significantly higher than all treatments of (1ET) and (1/2ET) which had mean values within the range of 1.87-2.43cm. At 4WAS, treatment (2ET, 400kg NPK) had the highest mean value of 4.50cm which was significantly higher than other treatments except (2ET,100kg NPK), (2ET, 200kg NPK), (2ET, 300kg). At 5WAS, treatment (2ET, 400NPK), had the highest mean value of 5.80cm which was not significantly higher than treatment (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK) but was significantly higher than the other treatments which had mean values within the range of 3.07-4.67cm. At 6WAS, treatment (1/2ET) and (1/2ET, 100kg NPK) had the lowest mean value of 3.23cm which was significantly lower than the rest of the treatments with treatment (2ET, 400kg NPK) recording the highest mean value of 6.30cm. At 7WAS, treatment of (2ET, 400kg NPK) recorded the highest mean value of 6.77cm which was not significantly higher than other treatments of 2ET and (6ET, 400kg NPK) however, it was significantly higher than other treatments with value ranging from 3.47-5.60cm. At 8WAS, treatment (1/2ET,200kg NPK) recorded the lowest mean value of 3.57cm while (2ET, 400kg NPK) had the highest mean value of 7.20cm. At 9 WAS, treatment (2ET, 400kg NPK) had the highest mean value of 7.67cm which was not significantly higher than all treatments of 2ET but was significantly higher than the rest which had a mean value ranging from 4.0-6.33cm. At 10WAS, treatment (2ET, 400kg NPK) had a peak mean value of 8.40cm which was not significantly higher than treatment (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET,100kg NPK) however, it was significantly higher than treatment (2ET, 100kg NPK) and other treatments with mean values ranging from 4.83-7.07cm.

Figure 4.4 and 4.5 presents the leaf length of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 2WAS, treatments (2ET, 100kg NPK) and (2ET, 200kg NPK) recorded the highest mean value of 4.37cm each which was significantly higher than only (2ET, 0kg NPK). At 3WAS, treatment (2ET, 200kg NPK) recorded the highest value of 7.50cm which was significantly higher than treatment (2ET, 0kg NPK), (3/2ET, 0kg NPK) and (2ET, 0kg NPK) with values ranging from 6.50-6.83cm. At 4WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 13.0cm which was significantly higher than the other treatments. At 5WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 13.33cm which was significantly higher than the rest of the treatments while treatment (1/2ET, 0kg NPK) recorded the lowest value of 7.67cm. At 6WAS, treatment (2ET, 100kg NPK) steadily increased and recorded the highest mean value of 13.5cm which was significantly higher than the rest although treatment (2ET, 200kg NPK) was next with a value of 12.50cm however, treatment (1/2ET, 0kgNPK) was the lest with a mean value of 7.93cm. At 9WAS, treatment (2ET, 100kg NPK) had the highest mean value of 13.9cm which was significantly higher than the rest of the treatments while treatment (2ET, 200kg NPK) was next with a value of 12.83cm however 8.0cm was the lest mean value obtained for treatment (1/2ET, 100kg NPK). At 10WAS, treatment (2ET, 100kg NPK) had a peak mean value of 13.97cm which was significantly higher than the rest of the treatments followed by treatment (2ET, 200kg NPK) and (2ET, 300kg NPK) with mean values of 12.83cm and 12.10cm respectively. However, treatment (1/2ET, 200kg NPK) recorded the lowest mean value of 7.67cm.

Figure 4.6 and 4.7 presents the leaf length of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (2ET, 100kg NPK) and (2ET, 200kg NPK) recorded the highest mean value of 4.50cm which was not significantly higher than any of the treatments. At 3WAS, treatment (2ET, 200kg NPK) had the highest value of 8.17cm which was significantly higher than the other treatments except (2ET, 100kg NPK), (2ET, 300kg NPK), (2ET, 400kg NPK), (3/2ET, 400kg NPK) and (3/2ET, 300kg NPK) with values ranging from 7.4-8.0cm. However, treatment (0.5ET, 200kg NPK) recorded the lowest value of 6.67cm. At 4WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 13.17cm which was significantly higher than the other treatments except (2ET, 200kg NPK) and (3/2ET, 400kg NPK) with same value of 11.83cm. At 5WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 13.33cm which was significantly higher than the other treatments except (2ET, 200kg NPK) which had a mean value of 12.0cm. The maximum value of leave length did not change from 6 to 8WAS. However, it increased slightly to a maximum mean value of 12.40cm at 9WAS which was significantly higher to the rest apart from treatment (2ET, 200kg NPK) which had a value of 12.50cm. At 10WAS, treatment (2ET, 100kg NPK) had the highest value of 13.47cm which was significantly higher than other treatments. However, treatment (1/2ET, 200kg NPK) recorded the lowest mean value of 7.84 cm.

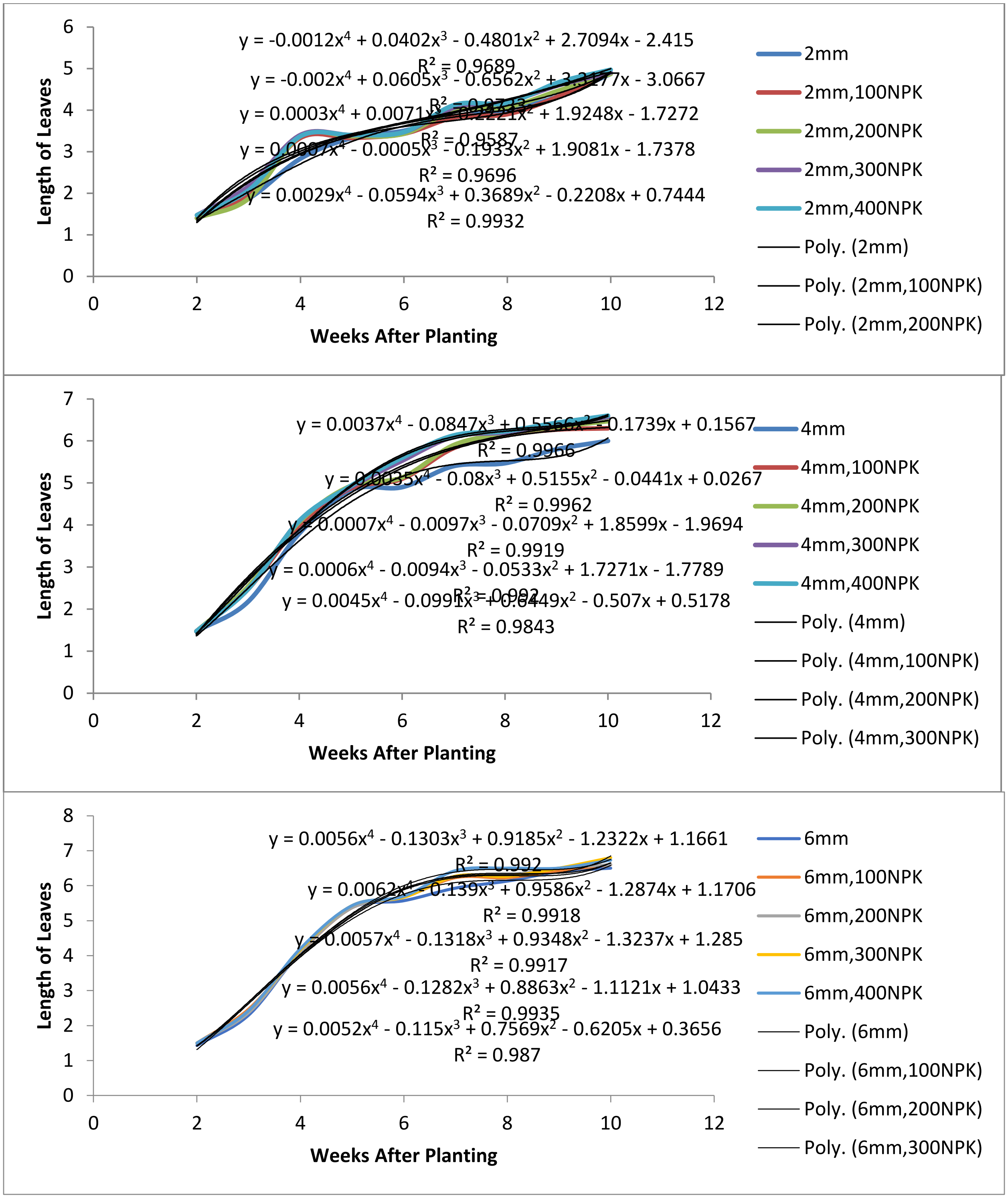


Figure 4.2: Length of Leaves vs Weeks After Planting for 2, 4, 6mm water depth in the Field

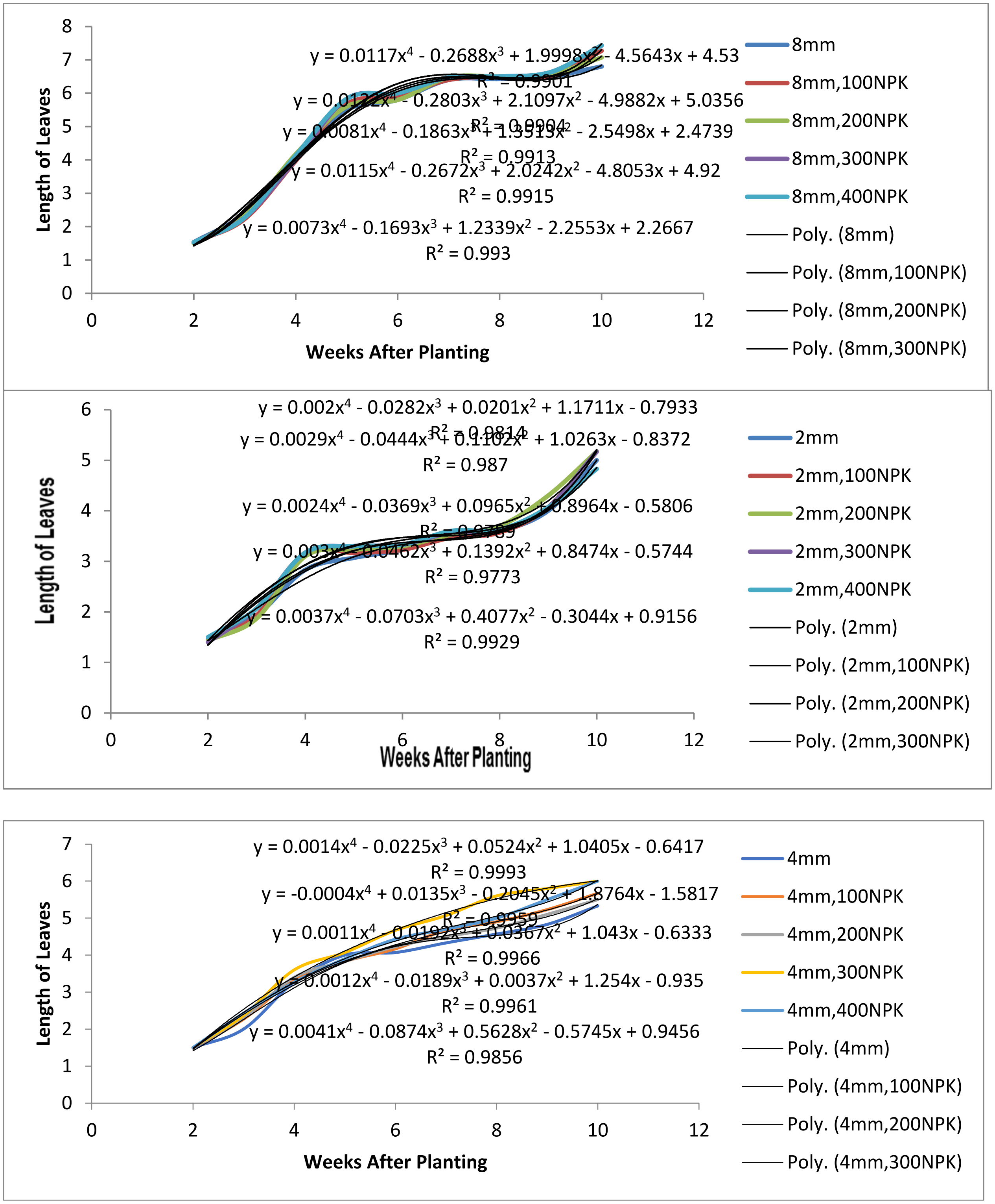


Figure 4.3: Length of Leaves vs Weeks After Planting for 8, 2, 4mm water depth

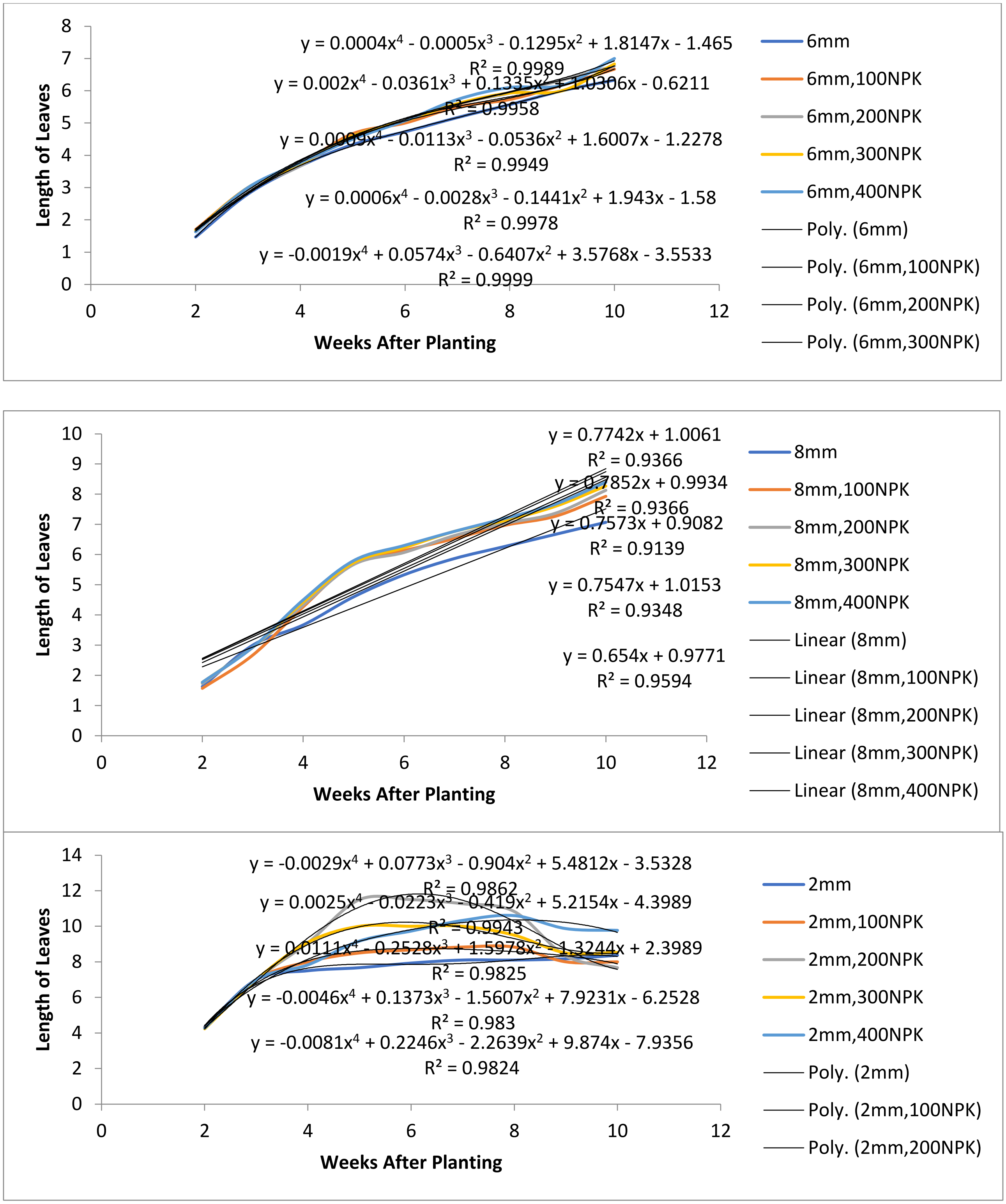


Figure 4.4: Length of Leaves vs Weeks After Planting for 6, 8mm water depth for field and 2mm water depth in greenhouse

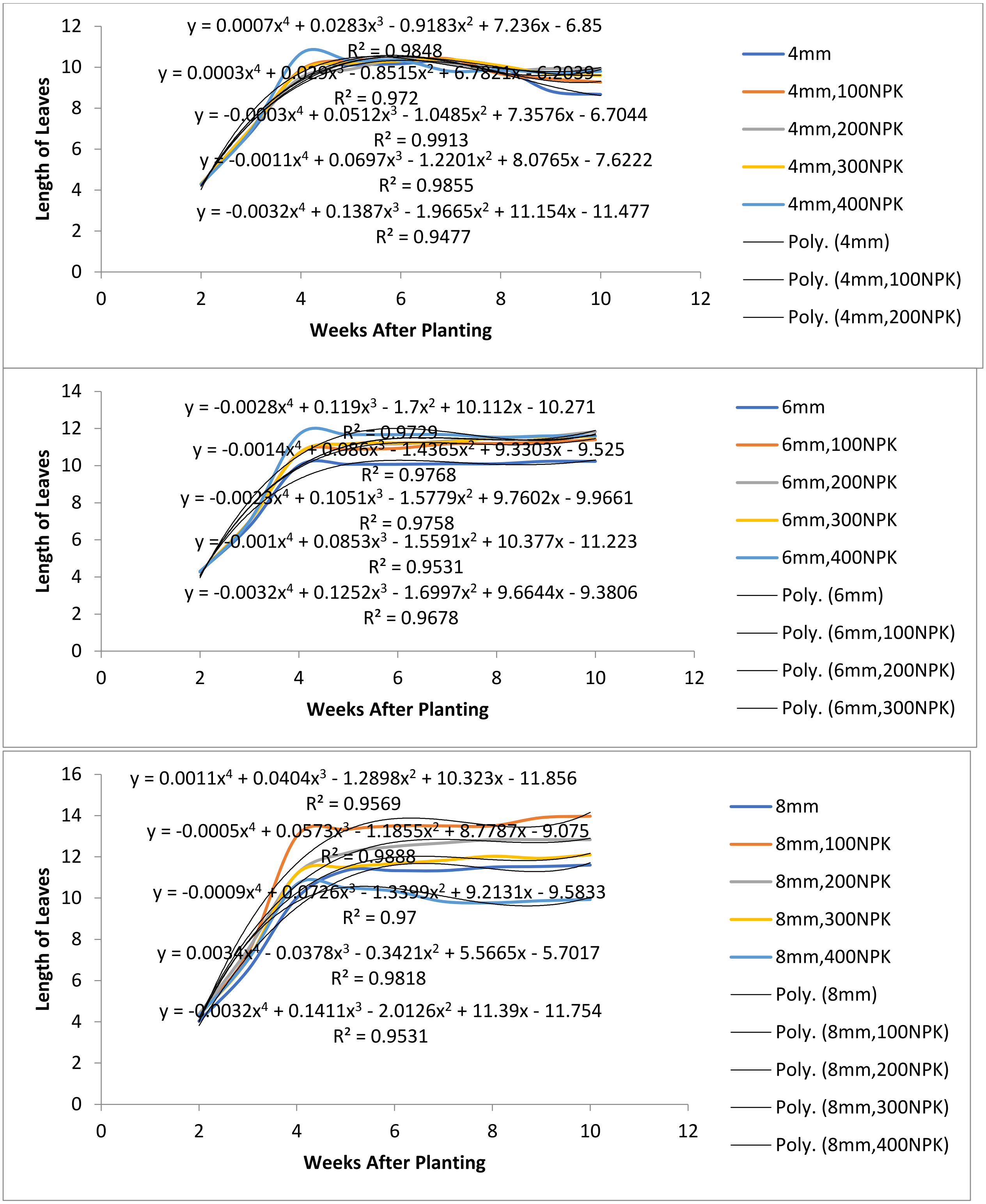


Figure 4.5: Length of Leaves vs Weeks After Planting for 4, 6, 8mm water depth in Greenhouse

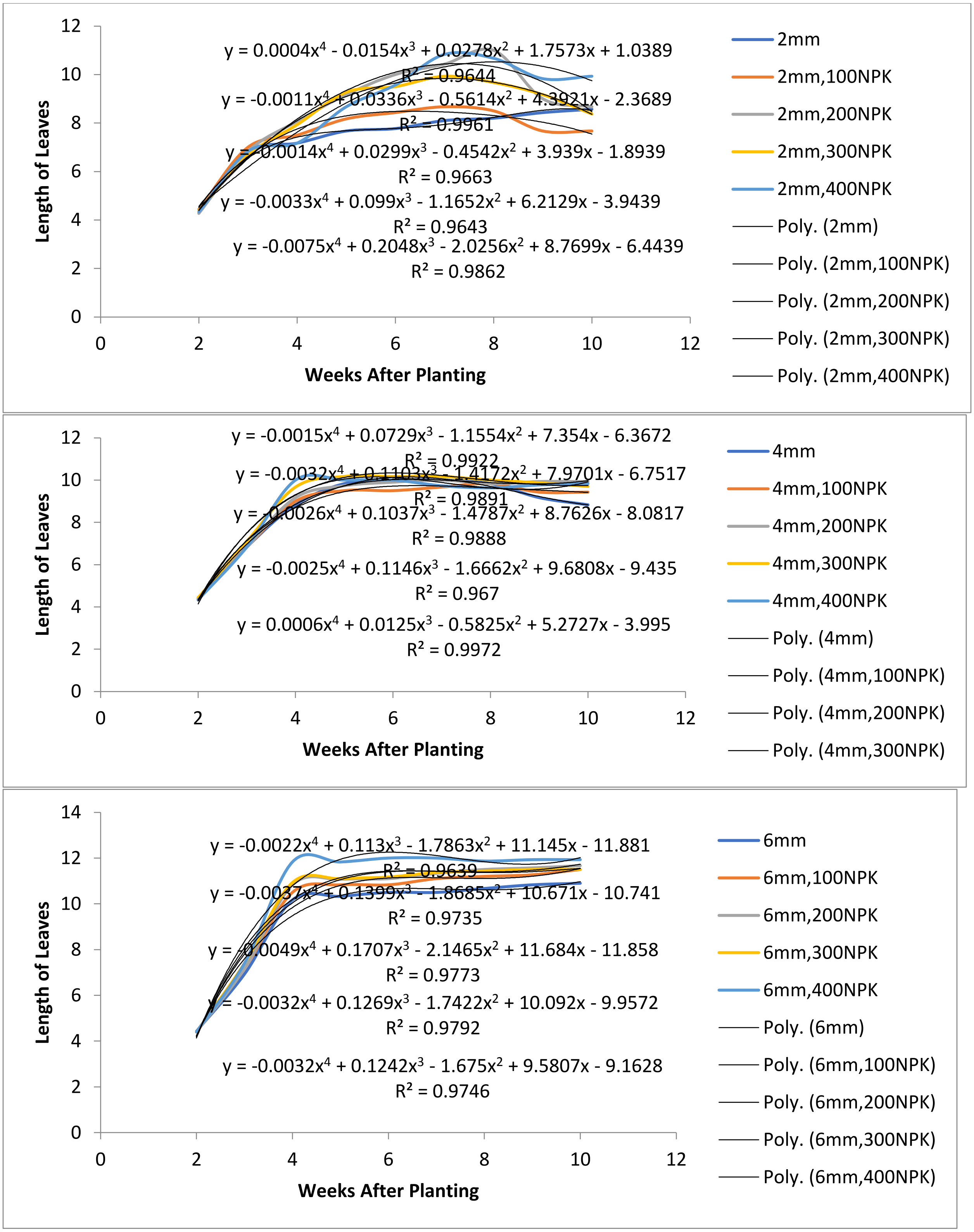


Figure 4.6: Length of Leaves vs Weeks After Planting for 2, 4, 6mm water depth in Greenhouse.

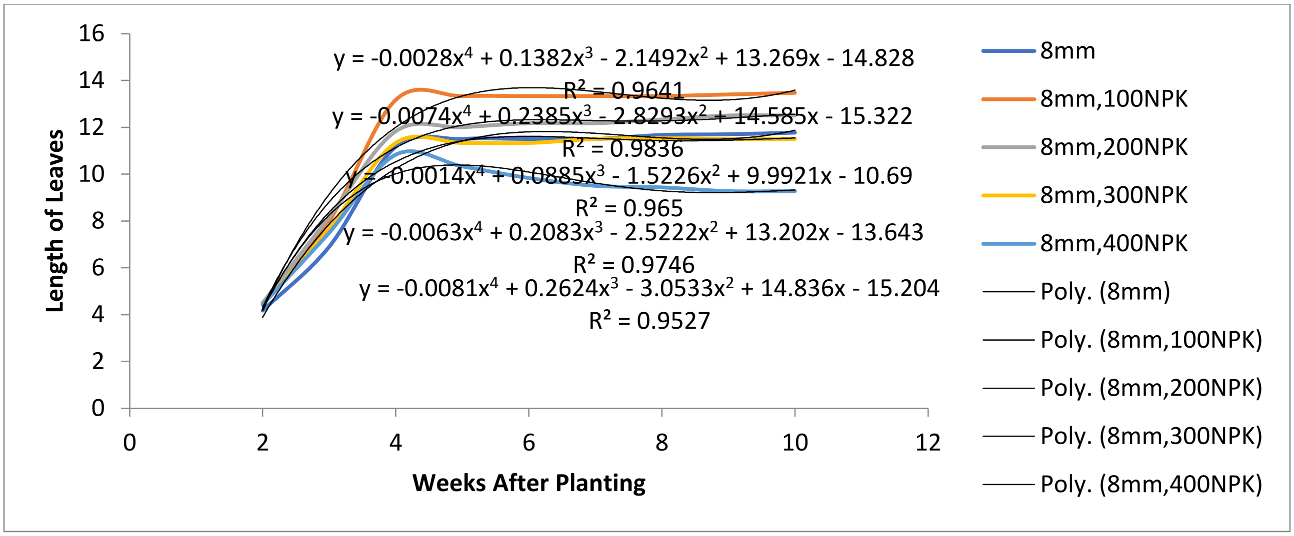


Figure 4.7: Length of Leaves vs Weeks After Planting for 8mm water depth in greenhouse

4.2.2 Number of Branches

Figure 4.8 and 4.9 present the number of branches of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 4WAS, the highest mean value of 5.0 for the number of branches was recorded in all the treatments involving (1ET), (3/2ET), (2ET) which was significantly higher than the other treatment. However, the lowest mean value of 4.0 was recorded for all the treatments involving (1/2ET). At 5WAS, the maximum mean value of 8.0 for the number of branches was recorded in all the treatments involving (1ET), (3/2ET), (2ET) which was significantly higher than the other treatment apart from (1ET). However, the treatment (1/2ET) and (1/2ET and 100kg NPK) had the lowest mean value of 6.0. At 6WAS, all treatments involving (2ET) had the highest value of 11.0 which was significantly higher than all treatments of 1/2ET and (1ET, 0kg NPK) which had mean values within the range of 7.0 and 9.0 approximately. At 7WAS, all treatments involving (2ET) had the highest value of 17.0 which was significantly higher than all treatments involving 1/2ET and 1ET apart from treatments (3/2ET, 0kg NPK) and (2ET, 100kg NPK) which had mean value of 14.0. At 8WAS, all treatments involving (2ET) had the highest value of 23.0 which was significantly higher than other treatments which had mean values ranging from 11-20. At 9WAS, all treatments involving 2ET had the maximum mean value of 26 which was significantly higher than other treatment. However, treatment (1/2ET, 0kg NPK) had the lowest mean value of 15.0. At 10WAS, treatments (2ET, 200kg NPK), (2ET, 300kg NPK) and (2ET, 400kg NPK) had the highest value of 34.0 each which was significantly higher than other treatments apart from treatment (2ET, 100kg NPK) which had a mean value of 33.0. However, treatment (1/2ET, 0kg NPK) recorded the least mean value of 19.0.

Figure 4.9 and 4.10 presents the number of branches of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 3WAS, all treatments of 2ET, 3/2ET, 1ET except (1ET, 0kg NPK) recorded a maximum mean value of 5.0 which was significantly higher than the rest. At 4WAS, all the treatment of 2ET, 3/2ET, 1ET except (1ET, 0kg NPK) had the highest mean value of 6.0 which was significantly higher than other treatments which had mean value of 5.0. At 5WAS, all treatments of 2ET apart from treatment (2ET, 0kg NPK) had the maximum mean value of 8.0 which was significantly higher than the rest of the treatments with mean values ranging from 6-7. At 6WAS, all treatments of 2ET, 3/2ET, 1ET except (2ET, 0kg NPK), (3/2ET, 0kg NPK), (3/2ET, 200kg), (1ET, 0kg NPK) recorded a maximum mean value of 9.0 which was significantly higher than the other treatments which had a mean value 8 and 7. At 7WAS, treatment (2ET, 200kg NPK), (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest value of 15.0 which was significantly higher than other treatments. However, treatment (1/2ET, 0kg NPK) recorded the lowest mean value of 7.0. At 8WAS, treatment (2ET, 300kg NPK) had the highest mean value of 20.0 which was significantly higher than other treatment which had values within the range of 10.0-19.0. At 9WAS, treatments (2ET, 200kg NPK), (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean value of 25.0 which was significantly higher than other treatments which had mean values within the range of 13.0-23.0. At 10WAS, treatments (2ET, 200kg NPK), (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean value of 31.0 which was significantly higher than other treatments which had mean values within the range of 14.0-30.0.

Figure 4.11 and 4.12 present the number of branches of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, most treatments had a maximum mean number of branches which was 4.0, however this was not significantly higher than the other treatments. At 3WAS, most treatments had a maximum mean number of branches which was 9.0, however this was not significantly higher than the other treatments. At 4WAS, treatment (1/2ET) had the lowest mean value of 8.0. However other treatments had values within the range of 9.0-11.0. At 5WAS, treatment (2ET, 100kg NPK) recorded the maximum mean value of 16.0 which was significantly higher than the other treatment. However, treatments (1/2ET, 0kg NPK) and (1/2ET, 100kg NPK) recorded the least mean value of 9.0. At 6WAS, treatment (2ET, 100kg NPK) recorded the maximum mean value of 29.0 which was significantly higher than the other treatment. At 7WAS, treatment (2ET, 100kg NPK) had the highest mean value of 31.0 which was significantly higher than other treatment. However, other treatments had values within the range of 9.0-24.0. At 8WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 34.0 which was significantly higher than the rest. However, other treatments had values within the range of 9.0-27.0. At 10WAS, treatment (2ET, 100kg NPK) had the highest mean value of 39.0 which was significantly higher than other treatments. However, other treatments had values within the range of 12.0-30.0. Although, treatment (1/2ET) and (1/2ET, 100kg NPK) had the least mean value of 12.0.

Figure 4.12 and 4.13 present the number of branches of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2 WAS, most treatments had a maximum mean number of branches which was 4.0 which was significantly higher than treatments (1/2ET, 100kg NPK) and (1/2ET, 200kg NPK) which had a mean value of 3.0. At 3WAS, all treatments of 2ET, 3/2ET had a maximum mean value of number of branches which was 9.0 apart from (3/2ET, 100kg NPK) and (3/2ET, 200kg NPK) which had a mean value of 8.0. At 4WAS, most treatments had a mean value of 11.0 apart from treatments (1/2ET), (1/2ET, 100kg NPK), (1/2ET, 200kg NPK) and (2ET) which had mean values of 9.0-10.0. At 5WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 15.0 which was significantly higher than other treatments which had mean values ranging from 9.0-14.0. At 6WAS, treatment (2ET, 100kg NPK) had the highest mean value of 34.0 which was significantly higher than other treatment which had values within the range of 10.0-25.0. At 7WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 36.0 which was significantly higher than other treatment which had values within the range of 10.0-27.0. At 9 WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 40.0 which was significantly higher than other treatment which had values within the range of 13.0-31.0. At 10WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 42.0 which was significantly higher than other treatment which had values within the range of 12.0-32.0.

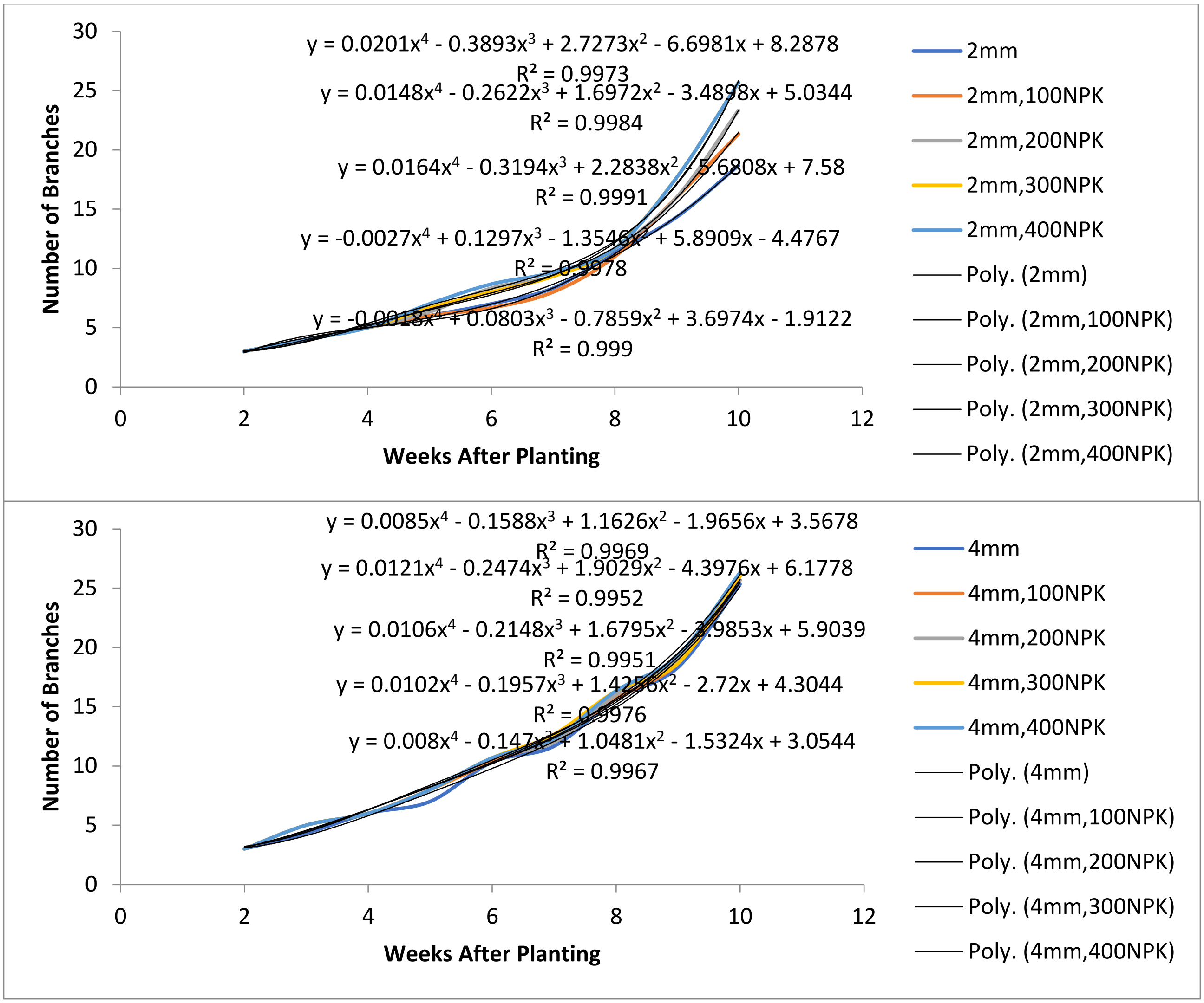


Figure 4.8: Length of Leaves vs Weeks After Planting for 8mm for greenhouse and Number of Branches vs Weeks After Planting for 2, 4 mm water depth in the Field

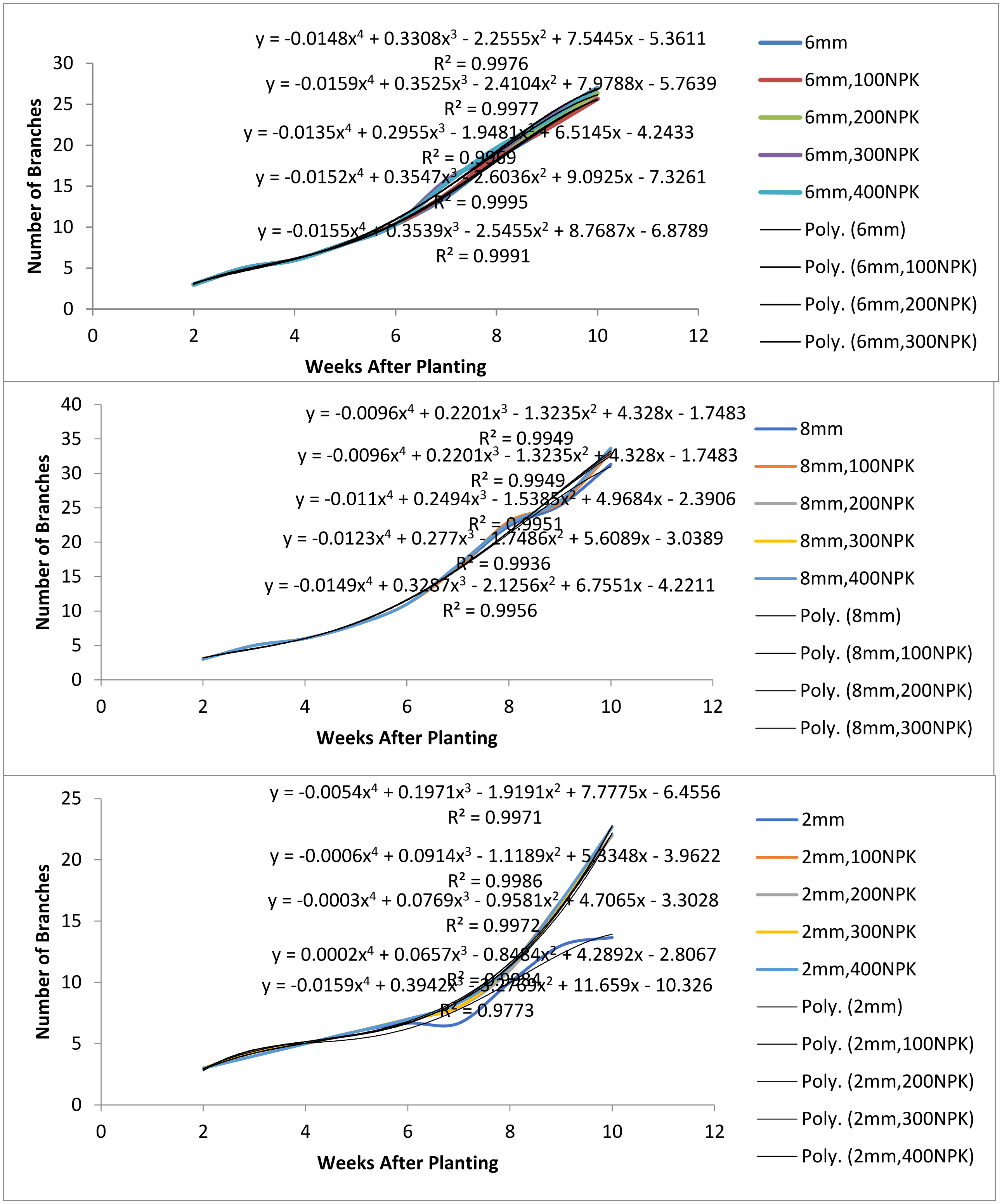


Figure 4.9: Number of Branches vs Weeks After Planting for 6, 8, 2 mm water depth in the Field

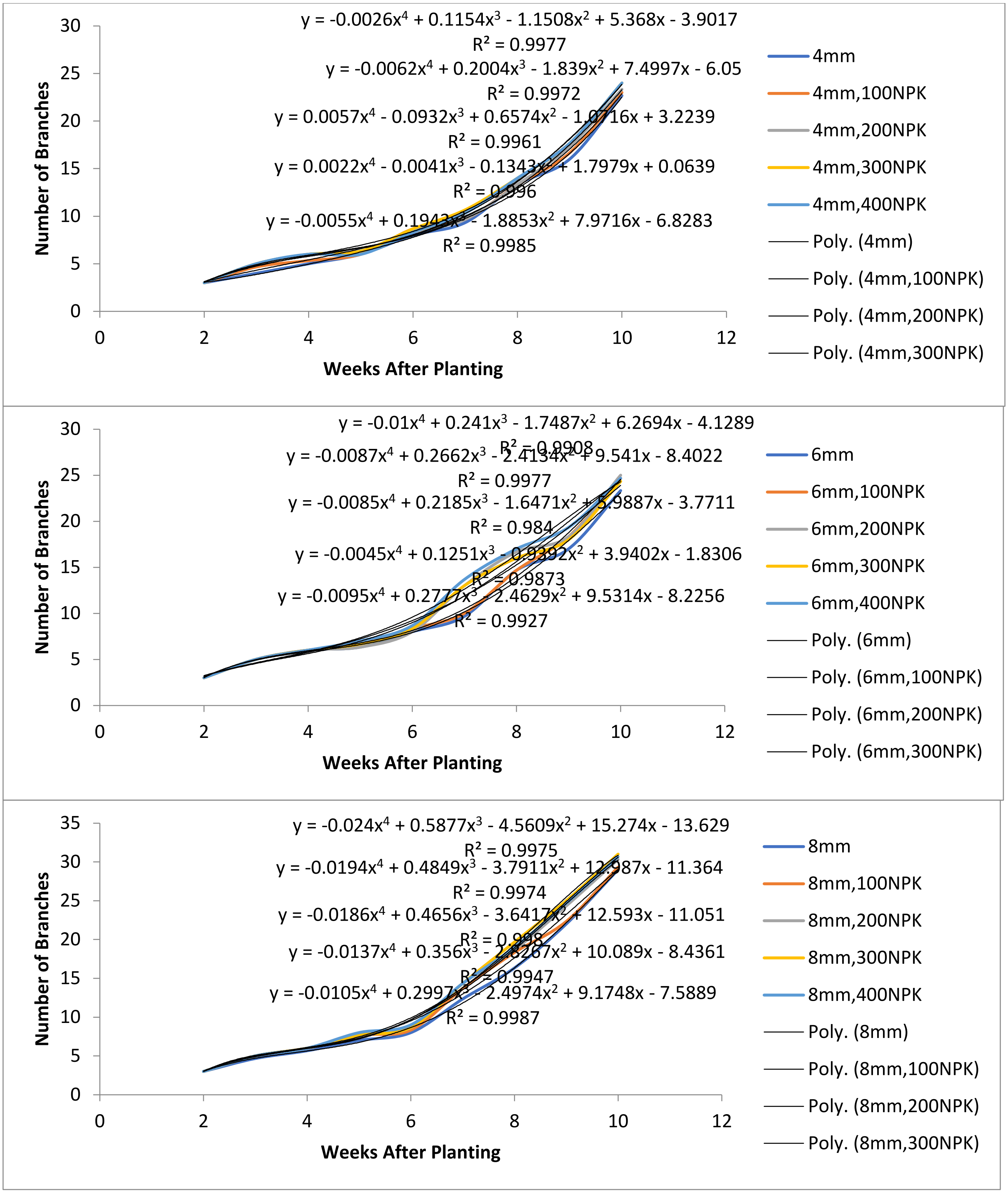


Figure 4.10: Number of Branches vs Weeks After Planting for 4, 6, 8mm water depth in the Field

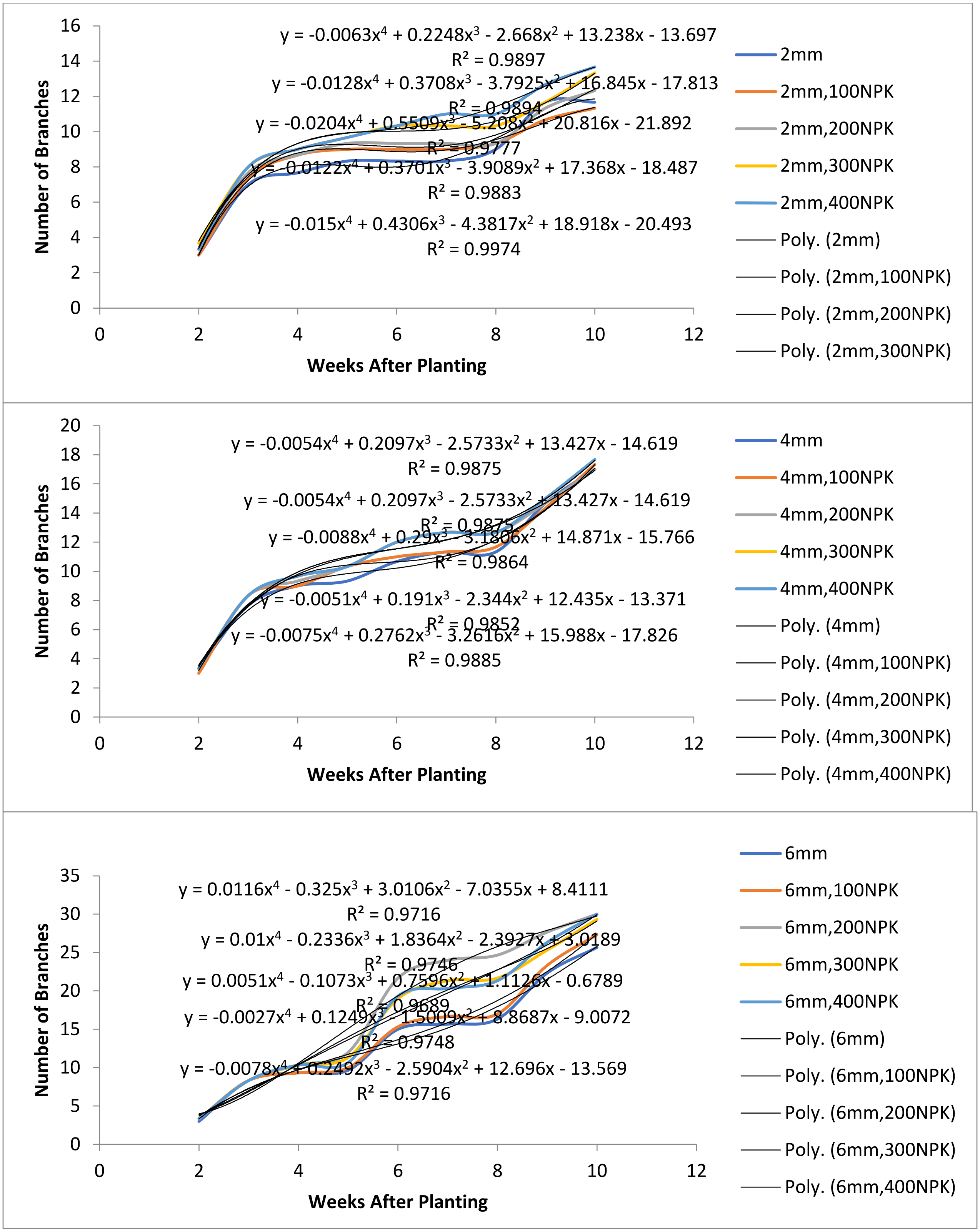


Figure 4.11: Number of Branches vs Weeks After Planting for 2, 4, 6 mm water depth in greenhouse

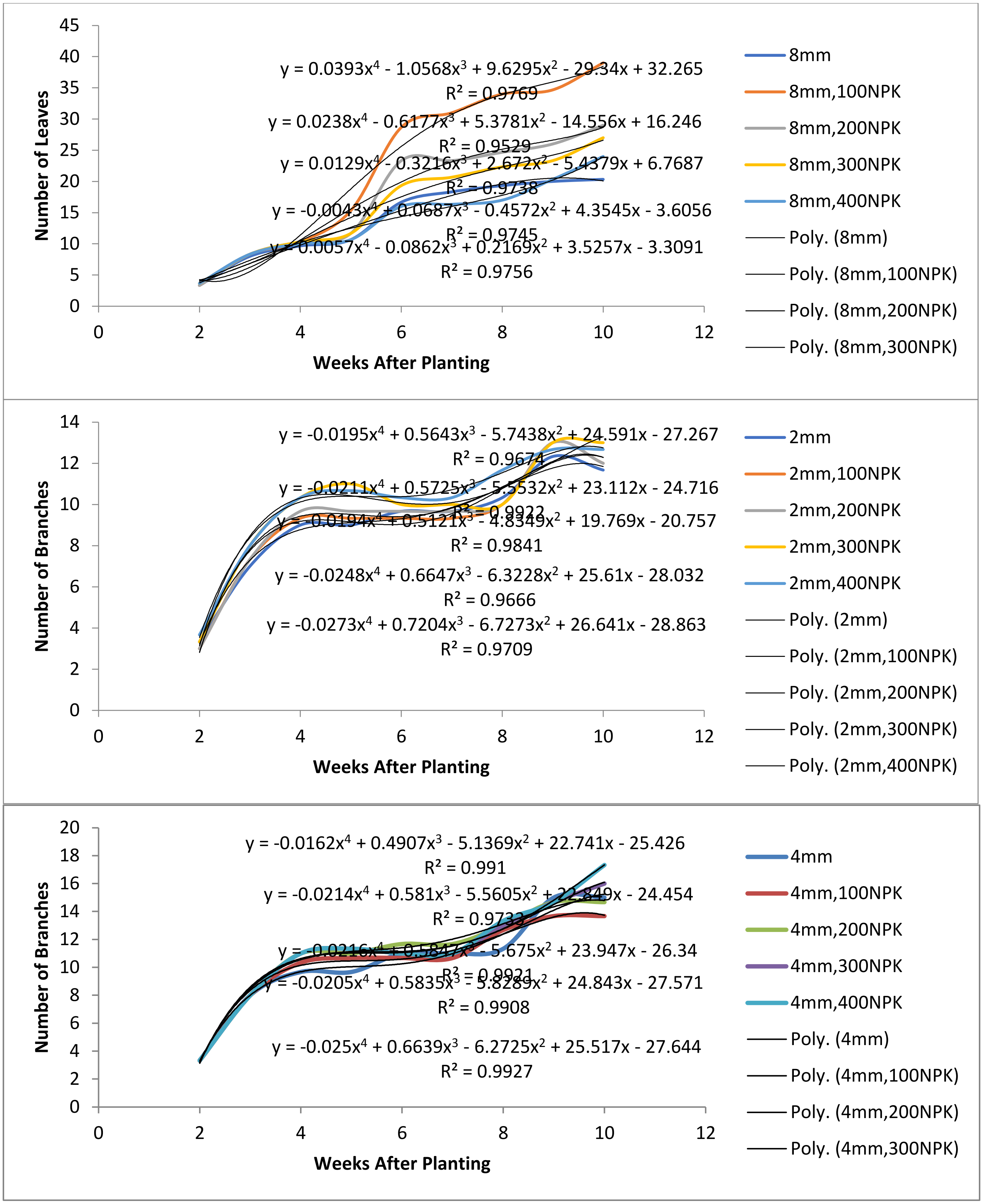


Figure 4.12: Number of Branches vs Weeks After Planting for 8, 2, 4mm water depth in the greenhouse

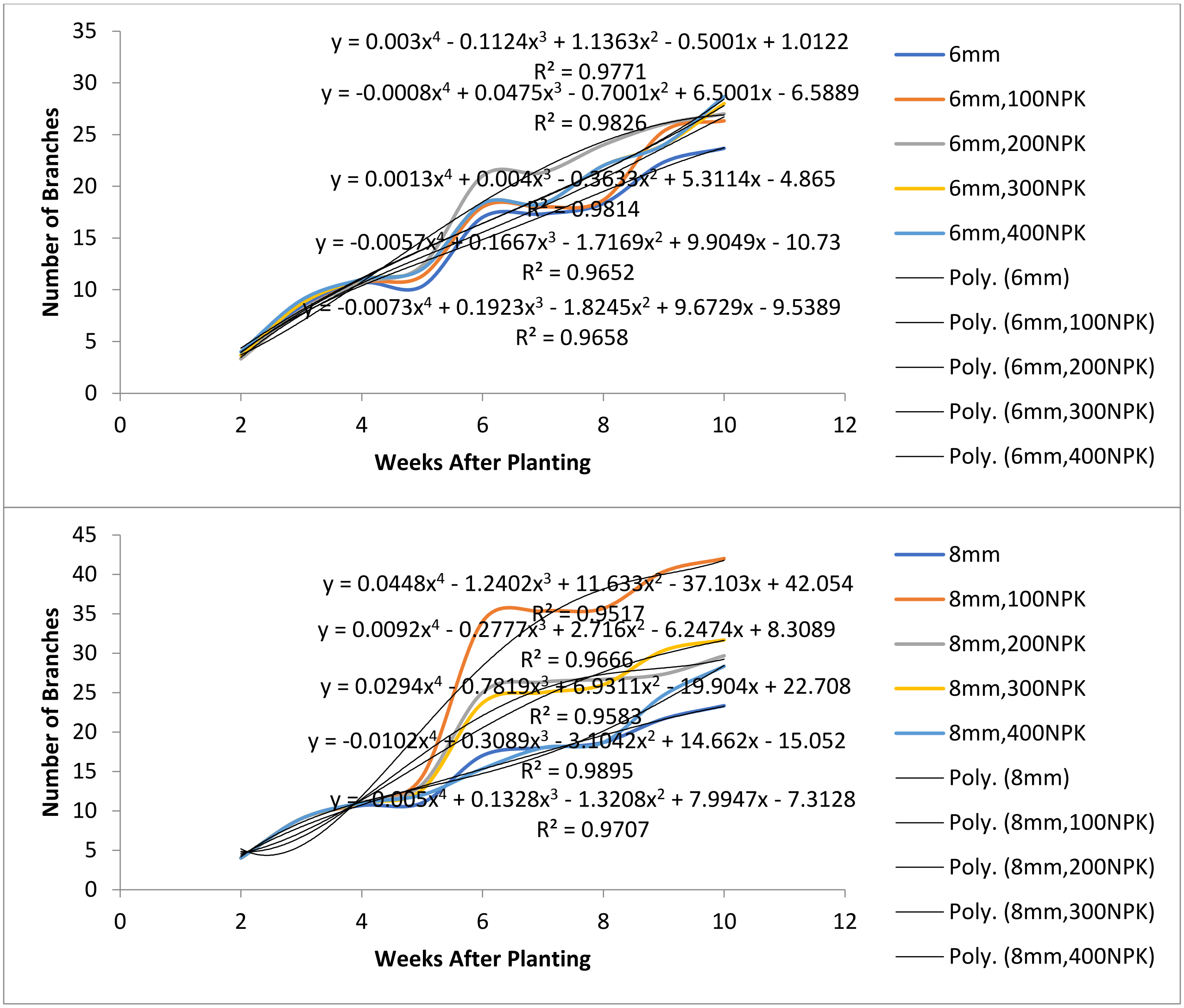


Figure 4.13: Number of Branches vs Weeks After Planting for 8, 2, 4mm water depth in the greenhouse

4.2.3 Number of Leaves

Figure 4.14 and 4.15 present the number of leaves of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 3WAS, all treatment of 2ET, 3/2ET and 1ET had the highest value of 6.0 which was significantly higher than treatments 1/2ET except (1ET, 0kg NPK) which had a mean value of 5.0. At 5WAS, all treatment of 2ET, 3/2ET and 1ET had the highest value of 9.0 which was significantly higher than treatments 1/2ET except (1ET, 0kg NPK) which had a mean value of 7.0. At 6WAS, treatments (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean value of 13.0 which was significantly higher than other treatments. However, other treatments had mean value ranging from 8.0-12.0. At 7WAS, treatments (2ET, 100kg NPK), (2ET, 200kg NPK), (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean value of 22.0 which was significantly higher than other treatments. However, other treatment recorded values within the range of 8.0-21.0. At 8 WAS, treatments (2ET, 200kg NPK) and (2ET, 300kg NPK) had the highest mean value of 31.0 which was significantly higher than other treatments, although the rest had mean values ranging from 12.0-30.0. At 9WAS, treatments (2ET, 300kg NPK) recorded the highest mean value of 43.0 which was significantly higher than other treatments. However, the least mean value of 16.0 was recorded for treatment (1/2ET, 0kg NPK). At 10WAS, treatments (2ET, 300kg NPK) recorded the highest mean value of 52.0 which was significantly higher than other treatments. However, the least mean value of 16.0 was also recorded for treatment (1/2ET, 0kg NPK).

Figure 4.15 and 4.16 present the number of leaves of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, all treatment recorded a maximum mean value of 4.0. At 3WAS, all treatment of 2ET, 3/2ET and 1ET had the highest mean value of 6.0 which was significantly higher than treatments 1/2ET which had a mean value of 5.0. At 4WAS, all treatment had mean value of 6.0 apart from treatment (1/2ET, 0kg NPK) which had a mean value of 5.0. At 5WAS, all treatments of 2ET recorded the maximum value of 10.0 which was significantly higher than other treatment. However, other treatments had values ranging from 7.0-9.0. At 6WAS, all treatment of 2ET recorded the highest mean value of 13.0 which was significantly higher than other treatments except for treatment (2ET, 0kg NPK) which had a mean value of 11.0. At 7WAS, all treatment of 2ET recorded the highest mean value of 24.0 which was significantly higher than other treatments except for treatment (2ET, 0kg NPK) which had a mean value of 21.0. However, other treatments had values which was within the range of 9.0-22.0. At 8WAS, all treatment of 2ET recorded the highest mean value of 34.0 which was significantly higher than other treatments except for treatment (2ET, 0kg NPK) which had a mean value of 27.0. However, other treatments had values which was within the range of 10.0-29.0. At 9WAS, all treatment of 2ET recorded the highest mean value of 48.0 which was significantly higher than other treatments except for treatment (2ET, 0kg NPK) which had a mean value of 45.0. However, other treatments had values which was within the range of 15.0-35.0. At 10WAS, treatments (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean value of 58.0 which was significantly higher than other treatments. However, other treatments had mean value ranging from 20.0-56.0, although treatment (1/2ET, 0kg NPK) had the lowest value.

Figure 4.16 and 4.17 present the number of leaves of *Corchorus olitorus* as influenced by water and fertilizer treatment in a greenhouse. At 2WAS, most treatments had a mean value of 6.0 apart from treatment (1/2ET, 0kg NPK) and (1/2ET, 100kg NPK) which had a mean value of 5. At 3WAS, all treatment of 2ET, 3/2ET had the highest mean value of 10.0 apart from treatments (3/2ET, 100kg NPK), (3/2ET, 200kg NPK) which had mean value of 9.0. At 4WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 16.0 which was significantly higher than other treatments. However, other treatments had values which was within the range of 10.0-15.0. Treatment (1/2ET, 0kg NPK) had the lowest value. At 5WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 19.0 which was significantly higher than other treatments which had values ranging from 9.0-18.0. At 6WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 36.0 which was significantly higher than other treatments which had values ranging from 9.0-28.0. At 8 WAS, treatment (2ET, 100kg NPK) had the highest mean value of 38.0 which was significantly higher than other treatments which had values ranging from 9.0-30.0. At 9WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 38.0, treatment (2ET, 200kg NPK) was next with a mean value of 36.0. These values were significantly higher than other treatments which had values ranging from 9.0-30.0. At 10 WAS, treatment (2ET, 100kg NPK) had the peak mean value of 44.0, treatment (2ET, 200kg NPK) was next with a mean value of 38.0. These values were significantly higher than other treatments which had values within the range of 9.0-37.0.

Figure 4.18 and 4.19 present the number of leaves of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, most treatments had a mean value of 6.0 apart from treatment (1/2ET, 0kg NPK), (1ET, 0kg NPK), (1ET, 200kg NPK), (1ET, 300kg NPK) and (1ET, 400kg NPK) which had a mean value of 5. At 3WAS, treatments (2ET, 400kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK), (3/2ET, 400kg NPK) and (3/2ET, 300kg NPK) had the maximum mean value of 10.0 which was significantly higher than other treatments. However, other treatments had mean values such as 9.0 and 8.0. At 4WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 15.0 which was significantly higher than other treatments. However, other treatments had values which was within the range of 9.0-14.0. At 5WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 19.0 which was significantly higher than other treatments which had values ranging from 9.0-18.0. At 6WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 37.0 which was significantly higher than other treatments which had values ranging from 9.0-28.0. At 9WAS, treatment (2ET, 100kg NPK) had the highest mean value of 40.0, treatment (3/2ET, 400kg NPK) was next with a mean value of 36.0. These values were significantly higher than other treatments which had values ranging from 10.0-34.0. At 10WAS, treatment (2ET, 100kg NPK) had the highest mean value of 42.0, treatment (3/2ET, 400kg NPK) was next with a mean value of 36.0. These values were significantly higher than other treatments which had values ranging from 11.0-35.0.

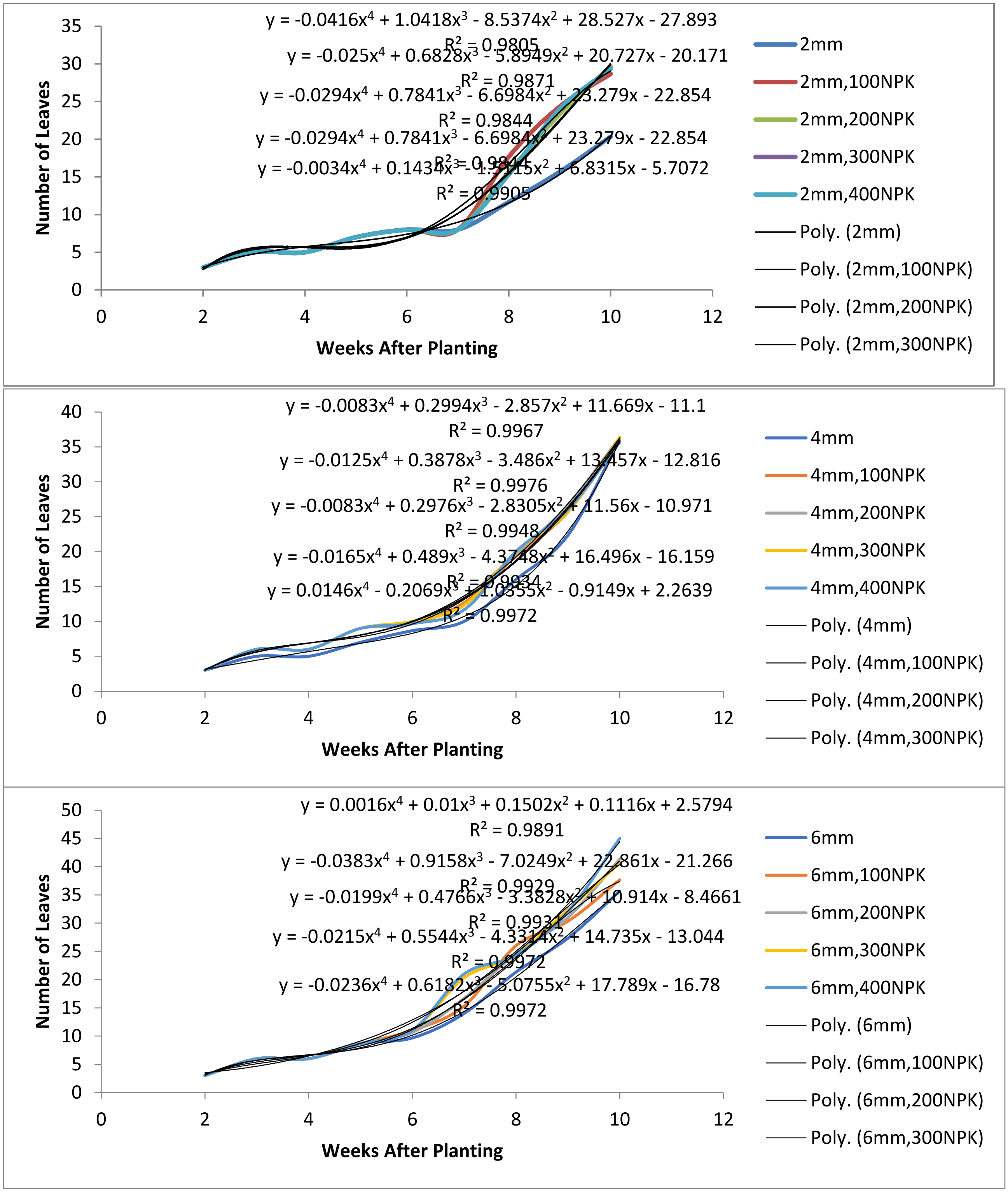


Figure 4.14: Number of Leaves vs Weeks After Planting for 4, 6 mm water depth in the Field

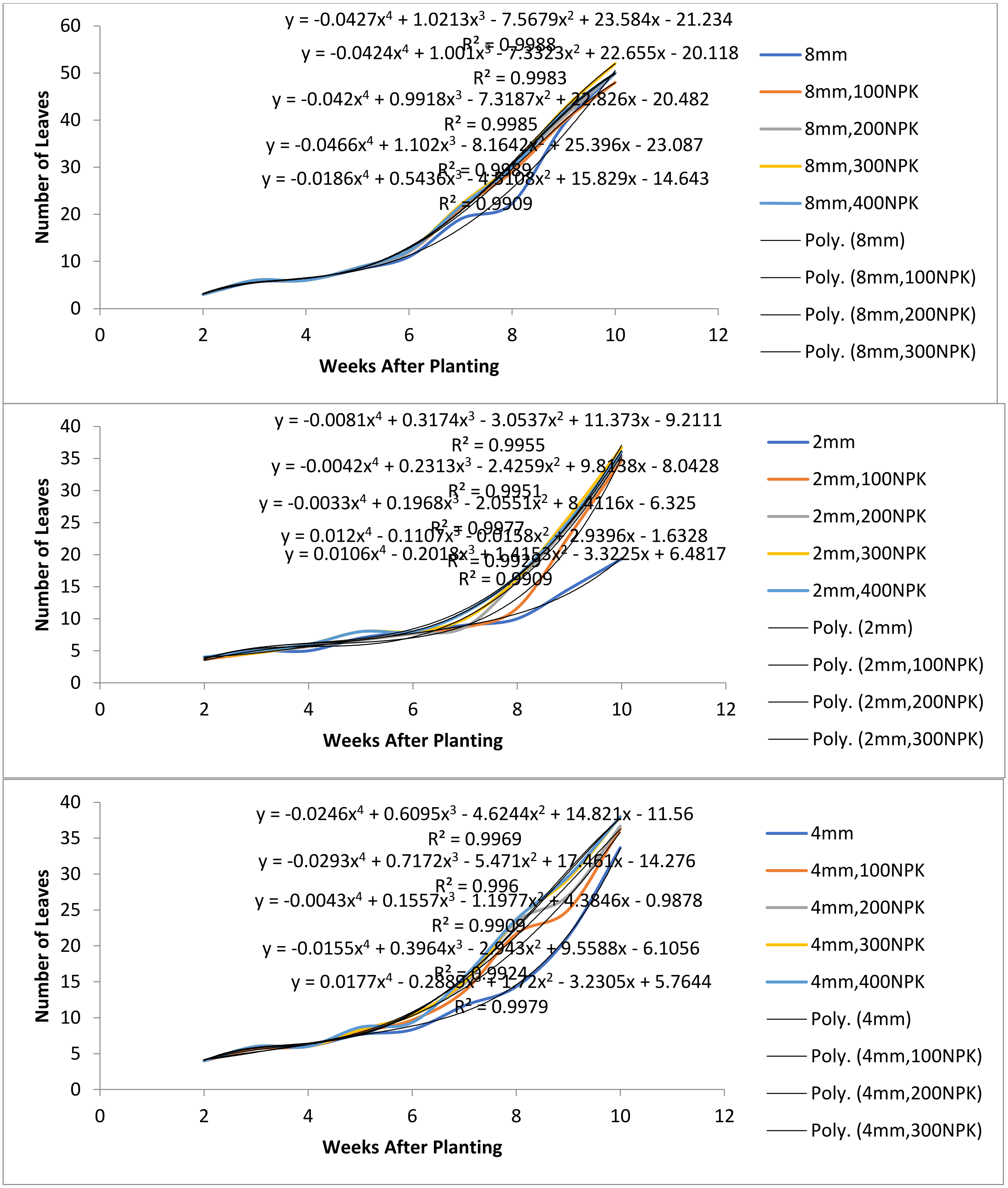


Figure 4.15: Number of Leaves vs Weeks After Planting for 8, 2, 4 mm water depth in the Field

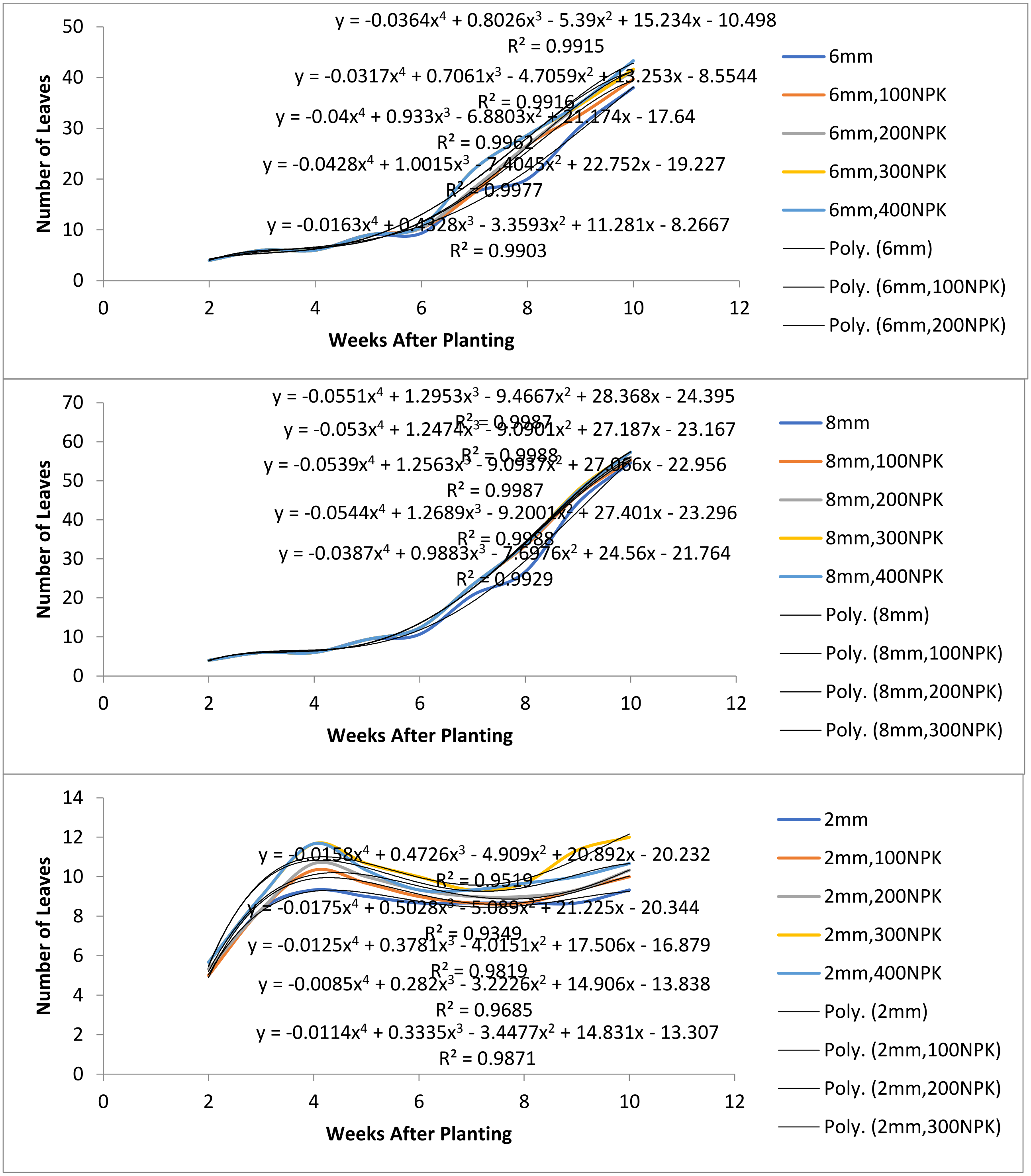


Figure 4.16: Number of Leaves vs Weeks After Planting for 6 and 8 mm water depth in the Field and 2mm for greenhouse

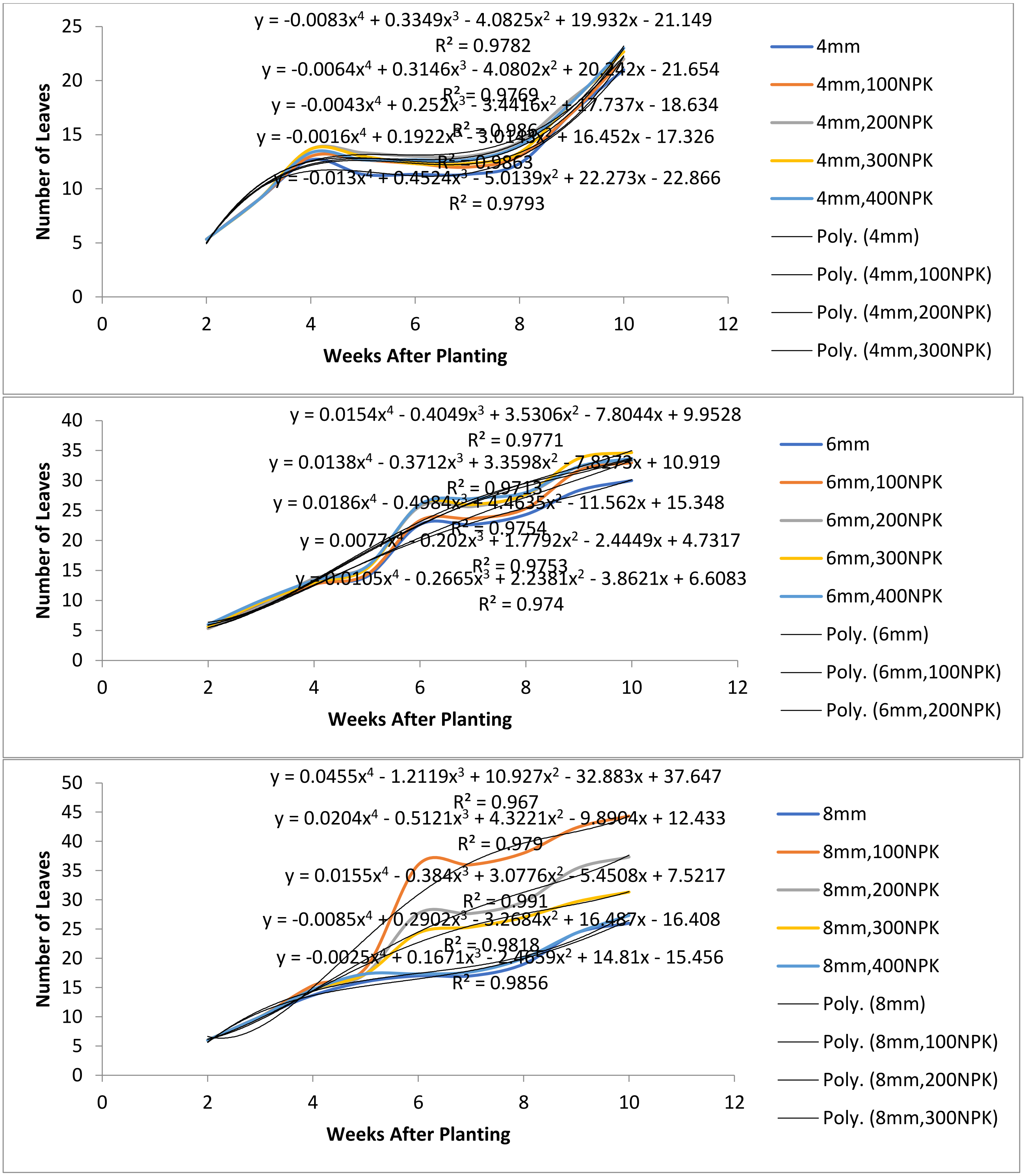


Figure 4.17: Number of Leaves vs Weeks After Planting for 4, 6, 8mm water depth in the greenhouse

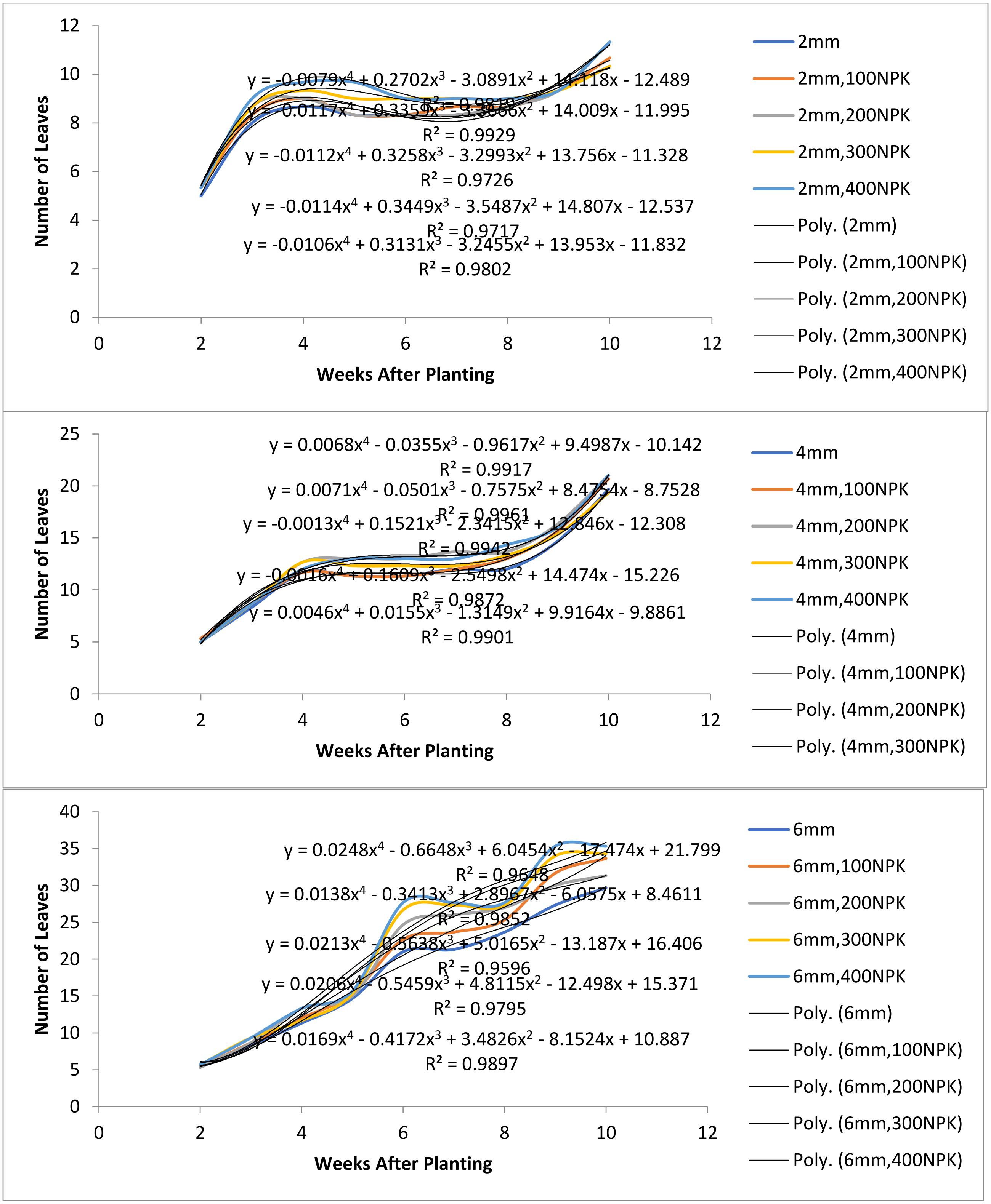


Figure 4.18: Number of Leaves vs Weeks After Planting for 2, 4, 6 mm water depth for greenhouse

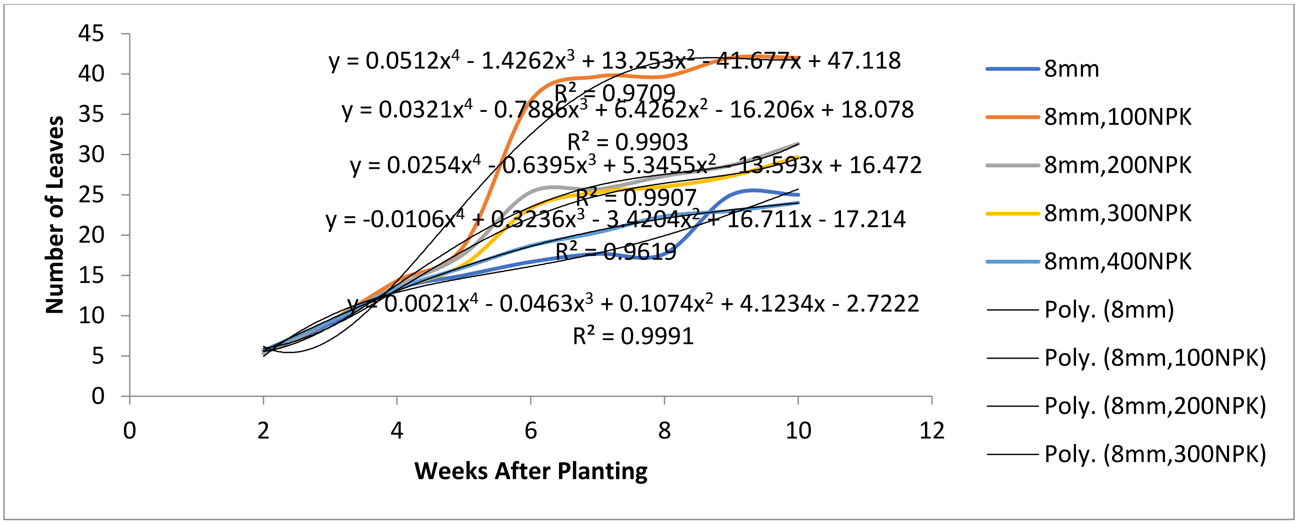


Figure 4.19: Number of Leaves vs Weeks After Planting for 8mm water depth in the greenhouse

4.2.4 Petiole

Figure 4.20 and 4.21 present the petiole of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (2ET, 400kg NPK) had the highest mean value of 0.7cm which was not significantly higher than other treatments. At 3WAS, most of the treatment of 2ET and 3/2ET) apart from treatment (3/2ET, 0kg NPK) had the highest mean value of 1.0cm which was not significantly higher than other treatments. However, treatment (1/2ET, 0kg NPK) had the lowest mean value of 0.77cm. At 4WAS, treatments (2ET, 400kg NPK), (2ET, 300kg NPK) and (2ET, 200kg NPK) had the maximum mean value of 2.0cm which was significantly higher than treatments involving 1/2ET and (1ET, 0kg NPK) (3/2ET, 0kg NPK) (2ET, 0kg NPK). At 7WAS, treatments (1ET, 300kg NPK) and (1ET, 400kg NPK) had the highest mean value of 2.07cm which was significantly higher than all treatments of 1/2ET and (1ET, 0kg NPK). At 8WAS, treatments (2ET, 400kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK) and (2ET, 100kg NPK) had the maximum mean value of 2.5cm which was significantly higher than all treatments of 1/2ET. At 9WAS, all treatments of 2ET recorded the maximum mean value of 2.5cm which was significantly higher than treatments (1/2ET, 100kg NPK), (1/2ET, 200kg NPK), (1ET, 0kg NPK) and (1/2ET, 0kg NPK). At 10WAS, treatment (1/2ET, 400kg NPK) had the highest mean value of 2.90cm which was significantly higher than other treatments except (1ET, 400kg NPK), (1ET, 300kg NPK) and (1/2ET, 300kg NPK) which had mean value of 2.83cm, 2.80cm and 2.80cm respectively.

Figure 4.21 and 4.22 present the petiole of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, all treatments had equal mean values of 0.63cm apart from treatment (3/2ET, 0kg NPK) which had a mean value of 0.60cm. At 3WAS, treatment (2ET, 0kg NPK) had the highest mean value of 0.7cm which was significantly higher than treatments (1/2ET, 0kg NPK), (1/2ET, 100kg NPK), (2ET, 100kg NPK), (1/2ET, 300kg NPK), (1/2ET, 400kg NPK), (1ET, 0kg NPK) which had values within the range of 0.83-0.93cm. At 4WAS, treatment (3/2ET, 400kg NPK) recorded the highest value of 1.83cm which was significantly higher than other treatments except treatments (2ET, 300kg NPK), (2ET, 400kg NPK), (2ET, 200kg NPK), and (3/2ET, 100kg NPK) which had mean values 1.80cm, 1.80cm, 1.80cm and 1.67cm respectively. At 5WAS, treatment (2ET, 400kg NPK), (2ET, 300kg NPK), and (2ET, 200kg NPK) had the highest mean value of 2.0cm each which was significantly higher than treatments involving 1/2ET and (1ET, 0kg NPK). 6WAS, treatments (2ET, 100kg NPK), (2ET, 200kg NPK), (2ET, 300kg NPK), (2ET, 400kg NPK), (3/2ET, 400kg NPK), (3/2ET, 300kg NPK), (1/2ET, 100kg NPK), (1/2ET, 200kg NPK), (1/2ET, 300kg NPK) and (1/2ET, 400kg NPK) which had the highest mean value of 2.0cm each was significantly greater than all treatments involving 1/2ET. At 7WAS, treatment (1ET, 300kg NPK) and (1ET, 400kg NPK) had the highest mean value of 2.07cm each which was significantly greater than all treatment involving 1/2ET and (3/2ET, 200kg NPK), (3/2ET, 100kg NPK). At 8WAS, treatments (2ET, 400kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK) and (2ET, 100kg NPK) had the highest mean value of 2.5cm which was significantly higher than other treatments. At 9WAS, treatments (2ET, 0kg NPK), (2ET, 400kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK) and (2ET, 100kg NPK) had the highest mean value of 2.5cm which was significantly higher than treatments (3/2ET, 0kg NPK), (3/2ET, 400kg NPK), (1/2ET, 100kg NPK), (1/2ET, 200kg NPK), (1/2ET, 0kg NPK) and (1ET, 0kg NPK) which had values within the range of 1.97-2.20cm.

Figure 4.22 and 4.23 present the petiole of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 3WAS, treatment (2ET, 300kg NPK) had the highest mean value of 1.70cm which was significantly higher than all the treatments of 1/2ET, 1ET apart from (1ET, 200kg NPK) and (1ET, 400kg NPK). At 9WAS, all treatment of 2ET had the highest mean value of 4.50cm each which was significantly higher than other treatments which had mean values within the range of 2.5-4.0cm. At 10WAS, treatments (2ET, 0kg NPK) recorded the peak mean value of 5.0cm which was significantly greater than other treatments except (2ET, 400kg NPK), (2ET, 200kg NPK) and (3/2ET, 400kg NPK) which had mean value of 4.83cm. However, the lowest mean value of 3.0cm was recorded for treatments (1/2ET, 0kg NPK), (1/2ET, 100kg NPK), (1/2ET, 200kg NPK), (1/2ET, 300kg NPK) and (1ET, 100kg NPK).

Figure 4.24 and 4.25 present the petiole of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 3WAS, all treatment involving 3/2ET and 2ET had the highest mean value of 1.70cm but was not significantly greater than other treatments. At 4WAS, all treatments of 2ET had the highest mean value of 3.0cm each which was significantly greater than treatments (1/2ET, 0kg NPK), (1/2ET, 100kg NPK), (1/2ET, 200kg NPK), (1/2ET, 300kg NPK) and (1/2ET, 400kg NPK) which had mean value of 2.33cm. At 5WAS, treatments (2ET, 0kg NPK), (2ET, 100kg NPK) recorded the highest mean value of 3.30cm which was significantly higher than other treatments except for treatment (3/2ET, 300kg NPK) which had a mean value of 3.17cm. At 6WAS, all treatments of 2ET had the highest mean value of 3.5cm each which was significantly greater than other treatments except for treatment (3/2ET, 300kg NPK) which had a mean value of 3.33cm. At 7WAS, all treatments of 2ET had the highest mean value of 4.5cm each which was significantly greater than other treatments. However, treatment (1/2ET, 0kg NPK) had the lowest mean value of 2.5cm. At 10WAS, treatment (2ET, 0kg NPK) recorded the highest mean value of 4.83cm which was significantly higher than other treatments except for treatment (3/2ET, 400kg NPK) which had a mean value of 4.67cm.

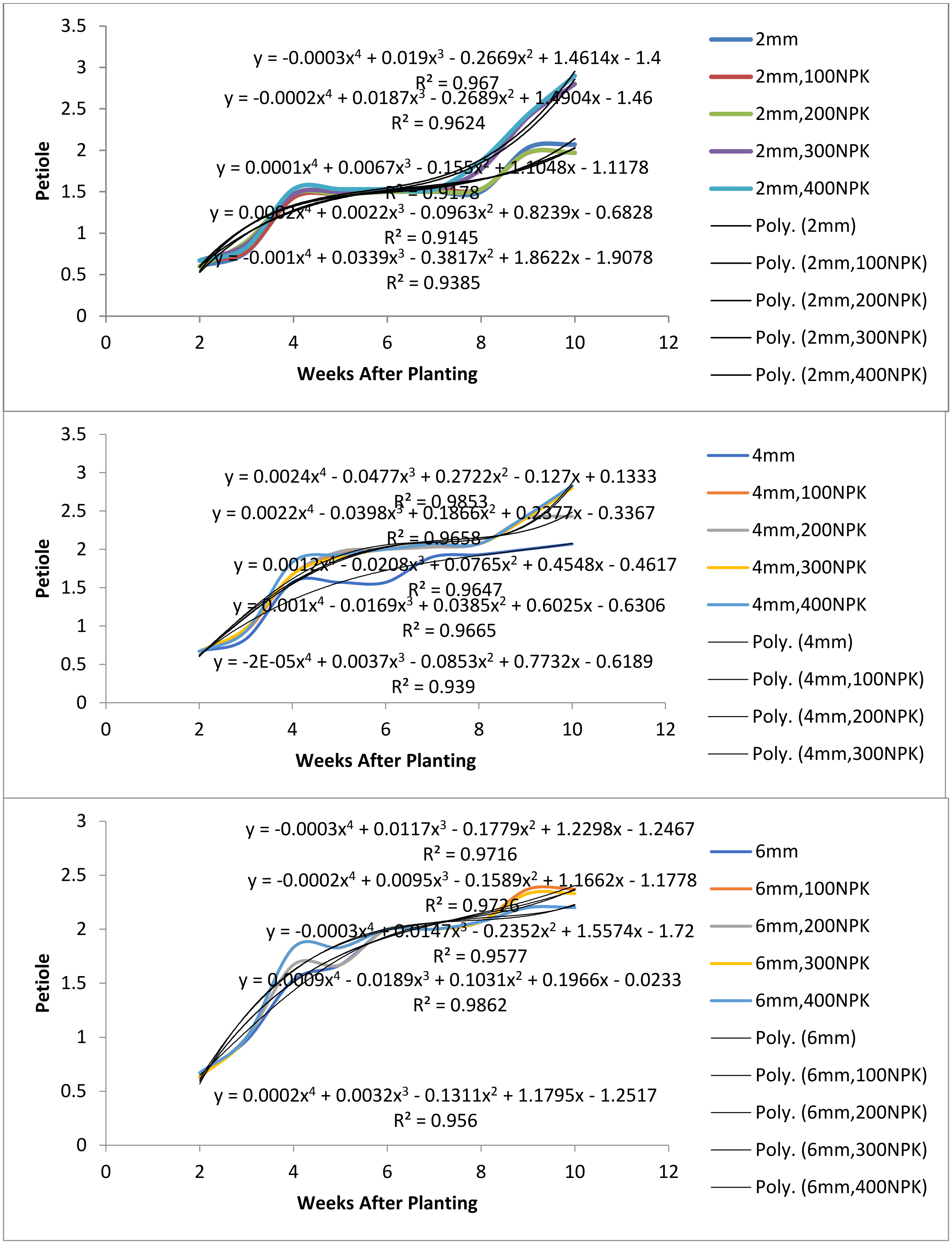


Figure 4.20: Petiole vs Weeks After Planting for 2, 4, 6mm water depth in the Field

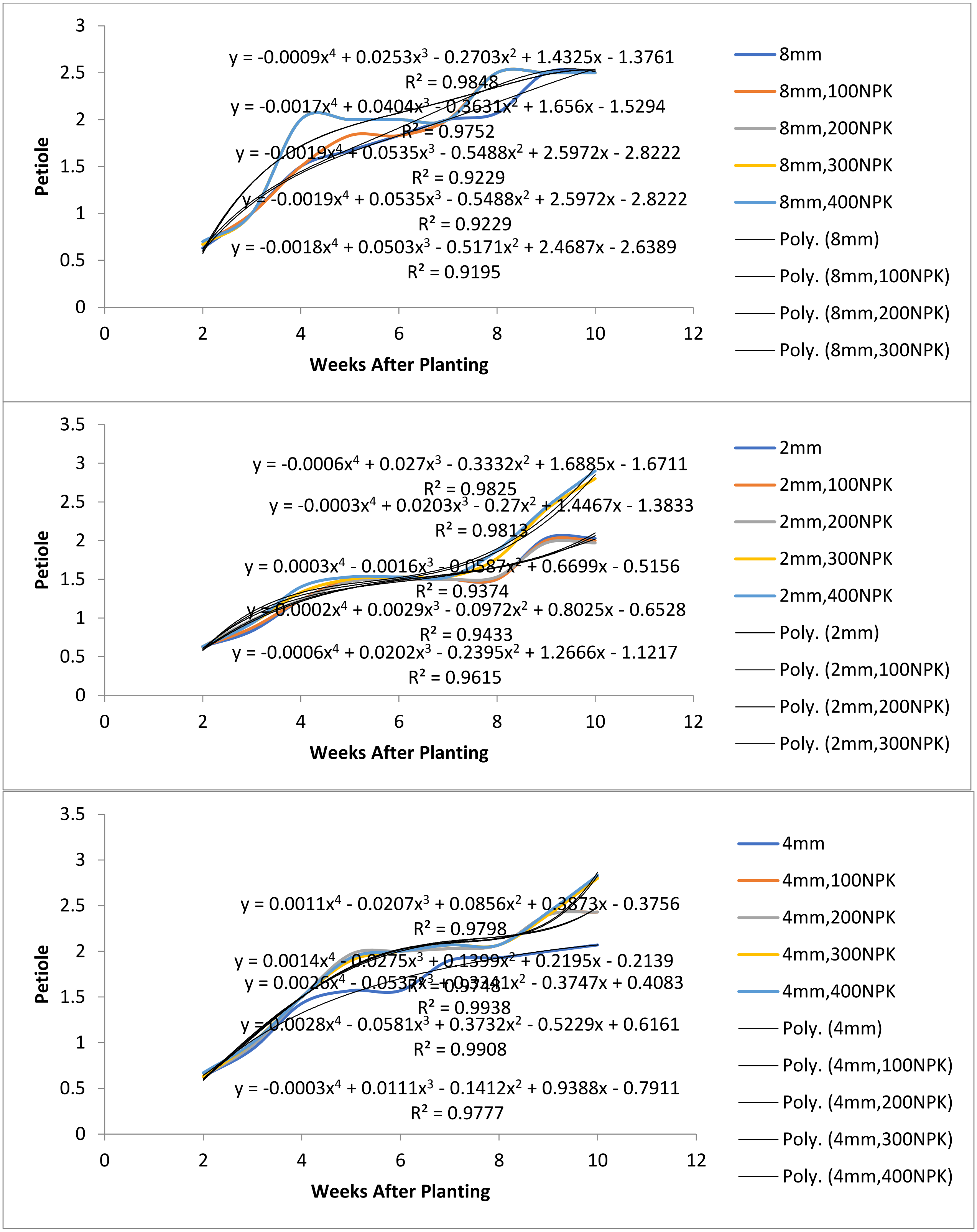


Figure 4.21: Petiole vs Weeks After Planting for 8, 2, 4mm water depth in the Field

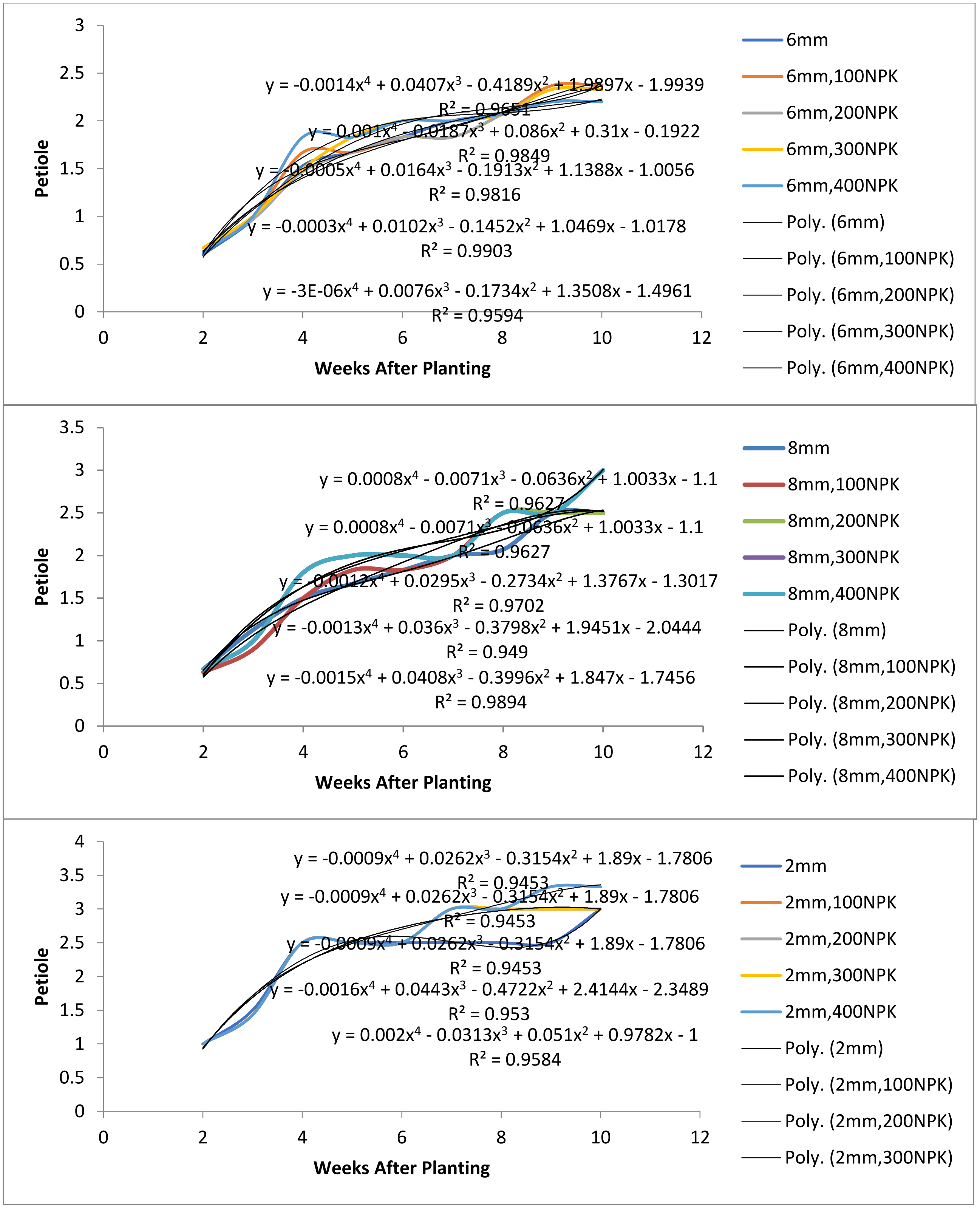


Figure 4.22: Petiole vs Weeks After Planting for 6, 8 mm water depth in the field and 2mm water depth for greenhouse

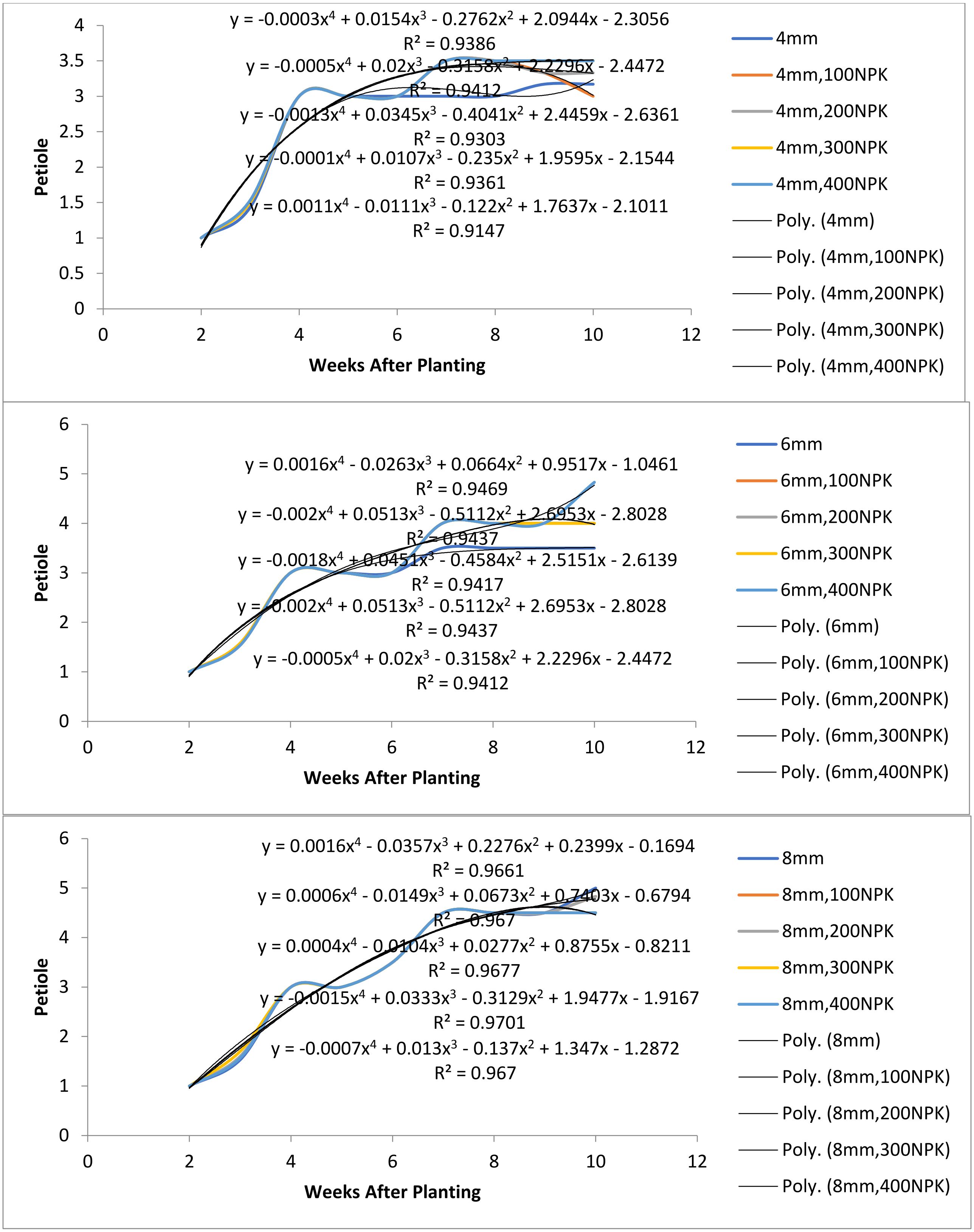


Figure 4.23: Petiole vs Weeks After Planting for 4, 6, 8 mm water depth in the greenhouse

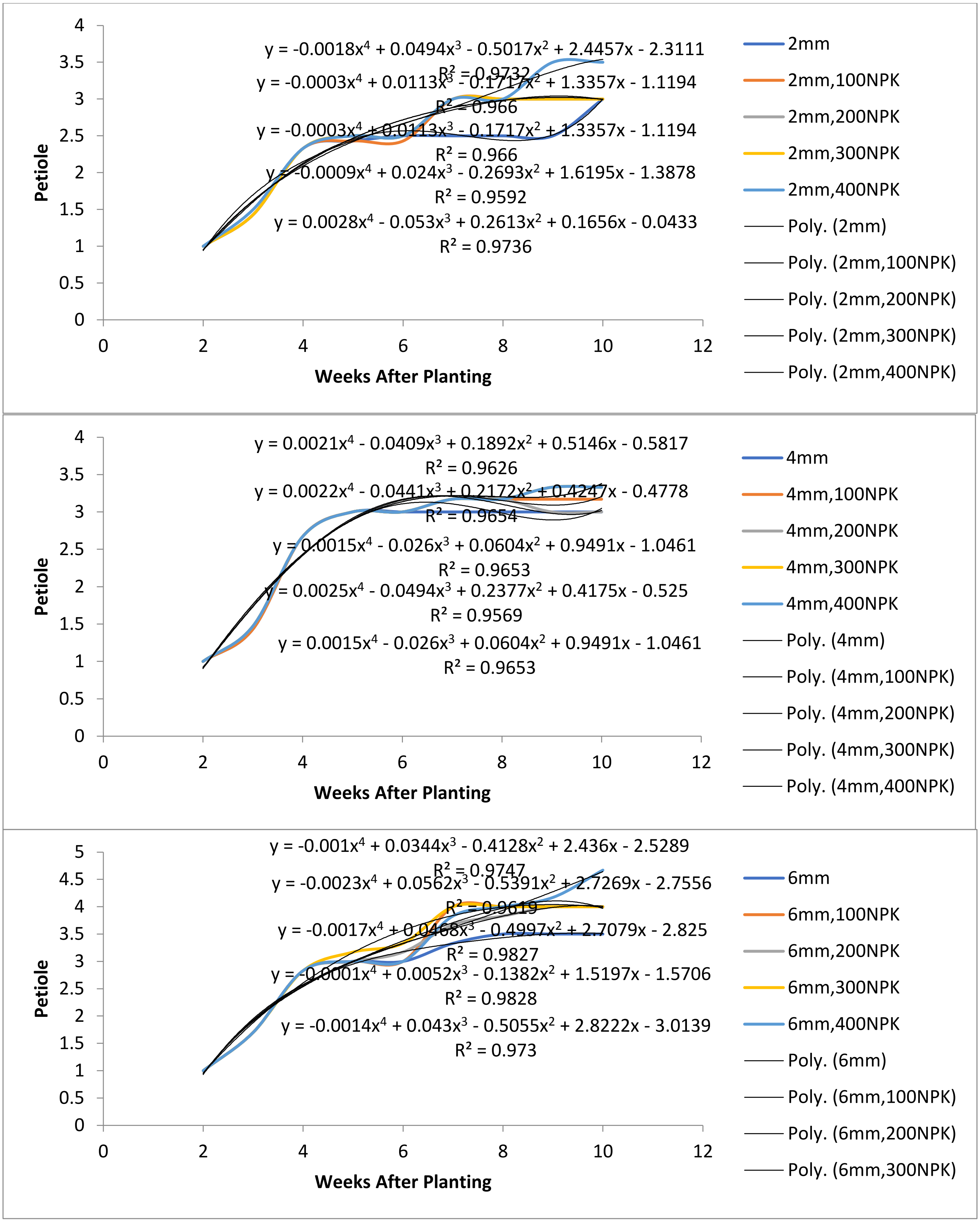


Figure 4.24: Petiole vs Weeks After Planting for 2, 4, 6mm water depth in the greenhouse

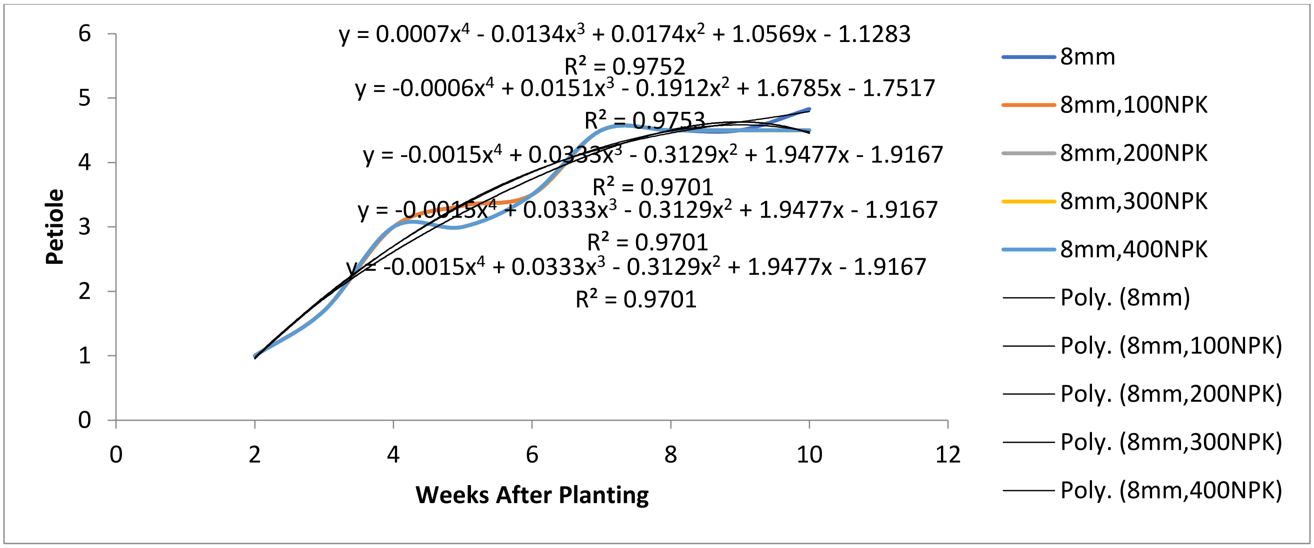


Figure 4.25: Petiole vs Weeks After Planting for 8 mm water depth in the greenhouse

4.2.5 Plant Height

Figure 4.26 and 4.27 present the plant height of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (1ET, 300kg NPK) recorded the highest mean value of 4.63cm which was significantly greater than (2ET, 100kg NPK), (1/2ET, 400kg NPK), (2ET, 400kg NPK), (1/2ET, 100kg NPK), (1/2ET, 200kg NPK), (1/2ET, 300kg NPK) and (1/2ET, 0kg NPK) which had mean values within the range of 4.07-4.27cm. At 3WAS, treatment (2ET, 200kg NPK) recorded the highest mean value of 9.63cm which was significantly greater than (1ET, 100kg NPK), (1ET, 300kg NPK), (1ET, 0kg NPK), (1/2ET, 400kg NPK), (1/2ET, 200kg NPK), (1/2ET, 300kg NPK), (1/2ET, 100kg NPK) and (1/2ET, 100kg NPK) which had mean values within the range of 5.47-7.87cm. At 4WAS, treatment (2ET, 300kg NPK) recorded the highest mean value of 15.73cm which was significantly greater than (1ET, 300kg NPK), (2ET, 100kg NPK), (3/2ET, 300kg NPK), (1ET, 100kg NPK), (2ET, 0kg NPK), (1ET, 200kg NPK), (3/2ET, 100kg NPK) (1/2ET, 400kg NPK), (1/2ET, 200kg NPK), (1/2ET, 300kg NPK), (1/2ET, 100kg NPK), (1ET, 0kg NPK) and (1/2ET, 0kg NPK) which had mean values within the range of 6.20-13.7cm. At 5WAS, treatment (2ET, 300kg NPK) recorded the highest mean value of 21.13cm which was significantly greater than other treatment except for treatment (2ET, 200kg NPK), (2ET, 400kg NPK), (3/2ET, 400kg NPK) which had mean values of 19.70cm, 19.03cm and 18.30cm respectively. At 6WAS, treatment (2ET, 400kg NPK) recorded the highest mean value of 26.07cm which was significantly greater than other treatment except for treatment (2ET, 200kg NPK) and (2ET, 300kg NPK) which had mean values of 25.4cm and 25.63cm respectively. However, treatment (1/2ET, 0kg NPK) had the lowest mean value of 12.90cm. At 7WAS, treatment (2ET, 400kg NPK) recorded the highest mean value of 35.90cm which was significantly greater than other treatments except for treatment (2ET, 200kg NPK) and (2ET, 300kg NPK) which had mean values of 34.50cm and 35.13cm respectively. However, treatment (1/2ET, 0kg NPK) had the lowest mean value of 14.80cm. At 8WAS, treatment (2ET, 400kg NPK) recorded the highest mean value of 45.30cm which was significantly greater than other treatments except for treatment (2ET, 300kg NPK) with a mean value of 44.27cm. However, treatment (1/2ET, 100kg NPK) had the lowest mean value of 17.97cm. At 9WAS, treatment (2ET, 300kg NPK) recorded the highest mean value of 53.5cm which was significantly higher than other treatments except for treatment (2ET, 400kg NPK) with a mean value of 53.2cm. However, treatment (1/2ET, 0kg NPK) had the least mean value of 22.63cm. At 10WAS, treatment (2ET, 300kg NPK) had a peak mean value of 62.23cm which was significantly higher than other treatments except for treatment (2ET, 400kg NPK) with a mean value of 61.6cm. However, treatment (1/2ET, 0kg NPK) had the least mean value of 25.0cm.

Figure 4.27 and 4.28 present the plant height of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (3/2ET, 100kg NPK) had the highest mean value of 4.33cm which was significantly higher than (1/2ET, 0kg NPK), (1ET, 300kg NPK), (3/2ET, 300kg NPK), (1ET, 0kg NPK), (3/2ET, 0kg NPK), (1/2ET, 300kg NPK), (1/2ET, 200kg NPK) (1/2ET, 400kg NPK) and (1/2ET, 100kg NPK) with mean values within the range of 3.30-3.83cm. At 3WAS, treatment (2ET, 200kg NPK) had the highest mean value of 8.57cm which was significantly higher than all the treatments of 1/2ET and (2ET, 100kg NPK), (1ET, 300kg NPK), (1ET, 100kg NPK), (2ET, 0kg NPK) and (1ET, 0kg NPK) which had mean value within the range of 5.33cm-7.13cm. At 4WAS, treatment (3/2ET, 400kg NPK) had the highest mean value of 14.03cm which was significantly higher than treatment (1ET, 300kg NPK), (3/2ET, 0kg NPK), (1ET, 0kg NPK) and all the treatments of 1/2ET which had mean value within the range of 6.07-10.13cm. At 5WAS, treatment (3/2ET, 400kg NPK) had the highest mean value of 19.77cm which was significantly higher than other treatments apart from (2ET, 300kg NPK), (2ET, 100kg NPK), (2ET, 200kg NPK), (3/2ET, 400kg NPK), (3/2ET, 300kg NPK), (3/2ET, 200kg NPK) and (2ET, 0kg NPK) which had mean values ranging from 17.5cm-19.30cm. At 6WAS, treatment (3/2ET, 400kg NPK) had the highest mean value of 27.50cm which was significantly higher than other treatments except (2ET, 200kg NPK), (2ET, 100kg NPK), (2ET, 300kg NPK) and (3/2ET, 400kg NPK) which had mean values ranging from 24.47-26.97cm. At 7WAS, treatment (3/2ET, 400kg NPK) had the highest mean value of 35.56cm which was significantly higher than other treatments except (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK), (2ET, 300kg NPK) and (3/2ET, 400kg NPK) which had mean values ranging from 30.73-33.40cm. At 8WAS, treatment (3/2ET, 400kg NPK) had the highest mean value of 43.97cm which was significantly higher than other treatments except (2ET, 300kg NPK), (2ET, 200kg NPK) and (2ET, 100kg NPK) which had mean values ranging from 40.1cm-41.9cm. At 9WAS, treatment (3/2ET, 400kg NPK) had the highest mean value of 50.10cm which was significantly higher than other treatments except (2ET, 300kg NPK), (2ET, 200kg NPK) and (2ET, 100kg NPK) which had mean values ranging from 47.3cm-48.8cm. At 10WAS, treatment (3/2ET, 400kg NPK) had the peak mean value of 58.43cm which was significantly higher than other treatments except (2ET, 300kg NPK), (2ET, 200kg NPK) and (2ET, 100kg NPK) which had mean values ranging from 55.37cm-57.77cm.

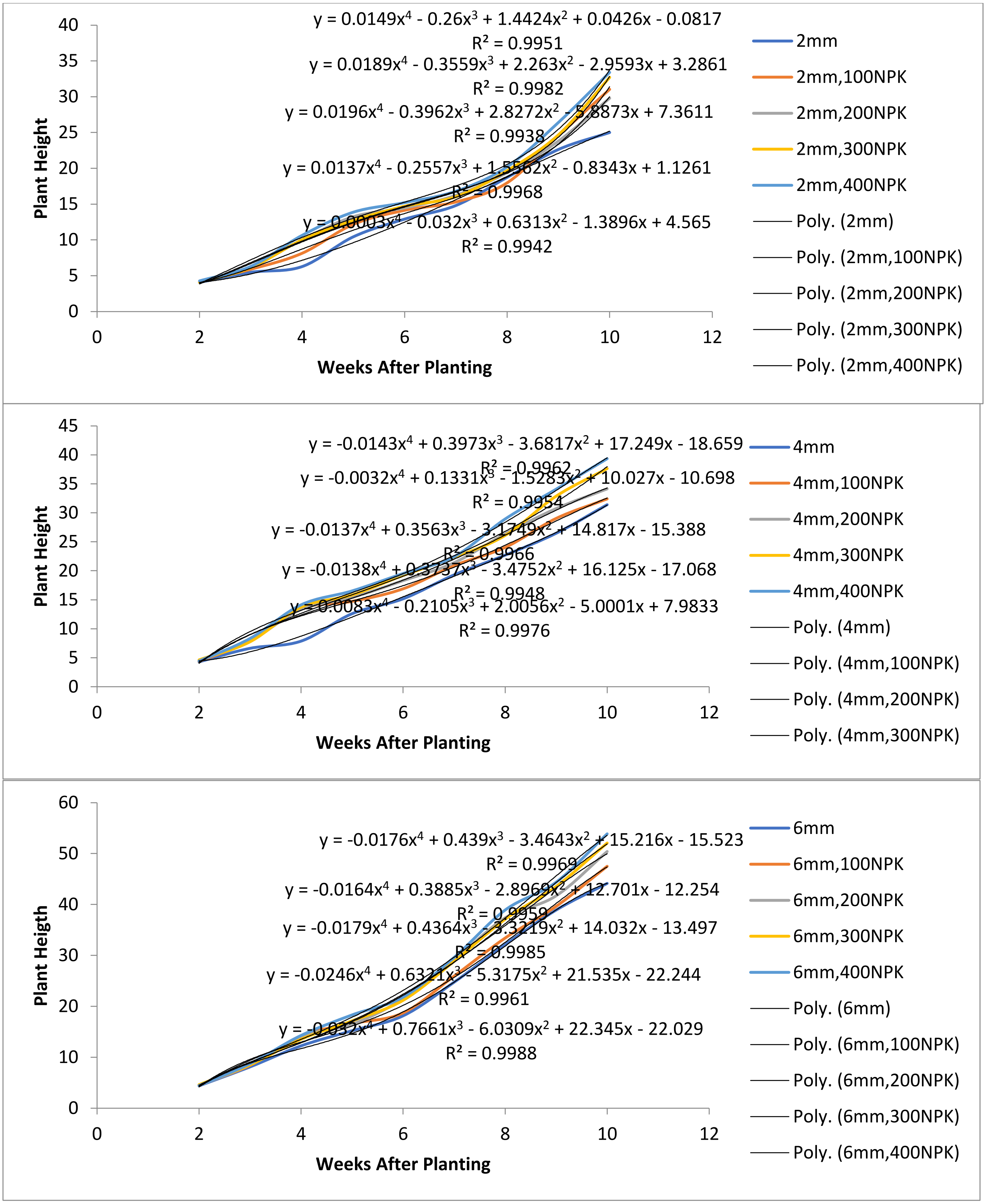


Figure 4.26: Plant Height vs Weeks After Planting for 2, 4, 6 mm water depth in the Field

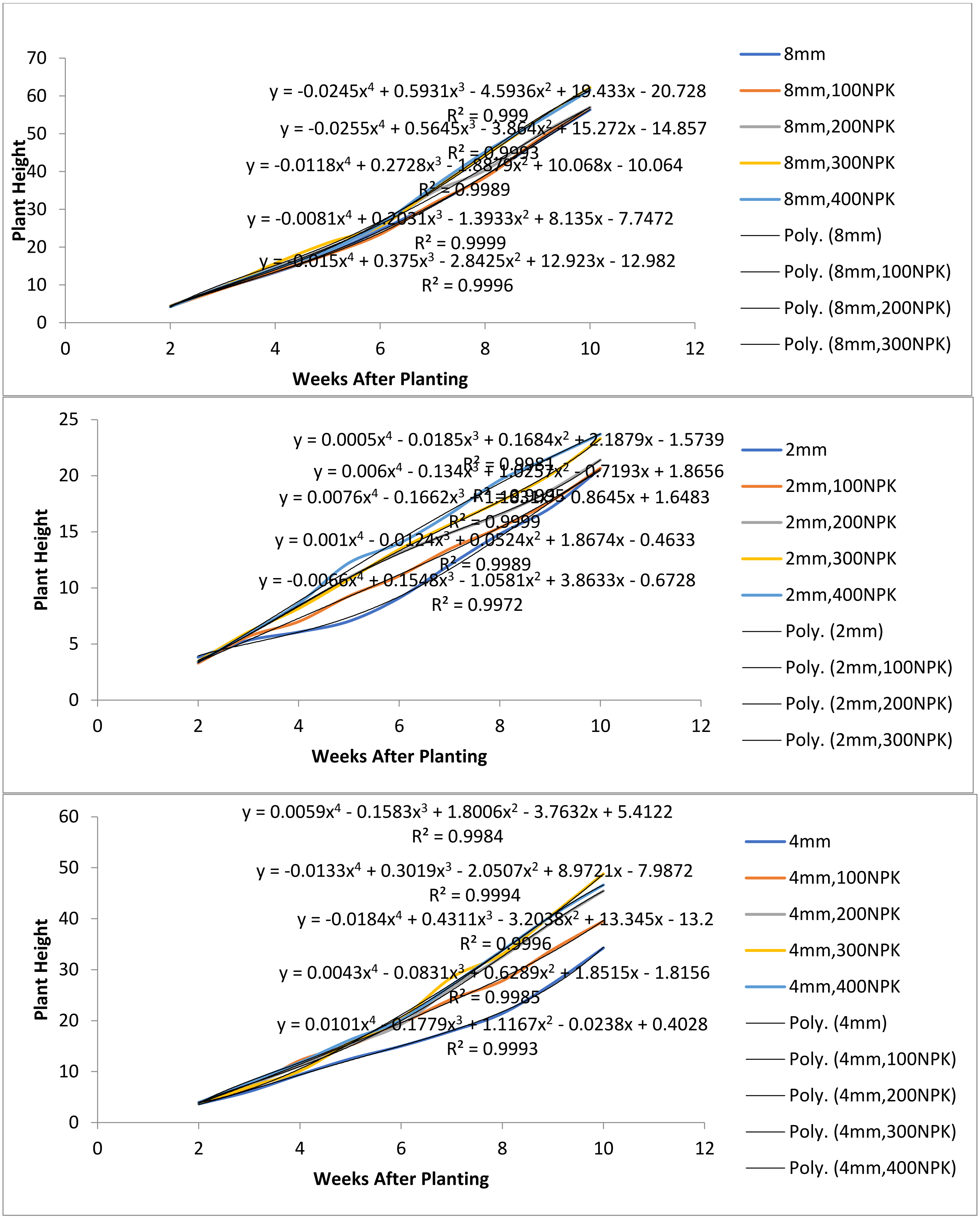


Figure 4.27: Plant Height vs Weeks After Planting for 8, 2, 4 mm water depth in the Field

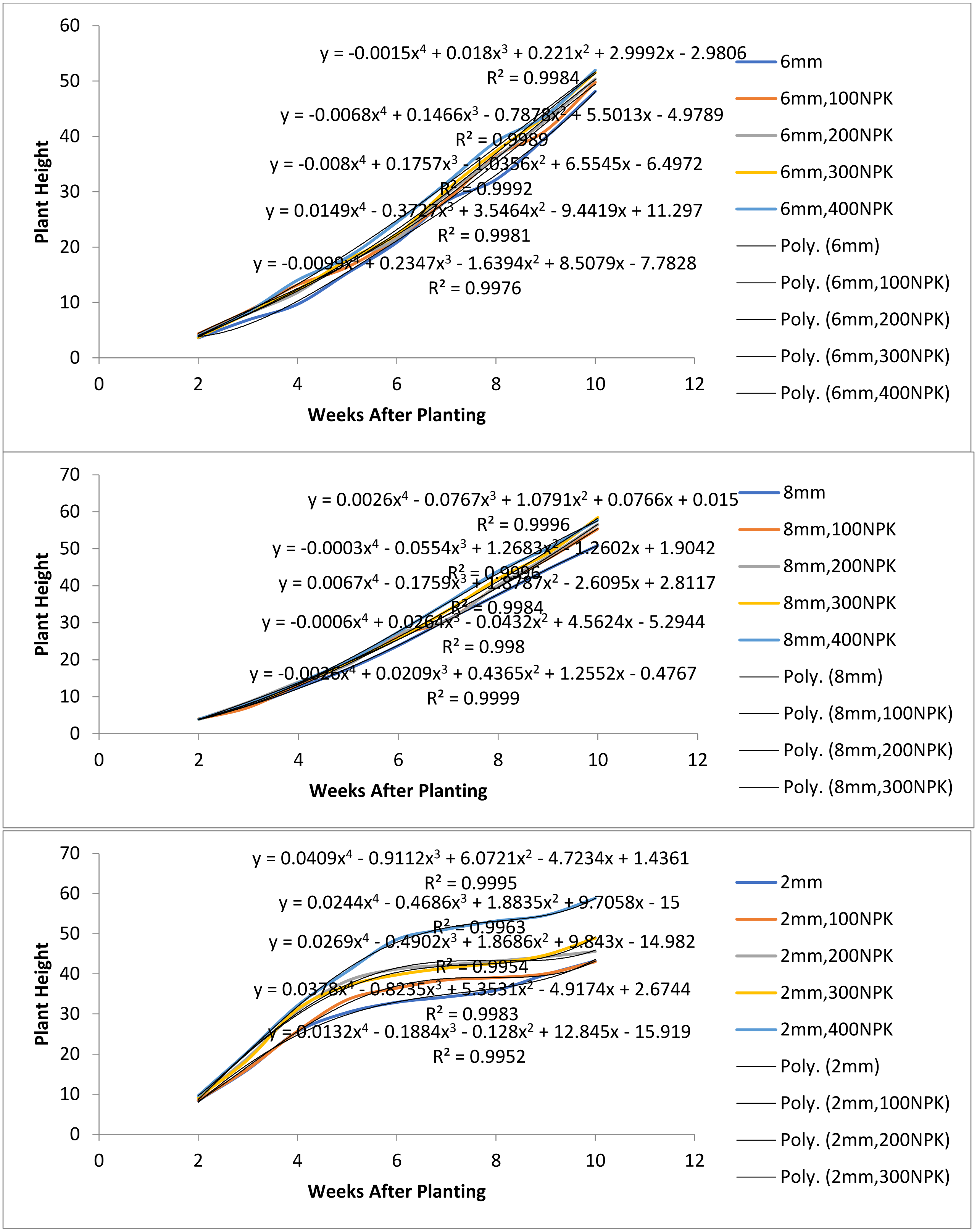


Figure 4.28: Plant Height vs Weeks After Planting for 6, 8mm water depth in the Field and 2 mm water depth in greenhouse

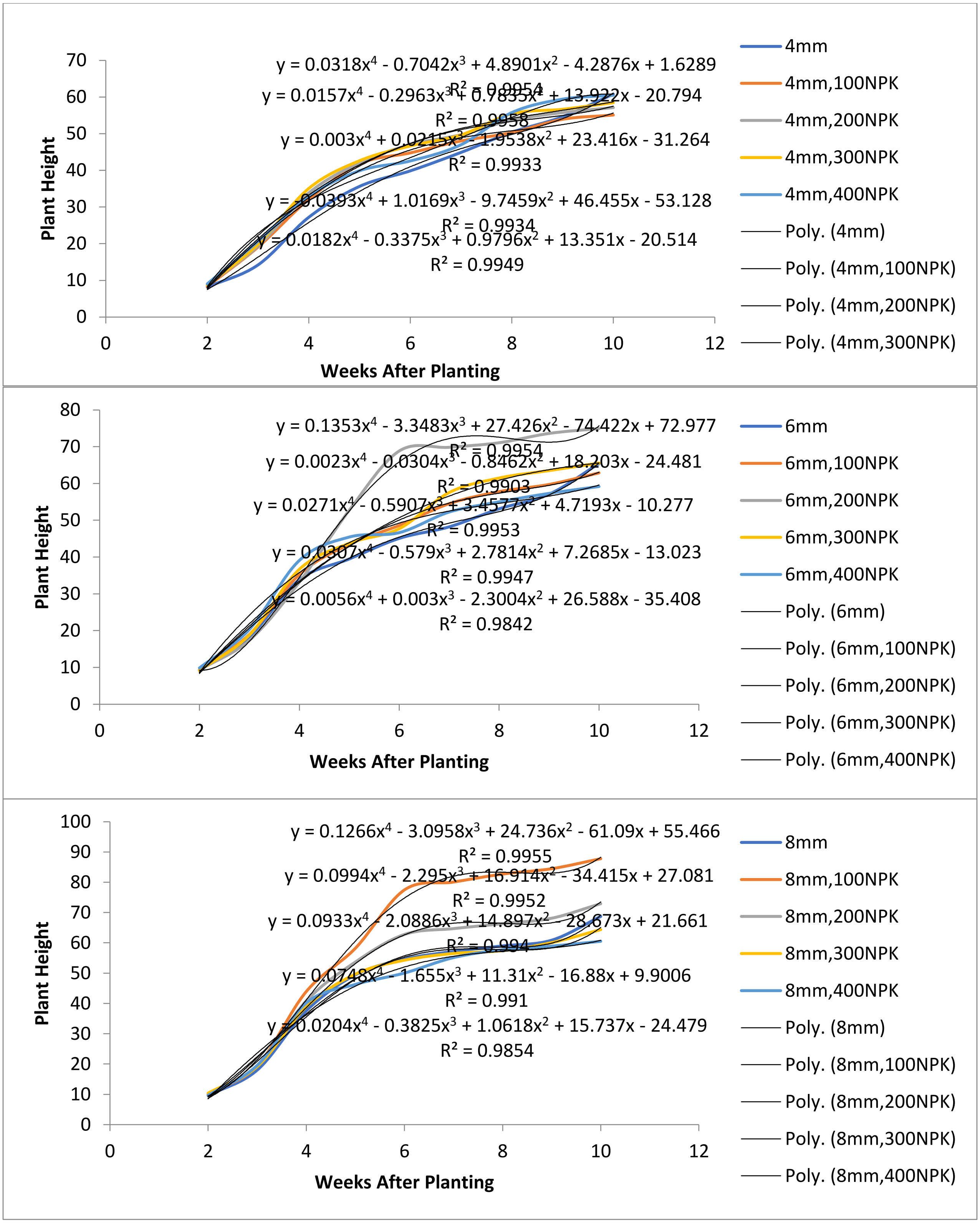


Figure 4.29: Plant Height vs Weeks After Planting for 4, 6, 8 mm water depth in the greenhouse

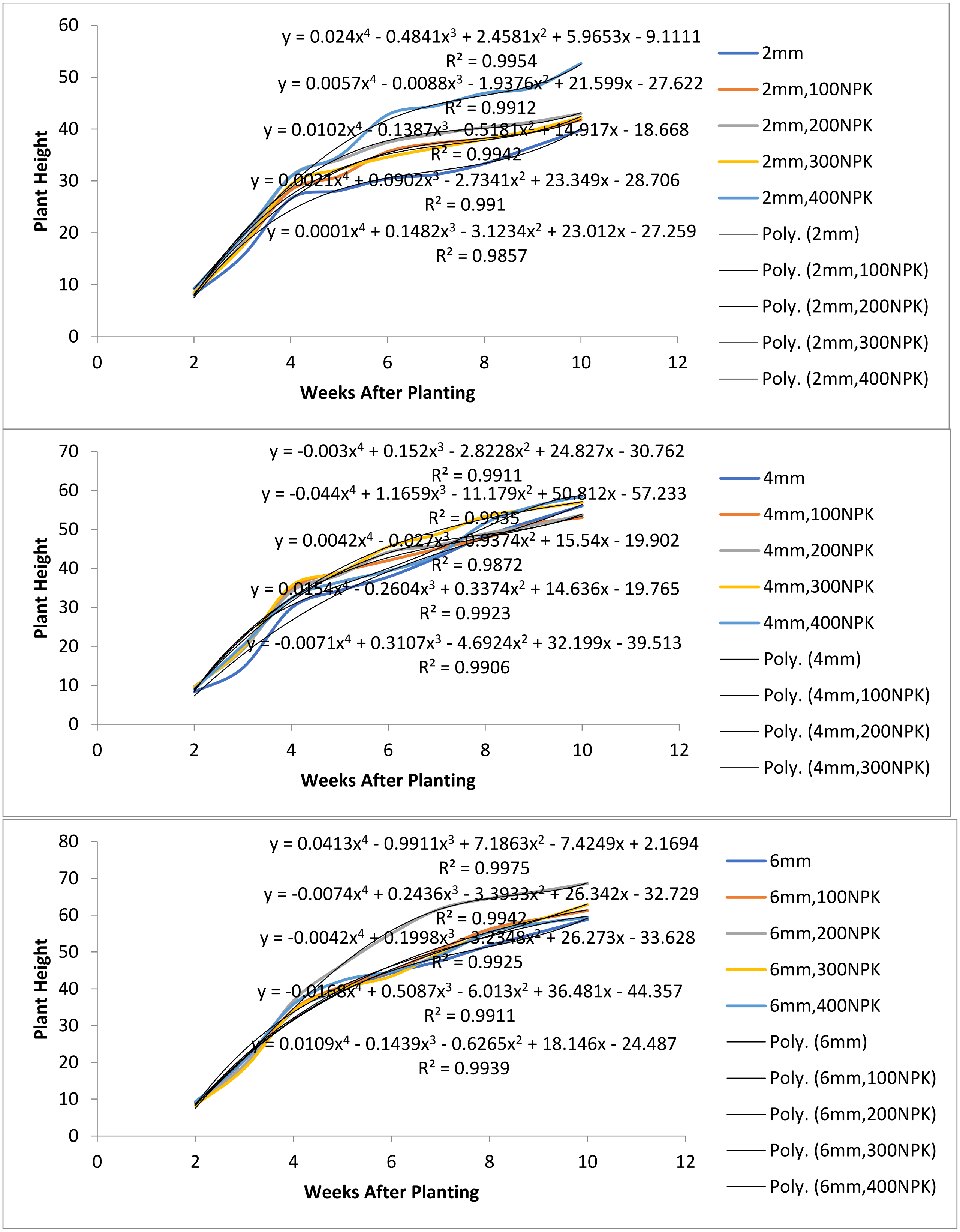


Figure 4.30: Plant Height vs Weeks After Planting for 2, 4, 6 mm water depth in the greenhouse

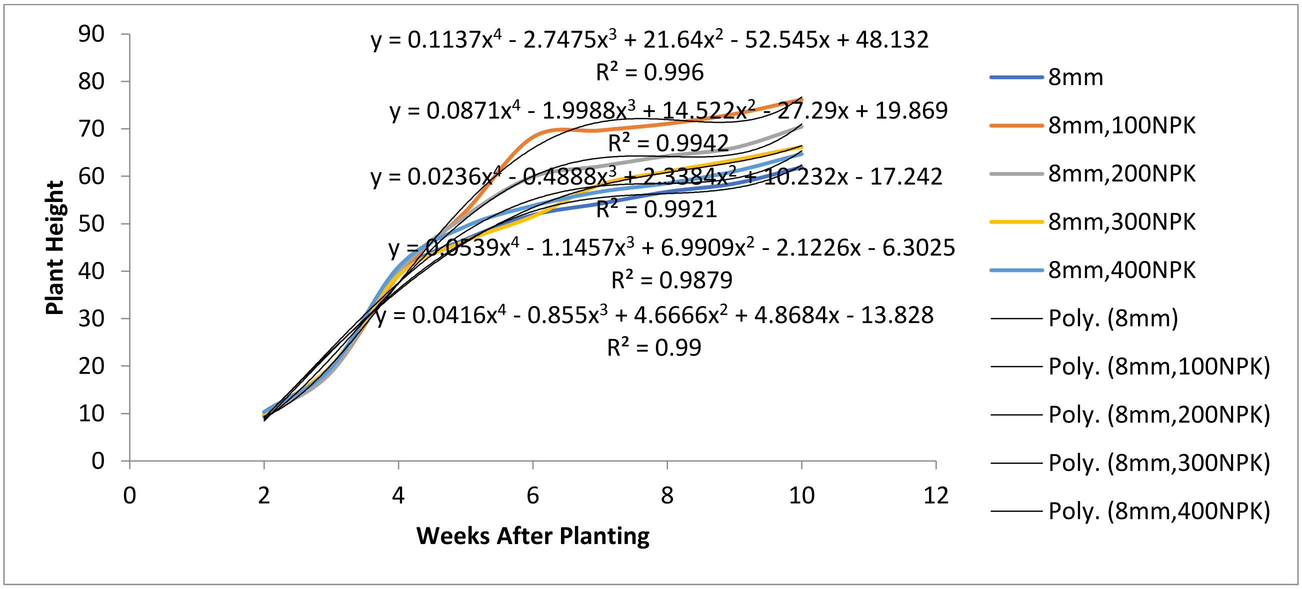


Figure 4.31: Plant Height vs Weeks After Planting for 8 mm water depth in the greenhouse

4.2.6 Stem Girth

Figure 4.32 and 4.33 presents the stem girth of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (1/2ET, 400kg NPK) had the highest mean value of 0.39cm which was significantly higher than treatment (3/2ET, 0kg NPK), (1/2ET, 0kg NPK), (3/2ET, 400kg NPK), (1/2ET, 200kg NPK) and (1ET, 0kg NPK) which had mean values ranging from 0.26-0.30cm. At 3WAS, treatment (2ET, 400kg NPK) had the highest mean value of 1.47cm which was significantly higher than other treatments apart from (2ET, 200kg NPK), (2ET, 0kg NPK), (2ET, 300kg NPK) and (2ET, 100kg NPK) which had mean values within the range of 1.33-1.35cm. At 4WAS, treatment (2ET, 400kg NPK) had the highest mean value of 2.21cm which was significantly higher than other treatments apart from (2ET, 0kg NPK), (2ET, 300kg NPK), (3/2ET, 300kg NPK), (3/2ET, 400kg NPK), (2ET, 100kg NPK), (2ET, 200kg NPK) and (3/2ET, 200kg NPK) which had mean values within the range of 2.01-2.10cm. At 5WAS, treatment (2ET, 200kg NPK) had the highest mean value of 3.04cm which was significantly higher than other treatments apart from (3/2ET, 400kg NPK), (2ET, 300kg NPK), (1ET, 300kg NPK), (2ET, 100kg NPK), (1ET, 400kg NPK), (3/2ET, 300kg NPK), (3/2ET, 100kg NPK), (2ET, 400kg NPK), (3/2ET, 200kg NPK) and (2ET, 0kg NPK) which had mean values within the range of 2.62-3.04cm. However, treatment (1/2ET, 100kg NPK) had the lowest value of 1.81cm. At 6WAS, treatment (2ET, 300kg NPK) had the highest mean value of 3.31cm which was significantly higher than other treatments except treatments (2ET, 200kg NPK), (2ET, 100kg NPK), (3/2ET, 400kg NPK), (3/2ET, 300kg NPK), (3/2ET, 100kg NPK), (1ET, 400kg NPK), (1ET, 300kg NPK), (2ET, 400kg NPK) and (3/2ET, 200kg NPK) which had mean values within the range of 3.09-3.30cm. However, treatment (1/2ET, 100kg NPK) had the lowest value of 1.99cm. At 7WAS, treatment (2ET, 300kg NPK) had the highest mean value of 3.52cm which was significantly higher than other treatments except treatments (2ET, 200kg NPK), (3/2ET, 400kg NPK), (2ET, 100kg NPK), (3/2ET, 300kg NPK), (1ET, 300kg NPK), (3/2ET, 100kg NPK), (1ET, 400kg NPK), (2ET, 400kg) and (3/2ET, 200kg NPK) which had mean values within the range of 3.26-3.51cm. However, treatment (1/2ET, 100kg NPK) had the lowest value of 2.08cm. At 8WAS, treatment (2ET, 300kg NPK) had the highest mean value of 3.62cm which was significantly higher than other treatments except treatments (2ET, 300kg NPK), (3/2ET, 400kg NPK), (2ET, 100kg NPK), (3/2ET, 300kg NPK), (1ET, 300kg NPK), (2ET, 400kg NPK), (3/2ET, 100kg NPK), (1ET, 400kg) and (3/2ET, 200kg NPK) which had mean values within the range of 3.38-3.61cm. However, treatment (1/2ET, 100kg NPK) had the lowest value of 2.16cm. At 9WAS, treatment (2ET, 200kg NPK) had the highest mean value of 3.72cm which was significantly higher than all treatments of 2ET and treatments (1ET, 0kg NPK), (1/2ET, 100kg NPK), (3/2ET, 0kg NPK) and (2ET, 0kg NPK) which had mean values within the range of 2.25-3.32cm. However, treatment (1/2ET, 200kg NPK) had the lowest value of 2.25cm. At 10WAS, treatment (2ET, 400kg NPK) had the highest mean value of 3.97cm which was significantly higher than all treatments of apart from (2ET, 300kg NPK), (2ET, 200kg NPK), (3/2ET, 400kg NPK) and (2ET, 100kg NPK) which had mean values within the range of 3.82-3.90cm. However, treatment (1/2ET, 200kg NPK) had the lowest value of 2.32cm.

Figure 4.33 and 4.34 present the stem girth of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (1/2ET, 0kg NPK) had the highest mean value of 0.38cm which was not significantly higher than any treatment. However, treatment (3/2ET, 200kg NPK) recorded the lowest mean value of 0.29cm. At 3WAS, treatment (1/2ET, 100kg NPK) had the highest mean value of 1.29cm which was significantly higher than treatments (1/2ET, 300kg NPK), (1/2ET, 200kg NPK), (1/2ET, 0kg NPK) and (1/2ET, 100kg NPK) which had mean values within the range of 0.9-1.04cm. At 4WAS, treatment (1ET, 300kg NPK) had the highest mean value of 1.96cm which was significantly higher than treatments (1/2ET, 100kg NPK), (3/2ET, 400kg NPK), (2ET, 100kg NPK), (2ET, 0kg NPK) and (1/2ET, 0kg NPK) which had mean values within the range of 1.34-1.57cm. At 5WAS, treatment (1ET, 400kg NPK) had the highest mean value of 2.79cm which was significantly higher than all treatments of 1/2ET and treatments (2ET, 0kg NPK) and (1ET, 0kg NPK) which had mean values within the range of 1.46-1.91cm. At 6WAS, treatment (1ET, 400kg NPK) recorded the highest mean value of 2.94cm which was significantly higher than all treatments of 1/2ET which had mean values within the range of 1.60-2.11cm. However, treatment (1/2ET, 0kg NPK) recorded the least value of 1.60cm. At 7WAS, treatment (1ET, 400kg NPK) had the highest mean value of 3.08cm which was significantly higher than all treatments of 1/2ET which had mean values within the range of 1.70-2.22cm except treatment (1/2ET, 0kg NPK) with a mean value of 2.41cm. However, treatment (1/2ET, 0kg NPK) recorded the least value of 1.76cm. At 8WAS, treatment (1ET, 400kg NPK) had the highest mean value of 3.24cm which was significantly higher than all treatments of 1/2ET which had mean values within the range of 2.05-2.44cm except treatment (1/2ET, 400kg NPK) with a mean value of 2.69cm. However, treatment (1/2ET, 0kg NPK) recorded the least value of 2.05cm. At 9WAS, treatment (2ET, 300kg NPK) had the highest mean value of 3.46cm which was significantly higher than all treatments of 1/2ET which had mean values within the range of 2.31-2.80cm except treatment (1/2ET, 400kg NPK) with a mean value of 3.03cm. However, treatment (1/2ET, 0kg NPK) recorded the least value of 2.31cm. At 10WAS, treatment (2ET, 400kg NPK) had a peak mean value of 3.77cm which was significantly higher than all treatments of 1/2ET and treatment (1ET, 0kg NPK) which had mean values within the range of 2.47-3.21cm. However, treatment (1/2ET, 100kg NPK) recorded the least value of 2.47cm.

Figure 4.34 and 4.35 present the stem girth of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 2WAS, treatment (1/2ET, 400kg NPK) recorded the maximum value of 1.19cm which was only significantly greater than treatment (1/2ET, 0kg NPK) which had a mean value of 0.97cm. At 3WAS, treatment (2ET, 100kg NPK) recorded the maximum value of 2.32cm which was significantly greater than treatments (3/2ET, 300kg NPK), (3/2ET, 400kg NPK), (1/2ET, 100kg NPK), (1ET, 200kg NPK), (2ET, 0kg NPK), (3/2ET, 0kg NPK), (1ET, 0kg NPK), (1ET, 100kg) and (1/2ET, 0kg NPK) which had values ranging from 1.38-1.96cm. At 4WAS, treatment (2ET, 100kg NPK) recorded the maximum value of 3.53cm which was significantly greater than other treatments apart from (3/2ET, 200kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 0kg NPK) and (3/2ET, 100kg NPK) which had values ranging from 3.21cm-3.18cm. However, treatment (1/2ET, 0kg NPK) recorded the lowest value of 1.74cm. At 5WAS, treatment (2ET, 100kg NPK) recorded the maximum value of 3.69cm which was significantly greater than other treatments except treatments (2ET, 300kg NPK), (3/2ET, 100kg NPK), (2ET, 0kg NPK) and (3/2ET, 200kg NPK) which had values ranging from 3.37-3.51cm. However, treatment (1/2ET, 0kg NPK) recorded the lowest value of 1.99cm. At 6WAS, treatment (2ET, 100kg NPK) recorded the maximum value of 3.93cm which was significantly greater than other treatments which had values ranging from 3.37-3.51cm. However, treatment (1/2ET, 0kg NPK) recorded the lowest value of 2.26cm. At 7WAS, treatment (2ET, 100kg NPK) recorded the maximum value of 4.11cm which was significantly greater than other treatments which had values ranging from 2.48-3.82cm. However, treatment (1/2ET, 0kg NPK) recorded the lowest value of 2.48cm. At 8WAS, treatment (2ET, 100kg NPK) had the highest value of 4.33cm which was significantly greater than other treatments which had values ranging from 2.76-4.07cm. However, treatment (1/2ET, 0kg NPK) recorded the lowest mean value. At 9WAS, treatment (2ET, 100kg NPK) had the highest value of 4.45cm which was significantly higher than other treatments which had values ranging from 2.92-4.20cm although treatment (3/2ET, 200kg NPK) had next highest value. However, treatment (1/2ET, 0kg NPK) recorded the lowest mean value. At 10WAS, treatment (2ET, 100kg NPK) had the highest value of 4.59cm which was significantly higher than other treatments which had values ranging from 3.14-4.40cm although treatment (3/2ET, 200kg NPK) and (2ET, 200kg NPK) was second and third with values 4.40cm and 4.25cm respectively. However, treatment (1/2ET, 0kg NPK) recorded the lowest mean value.

Figure 4.36 and 4.37 present the stem girth of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 2WAS, treatment (2ET, 200kg NPK) recorded the maximum value of 1.22cm which was only significantly greater than treatment (1ET, 0kg NPK) which had a mean value of 1.09cm. At 3WAS, treatment (2ET, 100kg NPK) recorded the maximum value of 2.53cm which was significantly greater than treatments (1ET, 200kg NPK), (1ET, 0kg NPK), (1/2ET, 100kg NPK), (1ET, 100kg NPK) and (1/2ET, 0kg NPK) which had values ranging from 1.43-1.84cm. At 4WAS, treatment (2ET, 100kg NPK) recorded the maximum value of 3.8cm which was significantly higher than other treatments which had values ranging from 1.74-3.4cm. At 5WAS, treatment (2ET, 100kg NPK) had the highest value of 4.10cm which was significantly higher than other treatments which had values ranging from 1.91-3.58cm. At 6WAS, treatment (2ET, 100kg NPK) had the highest value of 4.30cm which was significantly higher than other treatments which had values ranging from 2.22-3.78cm. However, (3/2ET, 200kg NPK) and (2ET, 200kg NPK) had values of 3.80cm and 3.61cm respectively while (1/2ET,0kg NPK) had the lowest value. At 7WAS, treatment (2ET, 100kg NPK) had the highest value of 4.58cm which was significantly higher than other treatments which had values ranging from 2.28-4.20cm. However, (2ET, 200kg NPK) and (3/2ET, 200kg NPK) had values of 4.20cm and 3.84cm respectively while (1/2ET,0kg NPK) had the lowest value. At 7WAS, treatment (2ET, 100kg NPK) had the highest value of 4.58cm which was significantly higher than other treatments which had values ranging from 2.28-4.20cm. However, (2ET, 200kg NPK) and (3/2ET, 200kg NPK) had values of 4.20cm and 3.84cm respectively while (1/2ET,0kg NPK) had the lowest value. At 8WAS, treatment (2ET, 100kg NPK) recorded the maximum value of 4.63cm which was significantly higher than other treatments which had values ranging from 2.35-4.46cm. However, (2ET, 200kg NPK) and (3/2ET, 200kg NPK) had values of 4.20cm and 3.95cm respectively while (1/2ET,0kg NPK) had the lowest value. At 9WAS, treatment (2ET, 100kg NPK) had the highest value of 4.78cm which was significantly higher than other treatments which had values ranging from 2.76-4.46cm. However, treatments (2ET, 200kg NPK) and (3/2ET, 300kg NPK) had values of 4.46cm and 4.13cm respectively while (1/2ET,0kg NPK) had the lowest value. At 10WAS, the peak value of 4.95cm was recorded for treatment (2ET, 100kg NPK) which was significantly higher than other treatments. However, treatments (2ET, 200kg NPK) and (3/2ET, 300kg NPK) was next with mean values of 4.46cm and 4.13cm. The lowest mean value recorded was 2.84cm which was for treatment (1/2ET, 0kg NPK).

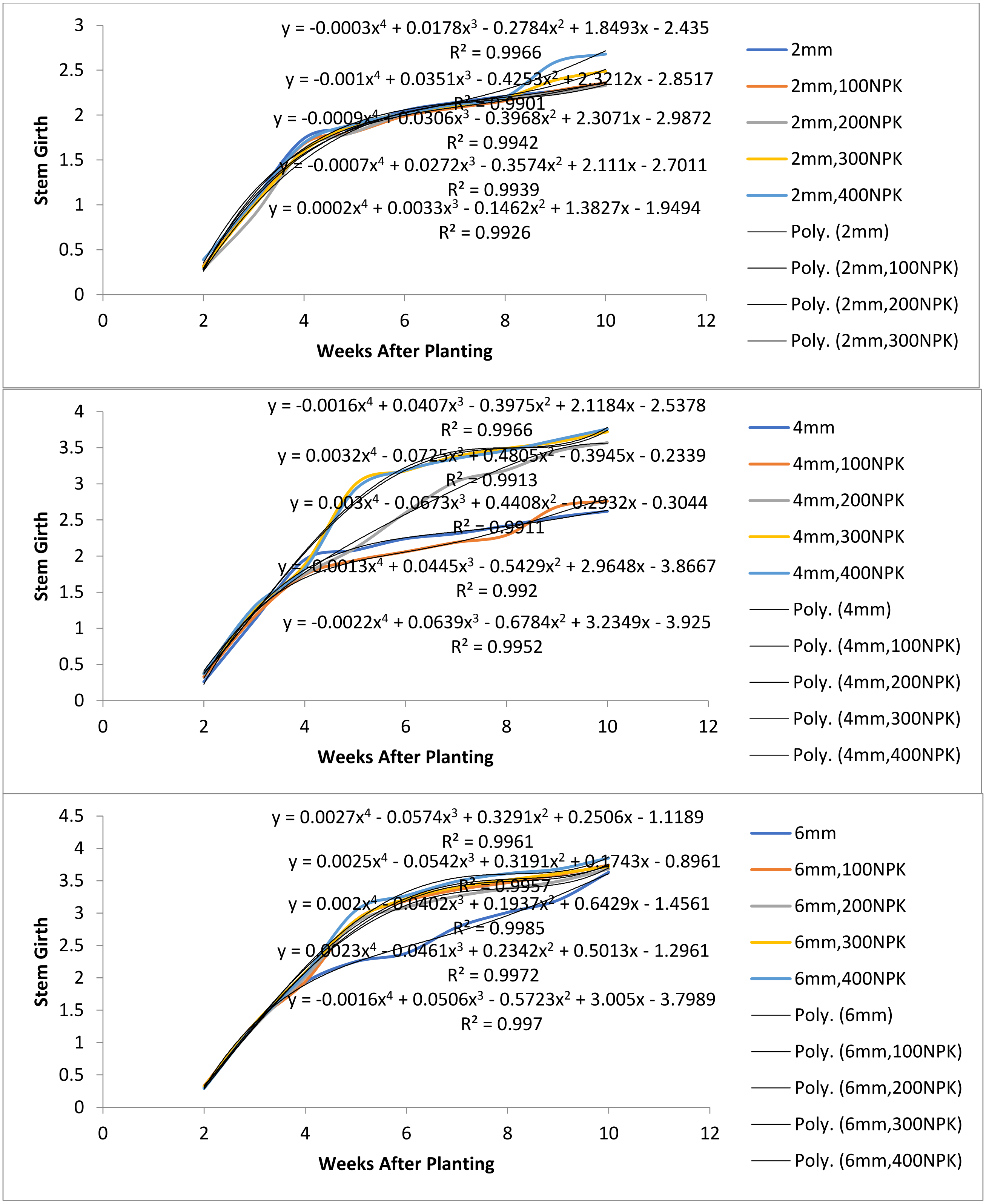


Figure 4.32: Stem Girth vs Weeks After Planting for 2, 4, 6 mm water depth for field

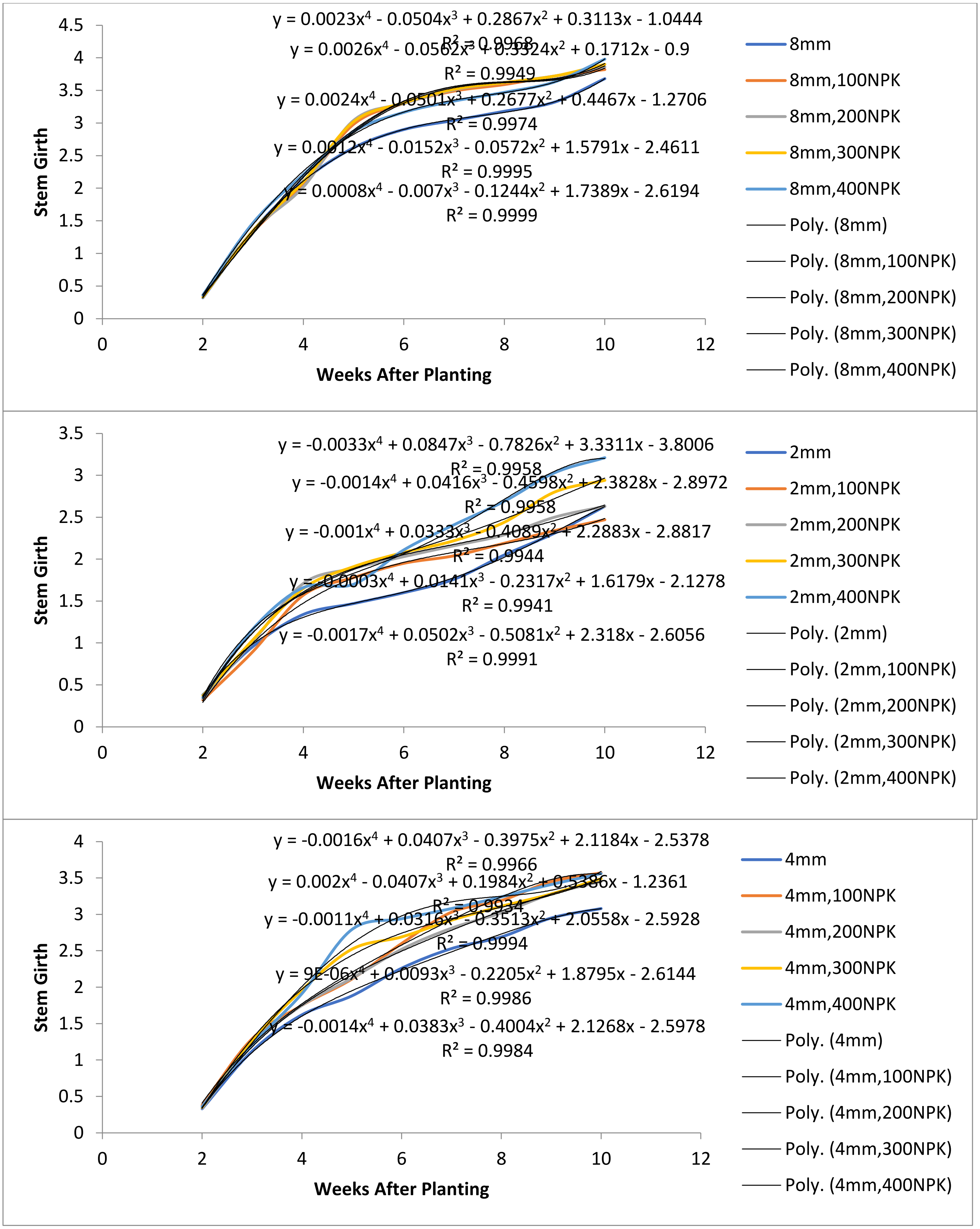


Figure 4.33: Stem Girth vs Weeks After Planting for 8, 2, 4 mm water depth in the Field

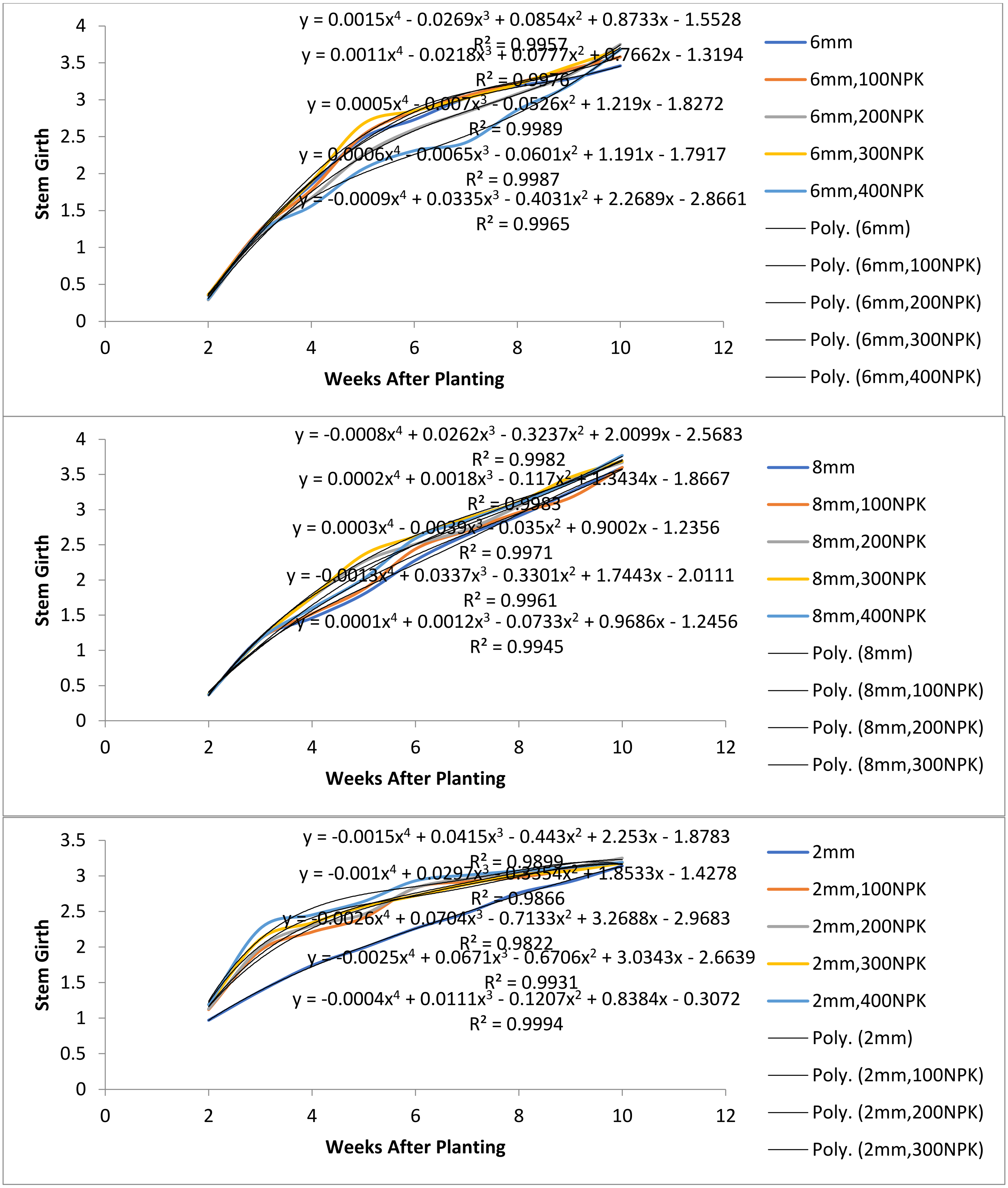


Figure 4.34: Stem Girth vs Weeks After Planting for 6 and 8 mm water depth in the Field and 2mm water depth for greenhouse

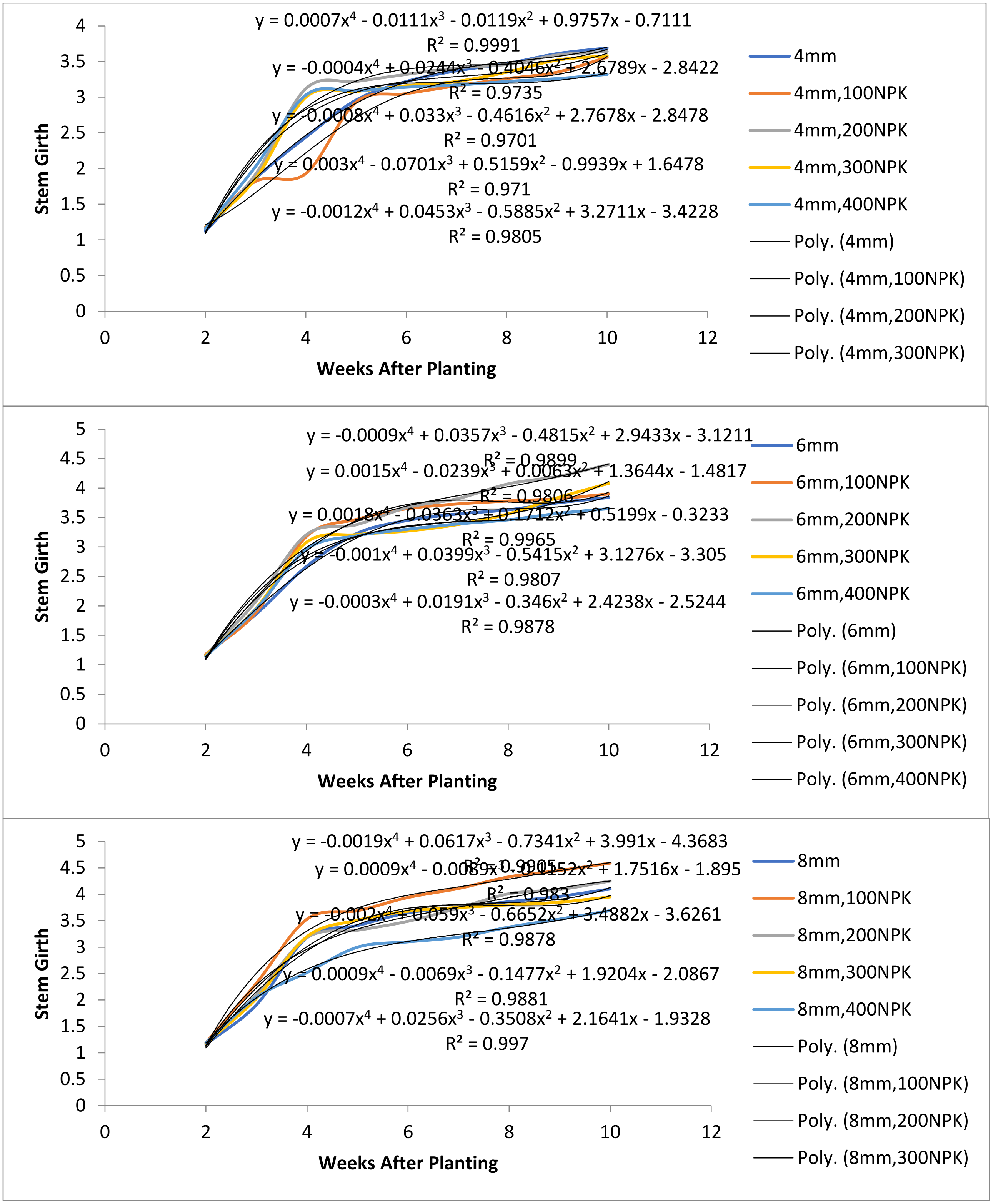


Figure 4.35: Stem Girth vs Weeks After Planting for 4, 6, 8 mm water depth for greenhouse

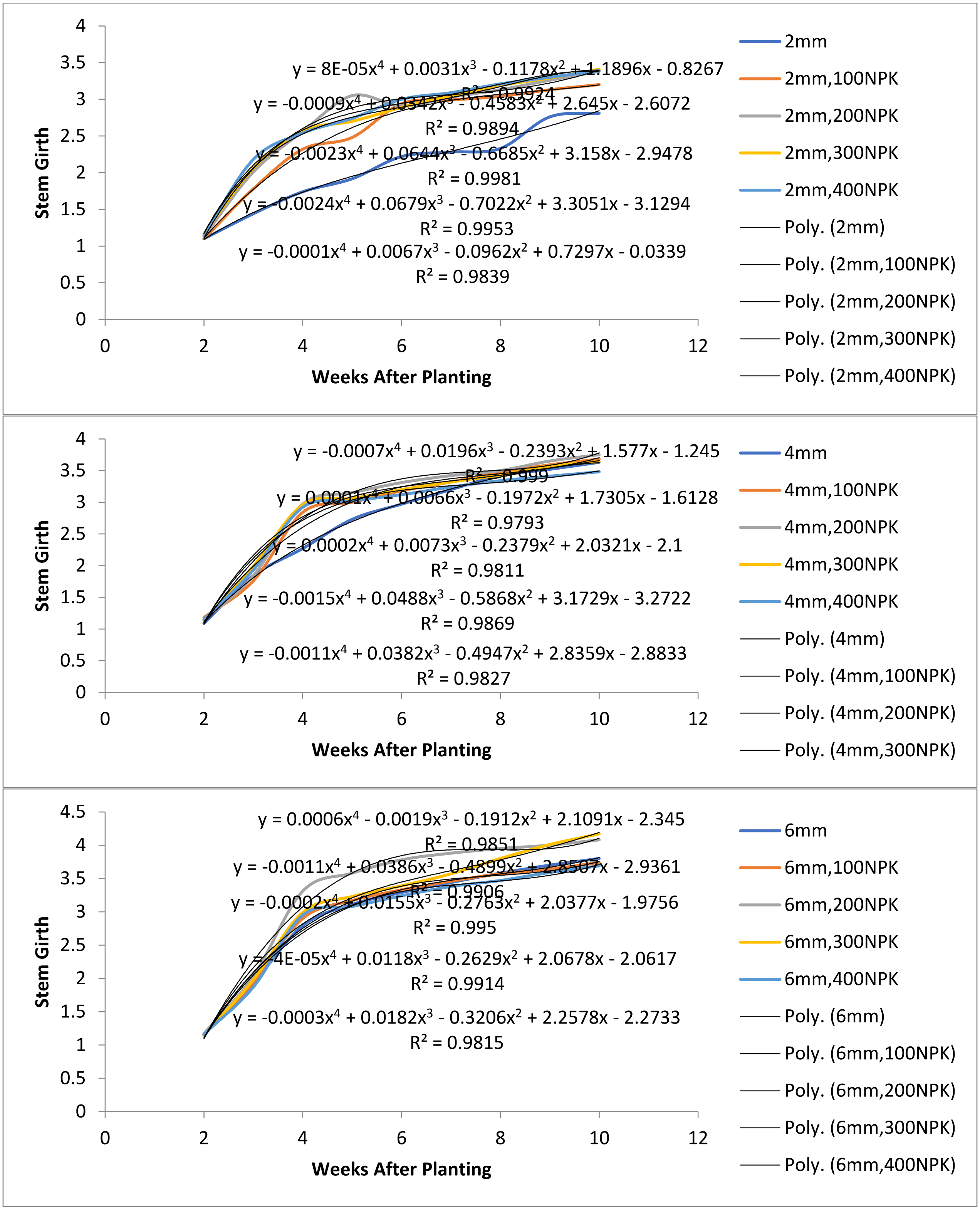


Figure 4.36: Stem Girth vs Weeks After Planting for 2, 4, 6 mm water depth in the greenhouse

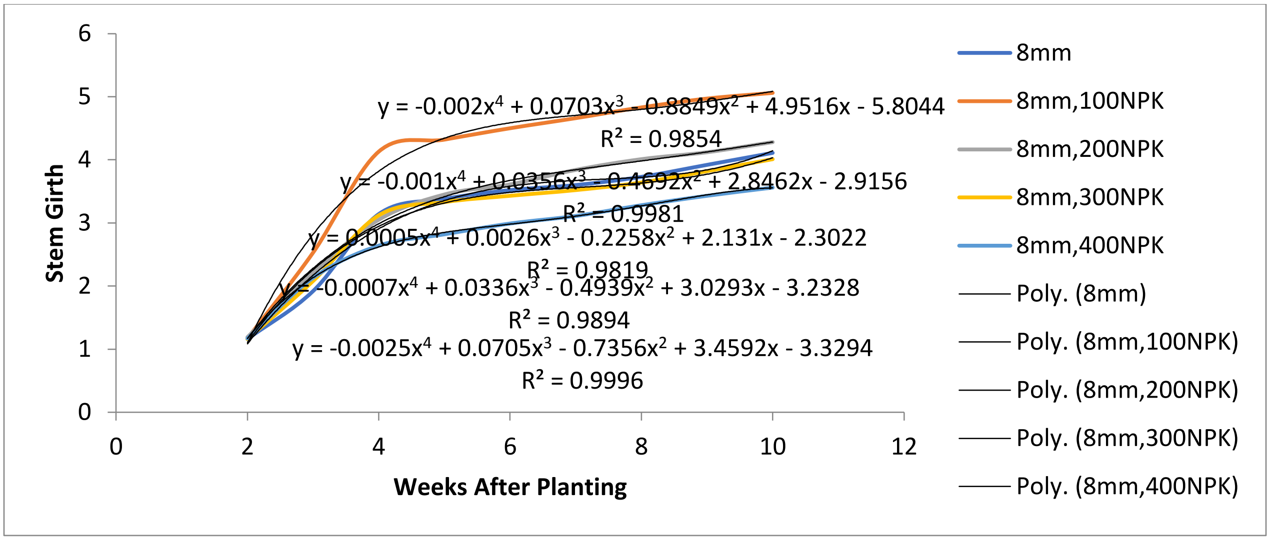


Figure 4.37: Stem Girth vs Weeks After Planting for 8 mm water depth in the greenhouse

4.2.7 Width of Leaves

Figure 4.38 and 4.39 present the width of leaves of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (2ET, 400kg NPK) recorded the highest mean value of 0.9cm which was not significantly different to other treatments. However, other treatments had mean values ranging from 0.80-0.87cm. At 3WAS, treatments (2ET, 400kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK), (2ET, 0kg NPK), (3/2ET, 400kg NPK) and (3/2ET, 300kg NPK) had maximum mean values of 1.30cm each which was significantly higher to other treatments except (3/2ET, 200kg NPK), (3/2ET, 100kg NPK), (3/2ET, 0kg NPK), (1ET, 400kg NPK) and (1ET, 100kg NPK) which had mean values of 1.27cm, 1.23cm, 1.23cm, 1.20cm and 1.20cm respectively. At 4WAS, treatments (2ET, 400kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK), (3/2ET, 400kg NPK), had highest mean values of 1.93cm each which was significantly higher to other treatments except (2ET, 100kg NPK), (2ET, 0kg NPK), (3/2ET, 300kg NPK), (3/2ET, 200kg NPK) and (3/2ET, 100kg NPK) which had mean values of 1.90cm, 1.83cm, 1.83cm, 1.83cm and 1.80cm respectively. However, treatment (1ET, 0kg NPK), (1/2ET, 200kg NPK) and (1/2ET, 100kg NPK) recorded the least mean value of 1.40cm. At 5WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 2.47cm which was not significant to treatments (3/2ET, 300kg NPK), (3/2ET, 400kg NPK), (2ET, 400kg NPK), (2ET, 0kg NPK), (3/2ET, 200kg NPK), (2ET, 300kg NPK) and (2ET, 200kg), (3/2ET, 100kg NPK), (1ET, 400kg NPK) and (1ET, 300kg NPK) with values ranging from 2.17-2.40cm but was significant to treatments with mean values within the range of 2.13cm-1.77cm but treatment (1ET, 0kg NPK) having the lowest value. At 7WAS, treatment (2ET, 300kg NPK) and (2ET, 400kg NPK) recorded the highest mean value of 2.53cm which was not significant to treatments (2ET, 100kg NPK), (2ET, 0kg NPK), (2ET, 200kg NPK), (3/2ET, 400kg NPK), (3/2ET, 300kg NPK), (3/2ET, 200kg NPK) and (3/2ET, 0kg NPK) which had values ranging from 2.36-2.50cm but was significant to other treatments with mean values within the range of 1.90-2.33cm but treatment (1/2ET, 100kg NPK) having the lowest value. At 8WAS, treatment (2ET, 400kg NPK) had the highest mean value of 2.87cm which was not significant to treatments (2ET, 100kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 0kg NPK), (3/2ET, 300kg NPK) and (1/2ET, 400kg NPK) which had values ranging from 2.60-2.73cm but was significant to other treatments with mean values within the range of 2.26-2.57cm. However, treatment (1/2ET, 100kg NPK) had the lowest value. At 9WAS, treatment (2ET, 400kg NPK) had the highest mean value of 3.50cm which was significantly higher than other treatments apart from treatments (2ET, 300kg NPK) and (2ET, 200kg NPK) which had values of 3.33cm each. However, mean values of treatments which were significant are within the range of 2.27-3.17cm although treatment (1/2ET, 0kg NPK) had the lowest value. At 10WAS, treatment (2ET, 400kg NPK) had the peak mean value of 3.70cm which was significantly higher than other treatments apart from treatments (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 0kg NPK) and (2ET, 100kg NPK) which had values within the range of 3.36-3.63cm. However, mean values of treatments which were significant were within the range of 2.40-3.30cm but treatment (1/2ET, 0kg NPK) had the lowest value

Figure 4.39 and 4.40 present the width of leaves of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (2ET, 300kg NPK) and (3/2ET, 300kg NPK) had the maximum mean value of 1.0cm which was not significantly higher than other treatments. At 3WAS, treatment (2ET, 400kg NPK) and (2ET, 300kg NPK) recorded the highest mean value of 1.5cm which was significantly higher than treatments (1ET, 300kg NPK), (1ET, 200kg NPK), (1/2ET, 0kg NPK), (1/2ET, 200kg NPK) and (1/2ET, 100kg NPK) which had mean values 1.27cm, 1.27cm, 1.23cm, 1.20cm and 1.20cm respectively. At 4WAS, treatment (2ET, 400kg NPK) and (2ET, 300kg NPK) had the highest mean value of 2.2cm which was significantly higher than other treatments apart from treatments (2ET, 200kg NPK), (2ET, 100kg NPK), (3/2ET, 400kg NPK), (2ET, 0kg NPK), (3/2ET, 300kg NPK), (3/2ET, 200kg NPK) and (3/2ET, 100kg) which had mean values ranging from 2.00-2.17cm. At 5WAS, treatment (2ET, 400kg NPK) and (2ET, 300kg NPK) recorded the highest mean value of 2.57cm which was significantly higher than other treatments except treatments (2ET, 200kg NPK), (2ET, 100kg NPK), (3/2ET, 400kg NPK), (3/2ET, 300kg NPK), (2ET, 0kg NPK), (3/2ET, 200kg NPK), (3/2ET, 100kg) and (1ET, 400kg NPK) with mean values ranging from 2.33-2.53cm. At 6WAS, treatment (2ET, 400kg NPK) and (2ET, 300kg NPK) had the maximum mean value of 2.63cm which was significantly higher than other treatments except for treatments (3/2ET, 300kg NPK), (2/4ET, 400kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK), (1/2ET, 400kg NPK) and (2ET, 0kg NPK) with mean values ranging from 2.43-2.57cm. However, mean values of treatments significantly lower ranged from 1.87-2.40cm but treatment (1/2ET, 100kg NPK) recorded the lowest value. At 8WAS, treatment (2ET, 400kg NPK), (2ET, 300kg NPK) recorded the highest mean value of 3.07cm which was significantly higher than other treatment. However, the mean values of the treatments ranged from 2.23-2.73cm. Although, treatment (1/2ET, 100kg NPK) had the lowest mean value. At 9WAS, treatment (2ET, 400kg NPK) and (2ET, 300kg NPK) had the highest mean value of 3.30cm which was significantly higher than other treatments except for treatments (2ET, 200kg NPK), (2ET, 100kg NPK), (2ET, 0kg NPK), (3/2ET, 300kg NPK) and (3/2ET, 400kg NPK) with mean values ranging from 3.03-3.23cm. However, treatments significantly lower than the highest mean value ranges from 2.33-3.00cm. At 10WAS, 3.67cm was recorded as the peak value obtained from treatments (2ET, 400kg NPK) and (2ET, 300kg NPK) which were significantly higher than other treatments apart from treatments (2ET, 200kg NPK), (2ET, 0kg NPK), (2ET, 100kg NPK), (3/2ET, 400kg NPK) and (3/2ET, 300kg NPK) which had mean values within the range of 3.53-3.63cm. However, 2.46-3.43cm were recorded for treatments significantly lower than the peak value.

Figure 4.40 and 4.41 present the width of leaves of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 2WAS, treatment (2ET, 400kg NPK) had the maximum mean value of 2.80cm which was significantly greater than other treatments except for treatments (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK) which had an equal mean value of 2.70cm while other treatments recorded value within the range of 2.27-2.50cm. At 3WAS, treatment (2ET, 400kg NPK) had the highest mean value of 3.83cm which was significantly higher than other treatments apart from treatments (2ET, 200kg NPK), (2ET, 300kg NPK), (3/2ET, 400kg NPK) (3/2ET, 300kg NPK), (3/2ET, 200kg NPK), (3/2ET, 100kg NPK), (2ET, 0kg NPK), (2ET, 400kg NPK), (1ET, 400kg NPK) which had mean values ranging from 3.30-3.67cm while other treatments recorded value within the range of 2.67-3.26cm. At 4WAS, treatment (2ET, 100kg NPK) had the highest mean value of 5.77cm which was significantly higher than all treatments of 2ET and 4ET which had mean values of 3.13-3.93cm apart from treatment (1ET, 400kg NPK) which had a mean value 4.20cm. At 5WAS, 6.10cm was recorded for treatment (2ET, 100kg NPK) which was the highest mean value and was significantly higher than other treatments apart from treatment (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 400kg NPK) (3/2ET, 300kg NPK), (2ET, 0kg NPK), (3/2ET, 400kg NPK), (3/2ET, 200kg NPK) and (3/2ET, 100kg NPK) which had mean values ranging from 4.70-5.83cm while other treatments recorded value within the range of 3.33-4.0cm. At 6WAS, treatment (2ET, 100kg NPK) had the highest mean value of 6.20cm which was significantly higher than other treatments except for treatments (2ET, 200kg NPK), (2ET, 300kg NPK) with mean values of 6.0cm and 5.9cm respectively. However, other treatments recorded values within the range of 3.67-5.06cm with treatment (1/2ET, 0kg NPK) having the least mean value. At 7WAS, treatment (2ET, 100kg NPK) had the highest mean value of 6.50cm which was significantly higher than other treatments except for treatments (2ET, 200kg NPK), (2ET, 300kg NPK) with mean values of 6.0cm and 5.9cm respectively. However, other treatments recorded value within the range of 3.73-5.30cm with treatment (1/2ET, 0kg NPK) having the least mean value. At 8WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 6.83cm which was significantly higher than other treatments while treatment (2ET, 200kg NPK) with a mean value of 6.1cm was next. However, other treatments recorded values within the range of 3.90-5.93cm with treatment (1/2ET, 0kg NPK) having the least mean value. At 10WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 6.83cm which was the same with the ninth week and it was significantly higher than other treatments while treatments (2ET, 200kg NPK) with mean value of 6.26cm was next. However, other treatments recorded values within the range of 3.90-5.93cm with treatment (1/2ET, 100kg NPK) having the least mean value.

Figure 4.42 and 4.43 present the width of leaves of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 2WAS, treatments (2ET, 200kg NPK) and (2ET, 100kg NPK) recorded the maximum mean value of 2.63cm each which was significantly higher than other treatments except for (2ET, 400kg NPK), (2ET, 300kg NPK), (3/2ET, 400kg NPK) (3/2ET, 300kg NPK), (3/2ET, 200kg NPK), (3/2ET, 100kg NPK), (1/2ET, 200kg NPK) which had values within the range of 2.47-2.60cm with treatment while treatments significantly lower ranges from 2.26-2.43cm. At 3WAS, treatments (2ET, 200kg NPK), (2ET, 300kg NPK) and (2ET, 100kg NPK) had the maximum mean value of 4.0cm which was significantly higher than other treatments with mean values within the range of 3.06-3.60cm. At 4WAS, 6.60cm was recorded for treatment (2ET, 100kg NPK) which was significantly higher than other treatments which had mean values ranging from 3.57-5.77cm. At 5WAS, treatment (2ET, 100kg NPK) had the maximum mean value of 6.73cm which was significantly higher than other treatments with mean values within the range of 3.77-6.07cm. However, treatment (2ET, 200kg NPK) had the next highest value second while treatment (1/2ET, 0kg NPK) was least. At 6WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 6.87cm which was significantly higher than other treatments with mean values within the range of 3.93-6.20cm. At 7WAS, 7.0cm was recorded for treatment (2ET, 100kg NPK) which was significantly higher than other treatments which had mean values ranging from 3.93-6.40cm. At 10WAS, the peak value of 7.17cm was recorded almost equal to 7.13cm and 7.07cm for week 9 and 8 respectively. These were significantly higher than mean values obtained from other treatments which fell within the range of 4.33-6.53cm.

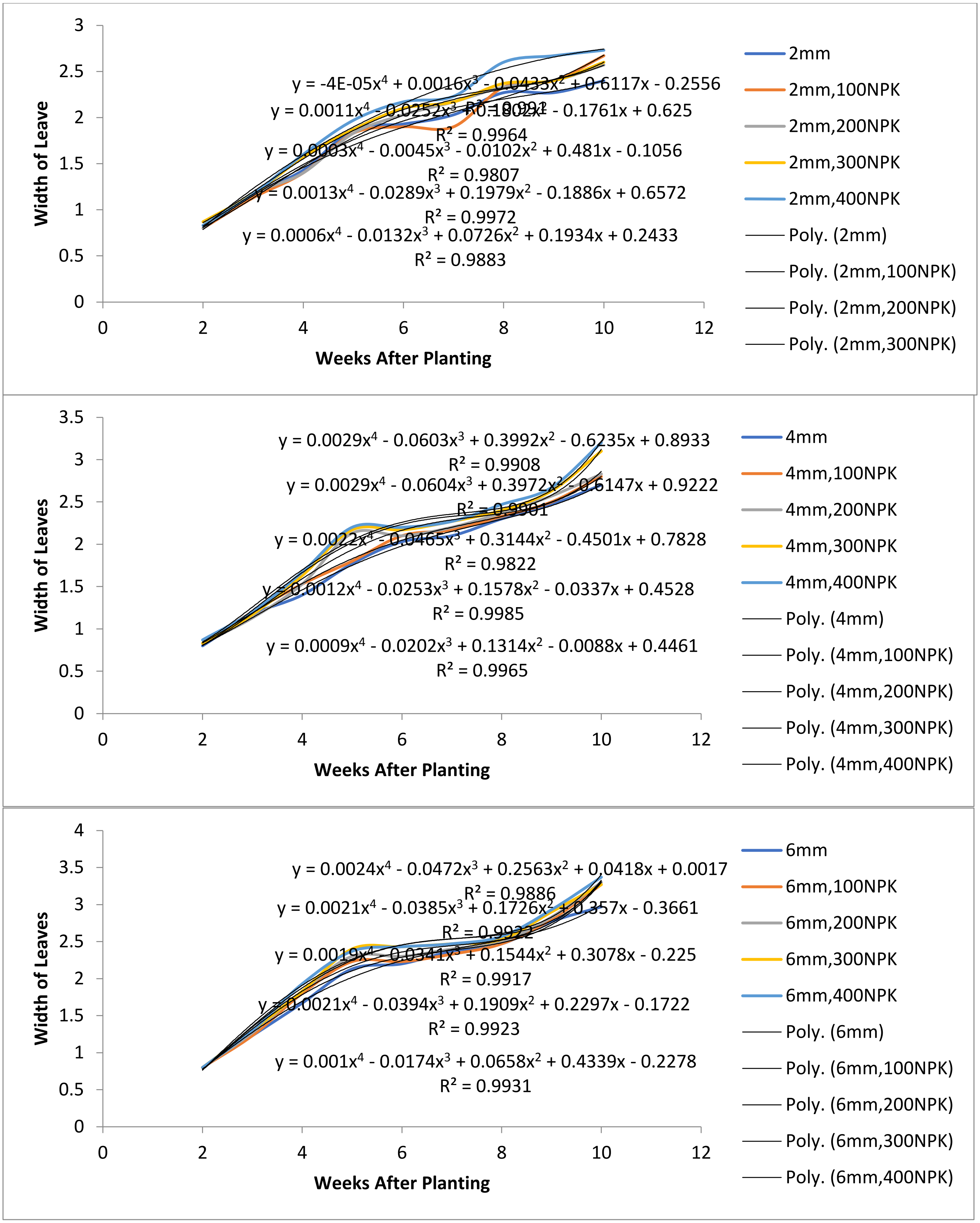


Figure 4.38: Width of Leave vs Weeks After Planting for 2, 4, 6 mm water depth in the Field

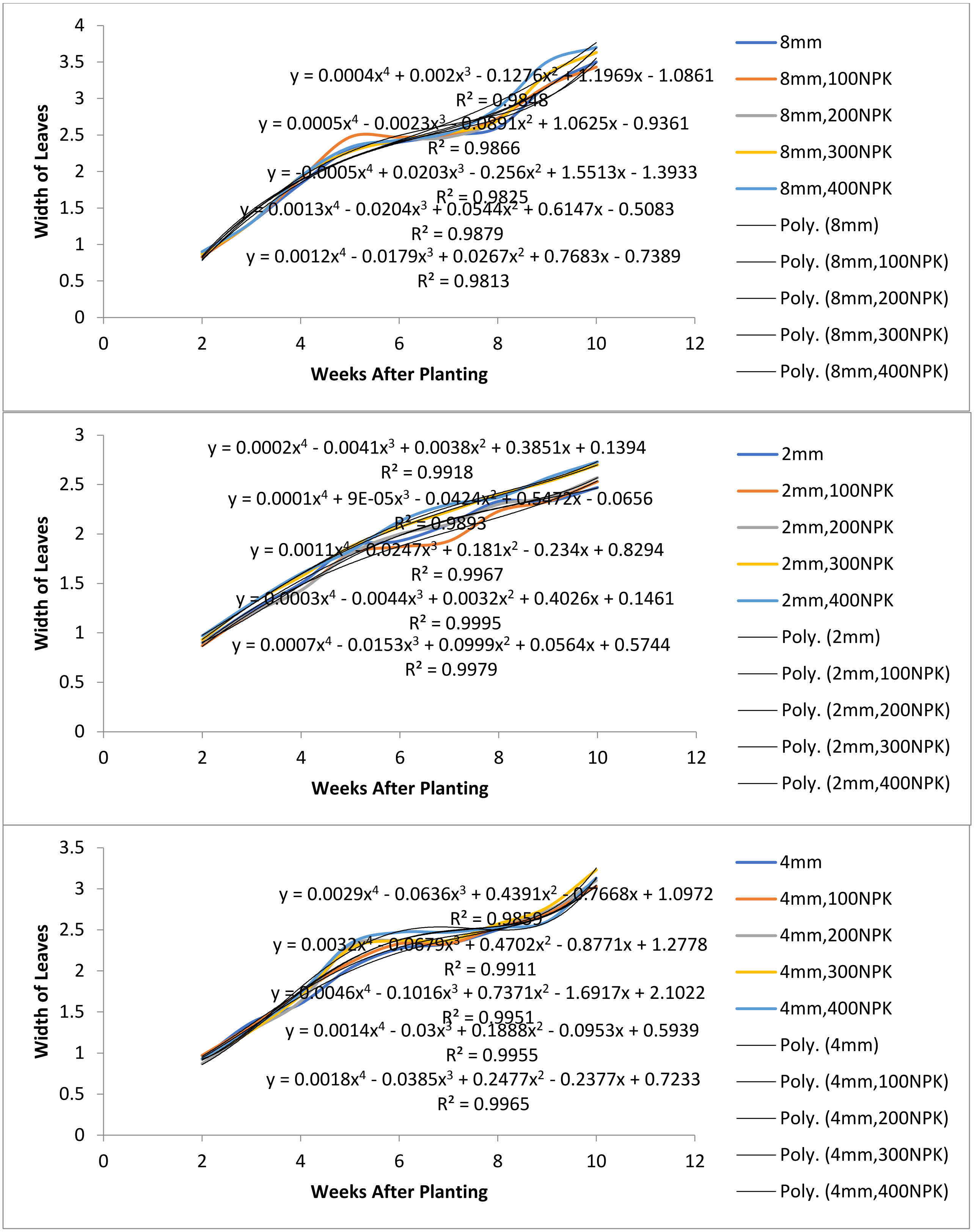


Figure 4.39: Width of Leave vs Weeks After Planting for 8, 2, 4 mm water depth in the Field

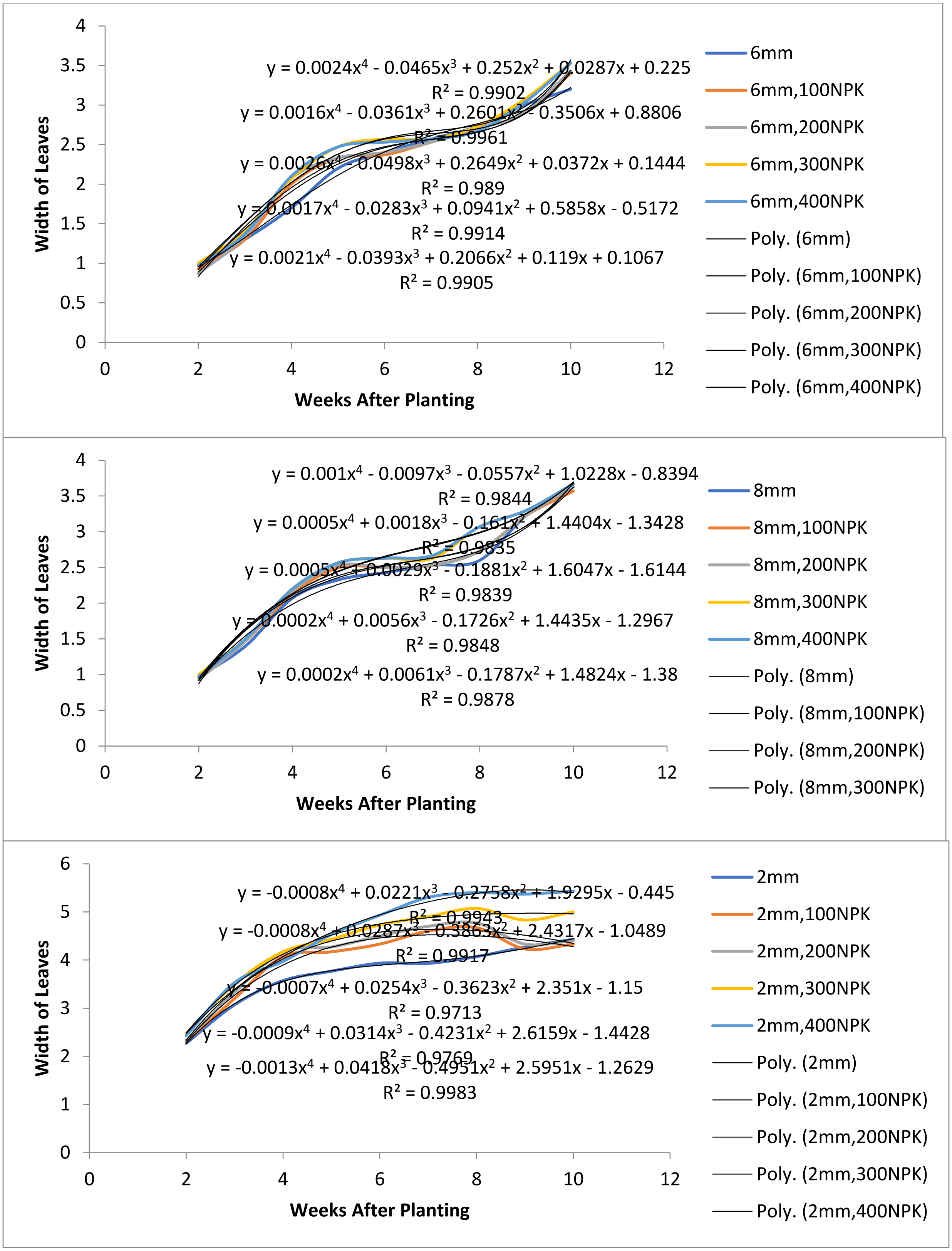


Figure 4.40: Width of Leave vs Weeks After Planting for 6, 8mm water depth in the Field and 2mm water depth for greenhouse

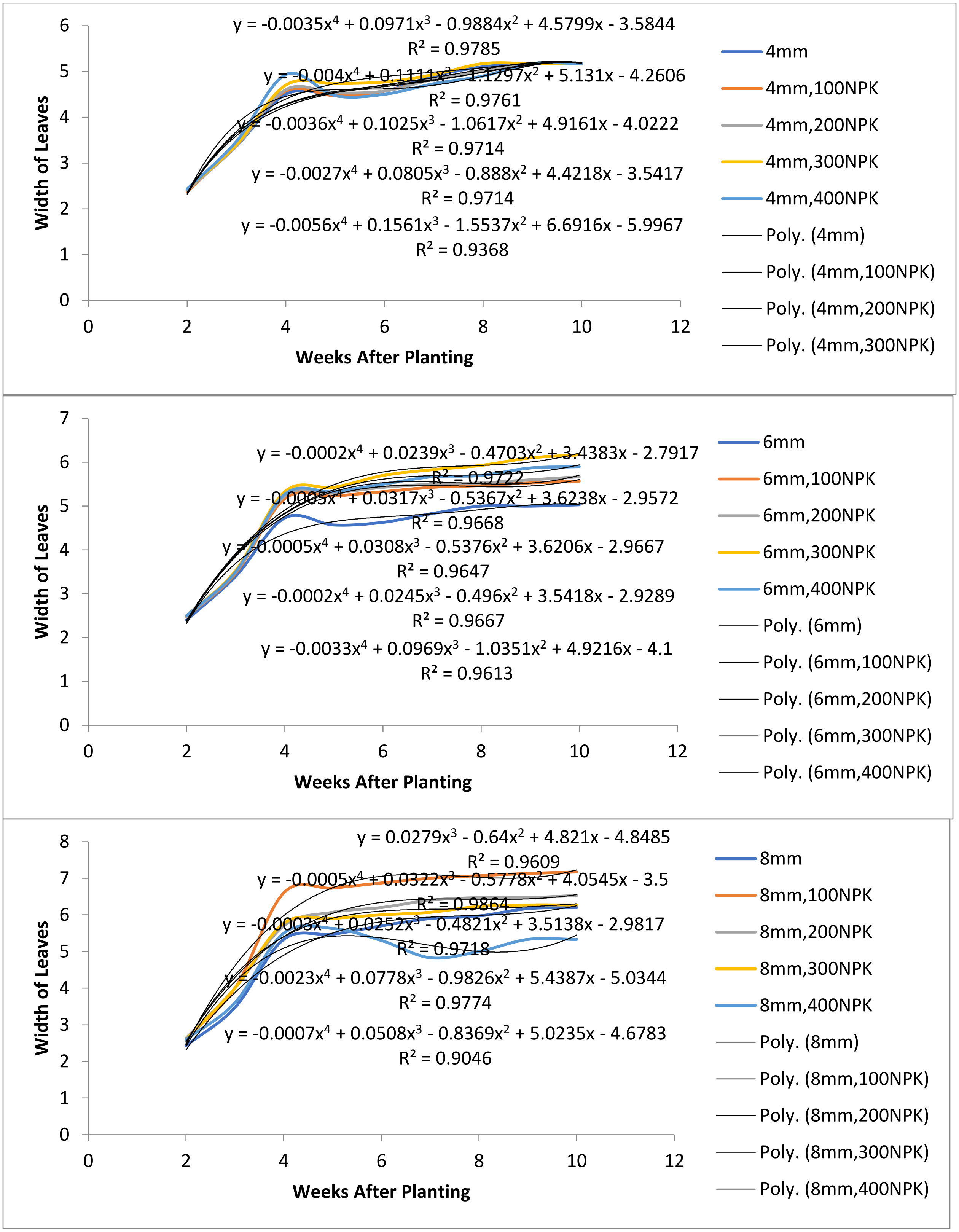


Figure 4.41: Width of Leave vs Weeks After Planting for 4, 6, 8 mm water depth in the greenhouse

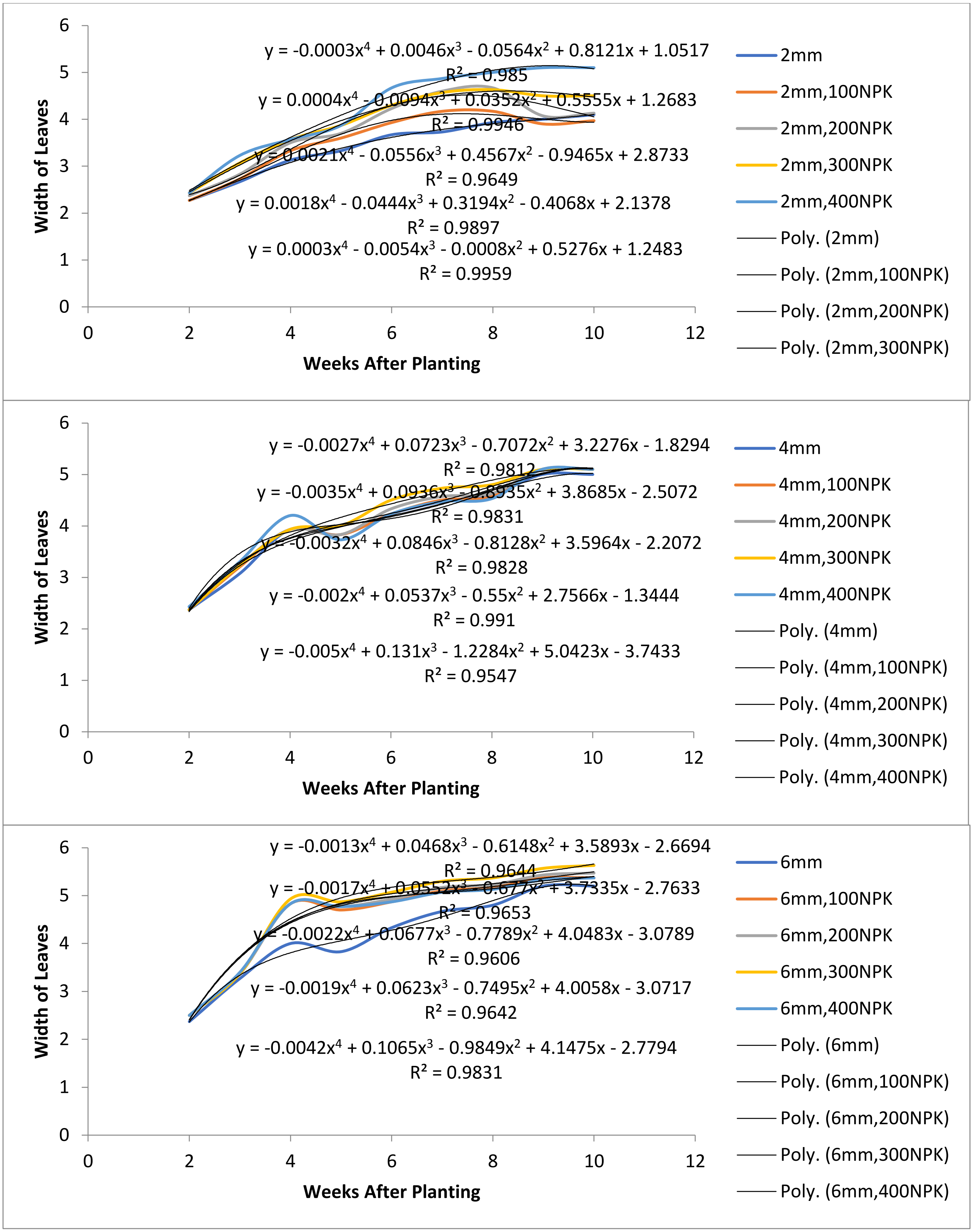


Figure 4.42: Width of Leave vs Weeks After Planting for 2, 4, 6 mm water depth in the greenhouse

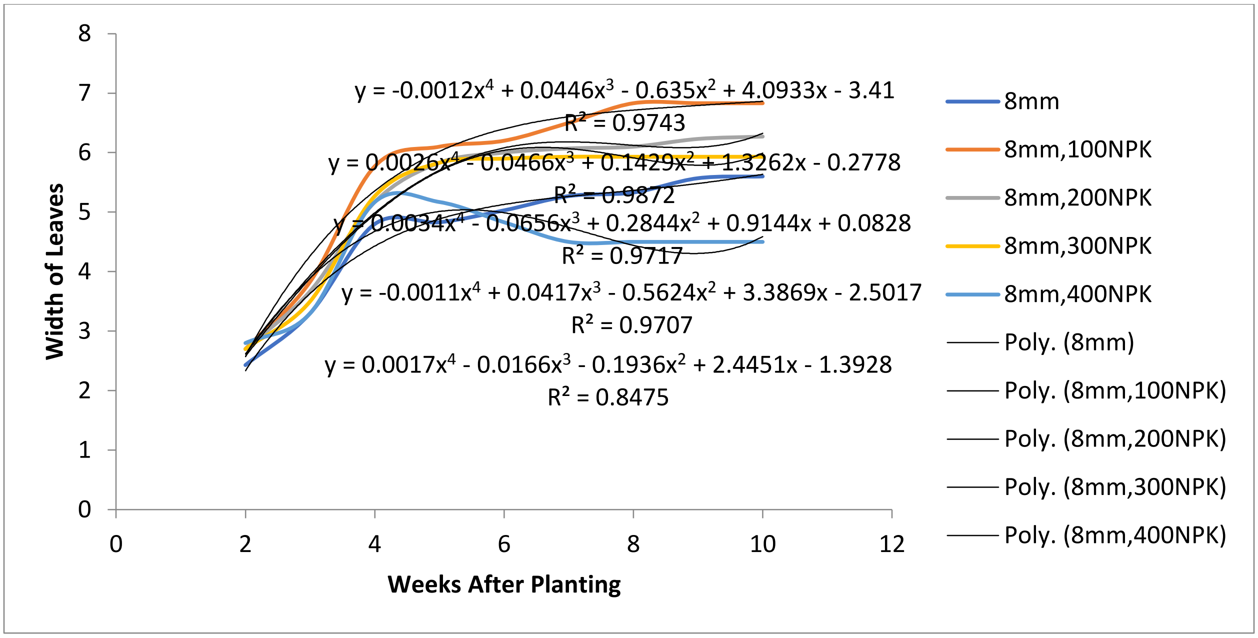


Figure 4.43: Width of Leave vs Weeks After Planting for 8 mm water depth in the greenhouse

4.2.8 Leaf Area

Figure 4.44 and 4.45 present the leaf area of *Corchorus olitorus* as influenced by water and fertilizer treatment in the field. At 6WAS, treatments (2ET, 0kg NPK), (3/2ET, 300kg NPK), (3/2ET, 400kg NPK) (2ET, 100kg NPK), (2ET, 200kg NPK), (2ET, 300kg NPK) which had mean values ranging from 12.66-13.77cm^2 were significantly higher than other treatments. At 7WAS, treatments (3/2ET, 200kg NPK), (3/2ET, 300kg NPK), (3/2ET, 400kg NPK) (2ET, 100kg NPK), (2ET, 0kg NPK), (3/2ET, 400kg NPK), (2ET, 200kg NPK) and (2ET, 300kg NPK) which had mean values ranging from 12.66-14.25cm^2 were significantly higher than other treatments with treatment (1/2ET, 100kg NPK) having the least mean value 0f 7.90cm^2. At 8WAS, treatments (2ET, 0kg NPK), (2ET, 100kg NPK), (2ET 200kg NPK), (2ET, 300kg NPK) with mean value of 14.88-17.63 cm^2 was significantly higher than other treatments. However, treatments (1/2ET 0kg NPK) recorded the lowest value of 11.27 cm^2. At 9WAS, treatments (2ET, 100kg NPK), (2ET, 100kg NPK), (2ET 200kg NPK), (2ET, 300kg NPK) with mean value of 24.65-26.24 cm^2 was significantly higher than other treatment. However, treatment (1/2ET 0kg NPK) recorded the lowest value of 11.27 cm^2. At 10WAS, treatments (2ET, 0kg NPK), (2ET, 100kg NPK), (2ET 200kg NPK), (2ET, 300kg NPK) (2ET, 400kg NPK) with mean value of 27.11-31.03 cm^2 was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the lowest value of 12.11 cm^2.

Figure 4.45 and 4.46 present the leaf area of *Corchorus olitorus* as influenced by water and fertilizer treatment in the greenhouse. At 2WAS, treatments (2ET, 100kg NPK), (2ET, 200kg NPK), (2ET, 300kg NPK) (2ET, 400kg NPK) had mean values ranging from 16.09-17.26cm^2 which were significantly higher than other treatments and treatment (1/2ET 0kg NPK) recorded the least value of 11.27cm^2. At 5WAS, treatments (2ET, 400kg NPK), (2ET, 200kg NPK), (2ET, 300kg NPK) (2ET, 100kg NPK) had mean values ranging from 59.34-83.30 cm^2 was significantly higher than other treatments with treatment (1/2ET, 0kg NPK) having the least mean value 0f 25.02 cm^2. At 6WAS, treatments (2ET, 300kg NPK), (2ET, 200kg NPK) and (2ET 100kg NPK) recorded mean values of 77.34-85.81 cm^2 which was significantly higher than other treatment. However, treatment (1/2ET 0kg NPK) recorded the lowest value of 29.84 cm^2. At 7WAS, treatments (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET 100kg NPK) with mean values of 78.20-94.27 cm^2 was significantly higher than other treatment. However, treatments

(1/2ET 0kg NPK) recorded the lowest value of 30.91 cm^2. At 8WAS, treatment (2ET, 100kg NPK) with mean value of 100.04 cm^2 which was significantly higher than other treatment. However, treatment (1/2ET 0kg NPK) recorded the lowest value of 34.29 cm^2. At 10WAS, treatment (2ET, 100kg NPK) with mean value of 100.10 cm^2 was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the lowest value of 34.81 cm^2.

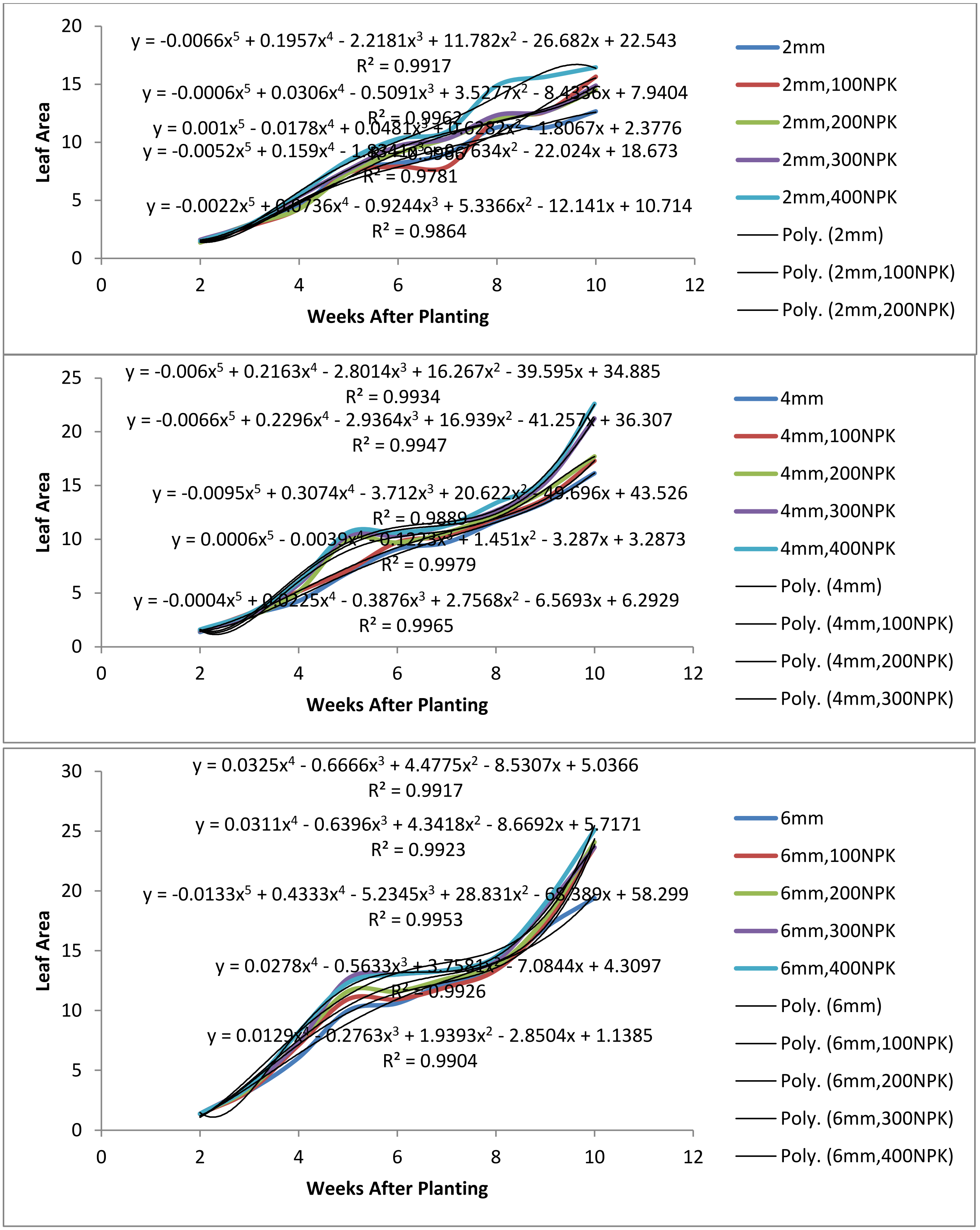


Figure 4.44: Leaf Area vs Weeks After Planting for 6, 8, 2 mm water depth in the field

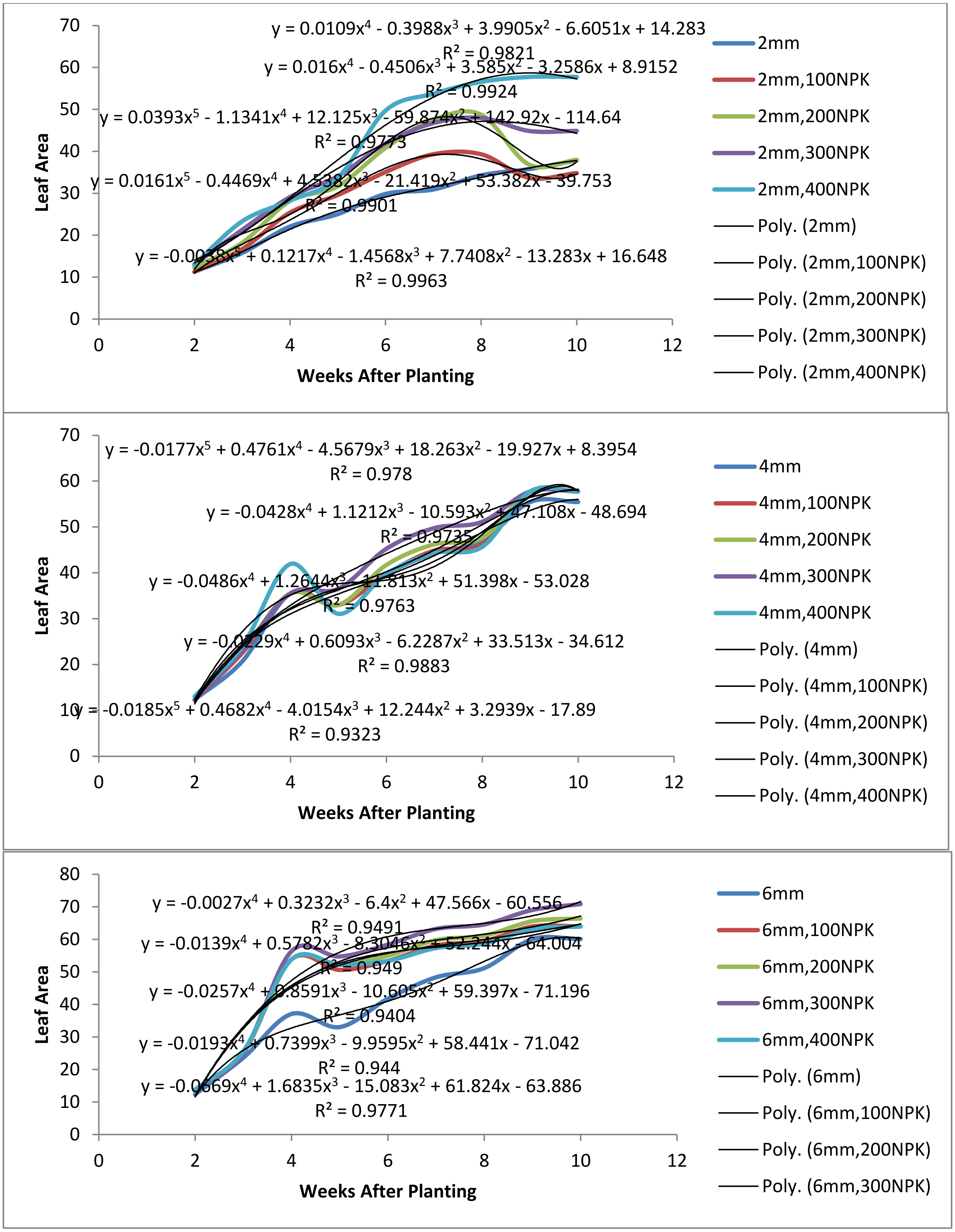


Figure 4.45: Leaf Area vs Weeks After Planting for 2, 4, 6 mm water depth in the greenhouse

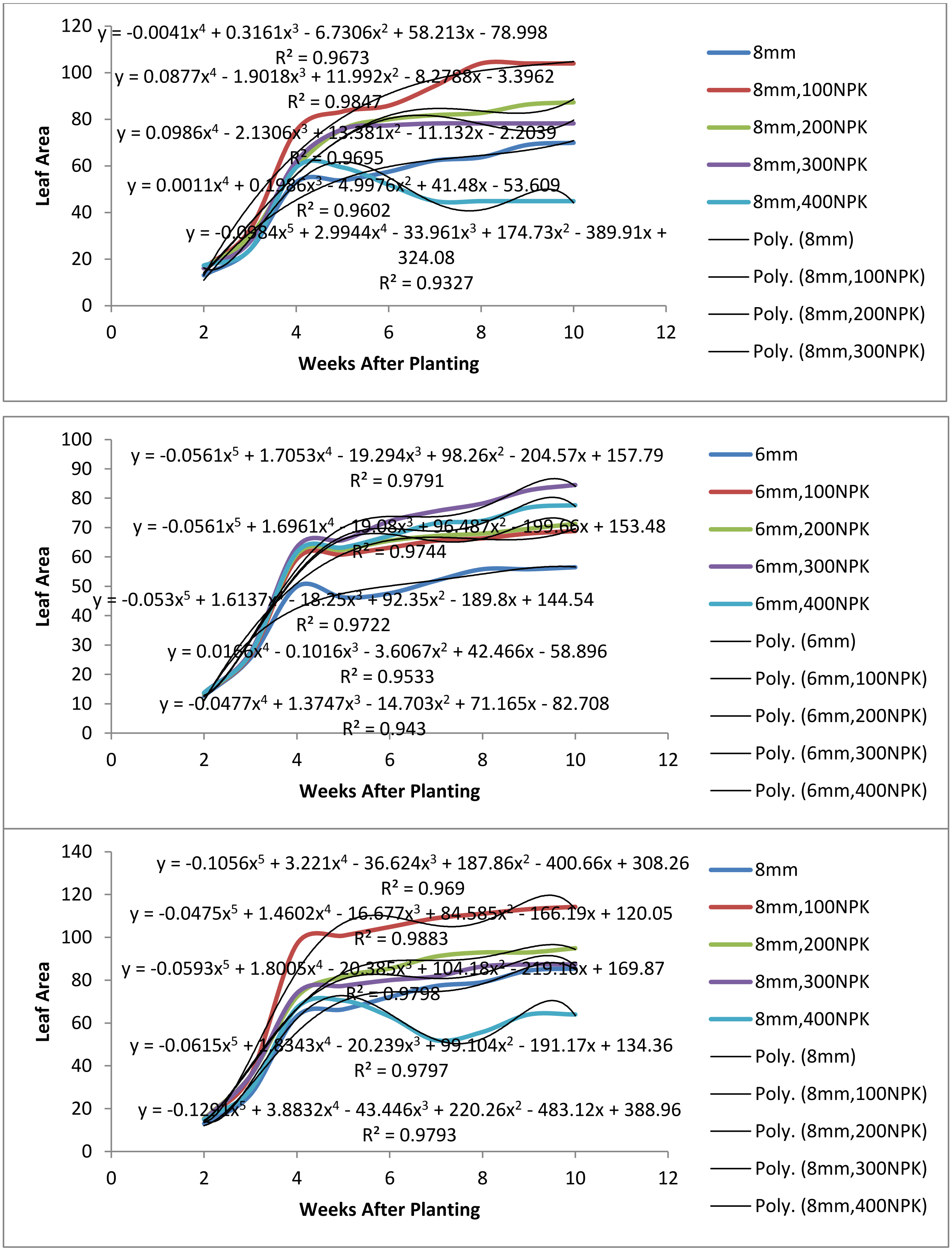


Figure 4.46: Leaf Area vs Weeks After Planting for 4, 6, 8 mm water depth in the greenhouse

4.2.9 Growth Index

Figure 4.47 and 4.48 present the growth index of *Corchorus olitorus* as influenced by water and fertilizer treatment in the field. At 4WAS, treatments (2ET, 300kg NPK) and (2ET 400kg NPK) had mean values of 9.35 and 9.68 respectively which was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the least value of 4.20. At 5WAS, treatments (2ET, 300kg NPK) and (2ET 400kg NPK) had mean values of 12.59 and 12.61 respectively which was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the least value of 6.52. At 6WAS, treatments (2ET 200kg NPK), (2ET, 300kg NPK) and (2ET 400kg NPK) had mean values of 14.75, 14.93 and 15.27 respectively which was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the least value of 7.81. At 7WAS, treatment (2ET 400kg NPK) had highest mean values of 20.76 which was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the least value of 8.87. At 8WAS, treatments (2ET, 300kg NPK) and (2ET 400kg NPK) had mean values of 24.43 and 25.11 respectively which was significantly higher than other treatments. However, treatment (1/2ET 100kg NPK) recorded the least value of 10.54. At 10WAS, treatment (2ET, 300kg NPK) and (2ET 400kg NPK) had mean values of 33.88 and 34,45 respectively which was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the least value of 14.32

Figure 4.49 and 4.50 present the growth index of *Corchorus olitorus* as influenced by water and fertilizer treatment in the greenhouse. At 4WAS, treatment (2ET, 100kg NPK) had the highest mean value of 26.67 which was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the least value of 15.46. At 5WAS, treatment (2ET, 100kg NPK) had the highest mean value of 33.96 which was significantly higher than other treatments. However, treatment (1/2ET 0kg NPK) recorded the least value of 17.33. Treatment (2ET, 100kg NPK) recorded the highest value up to 10WAS with a value of 49.08 which was significantly higher than other treatments. However, treatment (1/2ET 100kg NPK) recorded the least value of 24.51

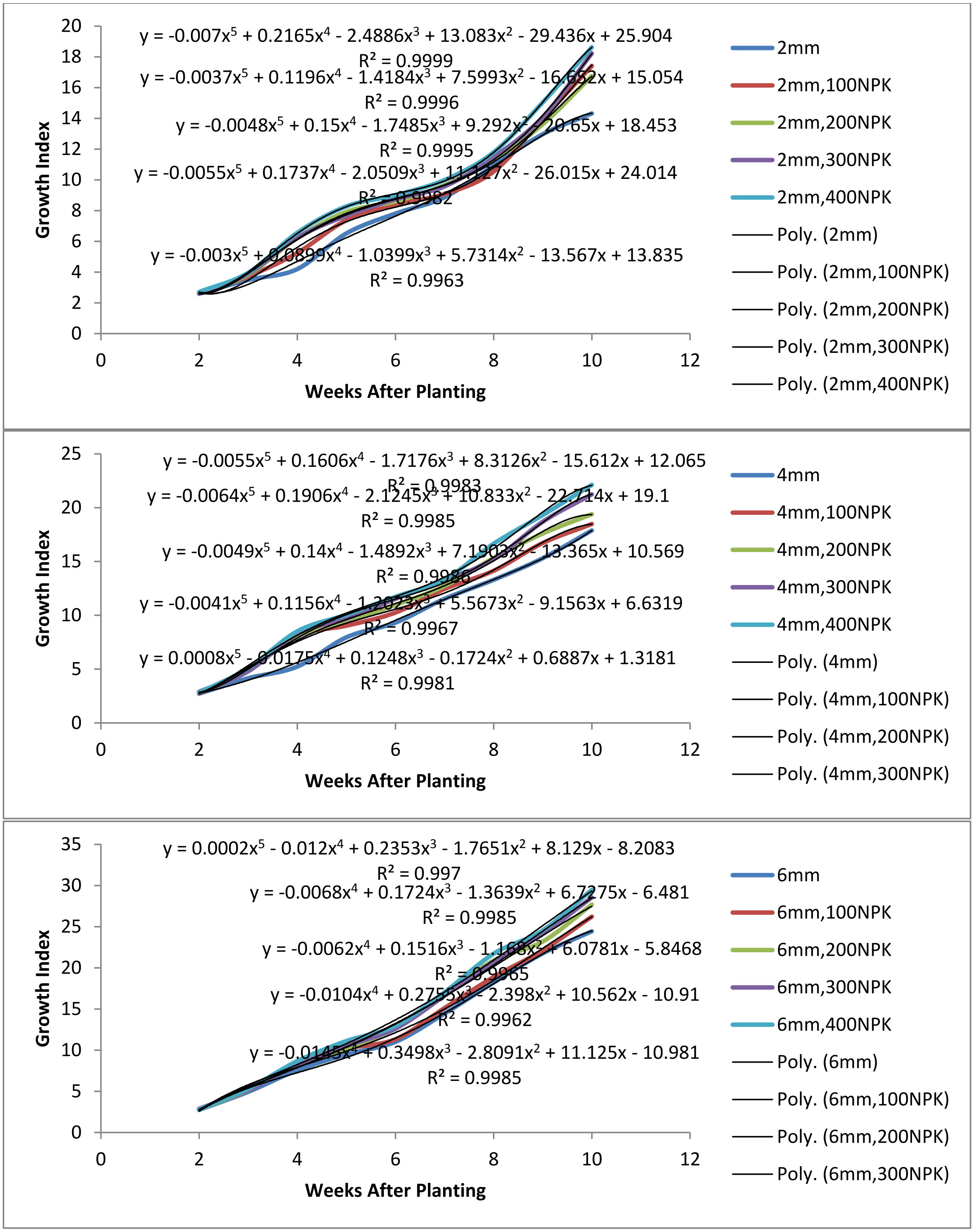


Figure 4.47: Growth Index vs Weeks After Planting for 2, 4, 6 mm water depth in the field

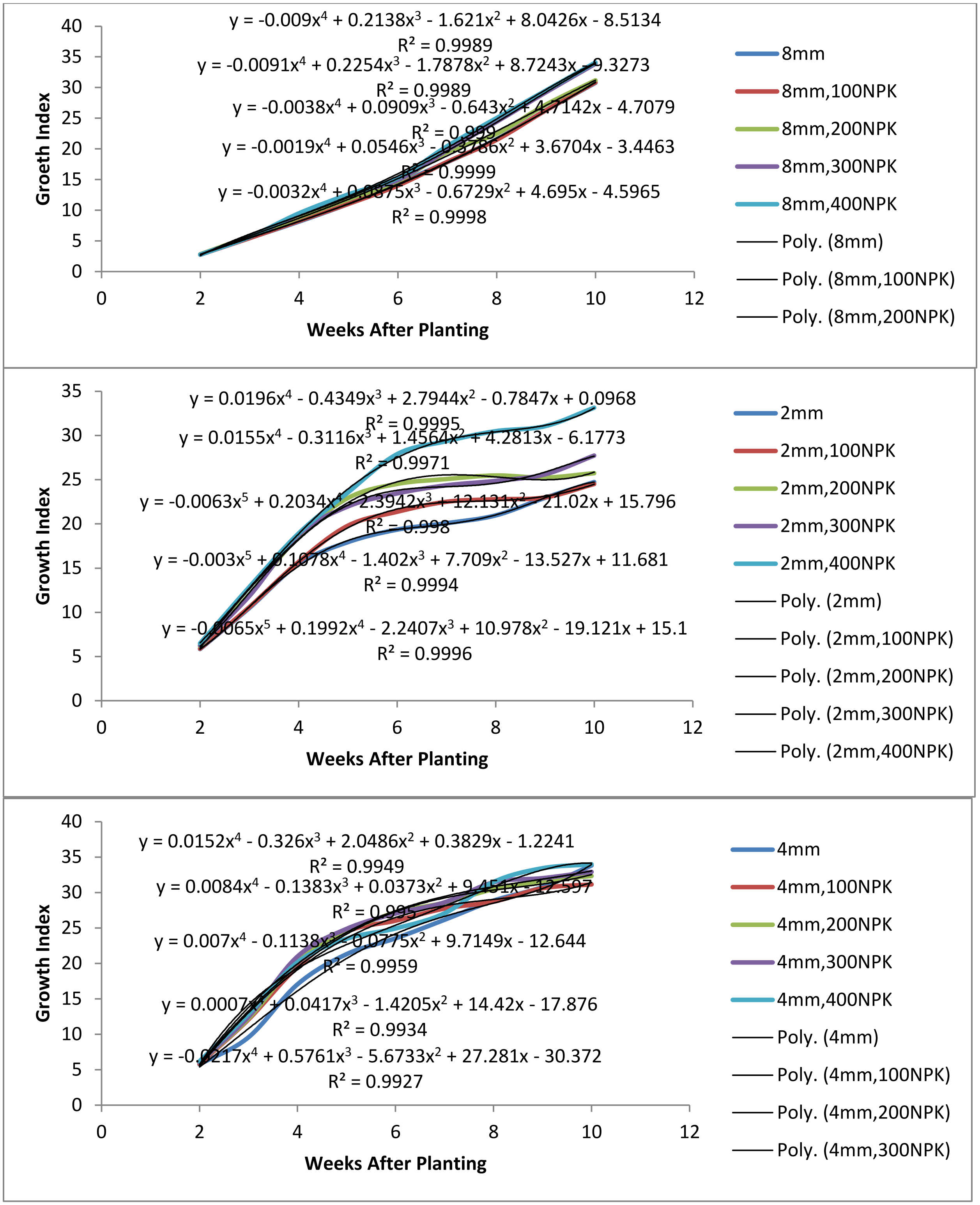


Figure 4.48: Growth Index vs Weeks After Planting for 8mm water depth for field, 2, 4 mm water depth in the greenhouse

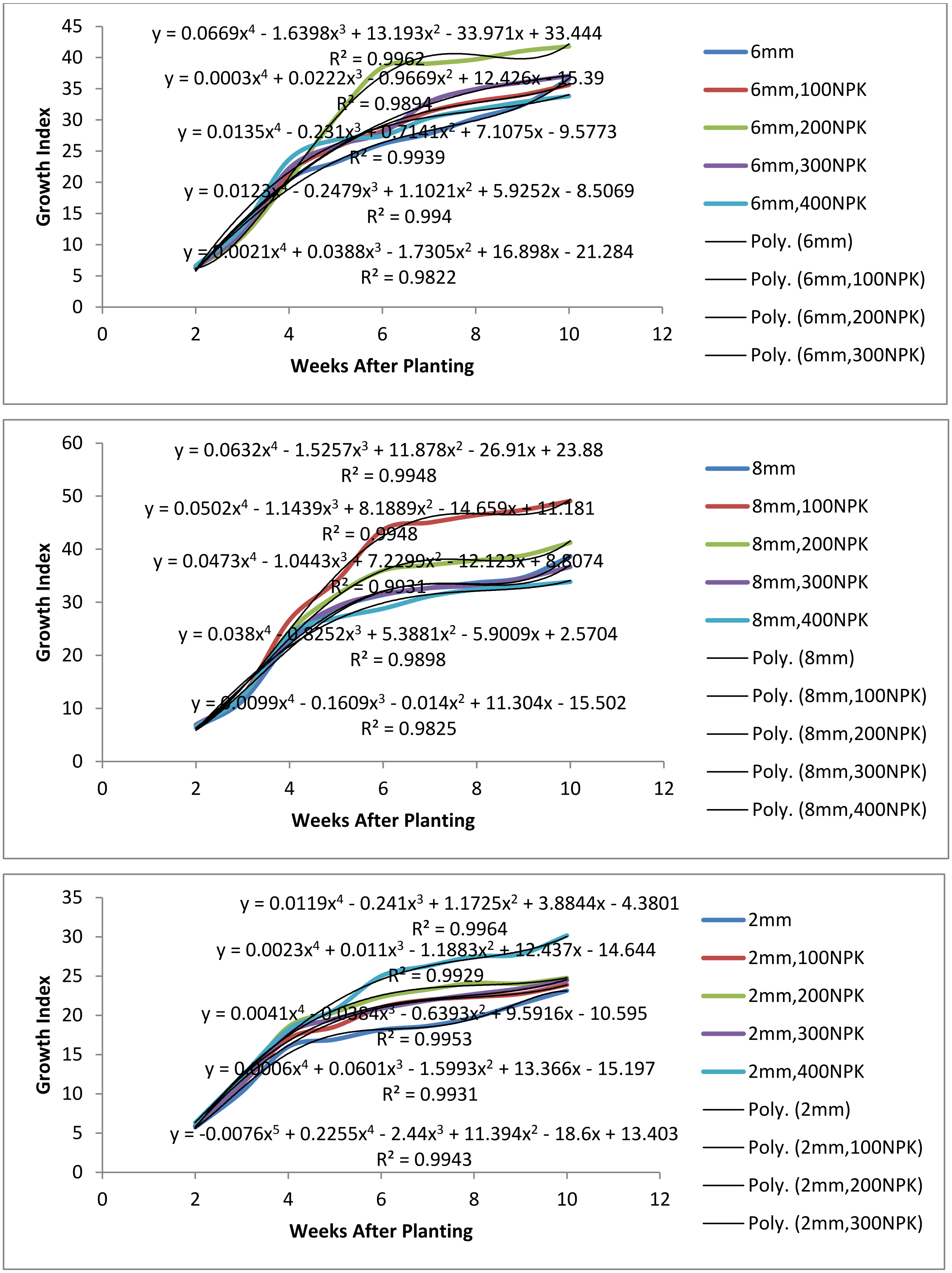


Figure 4.49: Growth Index vs Weeks After Planting for 6, 8, 2 mm water depth in the greenhouse

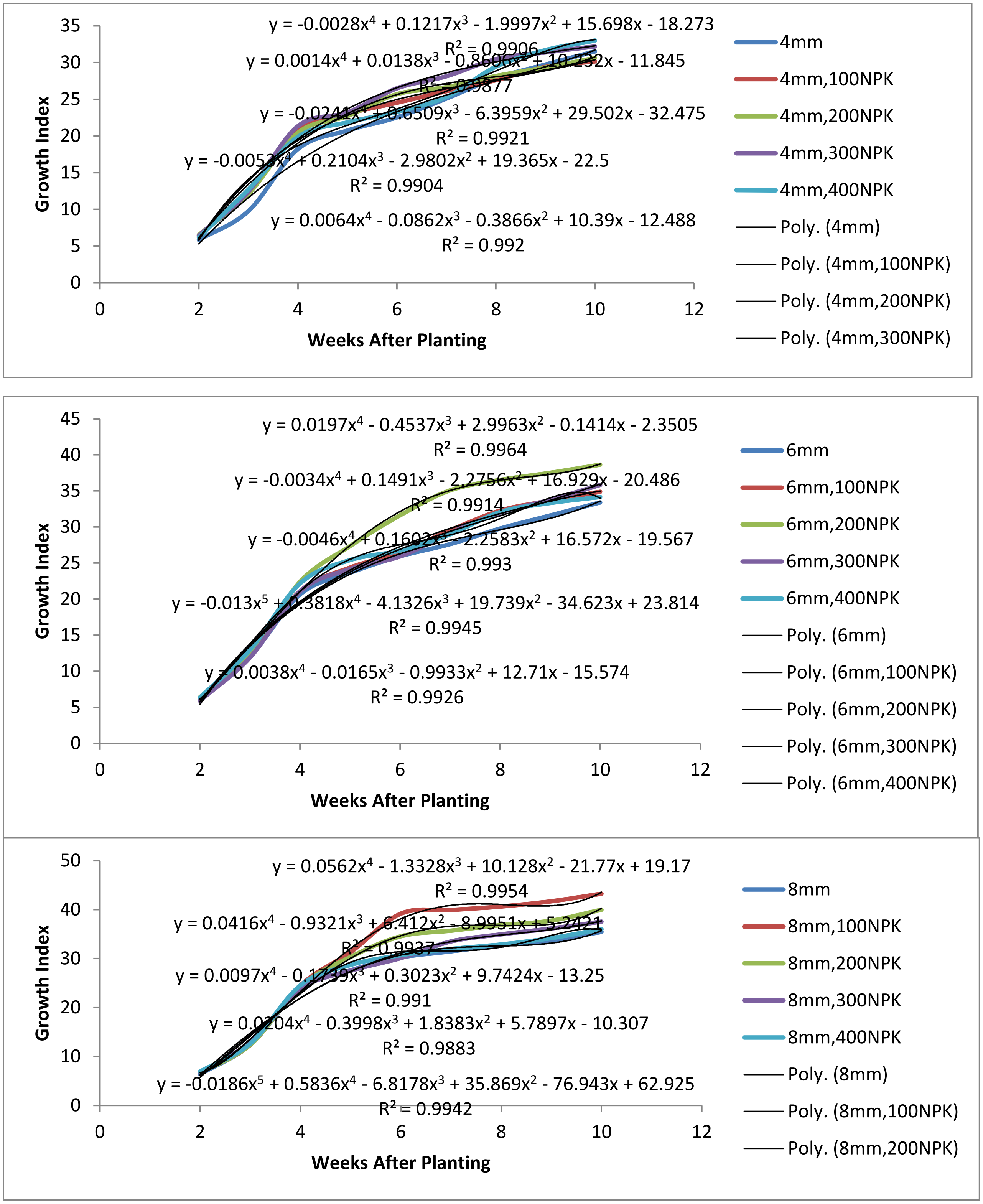


Figure 4.50: Growth Index vs Weeks After Planting for 4, 6, 8 mm water depth in the greenhouse

4.3 CHLOROPHYLL CONTENT

Figure 4.51 presents the chlorophyll content of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 2WAS, treatment (1/2ET, 400kg NPK) recorded the highest mean value of 38.89 µmol/m^2 for Chlorophyll content of the top leave which was significantly higher than other treatments except for treatments (1/2ET, 100kg NPK), (3/2ET, 200kg NPK), (2ET, 300kg NPK) and (1ET, 200kg NPK) which had mean value of 36.53 µmol/m^2, 36.06 µmol/m^2, 35.80 µmol/m^2 and 35.53 µmol/m^2 respectively. The mean values of other treatments are (3/2ET, 300kg NPK), 35.33 µmol/m^2 – (2ET, 400kg NPK), 30,07 µmol/m^2. At 4WAS, treatment (3/2ET, 300kg NPK) had the maximum mean value of 69.07 µmol/m^2 which was significantly greater than treatments (1ET, 200kg NPK), (1/2ET, 200kg NPK), (2ET, 400kg NPK), (1/2ET, 0kg NPK) and (2ET, 200kg NPK) which had mean values of 38.07µmol/m^2, 36.23µmol/m^2, 35.43 µmol/m^2 and 32.23µmol/m^2 respectively. At 6WAS, treatment (1/2ET, 400kg NPK) recorded the highest mean value of 77.80 µmol/m^2 for Chlorophyll content of the top leave which was significantly higher than treatments (1ET, 300kg NPK), (1/2ET, 0kg NPK), (1/2ET, 200kg NPK) (1ET, 400kg NPK), (1/2ET, 300kg NPK), (1ET, 200kg NPK), (1/2ET, 100kg NPK), (1ET, 100kg NPK), (3/2ET, 400kg NPK) and (2ET, 400kg NPK) which had mean value within the range of 29.63-50.47µmol/m^2. At 8WAS, 73.04µmol/m^2 was recorded as the highest mean value which was from treatment (2ET, 100kg NPK) which was significantly higher than other treatments apart from (3/2ET, 200kg NPK) which had a mean value of 67.30 µmol/m^2. However, other treatments had value within the range of 33.07-62.30 µmol/m^2. Although, the lowest mean value was obtained for treatment (1/2ET, 300kg NPK). At 10 WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 63.60 µmol/m^2 for Chlorophyll content of the top leave which was significantly higher than other treatments except for treatments (2ET, 0kg NPK), (2ET, 200kg NPK) and (3/2ET, 200kg NPK) which had mean value of 61.57 µmol/m^2, 59.67 µmol/m^2 and 57.2 µmol/m^2 respectively. However, other treatments had values ranging from 31.27-45.13 µmol/m^2 with treatment (3/2ET, 0kg NPK) recording the lowest value.

Figure 4.51 shows that at 2WAS, chlorophyll content from the bottom leave was highest in treatment (2ET, 300kg NPK) with mean value of 36.50 µmol/m^2 which was significantly higher than other treatments except for treatment (1/2ET, 400kg NPK) which had a mean value of 34.83

μmol/m^2. However, other treatments had mean values within the range of 26.97-34.03μmol/m^2 with treatment (2ET, 0kg NPK) having the least value. At 4WAS, treatment (3/2ET, 300kg NPK) had the highest mean value of 59.87 μmol/m^2 which was significantly higher than treatments (2ET, 0kg NPK), (1/2ET, 200kg NPK), (1/2ET, 200kg NPK) (1ET, 400kg NPK), (3/2ET, 400kg NPK), (3/2ET, 0kg NPK), (1ET, 0kg NPK), (1/2ET, 0kg NPK), (2ET, 400kg NPK) and (2ET, 200kg NPK) which had mean value of 31.0-37.40 μmol/m^2. However, treatment (2ET, 200kg NPK) had the lowest value. At 6WAS, treatment (1/2ET, 400kg NPK) had the maximum mean value of 56.13 μmol/m^2 which was significantly higher than other treatments expect for treatments (2ET, 100kg NPK), (2ET, 200kg NPK), (1ET, 100kg NPK) (3/2ET, 200kg NPK) and (3/2ET, 100kg NPK) which had mean values of 54.97 μmol/m^2, 54.76 μmol/m^2, 52.13 μmol/m^2, 46.27 μmol/m^2, and 42.97 μmol/m^2 respectively. However, mean values of other treatment were within the range of 21.07-35.4 μmol/m^2, although treatment (1/2ET, 100kg NPK had the lowest value. At 8WAS, chlorophyll content from the bottom leave was highest in treatment (2ET, 0kg NPK) with mean value of 57.43 μmol/m^2 which was significantly higher than other treatments except for treatment (2ET, 200kg NPK) which had a mean value of 56.03 μmol/m^2. However, results from other treatments had mean values within the range of 30.77-44.93 μmol/m^2 with treatment (1/2ET, 0kg NPK) having the lowest value. At 10WAS, chlorophyll content from the bottom leave was highest in treatment (2ET, 0kg NPK) with mean value of 49.07 μmol/m^2 which was significantly higher than other treatments which had mean values within the range of 28.20-42.50μmol/m^2 with treatment (3/2ET, 0kg NPK) having the lowest value.

Figure 4.52 presents the chlorophyll content of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse. At 2WAS, treatment (1ET, 400kg NPK) recorded the highest mean value of 35.97 μmol/m^2 for Chlorophyll content of the top leave which was significantly higher than treatments (3/2ET, 0kg NPK), (3/2ET, 100kg NPK), (3/2ET, 400kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK), (2ET, 400kg NPK), (1ET, 0kg NPK) and (2ET, 0kg NPK) which had mean value within the range of 28.63-32.47μmol/m^2 with treatment (2ET, 0kg NPK) having the lowest value. At 4WAS, treatment (1ET, 300kg NPK) recorded the maximum mean value of 77.13 μmol/m^2 for Chlorophyll content of the top leave which was significantly higher than treatments (1/2ET, 400kg NPK), (1ET, 200kg NPK), (1/2ET, 200kg NPK), (1ET, 100kg NPK), (1/2ET, 0kg NPK), (2ET, 200kg NPK) and (2ET, 400kg NPK) which had mean values within the range of 29.83-42.93µmol/m^2 with treatment (2ET, 400kg NPK) having the lowest value. At 6WAS, treatment (2ET, 400kg NPK) recorded the maximum mean value of 79.07 µmol/m^2 for Chlorophyll content of the top leave which was significantly higher than treatments (1ET, 0kg NPK), (1ET, 300kg NPK), (1/2ET, 0kg NPK), (1/2ET, 200kg NPK), (1ET, 400kg NPK), (1/2ET, 300kg NPK), (1ET, 200kg NPK), (1/2ET, 100kg NPK), (1ET, 100kg NPK), (3/2ET, 400kg NPK) and (2ET, 400kg NPK) which had mean values within the range of 28.43-52.03µmol/m^2 with treatment (2ET, 400kg NPK) having the lowest value. At 8WAS, treatment (1ET, 200kg NPK) had the maximum mean value of 76.70 µmol/m^2 which was significantly higher than other treatments except for treatments (1/2ET, 300kg NPK), (3/2ET, 0kg NPK) and (2ET, 400kg NPK) which had mean values of 66.23 µmol/m^2, 62.67 µmol/m^2 and 60.10 µmol/m^2 respectively. However, mean values of other treatment were within the range of 29.67-45.80 µmol/m^2 where treatment (3/2ET, 200kg NPK) had the lowest value. At 10WAS, treatment (1ET, 200kg NPK) had the maximum mean value of 74.13 µmol/m^2 which was significantly higher than other treatments except for treatments (3/2ET, 0kg NPK) which had a mean value of 62.03 µmol/m^2. However, mean values within the range of 27.23-55.23 µmol/m^2 was recorded for other treatments. However, treatment (3/2ET, 200kg NPK) had the lowest value.

Figure 4.52 shows that at 2WAS, 36.33 µmol/m^2 was the highest mean value recorded for treatment (2ET, 300kg NPK) as the bottom leave chlorophyll content which was significantly greater than other treatments except for treatments (3/2ET, 100kg NPK), (1/2ET, 400kg NPK) which had a mean value of 34.53 µmol/m^2 and 34.13 µmol/m^2 respectively. However, mean values within the range of 25.90-33.63 µmol/m^2 was recorded for other treatments. However, treatment (2ET, 0kg NPK) had the lowest value. At 4WAS, treatment (3/2ET, 100kg NPK) had the maximum mean value of 57.80 µmol/m^2 which was not significantly higher than other treatments. However, treatment (2ET, 4000kg NPK) had the least value of 30.07µmol/m^2. At 6WAS, treatment (3/2ET, 100kg NPK) recorded the maximum mean value of 55.97 µmol/m^2 for Chlorophyll content of the bottom leave which was significantly higher than other treatments apart from treatments (2ET, 100kg NPK), (1ET, 200kg NPK), (3/2ET, 0kg NPK), (1ET, 100kg NPK) and (1/2ET, 100kg NPK) which had mean values within the range of 22.86-54.33µmol/m^2 with treatment (1ET, 300kg NPK) having the lowest value. At 8WAS, 61.20 µmol/m^2 was the highest mean value recorded for treatment (1/2ET, 300kg NPK) as the bottom leave chlorophyll content which was significantly greater than other treatments except for treatments (3/2ET, 0kg NPK) and (2ET, 400kg NPK) which had a mean value of 57.37 µmol/m^2 and 57.03 µmol/m^2 respectively. However, mean values within the range of 27.97-43.06 µmol/m^2 was recorded for other treatments with treatment (1ET, 200kg NPK) having the least value. At 10WAS, treatment (3/2ET, 0kg NPK) recorded the maximum mean value of 53.03 µmol/m^2 for Chlorophyll content of the bottom leave which was significantly higher than other treatments apart from treatment (1/2ET, 100kg NPK) which had a mean value of 52.97µmol/m^2. However, other treatments had mean values within the range of 28.07-42.40µmol/m^2 with treatment (1ET, 300kg NPK) having the lowest value.

Figure 4.53 presents the chlorophyll content of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, 81.67 µmol/m^2 was the highest mean value recorded for treatment (1/2ET, 300kg NPK) as the top leave chlorophyll content which was not significantly greater than other treatments. However, mean values within the range of 64.10-73.23 µmol/m^2 was recorded for other treatments but treatment (2ET, 0kg NPK) had the lowest value. At 4WAS, treatment (2ET, 300kg NPK) recorded the maximum mean value of 77.40 µmol/m^2 for Chlorophyll content of top leave which was not significantly higher than other treatments. However, other treatments had mean values within the range of 62.27-73.63µmol/m^2 with treatment (1/2ET, 0kg NPK) having the lowest value. At 6WAS, treatment (2ET, 0kg NPK) recorded the maximum mean value of 75.96 µmol/m^2 for Chlorophyll content of top leave which was not significantly higher than other treatments. However, mean values within the range of 62.67-75.4µmol/m^2 was recorded for other treatment but treatment (1/2ET, 100kg NPK) had the lowest value. At 8WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 75.90 µmol/m^2 for Chlorophyll content which was significantly higher than treatments (2ET, 200kg NPK) and (2ET, 300kg NPK) with mean values of 64.43µmol/m^2-64.40µmol/m^2 but treatment (2ET, 300kg NPK) had the lowest value. At 10 WAS, treatment (2ET, 100kg NPK) recorded the highest mean value of 79.53 µmol/m^2 which was significantly higher than treatments (1/2ET, 200kg NPK) and (2ET, 0kg NPK) with mean values of 68.73µmol/m^2 and 67.93µmol/m^2 respectively where treatment (2ET, 0kg NPK) had the least value.

Figure 4.53 shows that at 2WAS, 38.73 µmol/m^2 was the highest mean value recorded for treatment (1/2ET, 300kg NPK) as the bottom leave chlorophyll content which was significantly greater than treatments (1ET, 400kg NPK), (3/2ET, 300kg NPK), (1ET, 300kg NPK), (3/2ET, 400kg NPK), (3/2ET, 200kg NPK) and (2ET, 200kg NPK) with mean values within the range of 31.57-32.8μmol/m^2 but treatment (2ET, 200kg NPK) had the lowest value. At 4WAS, 37.6 μmol/m^2 was the highest mean value recorded for treatment (1/2ET, 0kg NPK) which was significantly greater than treatments (2ET, 400kg NPK), (1ET, 0kg NPK), (2ET, 300kg NPK), (1ET, 300kg NPK) and (1ET, 100kg NPK) with mean values within the range of 28.87-31.57μmol/m^2 but treatment (2ET, 200kg NPK) had the lowest value. At 6WAS, treatment (1/2ET, 0kg NPK) had the maximum mean value of 74.13 μmol/m^2 which was significantly higher than other treatments except for treatments (3/2ET, 0kg NPK), (1/2ET, 100kg NPK), (1ET, 0kg NPK) and (3/2ET, 100kg NPK), which had mean values of 36.60 μmol/m^2, 35.67 μmol/m^2, 35.43 μmol/m^2 and 35.07 μmol/m^2 respectively. However, other treatments recorded a range of 29.07-35.0 μmol/m^2. However, treatment (2ET, 400kg NPK) recorded the lowest value. At 8WAS, treatment (1/2ET, 0kg NPK) recorded the highest mean value of 74.13 μmol/m^2 which was significantly higher than other treatments except for treatment (1/2ET, 100kg NPK) which had a mean value of 36.53 μmol/m^2. However, other treatments that were significantly lower recorded a range of 30.93-35.67 μmol/m^2. However, treatment (3/2ET, 300kg NPK) recorded the lowest value. At 10WAS, 43.30 μmol/m^2 was the maximum mean value recorded for treatment (1/2ET, 0kg NPK) which was significantly greater than other treatments. However, other treatments recorded a range of 31.13-38.80 μmol/m^2 where treatment (1ET, 100kg NPK) recorded the lowest value.

Figure 4.54 presents the chlorophyll content of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, 84.47 μmol/m^2 was the highest mean value recorded for treatment (1/2ET, 300kg NPK) as the top leave chlorophyll content which was not significantly higher than other treatments. However, mean values within the range of 70.70-83.70 μmol/m^2 was recorded for other treatments but treatment (2ET, 0kg NPK) had the lowest value. At 4WAS, treatment (2ET, 0kg NPK) recorded the maximum mean value of 83.73 μmol/m^2 which was not significantly higher than other treatments except for treatment (1/2ET, 300kg NPK) which was the lowest with mean value of 66.10μmol/m^2. However, other treatments had mean values within the range of 71.4-82.33μmol/m^2. At 6WAS, 83.73 μmol/m^2 was the highest mean value recorded for treatment (2ET, 0kg NPK) which was not significantly higher than other treatments apart from treatment (1/2ET, 300) with mean value 66.10 μmol/m^2 which was the lowest. However, mean values of 71.40-82.33 μmol/m^2 was recorded for other treatments. At 8WAS, 77.86 μmol/m^2 was the highest mean value recorded for treatment (1/2ET, 0kg NPK) which was not significantly higher than other treatments. However, mean values within the range of 76.87-68.0 μmol/m^2 was recorded for other treatments where treatment (1/2ET, 300kg NPK) had the lowest value. At 10WAS, treatment (2ET, 400kg NPK) had the maximum mean value of 85.43 μmol/m^2 which was not significantly higher than other treatments. However, other treatments recorded a range of 70.97-83.10 μmol/m^2 with treatment (2ET, 0kg NPK) recording the lowest value.

Figure 4.54 shows that at 2WAS, treatment (1/2ET, 300kg NPK) recorded the highest mean value of 39.27 μmol/m^2 for the bottom leave which was not significantly higher than other treatments. However, other treatments recorded mean values within the range of 33.43-39.0 μmol/m^2 with treatment (1/2ET, 0kg NPK) recording the least value. At 4WAS, 39.46 μmol/m^2 was the highest mean value recorded for treatment (1/2ET, 0kg NPK) which was significantly higher than other treatments apart from (2ET, 300kg NPK), (2ET, 0kg NPK), (3/2ET, 0kg NPK), (3/2ET, 100kg NPK), (1/2ET, 100kg NPK), (1ET, 200kg NPK), (3/2ET, 300kg NPK) and (2ET, 100kg NPK) with mean values within the range of 34.0-39.0 μmol/m^2 while treatments which were significantly lower ranged from 29.13-33.5 μmol/m^2 however, treatment (2ET, 400kg NPK) had the lowest value. At 6WAS, treatment (1ET, 100kg NPK) recorded the highest mean value of 35.27 μmol/m^2 which was significantly higher than treatments (3/2ET, 300kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK) and (2ET, 400kg NPK) which had mean values within the range of 34.0-39.0 μmol/m^2 while treatments which were significantly lower ranges from 28.73-30.8 μmol/m^2. However, treatment (2ET, 400kg NPK) had the lowest value. At 8WAS, 36.83 μmol/m^2 was the highest mean value recorded for treatment (1/2ET, 0kg NPK) which were significantly higher than other treatments apart from (2ET, 100kg NPK), (1ET, 100kg NPK), (3/2ET, 0kg NPK), (1/2ET, 200kg NPK), (3/2ET, 100kg NPK), (1ET, 0kg NPK), (2ET, 100kg NPK) and (1ET, 200kg NPK) with mean values within the range of 33.1-35.60 μmol/m^2 while treatments which were significantly lower ranged from 29.40-32.20 μmol/m^2 however, treatment (2ET, 400kg NPK) had the lowest value. At 10WAS, 39.73 μmol/m^2 was the highest mean value recorded for treatment (1/2ET, 0kg NPK) which was significantly higher than other treatments apart from (1/2ET, 300kg NPK), (2ET, 0kg NPK), (3/2ET, 0kg NPK), (3/2ET, 100kg NPK), (1/2ET, 200kg NPK) and (3/2ET, 400kg NPK) with mean values within the range of

35.57-37.73 µmol/m^2 while treatments which were significantly lower ranged from 28.50-35.07 µmol/m^2. However, treatment (1/2ET, 100kg NPK) had the lowest value.

Figure 4.51: Chlorophyll Content of Top and Bottom Leave of *Corchorus olitorus* in Greenhouse for Week 2, 4, 6, 8, 10

Figure 4.52: Chlorophyll Content of Top and Bottom Leave of *Corchorus olitorus* in Greenhouse

Figure 4.53: Chlorophyll Content of Top and Bottom Leave of *Corchorus olitorus* in the Field for Week 2, 4, 6, 8, 10

Figure 4.54: Chlorophyll Content of Top and Bottom Leave of *Corchorus olitorus* in the Field for Week 2, 4, 6, 8, 10

4.4 LEAF REFLECTANCE

Figure 4.55 presents the leaf reflectance of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, 17% was the highest mean value recorded for treatment (3/2ET, 400kg NPK) which was significantly higher than other treatments apart from treatments (3/2ET, 0kg NPK) and (3/2ET, 100kg NPK) with mean values of 15.0% and 13.67% respectively while treatments which were significantly lower ranged from 8.0-12.67%. with treatment (2ET, 400kg NPK) having the lowest value. At 4WAS, treatment (1/2ET, 0kg NPK) had the maximum mean value of 9.0% which was significantly higher than other treatments except for treatments (1/2ET, 100kg NPK), (1ET, 400kg NPK), (1ET, 0kg NPK), (1/2ET, 200kg NPK), (1ET, 100kg NPK), (1/2ET, 300kg NPK), (3/2ET, 0kg NPK) and (1ET, 300kg NPK) which had mean values within the range of 6.67-8.67%. However, other treatments significantly lower recorded a range of 5.0-6.33%. However, treatment (2ET, 200kg NPK) recorded the lowest value. At 6WAS, 13.33% was the highest mean value recorded for treatments (1/2ET, 0kg NPK) and (1ET, 0kg NPK) which were significantly higher than other treatments apart from treatments (1ET, 300kg NPK) and (3/2ET, 0kg NPK) with mean values of 13.0% and 11.33% respectively while treatments which were significantly lower ranged from 5.0-9.67%. with treatment (3/2ET, 400kg NPK) having the lowest value. At 8WAS, treatment (1/2ET, 0kg NPK) and (1/2ET, 100kg NPK) had the maximum mean value of 10.0% which was significantly higher than other treatments except for treatments (1/2ET, 400kg NPK), (1ET, 400kg NPK), (1/2ET, 300kg NPK) and (1/2ET, 200kg NPK) which had mean values 9.33%, 9.0%, 9.0% and 9.0%. However, other treatments significantly lower recorded a range of 7.0-8.33%. However, treatment (3/2ET, 200kg NPK) recorded the lowest value. At 10WAS, 15.0% was recorded as the highest mean value for treatments (1/2ET, 0kg NPK) and (1ET, 0kg NPK) which were significantly higher than other treatments apart from treatments (1ET, 300kg NPK) with a mean value of 13.33% while treatments which were significantly low, fell within 6.67-12.67%, with treatment (3/2ET, 400kg NPK) having the lowest value.

Figure 4.56 presents the leaf reflectance of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, treatment (1/2ET, 0kg NPK) had the maximum mean value of 13.33% which was significantly higher than other treatments except for treatments (1/2ET, 200kg NPK), (1/2ET, 100kg NPK) and (1/2ET, 400kg NPK) which had mean values of 12.67%, 12.67%, 12.33% while other treatments recorded a range of 7.33-11.67%. However, treatment (2ET, 0kg NPK) recorded the lowest value. At 4WAS, 10.67% was recorded as the highest mean value for treatment (1/2ET, 100kg NPK) which was significantly higher than other treatments apart from treatments (1ET, 400kg NPK), (1/2ET, 300kg NPK), (1/2ET, 200kg NPK), (1/2ET, 400kg NPK) and (1/2ET, 400kg NPK) with mean values of 10%, 10%, 10%, 9.67% and 9.67% respectively while other treatments fell within 7.67-9.33%, with treatment (2ET, 200kg NPK) having the lowest value. At 6WAS, treatment (1/2ET, 0kg NPK) had the highest mean value of 10.67% which was significantly higher than other treatments apart from treatments (1ET, 300kg NPK), (1ET, 400kg NPK), (1/2ET, 300kg NPK), (1/2ET, 100kg NPK), (1ET, 100kg NPK), (1/2ET, 200kg NPK), (1ET, 0kg NPK) and (1/2ET, 400kg NPK) which had mean values ranging from 9.33-10.33% while other treatments recorded a range of 7.33-9.0%. However, treatment (2ET, 100kg NPK) recorded the lowest value. At 8WAS, 10.33% was recorded as the highest mean value for treatments (1/2ET, 100kg NPK) which was significantly higher than other treatments apart from treatments (1/2ET, 300kg NPK), (1/2ET, 200kg NPK) and (1/2ET, 0kg NPK) with mean values of 9.67% each while other treatments fell within 7.33-9.33%, with treatment (3/2ET, 0kg NPK) having the lowest value. At 10WAS, treatment (1/2ET, 0kg NPK) had the maximum mean value of 10.67% which was significantly higher than other treatments expect for treatments (1/2ET, 300kg NPK) and (1/2ET, 100kg NPK) which had mean values of 10.0% each while other treatments recorded a range of 7.67-9.67%. However, treatment (2ET, 400kg NPK) recorded the lowest value.

Figure 4.57 presents the leaf reflectance of *Corchorus olitorus* as influenced by water and fertilizer treatment in the field. At 2WAS, treatment (1/2ET, 0kg NPK) had the maximum mean value of 20.33% which was significantly higher than other treatments except for treatments (1/2ET, 100kg NPK), (3/2ET, 100kg NPK), (3/2ET, 200kg NPK) and (1/2ET, 200kg NPK) which had mean values of 19.33%, 19.0%, 18.66% and 18.33% while other treatments recorded a range of 13.33-17.0% with treatment (2ET, 100kg NPK) having the lowest value. At 4WAS, 6.67% was recorded as the highest mean value for treatments (1/2ET, 0kg NPK) which was significantly higher than only treatment (2ET, 200kg NPK) with mean values of 5.0% which was the lowest while other treatments fell within 5.33-6.33%. At 6WAS, treatments (1ET, 100kg NPK), (1/2ET, 300kg NPK) and (1/2ET, 0kg NPK) recorded the highest value of 6.33% which was significantly higher than treatment (2ET, 200kg NPK) with mean values of 5.0% which was the lowest while other treatments fell within 5.33-6.0%. At 8WAS, treatments (1ET, 200kg NPK), (1/2ET, 400kg NPK) (1/2ET, 200kg NPK), (1/2ET, 100kg NPK) and (1/2ET, 0kg NPK) recorded the highest value of 6.33% which was significantly higher than treatment (2ET, 200kg NPK) and (3/2ET, 300kg NPK) with mean values of 5.0% each which was the lowest while other treatments fell within 5.33-6.0%. At 10WAS, treatment (1/2ET, 300kg NPK) recorded the highest mean value of 6.67% which was significantly higher than other treatments apart from treatments (1ET, 300kg NPK), (1/2ET, 400kg NPK), (1ET, 400kg NPK), (1ET, 100kg NPK), (1/2ET, 200kg NPK), (1/2ET, 100kg NPK) and (1/2ET, 0kg NPK) with mean values ranging from 6.0-6.33% while treatments such as (2ET, 400kg NPK), (2ET, 0kg NPK) and (3/2ET, 0kg NPK) had the lowest value of 5.0% each.

Figure 4.58 presents the leaf reflectance of *Corchorus olitorus* as influenced by water and fertilizer treatment. At 2WAS, 18.67% was recorded as the highest mean value for treatments (1/2ET, 100kg NPK) which was significantly higher than most of the treatment apart from treatment (1/2ET, 200kg NPK), (1ET, 100kg NPK), (1/2ET, 400kg NPK), (1/2ET, 0kg NPK) and (1ET, 400kg NPK) with mean values within the range of 17.33-18.33% while other treatments fell within the range 13.67-16.67%. However, treatment (2ET, 0kg NPK) and (3/2ET, 0kg NPK) had the lowest value of 13.67%. At 4WAS, treatments (1/2ET, 400kg NPK), (1/2ET, 300kg NPK), (1/2ET, 200kg NPK), (1/2ET, 100kg NPK) and (1/2ET, 0kg NPK) recorded the highest value of 9.33% which was significantly higher than treatment (2ET, 400kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK) with mean values of 8.0% which was the lowest while other treatments fell within 8.33-9.0%. At 6WAS, treatments (1/2ET, 300kg NPK) recorded the highest value of 9.33% which was significantly higher than treatments (2ET, 400kg NPK), (2ET, 300kg NPK), (3/2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 0kg NPK), (3/2ET, 200kg NPK), (3/2ET, 0kg NPK) and (2ET, 100kg NPK) with mean values of 7.67-8.33%. At 8WAS, treatments (1ET, 0kg NPK), (1/2ET, 100kg NPK) and (1/2ET, 0kg NPK) recorded the highest value of 9.67% which was significantly higher than most treatments except for treatments (1/2ET, 200kg NPK), (1ET, 400kg NPK), (1ET, 200kg NPK), (1/2ET, 400kg NPK) and (2ET, 300kg NPK) with mean values of 9.0-9.30% while other treatments ranged from 8.0-8.67% with (2ET, 400kg NPK), (2ET, 300kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK) and (2ET, 300kg NPK) having a mean value of 8% each. At 10WAS, treatments (1ET, 200kg NPK), (1/2ET, 200kg NPK), (1/2ET, 100kg NPK) and (1/2ET, 0kg NPK) recorded the highest value of

9.33% which was significantly higher than treatments (2ET, 300kg NPK), (3/2ET, 400kg NPK), (3/2ET, 300kg NPK), (3/2ET, 100kg NPK), (2ET, 400kg NPK), (2ET, 200kg NPK), (2ET, 100kg NPK), (2ET, 0kg NPK) and (3/2ET, 200kg NPK) with mean values of 8.0-8.33%.

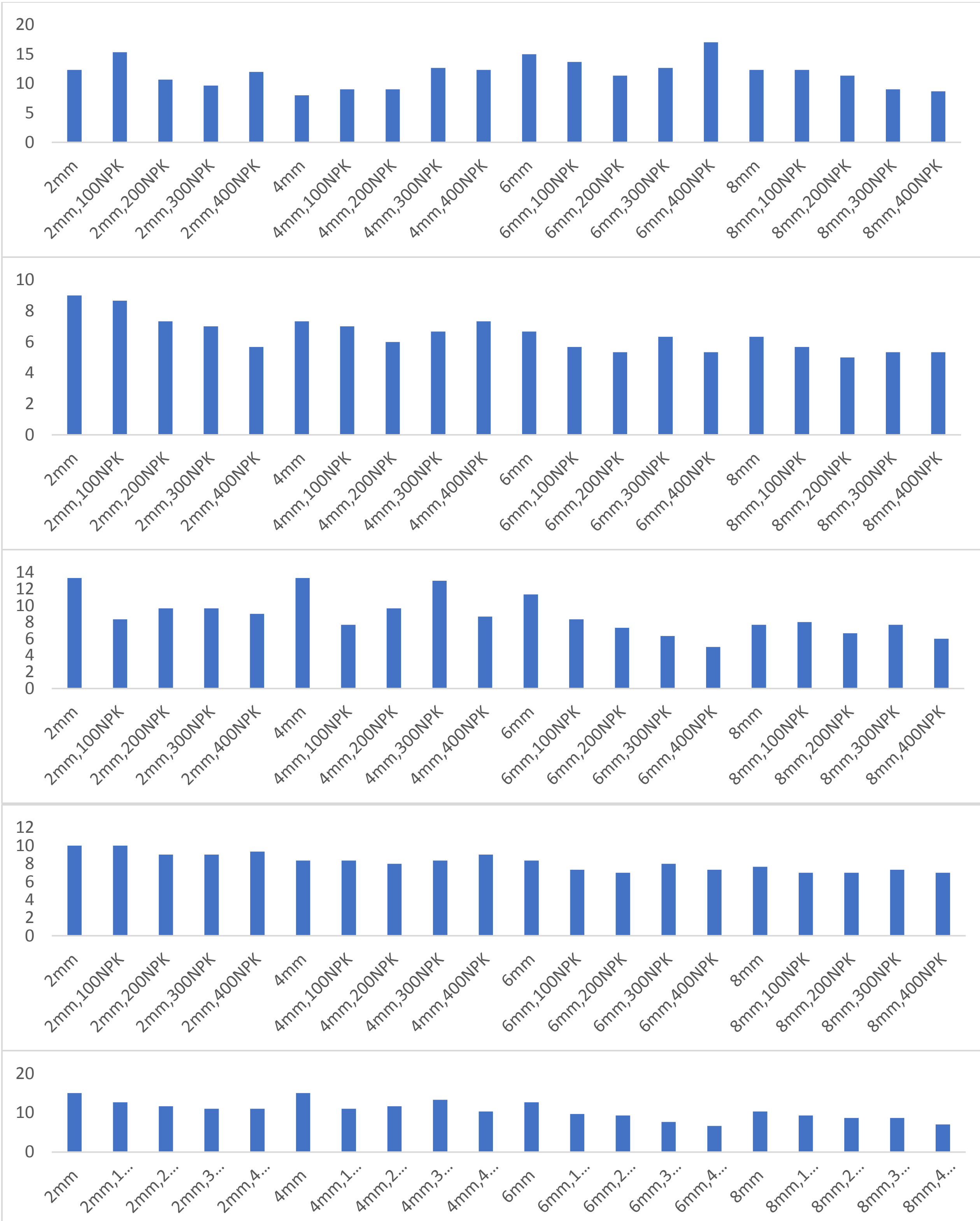


Figure 4.55: Leaf Reflectance of *Corchorus olitorus* in Greenhouse for Week 2, 4, 6, 8, 10

Figure 4.56: Leaf Reflectance of *Corchorus olitorus* in Greenhouse for Week 2, 4, 6, 8, 10

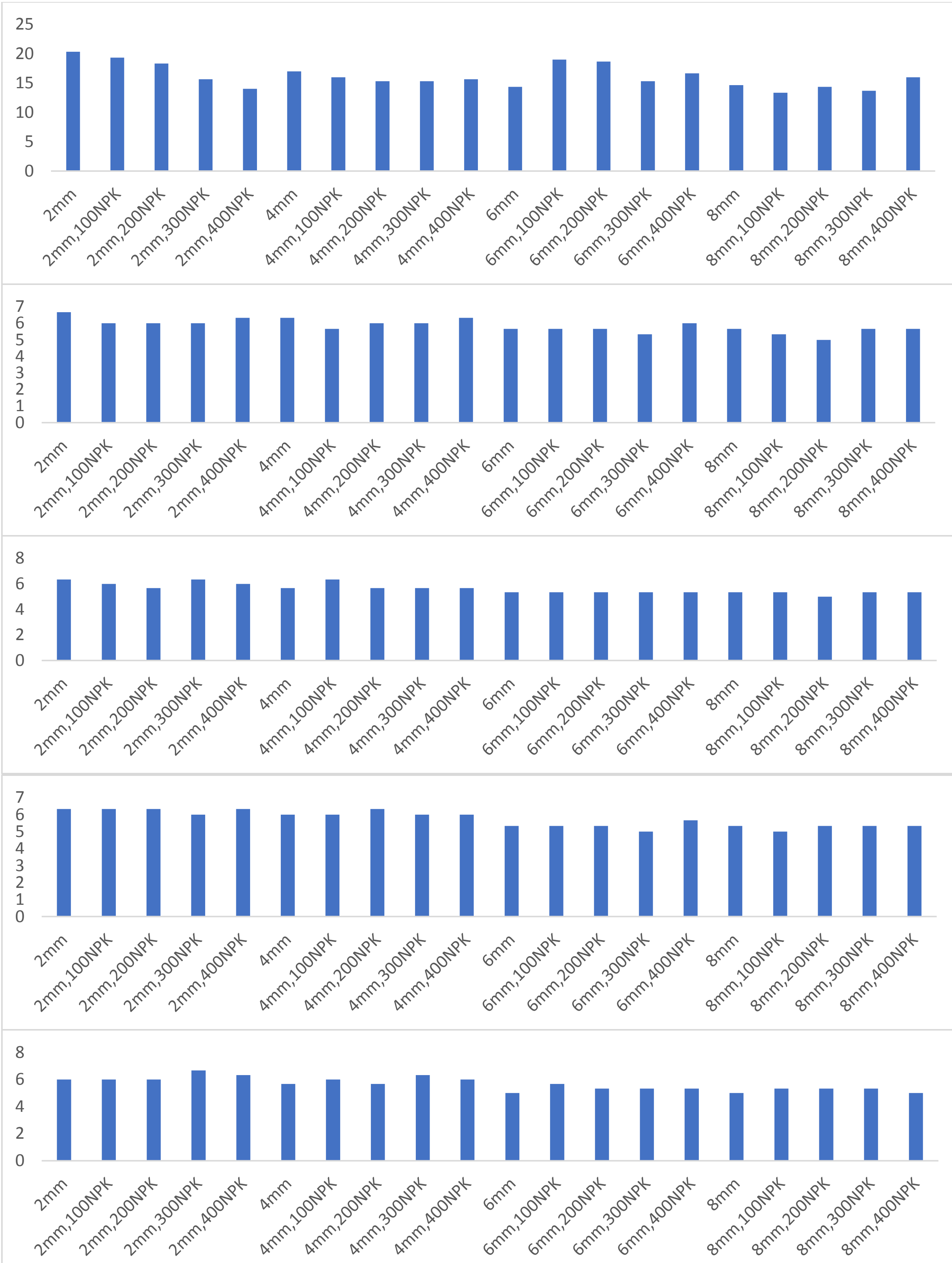


Figure 4.57: Leaf Reflectance of *Corchorus olitorus* in the Field for Week 2, 4, 6, 8, 10

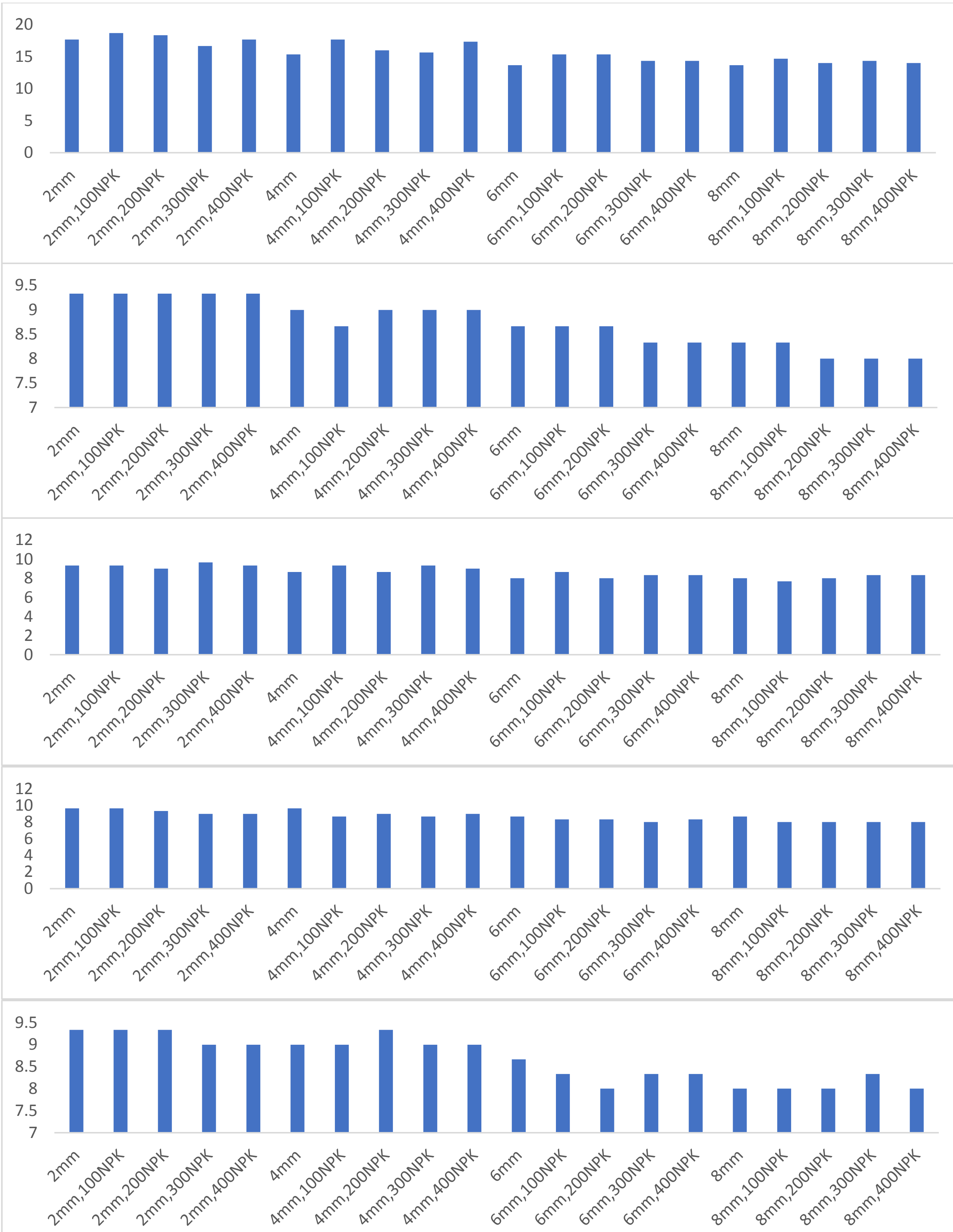


Figure 4.58: Leaf Reflectance of *Corchorus olitorus* in the Field for Week 2, 4, 6, 8, 10

Table 4.3: Maximum and Minimum Temperature, Mean Substrate Temperature, Potential Evapotranspiration, Growing Degree Days in the Field During Rainy Season

Day	Max temp	Min temp	Substrate Temp field rain	ETo	GDD	GDD/Week	Substrate Temp Cumm.	ETo Cumm.	GDD Cumm.
Aug. 4-11	29.6	22.1	29.5	3.41	15.85	110.95	29.5	23.87	110.95
11-18	30.1	23.1	29.5	3.86	16.6	116.2	59	50.89	227.15
18-25	30.5	22.0	29.5	4.11	16.25	113.75	88.5	79.66	340.90
25-1Sept	31.2	22.5	29.5	4.22	16.85	117.95	118	109.2	458.85
1-8	31.6	22.6	29.5	4.14	17.1	119.7	147.5	138.18	578.55
8-15	30.4	22.2	29.5	3.83	16.3	114.1	177	164.99	692.65
15-22	32.1	22.0	29.5	3.97	17.05	119.35	206.5	192.78	812.0
22-29	32.4	22.4	29.5	4.02	17.4	121.8	236	220.92	933.80
29-6Oct	32.6	22.4	29.5	4.05	17.5	122.5	265.5	249.27	1056.30
6-13	32.6	22.4	29.5	3.94	17.5	122.5	295	276.85	1178.8

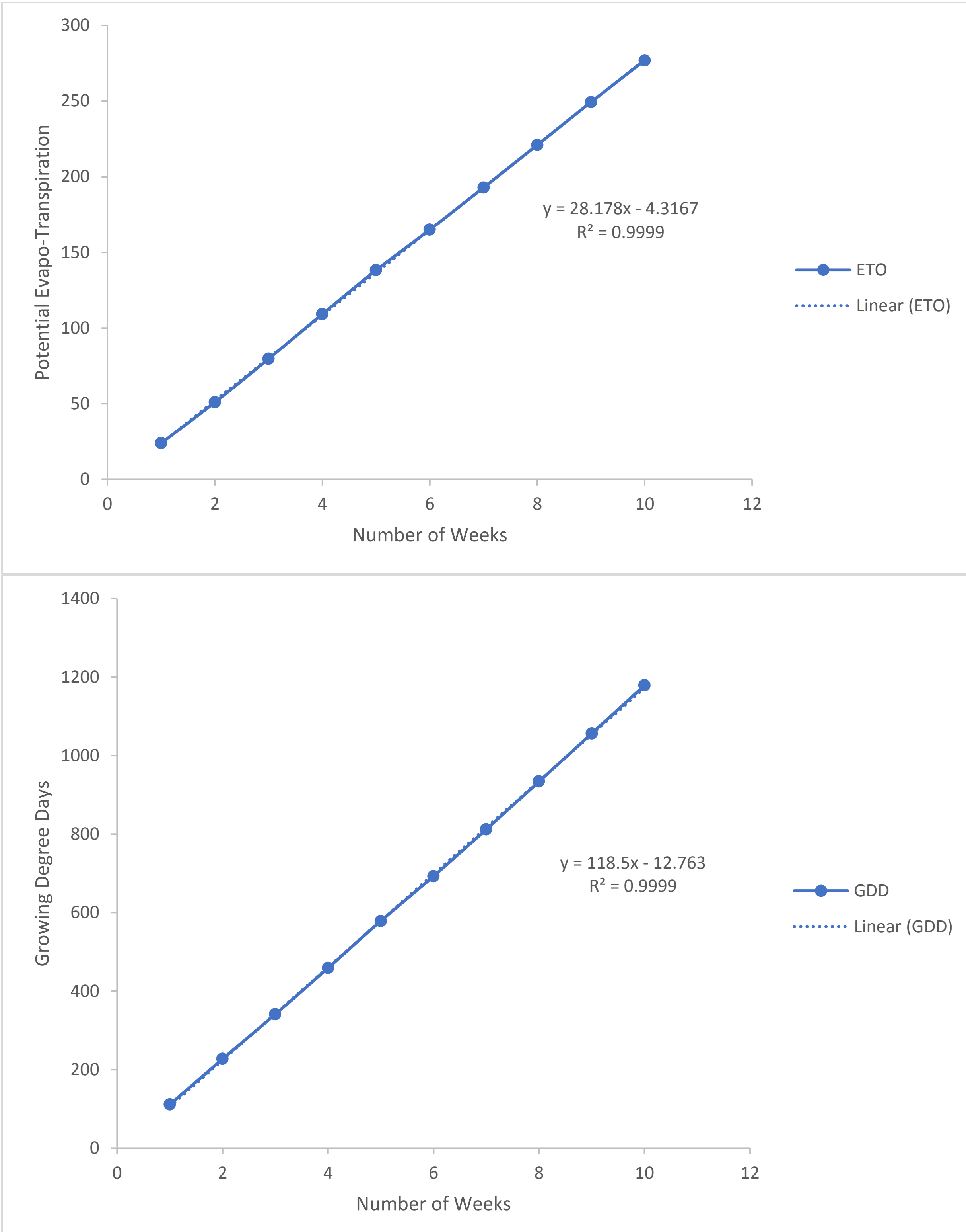
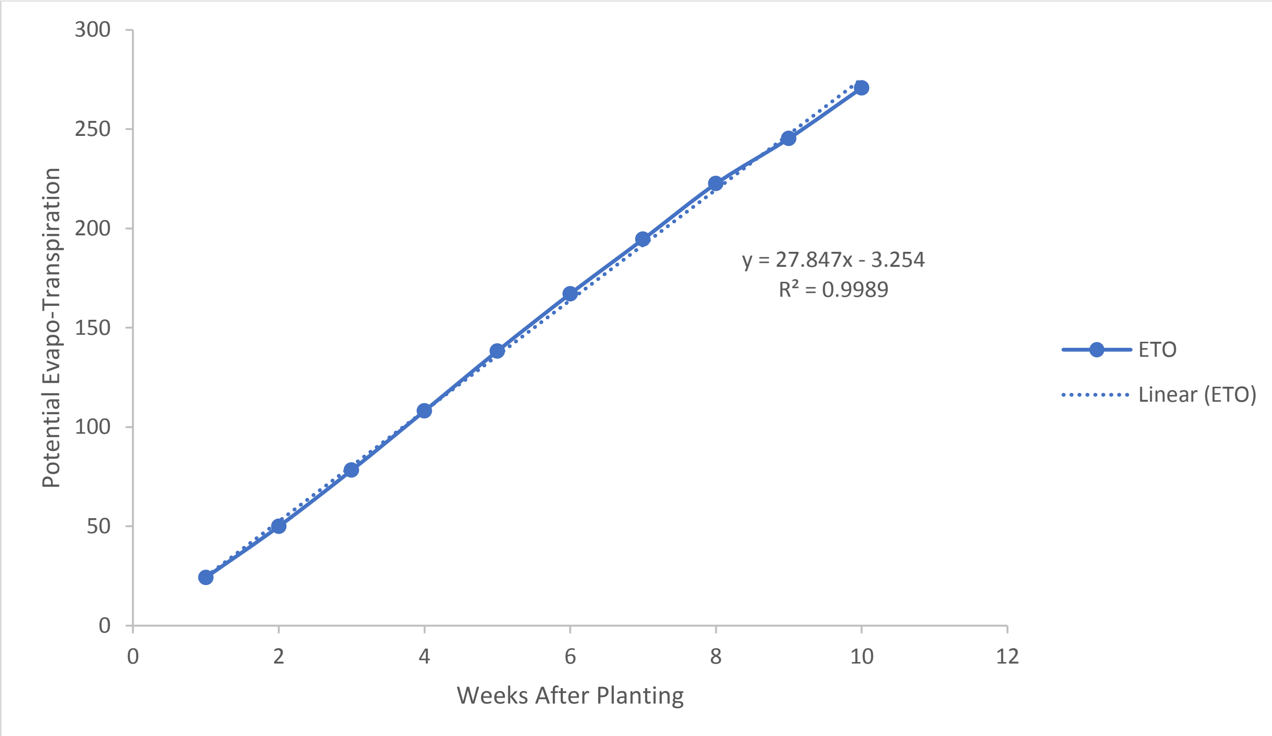


Figure 4.59: Potential Evapo-Transpiration against Time and Growing Degree days against Time

Table 4.4: Maximum and Minimum Temperature, Mean Substrate Temperature, Potential Evapotranspiration, Growing Degree Days in the Field During Dry Season 2016

Day	Max temp	Min temp	Substrate Temp field dry	ET0	GDD	GDD/Week	Substrate Temp Cumm.	ETO Cumm.	GDD Cumm.
21-28Oct	33.6	22.4	39.5	3.47	18	126	39.5	24.29	126.0
28-4Nov	34.3	22.3	39.5	3.67	18.3	128.1	79	49.98	254.10
4-11Nov	34.6	23.4	39.5	4.04	19	133	118.5	78.26	387.10
11-18	34.6	24.7	39.5	4.26	19.65	137.55	158	108.08	524.65
18-21	35.1	23.1	39.5	4.31	19.1	133.7	197.5	138.25	658.35
21-28	35.5	25.4	39.5	4.12	20.45	143.15	237	167.09	801.50
28-2Dec	35.6	23.3	39.5	3.92	19.45	136.15	276.5	194.53	937.65
2-9	34.3	22.2	39.5	4.00	18.25	127.75	316	222.53	1065.40
16-23	36.1	21.5	39.5	3.92	18.8	131.6	355.5	245.27	1197.0
23-30	35.6	18.5	39.5	3.64	17.05	119.35	395	270.75	1316.35



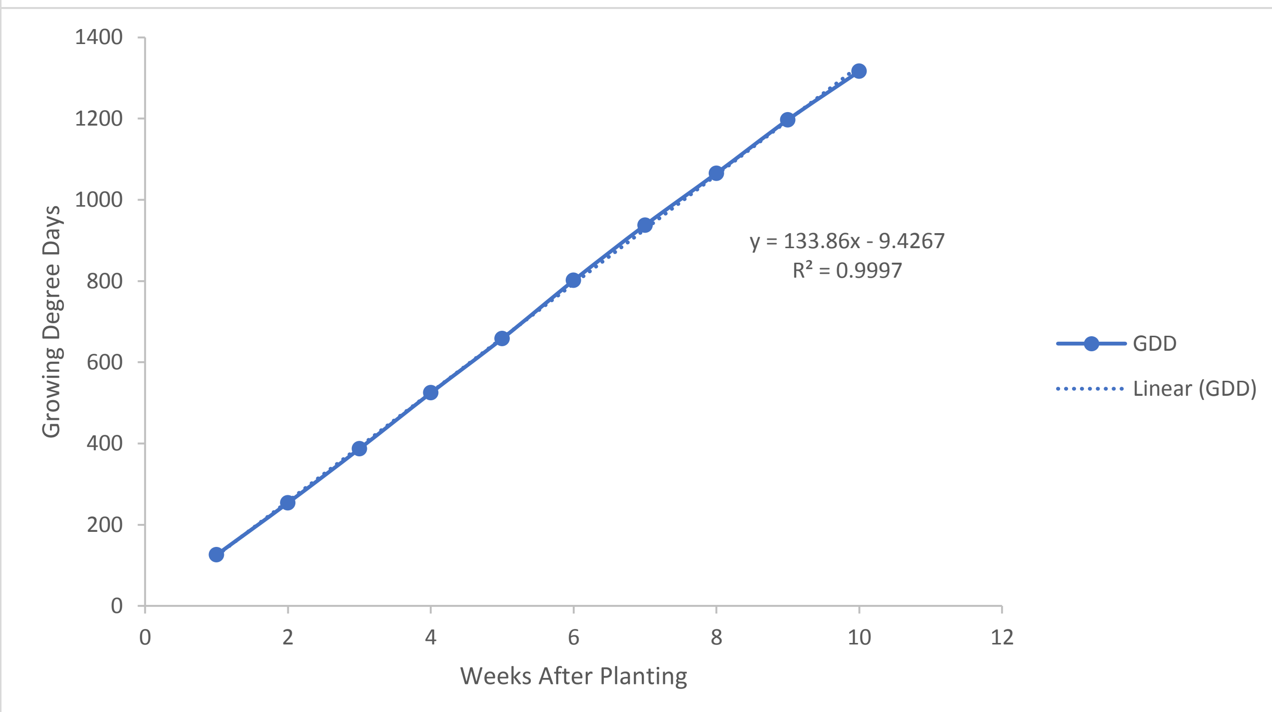


Figure 4.60: Potential Evapo-Transpiration against Time and Growing Degree days against Time

Table 4.5: Maximum and Minimum Temperature, Mean Substrate Temperature, Potential Evapotranspiration, Growing Degree Days in the Field During Dry Season 2017

Day	Max temp	Min temp	Substrate Temp field dry	ETo	GDD	GDD/Week	Substrate Temp Cumm.	ETo Cumm.	GDD Cumm.
11-18 Jan	35.7	19.5	39.5	3.55	17.6	123.2	39.5	24.85	123.20
18-25	36.6	20.7	39.5	3.58	18.65	130.55	79	49.91	253.75
25-1Feb	36.1	25.1	39.5	3.97	20.6	144.2	118.5	77.7	397.95
1-8	36.0	24.1	39.5	4.37	20.05	140.35	158	108.29	538.30
8-15	36.1	25.0	39.5	4.41	20.55	143.85	197.5	139.16	682.15
15-22	36.4	25.5	39.5	3.26	20.95	146.65	237	161.98	828.80
22-1Mar	36.3	25.2	39.5	3.30	20.75	145.25	276.5	185.08	974.05
1-8	36.2	24.3	39.5	4.28	20.25	141.75	316	215.04	1115.8
8-15	36.5	24.0	39.5	3.97	20.25	141.75	355.5	242.83	1257.55
15-22	30.9	29.0	39.5	3.83	19.95	139.65	395	269.64	1397.2

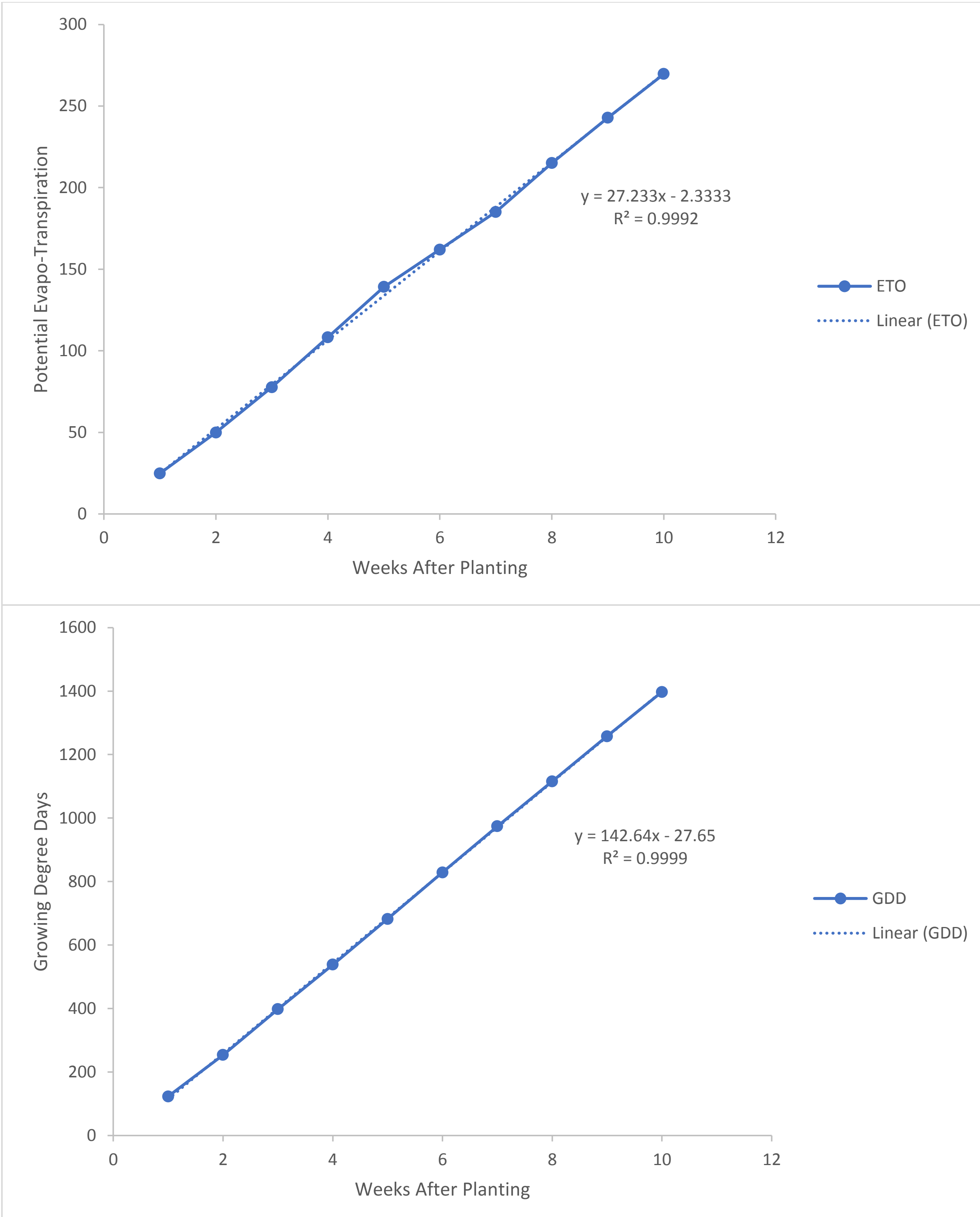
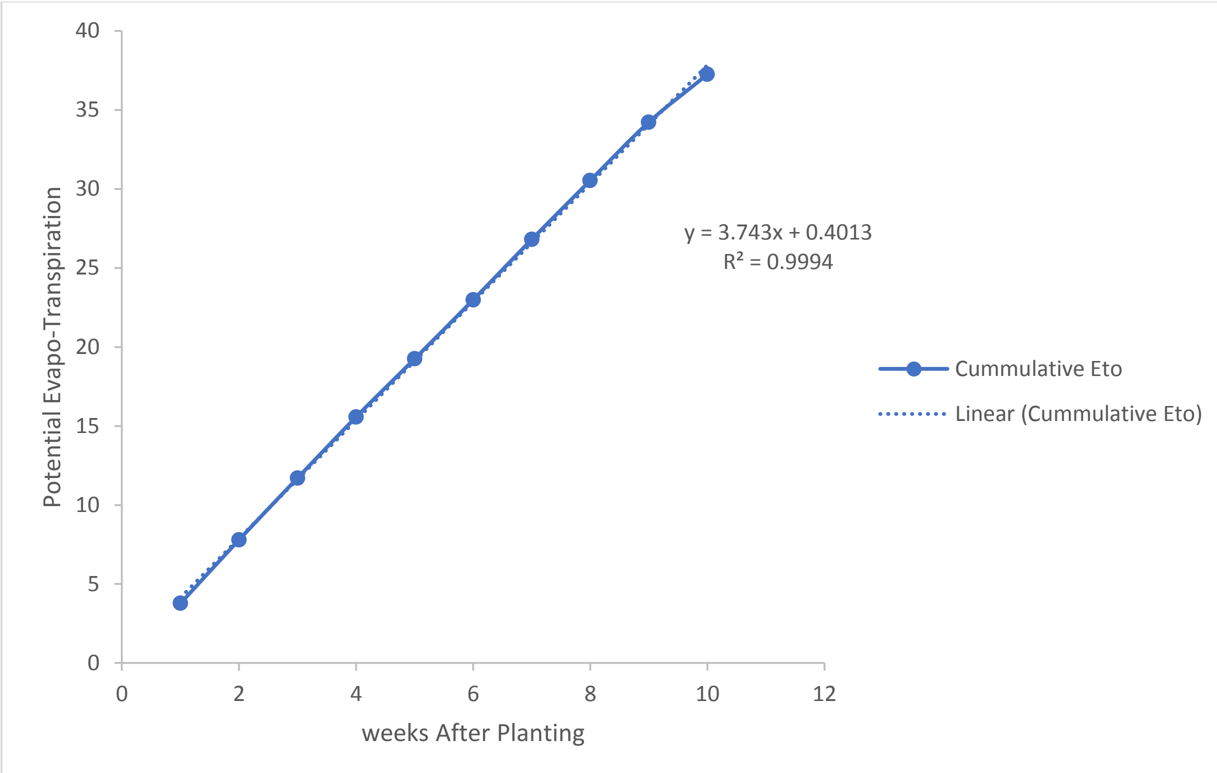


Figure 4.61: Potential Evapo-Transpiration against Time and Growing Degree days against Time

Table 4.6: Maximum and Minimum Temperature, Mean Substrate Temperature, Potential Evapotranspiration, Growing Degree Days in the greenhouse 2017

Day	Max temp	Min temp	Substrate Temp field dry	ETo	GDD	GDD/Week	ETo Cumm.	GDD Cumm.
17-24 Oct	34.6	22.0	34-37	3.78	18.3	128.1	3.78	128.1
24-31	35.0	22.4	34-37	4.02	18.7	130.9	7.8	259.0
31-7Nov	35.1	22.3	34-37	3.91	18.7	130.9	11.71	389.9
7-14	35.1	23.4	34-37	3.86	19.3	134.8	15.57	524.7
14-21	35.0	23.4	34-37	3.68	19.2	134.4	19.25	659.1
21-28	35.3	23.1	34-37	3.73	19.2	134.4	22.98	793.5
28-5 Dec	35.2	25.0	34-37	3.82	20.1	140.7	26.8	934.2
5-12	34.8	22.2	34-37	3.73	18.5	129.5	30.53	1063.7
12-19	35.0	22.2	34-37	3.69	18.6	130.2	34.22	1193.9
19-26	34.7	19.0	34-37	3.02	16.9	118.0	37.24	1311.8



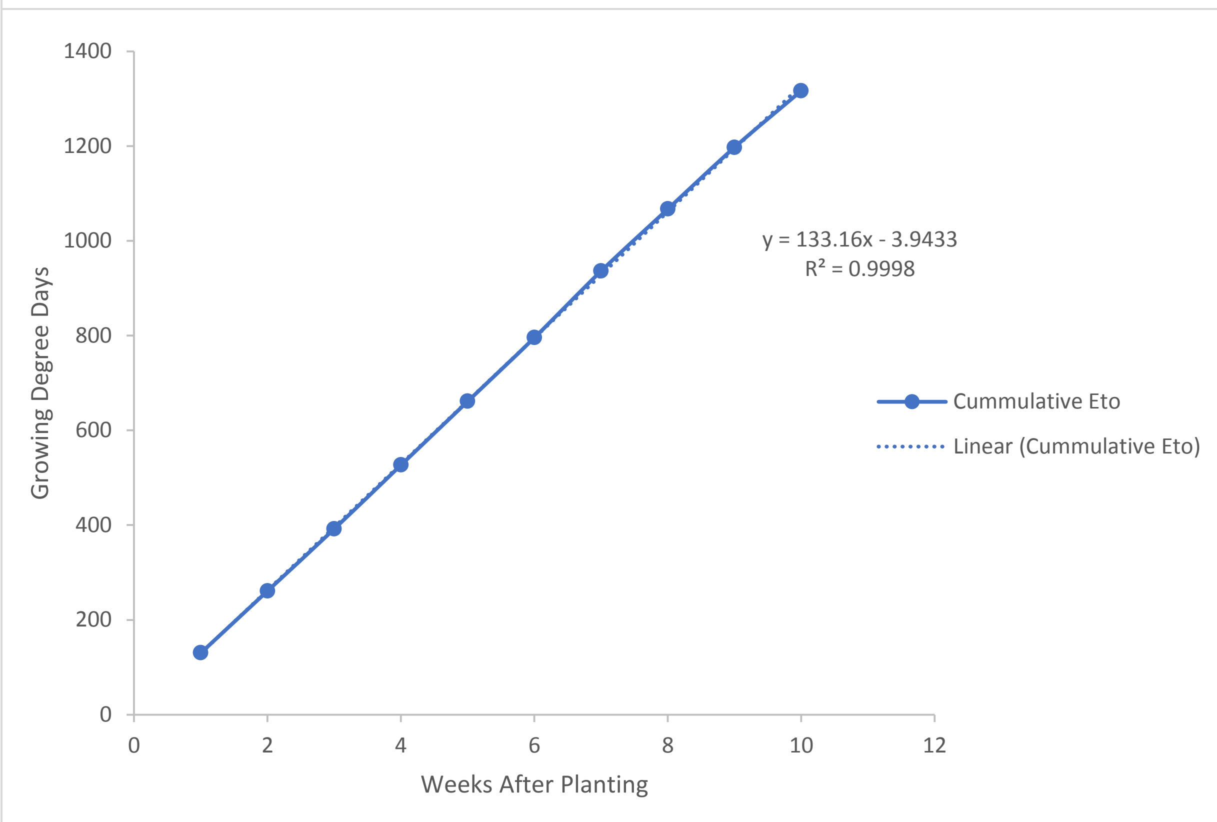


Figure 4.62: Potential Evapo-Transpiration against Time and Growing Degree days against Time

Table 4.7: Maximum and Minimum Temperature, Mean Substrate Temperature, Potential Evapotranspiration, Growing Degree Days in the greenhouse

Day	Max temp	Min temp	Substrate Temp field dry	ETo	GDD	GDD/Week	ETo Cumm.	GDD Cumm.
19-26 Jan	35.0	25.1	34-37	4.17	20.05	140.35	4.17	140.35
26-2 Feb	35.0	24.1	34-37	4.18	19.55	136.85	8.35	277.20
2-9	35.2	25.0	34-37	4.05	20.10	140.70	12.4	417.9
9-16	35.3	25.5	34-37	2.91	20.40	142.80	15.31	560.70
16-23	35.0	25.2	34-37	2.96	20.10	140.70	18.27	701.4
23-2 Mar	34.8	24.3	34-37	3.99	19.55	136.85	22.26	838.25
2-9	35.0	24.0	34-37	4.00	19.50	136.50	26.26	974.75
9-16	35.1	24.0	34-37	3.87	19.55	136.85	30.13	1111.6
16-23	34.3	25.0	34-37	3.11	20.15	141.05	33.24	1249.15
23-30	30.2	25.5	34-37	3.21	20.35	142.45	36.45	1374.10

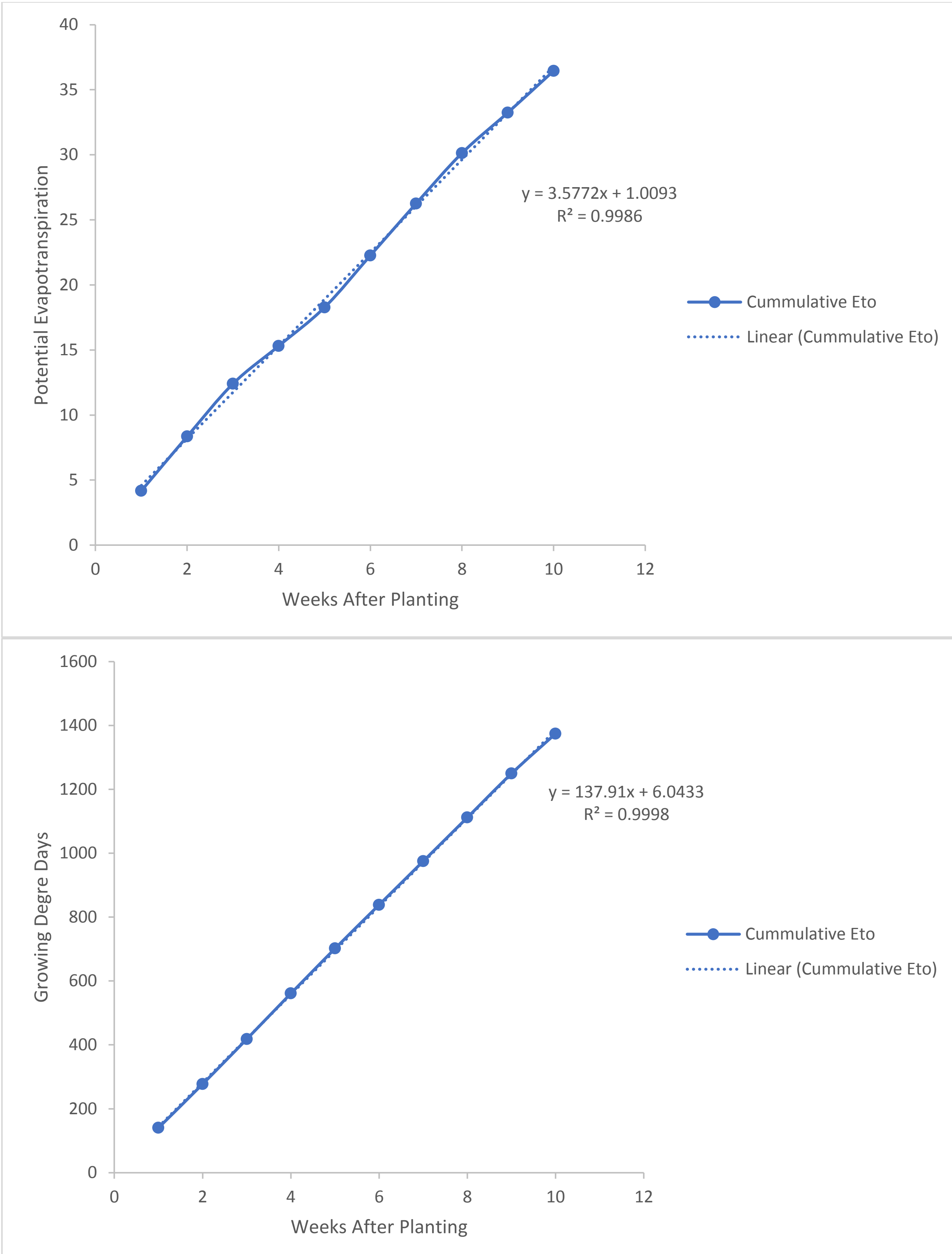


Figure 4.63 Potential Evapo-Transpiration against Time and Growing Degree days against Time

Table 4.8: Actual evapotranspiration at different depth of water (ET_c), Potential evapotranspiration (ET_o), Crop Co-efficient (K_c)

Week	ETc								ETo		Kc
	2mm	2mm	4mm	4mm	6mm	6mm	8mm	8mm	mm	mm	
1	0.63±0.05	4.41	1.18±0.06	8.26	1.47±0.04	10.29	1.74±0.08	12.18	4.04	28.28	0.431
2	0.70±0.05	9.31	1.23±0.05	16.87	1.58±0.06	21.35	1.87±0.06	25.27	4.26	58.10	0.439
3	0.75±0.03	14.56	1.33±0.06	26.18	1.83±0.06	34.16	2.00±0.11	39.27	4.31	88.27	0.464
4	0.86±0.03	20.58	1.33±0.04	35.49	2.11±0.06	48.93	2.50±0.10	56.77	4.12	117.11	0.607
5	0.89±0.05	26.81	1.47±0.04	45.78	2.00±0.09	62.93	2.39±0.06	73.50	3.92	144.55	0.610
6	0.89±0.05	33.04	1.77±0.07	58.17	2.71±0.03	81.90	3.25±0.07	96.25	4.00	172.55	0.813
7	0.86±0.04	39.06	1.83±0.08	70.98	2.86±0.08	101.92	3.48±0.10	120.61	3.92	199.99	0.888
8	0.89±0.03	45.29	1.85±0.13	83.93	3.00±0.10	122.92	3.57±0.06	145.6	3.64	225.47	0.981
9	0.77±0.03	50.68	1.85±0.09	96.88	3.06±0.08	144.34	3.14±0.10	167.58	3.55	250.32	0.885
10	0.73±0.03	55.79	0.94±0.05	103.46	1.20±0.09	152.74	2.20±0.09	182.98	3.58	275.38	0.615

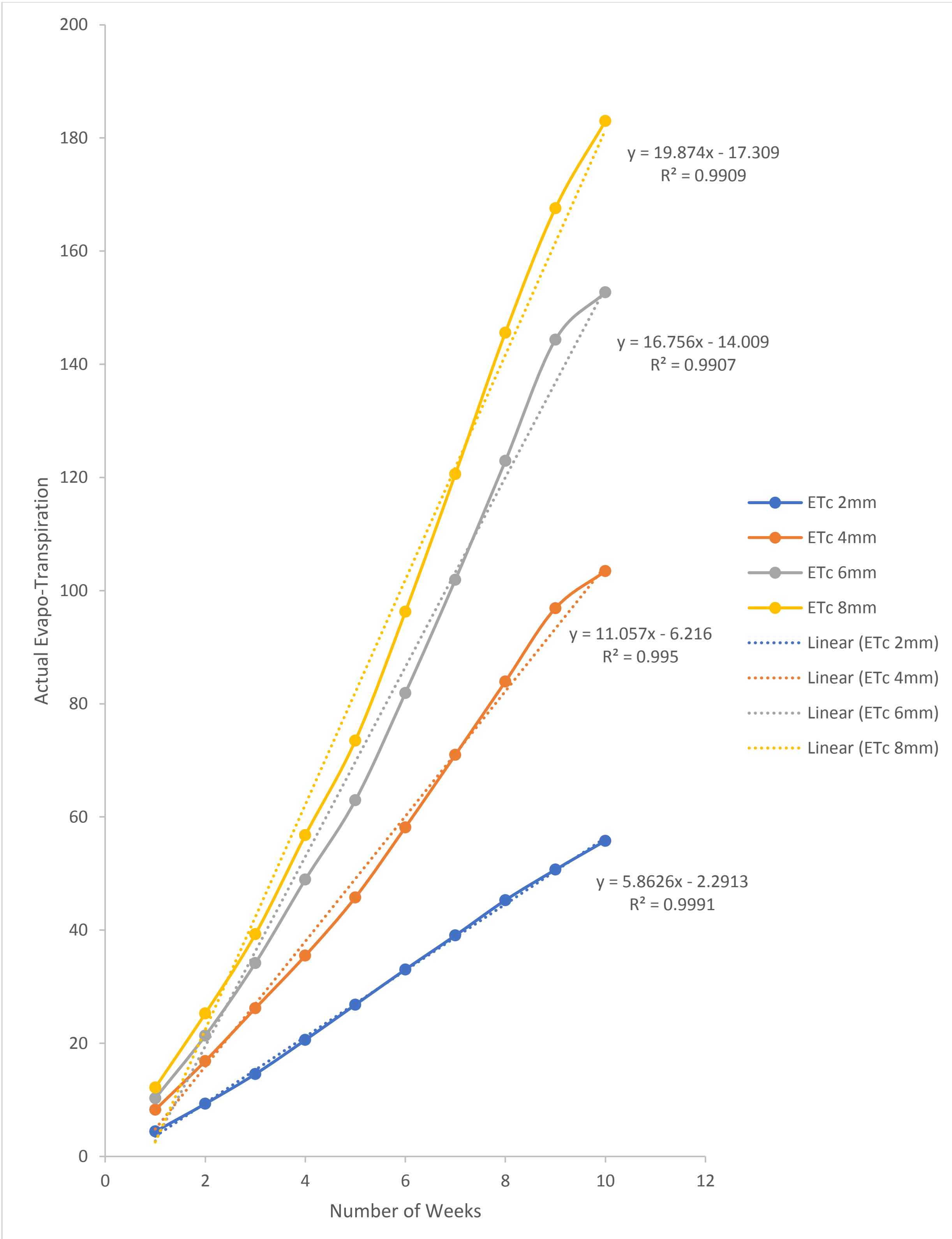


Figure 4.64: Actual Evapo-Transpiration against Time

4.5 ESTIMATING PLANT GROWTH PARAMETERS AND WATER STRESS PARAMETERS USING ACTUAL EVAPOTRANSPIRATION AND GROWING DEGREE DAYS (HEAT UNITS)

Modern innovative agricultural techniques for estimating plant growth and water stress parameters have become necessary for proper water and climate change impact management in water balance studies at different scales for proper decision making and profitability. The conventional approach of determining plant growth parameters by taking measurement directly from the plants in the field can be addressed using timely and innovative tool. This reduces the stress of going to the field and taking measurements. The visualization of plant development at any point in time helps in achieving precision agriculture and reducing wastages and cost. Plant growth and development is affected by temperature which plays a significant role in influencing the rate of evapotranspiration and accumulation of heat which can be referred to as the growing degree days (GDD). The need to predict plant growth parameters using actual evapotranspiration and growing degree days, two key parameters influenced by temperature becomes necessary. It becomes pertinent to note that, heat energy required by crops to develop from seeding to maturity is constant from one year to another but the time in days vary because of changes in weather conditions. It was observed that changes occurred in the cumulative growing degree days (GDD) when comparing results from the field to that from the greenhouse. The results from table 4.3-4.6 show that the differences between cumulative GDD from greenhouse compared to field was not much. This creates an important information that a slight change in temperature affects plant growth that cognisance of the fact that the crop water requirement must not be neglected. However, the substrate temperature cannot be ignored because plant absorbs water and nutrient from the soil which is important for plant growth and development. Statistical models were generated using actual evapotranspiration and the accumulated heat energy also known as growing degree days to determine the growth of plant and development using essential crop growth and water stress parameters. The need to achieve a reliable and acceptable statistical model using a 3D surface methodology graph with co-efficient of regression $R^2 = 1$ was achieved as shown in Appendices 4 -63

Table 4.9: Actual evapo-transpiration, Yield, Nitrogen uptake, Water use efficiency, Fertilizer use efficiency of *Corchorus olitorus* in field

Parameter	ETc	Y(t/ha)	N	Nup	1-Nup/Nma	1-(ETa/ETm)	1-Ya/Ym	WUE	FUE	WUE/FUE
2mm	7.97	0.73	0	14.71	0.00	0.80	0.95	0.09	0.05	1.85
2mm,100kg	8.47	0.73	33.3	10.72	0.68	0.79	0.95	0.09	0.07	1.27
2mm,200kg	8.97	0.8	66.7	10.11	0.85	0.77	0.95	0.09	0.08	1.13
2mm,300kg	9.47	0.87	100	10.24	0.90	0.76	0.94	0.09	0.09	1.08
2mm,400kg	9.97	0.8	133.3	10.45	0.92	0.75	0.95	0.08	0.08	1.05
4mm	14.78	1.27	0	12.77	0.00	0.62	0.92	0.09	0.10	0.86
4mm,100kg	15.28	1.3	33.3	6.32	0.81	0.61	0.92	0.09	0.21	0.41
4mm,200kg	16.78	1.33	66.7	18.65	0.72	0.57	0.92	0.08	0.07	1.11
4mm,300kg	17.28	1.43	100	15.21	0.85	0.56	0.91	0.08	0.09	0.88
4mm,400kg	18.78	1.47	133.3	15.22	0.89	0.52	0.91	0.08	0.10	0.81
6mm	21.82	2.63	0	27.03	0.00	0.45	0.83	0.12	0.10	1.24
6mm,100kg	22.32	2.87	33.3	25.76	0.23	0.43	0.82	0.13	0.11	1.15
6mm,200kg	22.82	2.8	66.7	30.28	0.55	0.42	0.82	0.12	0.09	1.33
6mm,300kg	23.32	2.8	100	31.63	0.68	0.41	0.82	0.12	0.09	1.36
6mm,400kg	24.82	2.97	133.3	29.93	0.78	0.37	0.81	0.12	0.10	1.21
8mm	26.14	3.53	0	28.15	0.00	0.34	0.77	0.14	0.13	1.08
8mm,100kg	26.64	3.87	33.3	23.33	0.30	0.32	0.75	0.15	0.17	0.88
8mm,200kg	27.14	3.77	66.7	46.80	0.20	0.31	0.76	0.14	0.08	1.72
8mm,300kg	27.64	4.23	100	28.43	0.72	0.30	0.73	0.15	0.15	1.03
8mm,400kg	28.14	4.03	133.3	31.10	0.77	0.29	0.74	0.14	0.13	1.11

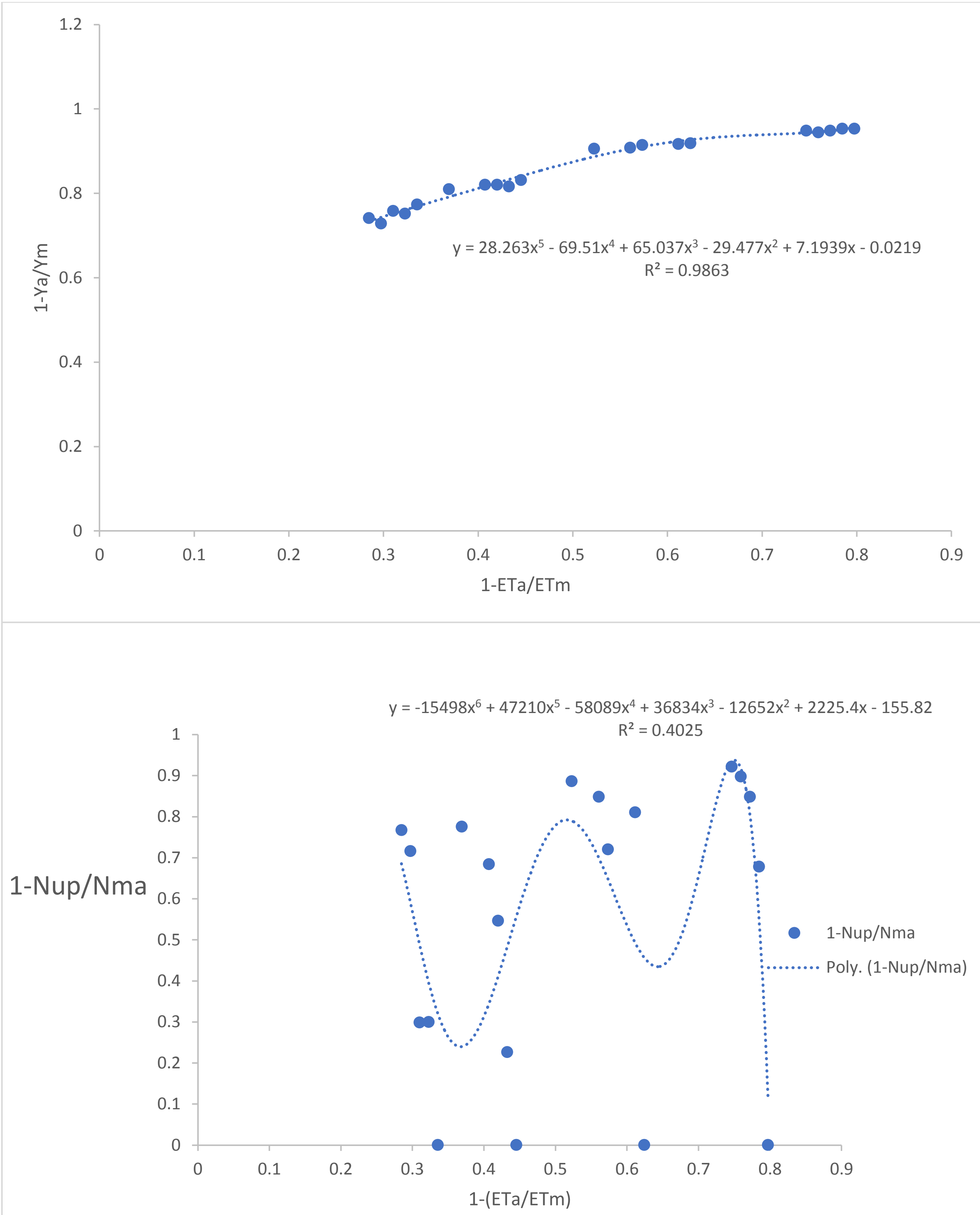


Figure 4.65: Yield reduction (1-Ya/Ym) against Evapotranspiration reduction (1-(ETa/ETm)) and Nitrogen uptake reduction (1-Nup/Nma) against Evapotranspiration reduction

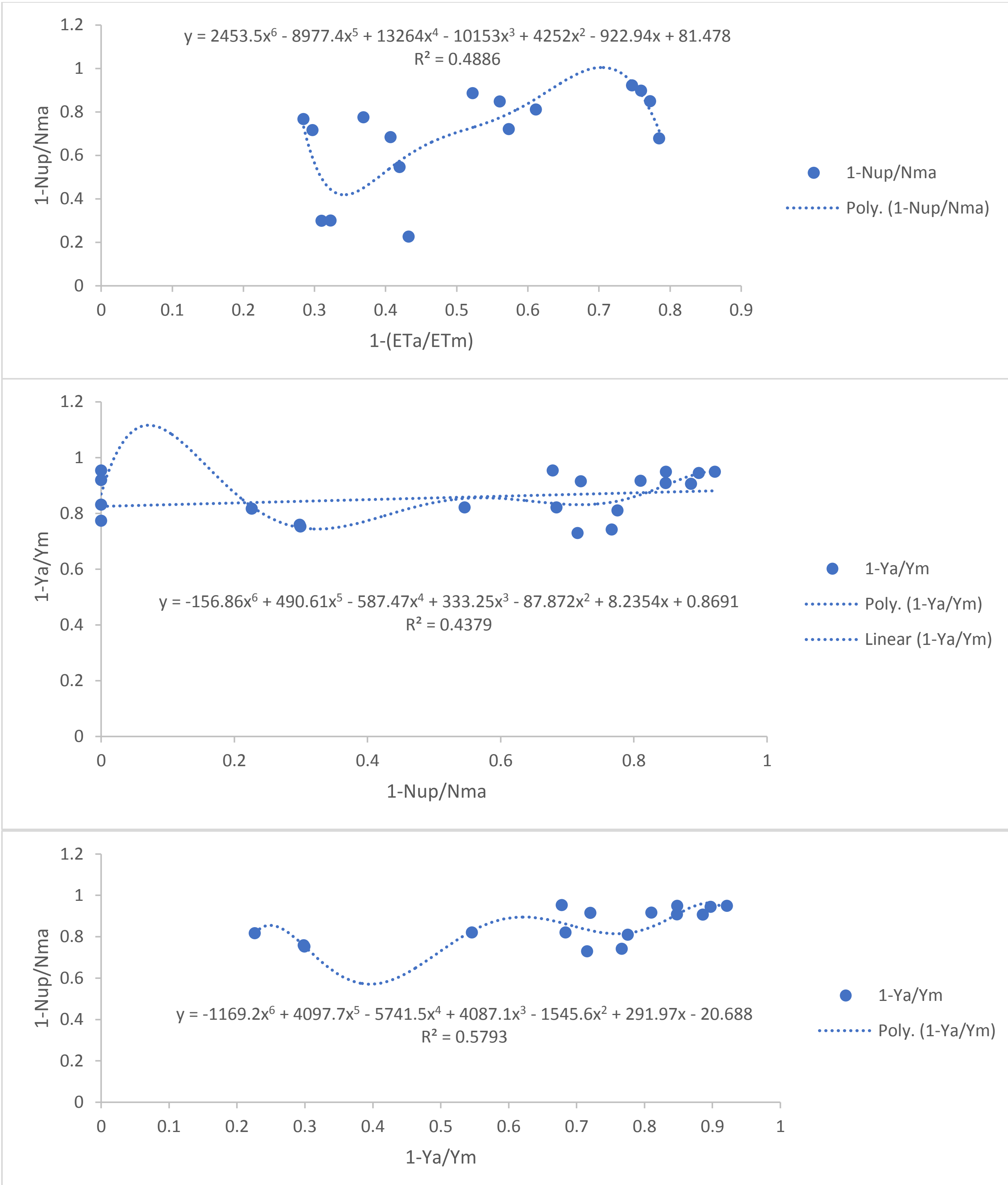
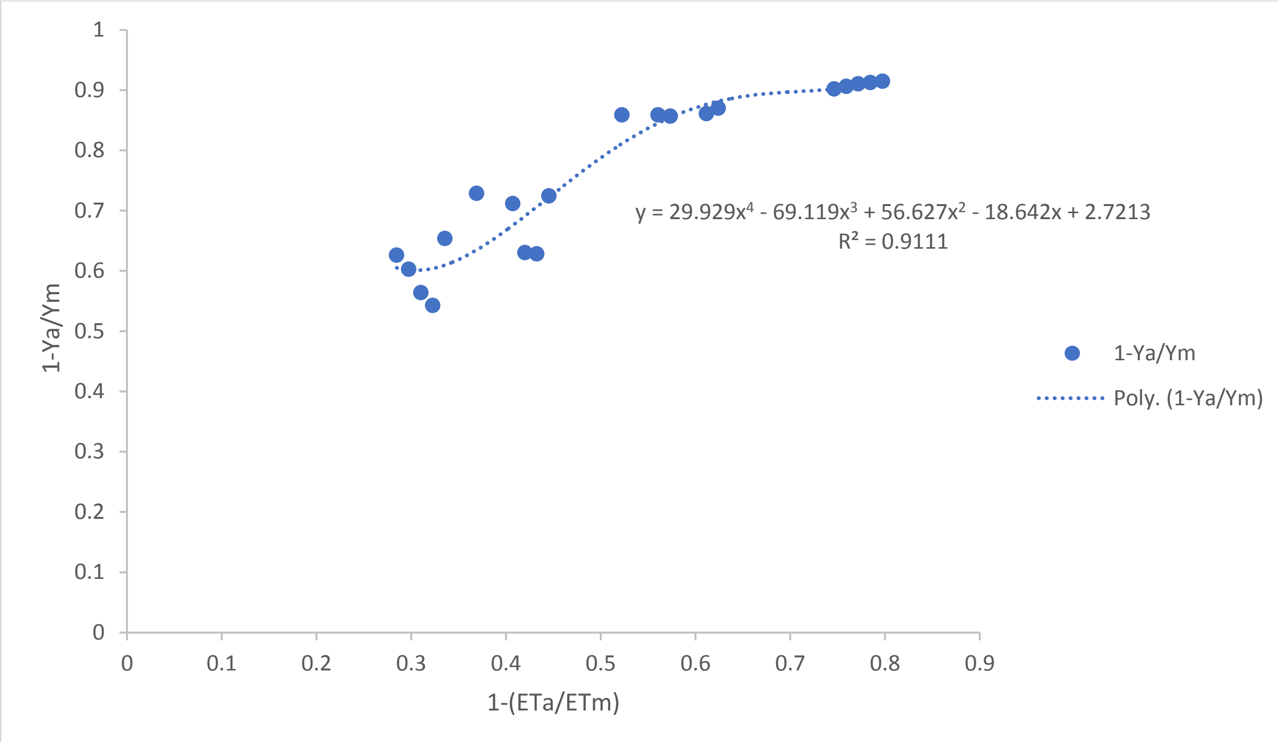


Figure 4.66: Nitrogen uptake reduction against evapotranspiration reduction, Yield reduction against Nitrogen uptake reduction and Nitrogen uptake reduction against yield reduction

Table 4.10: Actual evapo-transpiration, Yield, Nitrogen uptake, Water use efficiency, Fertilizer use efficiency of *Corchorus Olitorus* for greenhouse

Parameter	ETc	Y(t/ha)	N	Nup	1-Nup/Nma	1-(ETa/ETm)	1-Ya/Ym	WUE	FUE	WUE/FUE
2mm	7.97	1.33	0	11.48	0	0.80	0.92	0.17	0.12	1.44
2mm,100kg	8.47	1.37	33.3	10.04	0.70	0.79	0.91	0.16	0.14	1.19
2mm,200kg	8.97	1.4	66.7	12.59	0.81	0.77	0.91	0.16	0.11	1.40
2mm,300kg	9.47	1.47	100	13.03	0.87	0.76	0.91	0.16	0.11	1.38
2mm,400kg	9.97	1.53	133.3	13.23	0.91	0.75	0.90	0.15	0.12	1.33
4mm	14.78	2.03	0	11.04	0	0.62	0.87	0.14	0.18	0.75
4mm,100kg	15.28	2.17	33.3	11.07	0.67	0.61	0.86	0.14	0.20	0.73
4mm,200kg	16.78	2.23	66.7	15.70	0.77	0.57	0.87	0.13	0.14	0.94
4mm,300kg	17.28	2.2	100	14.58	0.85	0.56	0.86	0.13	0.15	0.84
4mm,400kg	18.78	2.2	133.3	14.14	0.89	0.52	0.86	0.12	0.16	0.75
6mm	21.82	4.3	0	26.46	0	0.45	0.72	0.20	0.16	1.21
6mm,100kg	22.32	5.8	33.3	23.96	0.28	0.43	0.63	0.26	0.24	1.07
6mm,200kg	22.82	5.77	66.7	22.70	0.66	0.42	0.63	0.25	0.25	1.0
6mm,300kg	23.32	4.5	100	27.61	0.72	0.41	0.71	0.19	0.16	1.18
6mm,400kg	24.82	4.23	133.3	22.48	0.83	0.37	0.73	0.17	0.19	0.91
8mm	26.14	5.4	0	26.85	0	0.34	0.65	0.21	0.20	1.03
8mm,100kg	26.64	7.133	33.3	28.95	0.13	0.32	0.54	0.27	0.25	1.09
8mm,200kg	27.14	6.8	66.7	28.97	0.57	0.31	0.56	0.25	0.24	1.07
8mm,300kg	27.64	6.2	100	26.80	0.73	0.30	0.60	0.22	0.23	1.00
8mm,400kg	28.14	5.83	133.3	28.47	0.79	0.29	0.63	0.21	0.21	1.01



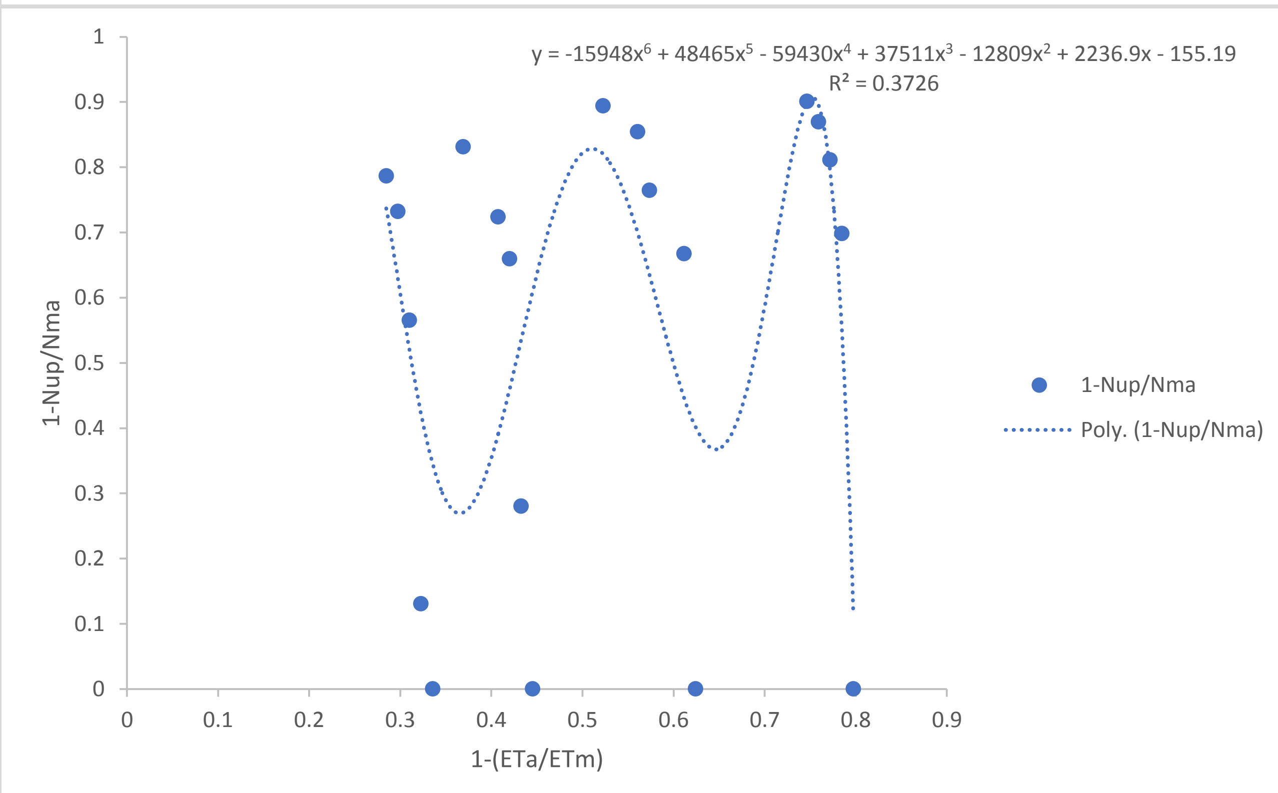


Figure 4.67: Yield reduction against Evapo-transpiration reduction and Nitrogen uptake reduction against yield reduction

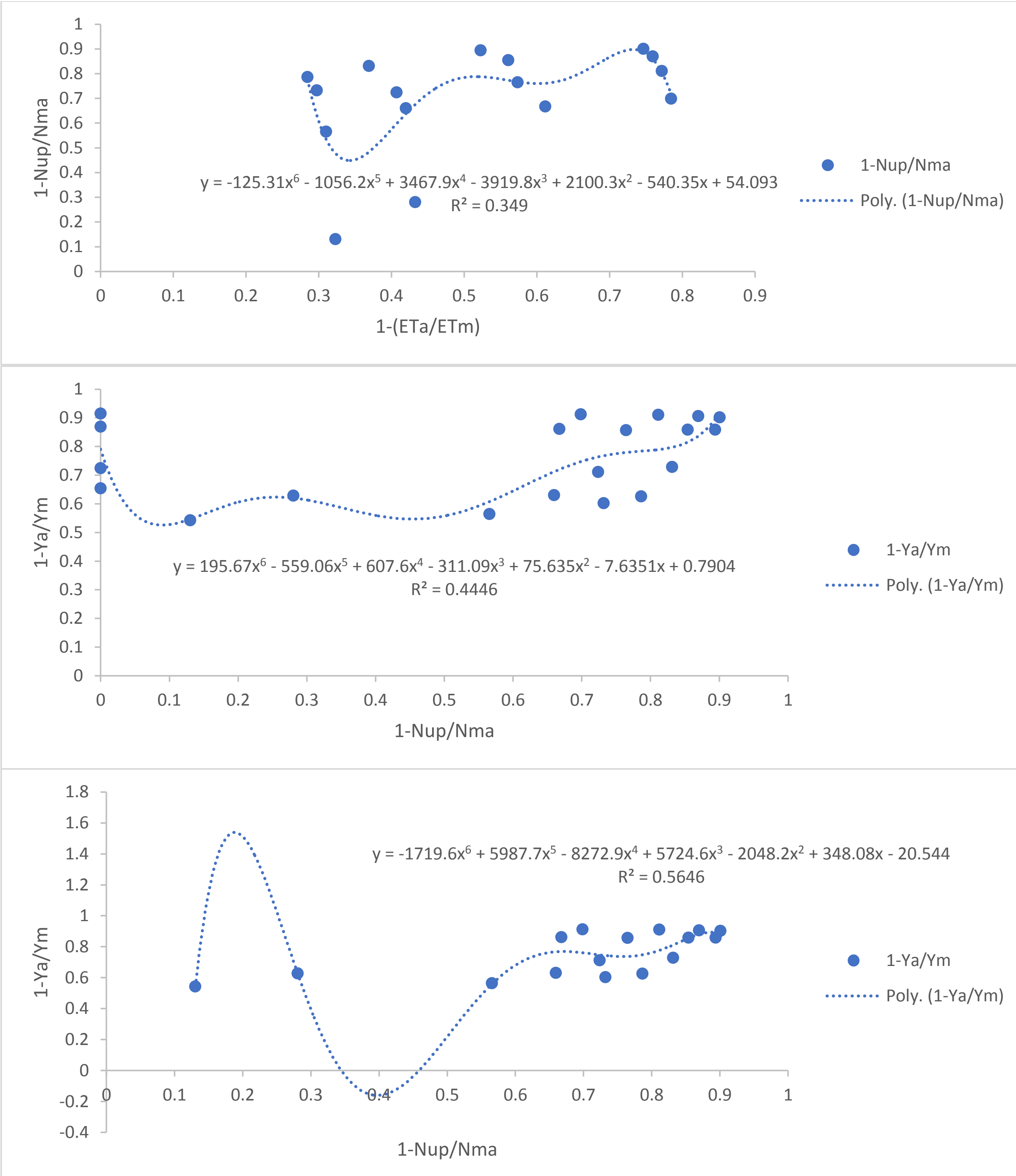


Figure 4.68: Nitrogen uptake reduction against Evapo-transpiration reduction, yield reduction against Nitrogen uptake reduction and Yield reduction against Nitrogen uptake reduction

4.5.1 Simulation using CROPWAT Model

CROPWAT model was used in simulating the crop growth coefficient, crop water requirement (ET_c) which is equal to the irrigation requirement of the crop. The results from table 4.11 showed that the values of the simulated crop growth coefficient (K_c) were similar to the values obtained from field experiments. This shows that the simulation model used was reliable and accurate. The values of the crop coefficient were increasing from the initial stage and peaked at the beginning of the late stage (0.92). This shows that at the beginning of the late stage, the crop water requirement of the crop was almost the same with the potential evapotranspiration which is influenced by the climatic characteristics of the area of study. The values of the crop growth coefficient began to decline and dipped to 0.55. The cumulative amount of the crop water requirement from initial stage to late stage was 142.5mm. This shows that the irrigation requirement is also 142.5mm. However, the volume of water that was supplied can be calculated by multiplying the planted area by the crop water requirement. The crop evapotranspiration was at maximum (2.68 mm/day) at the beginning of the late stage, it slightly reduced to (2.26 mm/day) and attained a bottom value of 1.65 mm/day.

Table 4.11 and 4.12 show that the simulated irrigated field of crop was carried out using the criteria of a fixed interval of 2 days with irrigation application of fixed depth from the day of sowing. It was observed that due to the nature of the soil 0.0mm of water is lost. The main cause for not losing any irrigation water is because the soil was well packed and the strata intact. The relationship between soil moisture deficit and readily available moisture is important in understanding if the crop is experiencing water stress and most be considered in irrigation regimes but having little differences in value as compared to rain fed condition simulation. However, rainfall effect was negligible because the experiment was carried out in dry season. The largest yield reduction (1.3%) occurred in the initial growth stage of the crop. Fig 4.3 showed the Simulation of estimated cumulative yield reduction of 0.2% for the crop throughout the growing season under irrigated condition. The initial soil moisture depletion was 50%, maximum infiltration rate of 52mm/day, maximum rooting depth of 48cm, total available soil moisture of 110.0mm/meter, yield response factor of 0.42, crop depletion fraction of 0.13 and maximum rooting depth of 0.3m. The crop growth stages in days recorded: initial (15days), development (21days), mid-season (8) and late season (27days) making a total of 71days.

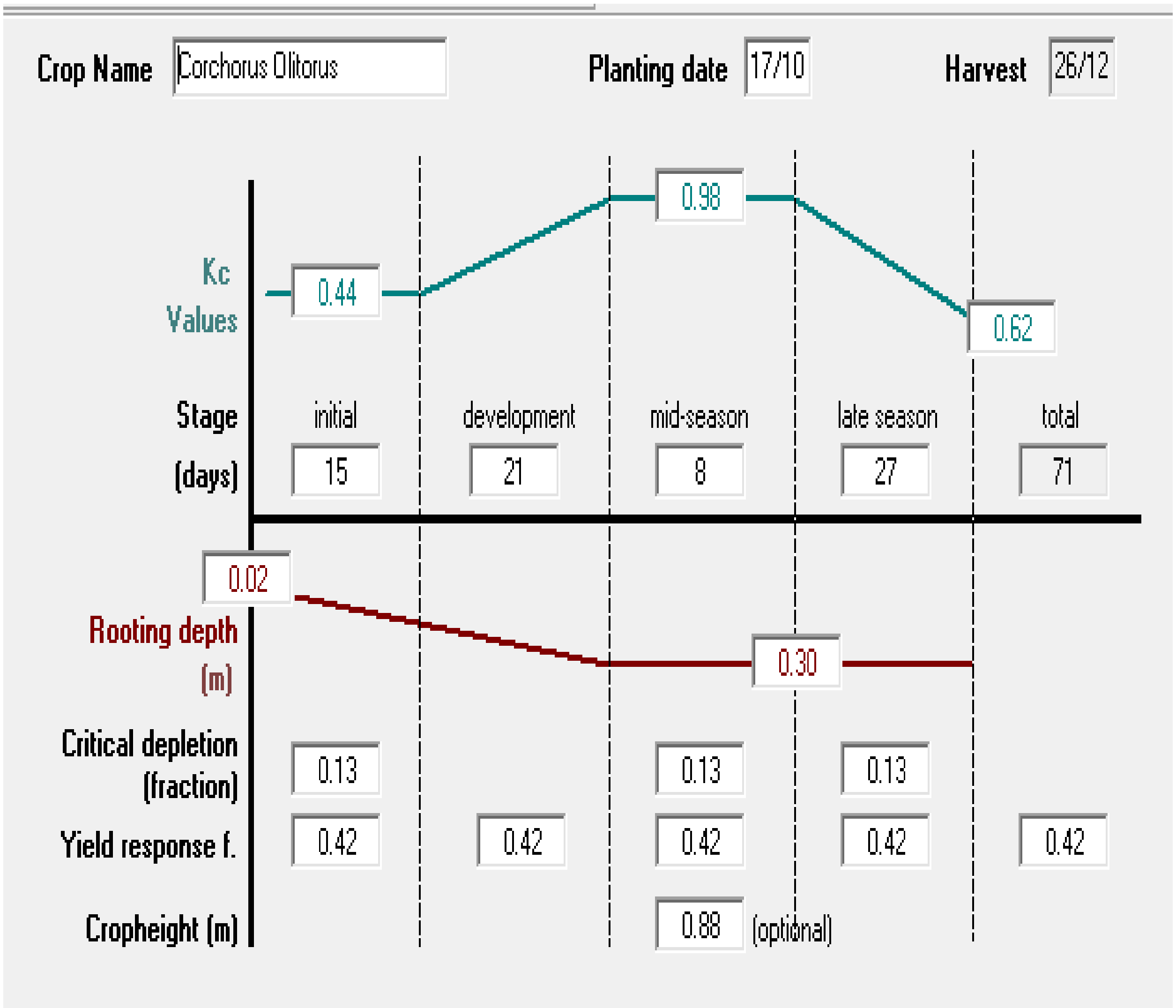


Figure 4.69: Simulation using crop growth parameters

Table 4.11: Simulated results from CROPWAT model compared with Crop Coefficient from field experiment

Month	Decade	Stage	Kc CropWAT	Kc Field	ETc mm/day	ETc	Eff. Rain	Irrigation Requirement
Oct	2	Init	0.44	0.43	1.62	6.5	0.0	6.5
Oct	3	Init	0.44	0.44	1.53	16.8	0.0	16.8
Nov	1	Deve	0.57	0.61	1.84	18.4	0.0	18.4
Nov	2	Deve	0.80	0.81	2.40	24.0	0.0	24.0
Nov	3	Late	0.92	0.98	2.68	26.8	0.0	26.8
Dec	1	Late	0.82	0.89	2.26	22.6	0.0	22.6
Dec	2	Late	0.67	0.61	1.75	17.5	0.0	17.5
Dec	3	Late	0.55	0.61	1.65	9.9	0.0	9.9
						142.5		142.5

Table 4.12: Simulated results from CROPWAT model

Date	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
17-31st Oct	Ini	0.0	0.57-1.0	57-100	13-81	2.0-2.5	0.0	0.0	2.8-3.5	0.32-0.41
1-20th Nov.	Dev.	0.0	1.0	100	14-23	2.3-5.7	0.0	0.0	3.3-8.1	0.73-0.47
21-30th Nov.	Mid	0.0	1.0	100	14-16	5.4	0.0	0.0	7.7	0.44
1-26th Dec	End	0.0	1.0	100	14-16	4.5-5.4	0.0	0.0	6.5-7.7	0.27-0.44

Table 4.13: Simulated results from CropWAT model

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
17 Oct	1	Init	0.0	0.57	57	81	2.5	0.0	0.0	3.5	0.41
18 Oct	2	Init	0.0	1.00	100	53	2.1	0.0	0.0	2.9	0.34
19 Oct	3	Init	0.0	1.00	100	43	2.1	0.0	0.0	2.9	0.34
20 Oct	4	Init	0.0	1.00	100	37	2.1	0.0	0.0	2.9	0.34
21 Oct	5	Init	0.0	1.00	100	30	2.0	0.0	0.0	2.8	0.32
22 Oct	6	Init	0.0	1.00	100	27	2.0	0.0	0.0	2.8	0.32
23 Oct	7	Init	0.0	1.00	100	24	2.0	0.0	0.0	2.8	0.32
24 Oct	8	Init	0.0	1.00	100	22	2.0	0.0	0.0	2.8	0.32
25 Oct	9	Init	0.0	1.00	100	20	2.0	0.0	0.0	2.8	0.32
26 Oct	10	Init	0.0	1.00	100	18	2.0	0.0	0.0	2.8	0.32
27 Oct	11	Init	0.0	1.00	100	17	2.0	0.0	0.0	2.8	0.32
28 Oct	12	Init	0.0	1.00	100	16	2.0	0.0	0.0	2.8	0.32
29 Oct	13	Init	0.0	1.00	100	15	2.0	0.0	0.0	2.8	0.32
30 Oct	14	Init	0.0	1.00	100	14	2.0	0.0	0.0	2.8	0.32
31 Oct	15	Init	0.0	1.00	100	13	2.0	0.0	0.0	2.8	0.32
1 Nov	16	Dev	0.0	1.00	100	14	2.3	0.0	0.0	3.3	0.38
2 Nov	17	Dev	0.0	1.00	100	14	2.3	0.0	0.0	3.3	0.38
4 Nov	19	Dev	0.0	0.98	99	24	4.5	0.0	0.0	6.5	0.37
6 Nov	21	Dev	0.0	0.99	100	23	4.5	0.0	0.0	6.5	0.38
8 Nov	23	Dev	0.0	1.00	100	21	4.6	0.0	0.0	6.5	0.38
10 Nov	25	Dev	0.0	1.00	100	19	4.6	0.0	0.0	6.5	0.38
12 Nov	27	Dev	0.0	1.00	100	22	5.7	0.0	0.0	8.1	0.47
14 Nov	29	Dev	0.0	1.00	100	21	5.7	0.0	0.0	8.1	0.47
16 Nov	31	Dev	0.0	1.00	100	20	5.7	0.0	0.0	8.1	0.47
18 Nov	33	Dev	0.0	1.00	100	19	5.7	0.0	0.0	8.1	0.47
20 Nov	35	Dev	0.0	1.00	100	18	5.7	0.0	0.0	8.1	0.47
22 Nov	37	Mid	0.0	1.00	100	16	5.4	0.0	0.0	7.7	0.44
24 Nov	39	Mid	0.0	1.00	100	16	5.4	0.0	0.0	7.7	0.44

26 Nov	41	Mid	0.0	1.00	100	16	5.4	0.0	0.0	7.7	0.44
28 Nov	43	Mid	0.0	1.00	100	16	5.4	0.0	0.0	7.7	0.44
30 Nov	45	End	0.0	1.00	100	16	5.4	0.0	0.0	7.7	0.44
2 Dec	47	End	0.0	1.00	100	14	4.5	0.0	0.0	6.5	0.37
4 Dec	49	End	0.0	1.00	100	14	4.5	0.0	0.0	6.5	0.37
6 Dec	51	End	0.0	1.00	100	14	4.5	0.0	0.0	6.5	0.37
8 Dec	53	End	0.0	1.00	100	14	4.5	0.0	0.0	6.5	0.37
10 Dec	55	End	0.0	1.00	100	14	4.5	0.0	0.0	6.5	0.37
13 Dec	58	End	0.0	1.00	100	16	5.2	0.0	0.0	7.5	0.29
16 Dec	61	End	0.0	1.00	100	16	5.2	0.0	0.0	7.5	0.29
19 Dec	64	End	0.0	1.00	100	16	5.2	0.0	0.0	7.5	0.29
22 Dec	67	End	0.0	1.00	100	15	5.1	0.0	0.0	7.2	0.28
25 Dec	70	End	0.0	1.00	100	15	5.0	0.0	0.0	7.1	0.27
26 Dec	End	End	0.0	1.00	0	0					

Table 4.14: Yield and Stress Tolerance Index of *Corchorus olitorus*

Parameter	Yield Field 16	STI	Yield Field 17	STI	Yield Screen 16	STI	Yield Screen 17	STI
2mm	0.80±0.12	0.073	0.73±0.15	0.067	0.97±0.14	0.088	1.33±0.21	0.121
2mm,100kg	0.90±0.11	0.082	0.73±0.14	0.067	1.00±0.11	0.091	1.37±0.15	0.124
2mm,200kg	0.90±0.14	0.082	0.80±0.12	0.073	1.03±0.12	0.094	1.40±0.12	0.127
2mm,300kg	0.93±0.12	0.085	0.87±0.13	0.079	1.17±0.11	0.106	1.47±0.11	0.133
2mm,400kg	0.93±0.15	0.085	0.80±0.15	0.073	1.17±0.21	0.106	1.53±0.15	0.139
4mm	1.80±0.15	0.164	1.27±0.12	0.115	1.60±0.13	0.145	2.03±0.16	0.185
4mm,100kg	1.87±0.15	0.170	1.30±0.14	0.118	1.77±0.12	0.161	2.17±0.16	0.197
4mm,200kg	2.07±0.13	0.188	1.33±0.16	0.121	2.27±0.21	0.206	2.23±0.13	0.203
4mm,300kg	2.37±0.21	0.215	1.43±0.11	0.130	2.20±0.27	0.200	2.20±0.20	0.200
4mm,400kg	2.47±0.35	0.224	1.47±0.14	0.133	2.13±0.23	0.194	2.20±0.13	0.200
6mm	3.47±0.20	0.315	2.63±0.13	0.239	3.53±0.50	0.321	4.30±0.90	0.391
6mm,100kg	3.60±0.36	0.327	2.87±0.21	0.261	5.03±0.68	0.458	5.80±0.61	0.527
6mm,200kg	4.03±0.25	0.367	2.80±0.36	0.255	5.73±0.38	0.521	5.77±0.38	0.524
6mm,300kg	4.03±0.35	0.367	2.80±0.30	0.255	3.77±0.16	0.342	4.50±0.36	0.409
6mm,400kg	4.20±0.27	0.382	2.97±0.36	0.270	3.25±0.36	0.296	4.23±0.50	0.385
8mm	4.27±0.16	0.388	3.53±0.57	0.321	4.63±0.84	0.421	5.40±0.91	0.491
8mm,100kg	4.47±0.45	0.406	3.87±0.42	0.352	6.90±0.27	0.627	7.13±0.38	0.649
8mm,200kg	4.83±0.38	0.439	3.77±0.21	0.342	6.50±0.33	0.591	6.80±0.36	0.618
8mm,300kg	5.07±0.35	0.461	4.23±0.21	0.385	4.50±0.61	0.409	6.20±0.40	0.564
8mm,400kg	4.97±0.41	0.452	4.03±0.35	0.367	4.03±0.33	0.367	5.83±0.38	0.530

4.6 WEIGHT OF FRESH PLANT, WEIGHT OF DRY PLANT AND YIELD

Figure 4.70 presents the weight of fresh plant, weight of dry plant and yield of *Corchorus olitorus* as influenced by water and fertilizer treatment in greenhouse for the first two charts. After harvesting, treatment (2ET, 100kg NPK) from the first trial recorded the highest mean value of 23.03g for the fresh weight of plant which was observed to be significantly higher than other treatments apart from treatment (2ET, 200kg NPK) only which had a mean value of 21.68g. Treatment (3/2ET, 200kg NPK) was the next with a mean value of 19.05g which was significantly higher than other treatments within the range of 3.03-16.71g where treatment (1/2ET, 0kg NPK) had the lowest value. At the end of the second trial, the fresh weight of plant for treatment (2ET, 100kg NPK) had the highest mean value of 26.54g which was not significantly greater than treatment (2ET, 200) which recorded a mean value of 25.16g but was significantly greater than other treatment which were within the range of 4.37-22.63g where treatment (1/2ET, 0kg NPK) recorded the least value

At the end of the first trial, treatment (2ET, 100kg NPK) had the highest mean value of 3.0g for the weight of dry plant which was observed to be significantly higher than other treatments apart from treatment (2ET, 200kg NPK) only which had a mean value of 2.82g. Treatment (2ET, 400kg NPK) was the next with a mean value of 2.71g which was observed to be significantly higher than other treatments within the range of 1.0-2.37g where treatment (1/2ET, 100kg NPK) had the lowest value. At the end of the second trial, treatment (2ET, 100kg NPK) had the highest mean value of 3.03g for the weight of dry plant which was significantly higher than other treatments apart from treatment (2ET, 100kg NPK) only which had a mean value of 3.0g. Treatment (2ET, 400kg NPK) was the next with a mean value of 2.46g which was significantly higher than other treatments except for treatment (2ET, 300kg NPK) with a mean value of 2.37g. Other treatments had mean values within the range of 1.0-2.33g where treatment (1/2ET, 0kg NPK) and (1/2ET, 100kg NPK) had the lowest value.

At the end of the first trial, 6.90t/ha was recorded as the highest yield from treatment (2ET, 100kg NPK) which was significantly higher than other treatments apart from treatment (2ET, 200kg NPK) only which had a mean value of 6.50t/ha. Treatment (3/2ET, 200kg NPK) was the next with a mean value of 5.73g which was significantly higher than other treatments within the range of 0.97-5.03t/ha where treatment (1/2ET, 0kg NPK) had the lowest value. At the end of the second trial, the fresh weight of plant for treatment (2ET, 100kg NPK) had the highest mean value of 7.13t/ha which was not significantly greater than treatment (2ET, 200kg NPK) which recorded a mean value of 6.80t/ha but was significantly greater than other treatment which were within the range of 1.33-6.20t/ha. However, no significant difference was observed between treatments (2ET, 200kg NPK) and (2ET, 300kg NPK) but treatment (1/2ET, 0kg NPK) recorded the least value

Figure 4.70 presents the weight of fresh plant, weight of dry plant and yield of *Corchorus olitorus* as influenced by water and fertilizer treatment in the field. After harvesting, for the fresh weight of plant, treatment (2ET, 300kg NPK) from the first trial recorded the highest mean value of 16.78g which was significantly higher than other treatments apart from treatments (2ET, 400kg NPK) and (2ET, 200kg NPK) which had mean values of 16.43g and 16.13g respectively. Treatment (3/2ET, 100kg NPK) was the next with a mean value of 14.87g which was significantly higher than other treatments within the range of 2.83-14.11g where treatment (1/2ET, 100kg NPK) had the lowest value. At the end of the second trial, treatment (2ET, 400kg NPK) had the highest mean value of 13.43g for the fresh weight of the plant which was not significantly greater than treatment (2ET, 300kg NPK), (2ET, 100kg NPK), (2ET, 200kg NPK) and (2ET, 0kg NPK) which recorded mean values of 13.21g, 12.74g, 12.68g and 11.78g respectively but was significantly greater than other treatments which had mean values within the range of 2.41-9.84g where treatment (1/2ET, 0kg NPK) recorded the least value

At the end of the first trial, treatment (3/2ET, 400kg NPK) had the highest mean value of 1.20g for the weight of dry plant which was significantly higher than treatments (1ET, 0kg NPK), (1ET, 300kg NPK), (1ET, 200kg NPK), (1/2ET, 400kg NPK), (1/2ET, 300kg NPK), (1ET, 100kg NPK), (1/2ET, 200kg NPK), (2ET, 100kg NPK) and (1/2ET, 0kg NPK) with mean values within the range of 1.0-1.08g. Treatment (2ET, 400kg NPK) was the next with a mean value of 1.18g which was not significantly lower than treatment (3/2ET, 400kg NPK). However, treatment (1/2ET, 0kg NPK), (1ET, 100kg NPK), (1/2ET, 200kg NPK) and (1/2ET, 100kg NPK) had the lowest value. At the end of the second trial, treatment (3/2ET, 400kg NPK) had the highest mean value of 1.23g for the weight of dry plant which was significantly higher than treatments (2ET, 0kg NPK), (2ET, 100kg NPK), (1ET, 0kg NPK), (1/2ET, 400kg NPK), (1/2ET, 300kg NPK), (1ET, 200kg NPK), (1/2ET, 200kg NPK), (1/2ET, 100kg NPK), (1ET, 300kg

NPK) (1ET, 100kg NPK) and (1/2ET, 0kg NPK) which had mean values of 1.0-1.15g. Treatment (1ET, 400kg NPK) was the next with a mean value of 1.19g which was not significantly lower than the maximum value obtained. However, treatment (1/2ET, 0kg NPK) had the lowest value.

At the end of the first trial, 5.07t/ha was recorded as the highest yield from treatment (2ET, 300kg NPK) which was significantly higher than other treatments apart from treatment (2ET, 400kg NPK) and (2ET, 200kg NPK) which had mean values of 4.97t/ha and 4.83t/ha respectively. Other treatments which were significantly lower where within the range of 0.8-4.46t/ha where treatment (1/2ET, 0kg NPK) had the lowest value. At the end of the second trial, the yield for treatment (2ET, 300kg NPK) had the highest mean value of 4.23t/ha which was not significantly greater than treatment (2ET, 400kg NPK) and (2ET, 100kg NPK) with mean values of 4.03t/ha and 3.87t/ha respectively. However, other treatments were within the range of 0.73-3.77t/ha but treatment (2ET, 200kg NPK) and (1/2ET, 0kg NPK) recorded the least value.

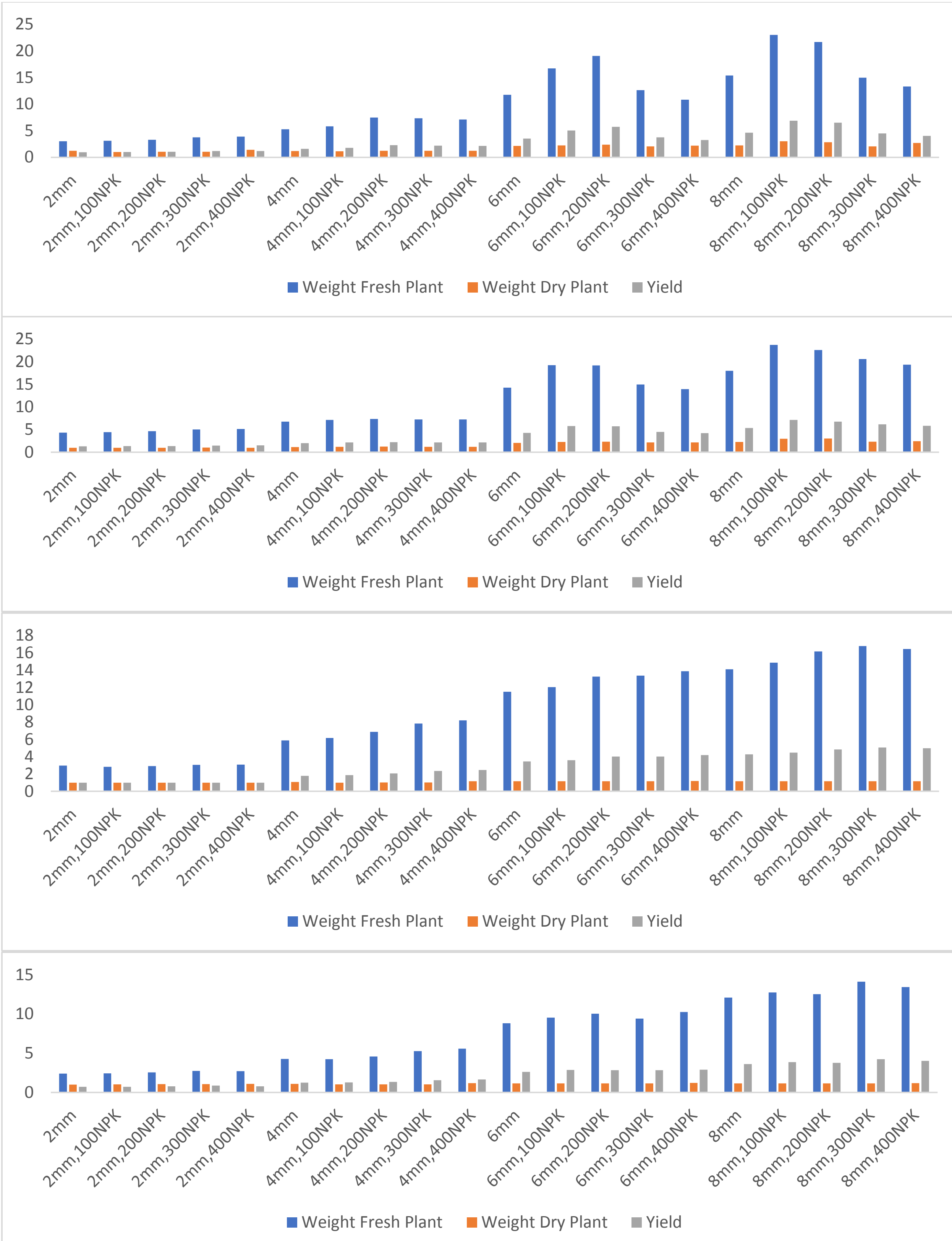


Figure 4.70: Graph of Weight fresh plant, weight dry plant and yield for greenhouse and field experiment 2016 and 2017

4.7 YIELD PREDICTIONS

This results from figure 4.71-4.74 show regression equations that can be used to predict yield of *Corchorus olitorus* from both field and greenhouse at different irrigation regimes and fertilizer application. Most of the results had R^2>0.9 which implies a high level of reliability of the model. The results from fig. 4.71, show that the value of the yield recorded a maximum value from the experiment carried out in the greenhouse as compared to the values from the field. Empirical models developed are $y=-7E-15x^3+0.007x^2+0.008x+1.319$, $R^2 = 0.9973$ and $y=-0.0112x^3+ 0.103x^2-0.2218x+1.1018$,$R^2= 0.9548$ (greenhouse) while $y=0.0056x^3-0.0669x^2+0.2615x+0.5998$, $R^2 = 1$, was developed for field trials. Figure 4.72 shows models developed for irrigation regime of 4mm at different fertilizer application are $y=0.0084x^3-0.102x^2+0.3926x+1.7316$, $R^2 = 0.9845$ and $y = -0.0278x^3 + 0.2616x^2 - 0.5426x+2.1126$, $R^2 = 0.9971$ for greenhouse, while $y=-0.0277x^3+0.1758x^2-0.0614x+1.4924$, $R^2= 0.9104$ and $y=-0.0055x^3+0.0549x^2-0.1086x+1.3294$, $R^2 = 0.9773$, were developed for field experiment. Empirical models of $y=0.2111x^3-2.2403x^2+6.8816x-0.58$, $R^2 = 0.9788$ and $y=-0.0111x^3+0.0737x^2+0.0848x+3.3006$, $R^2 = 0.9361$, were developed for greenhouse experiment while models $y =0.1877x^3 - 2.1671x^2 + 7.1152x - 1.6882$, $R^2=0.8876$ and $y=0.039x^3-0.3558x^2+1.0092x+1.9444$, $R^2 = 0.9827$, were developed for 6mm at different fertilizer application. Figure 4.73 shows empirical models developed to predict yield at 8mm water application depth with different fertilizer application rate. The models generated from the greenhouse are $y=0.1916x^3-2.0433x^2+6.4291x+0.8412$, $R^2 = 0.9878$ and $y=-0.0417x^3+0.3227x^2-0.4696x+ 4.4542$, $R^2 = 0.9997$ while $y=0.35x^3-3.6549x^2+10.929x-3.0208$, $R^2 = 0.9909$ and $y = -0.0193x^3+0.1381x^2- 0.1045x+3.5506$, $R^2 = 0.7469$, were developed for field trials. The yield recorded from the greenhouse increased as the amount of fertilizer applied increased. However, it got to a point where an increase in the amount of fertilizer applied resulted to a decrease in yield. This implies the right amount of fertilizer should be added during planting for farmers to make profit. The yield recorded from the greenhouse was higher than those recorded from the field. This is because the plants in the field experience more stress compared to plants in the greenhouse. It is therefore important to note that planting of crops in the greenhouse are more profitable than planting in the field. The initial cost of setting up a greenhouse might be high. However, crop cultivation in greenhouse are more profitable than the field.

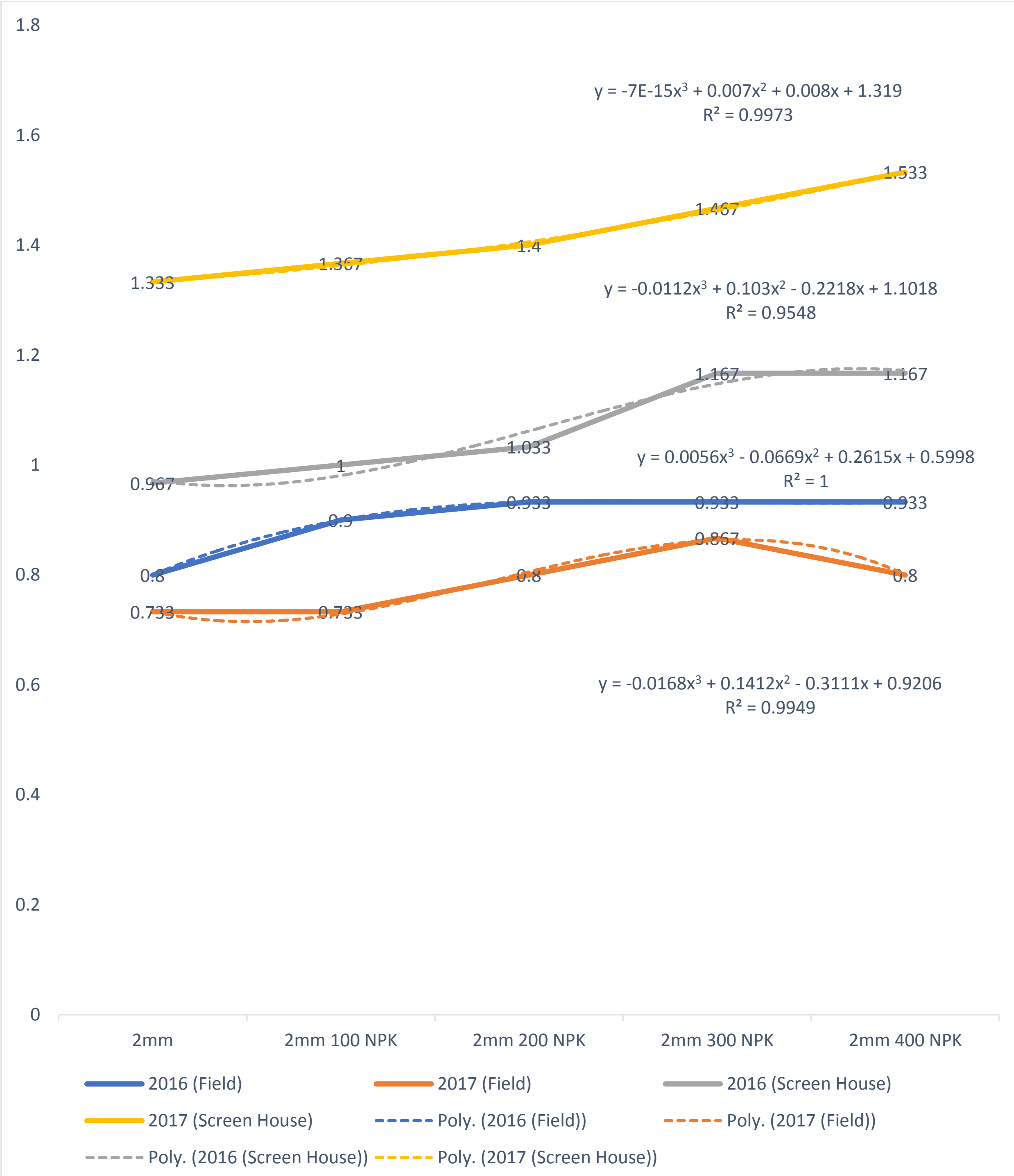


Figure 4.71: Yield (t/ha) against Treatments (water application and fertilizer application) for 2mm at year 2016 and 2017 for both Field and greenhouse

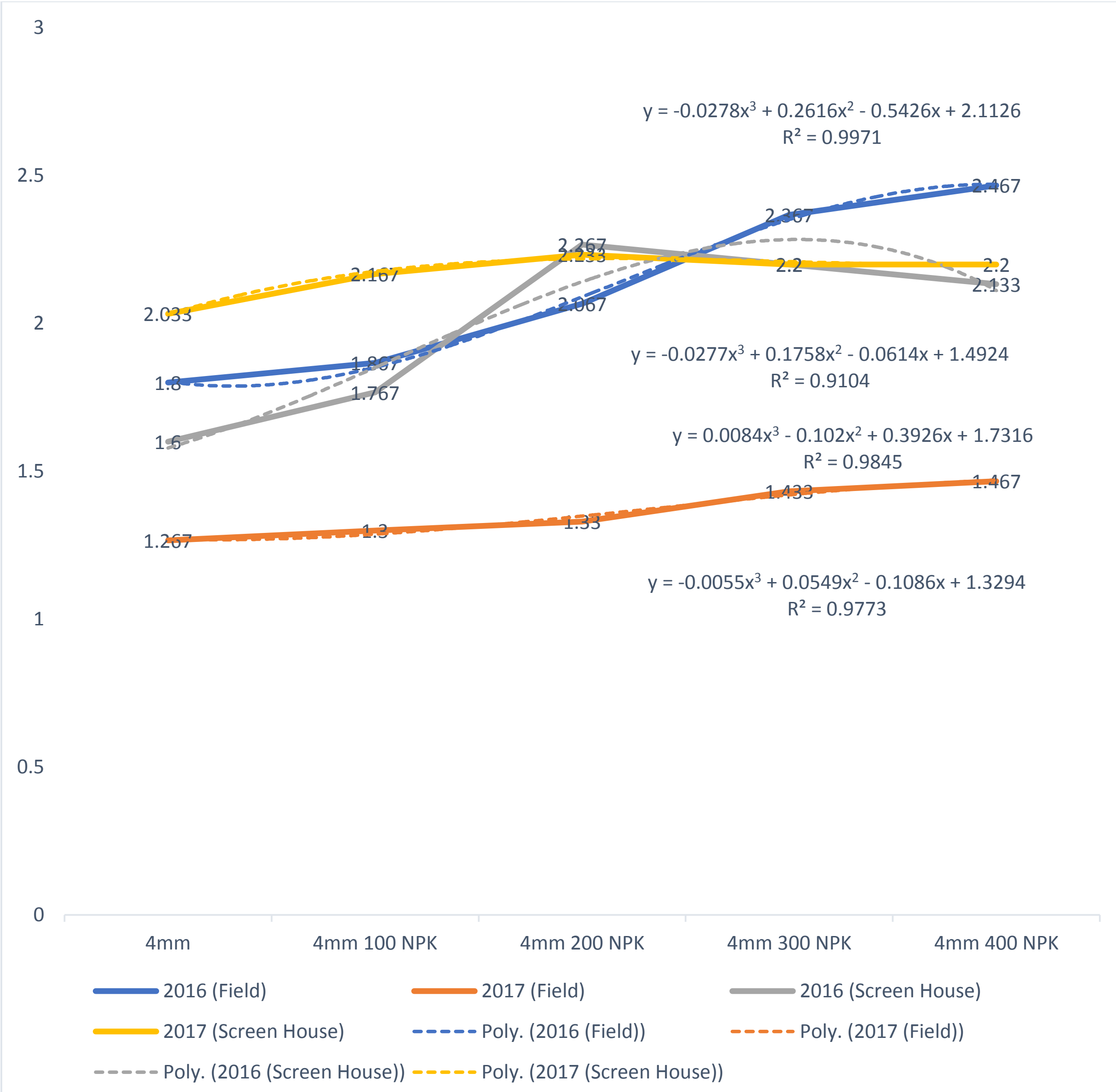


Figure 4.72: Yield (t/ha) against Treatments (water application and fertilizer application) for 4mm at year 2016 and 2017 for both Field and greenhouse

Figure 4.73: Yield (t/ha) against Treatments (water application and fertilizer application) for 6mm at year 2016 and 2017 for both Field and greenhouse

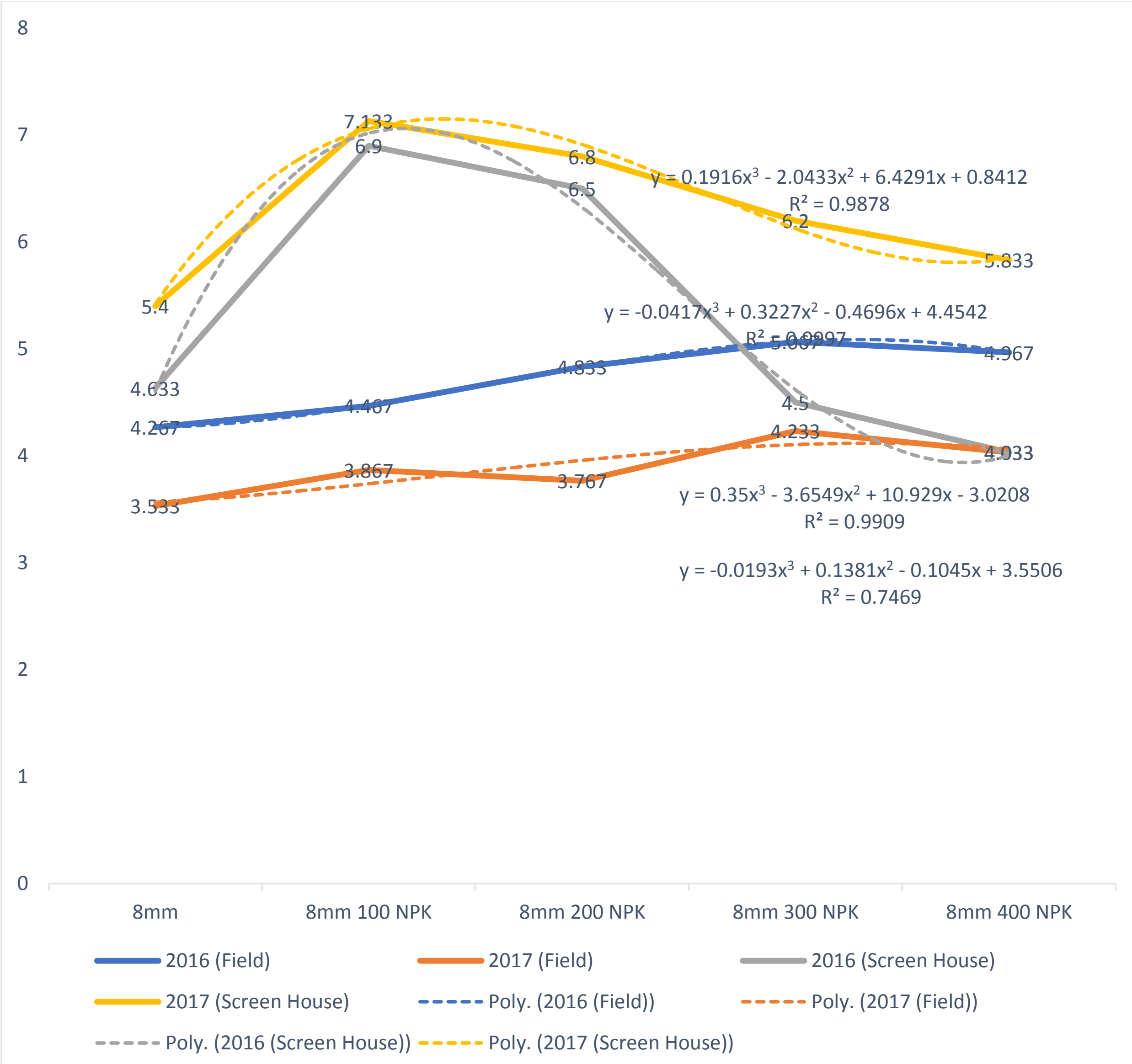


Figure 4.74: Yield (t/ha) against Treatments (water application and fertilizer application) for 8mm at year 2016 and 2017 for both Field and greenhouse

4.8 PROXIMATE ANALYSIS

4.8.1 Crude Protein Content

Figure 4.75 shows the crude protein content of *Corchorus olitorus* as influenced by water and fertilizer treatment. At the end of the first trial, 25.15% was recorded as the highest mean value for crude protein content from treatments with 100kg NPK which was significantly higher than mean values obtained from other treatments. Plants with treatments 200kg NPK recorded a value of 23.56%, which was significantly higher than treatments 300kg NPK and 400kg NPK. 17.77% was obtained for treatments of 300kg NPK which was significantly higher than treatment 400kg NPK which recorded the least value.

At the end of the second trial, crude protein content from treatment with 100kg had the highest mean value of 18.29% which was significantly higher than other treatments. However, treatment 400kg NPK had the lowest value of 11.90% for figure 4.76.

4.8.2 Crude Fat Content

Figure 4.75 shows the crude fat of *Corchorus olitorus* as influenced by water and fertilizer treatment. At the end of the first trial, a mean value of 9.99% was recorded as the highest crude fat content from treatments with 100kg NPK which was significantly higher than the mean values of crude fat from other treatments. Plants with treatments 200kg NPK recorded a mean value of 7.22%, which was significantly higher than mean values obtained from treatments 300kg NPK and 400kg NPK. 5.92% was obtained as the mean value of crude fat for treatments of 300kg NPK which was significantly higher than treatment 400kg NPK which recorded the least mean value of 3.90%.

At the end of the second trial, 8.02% was recorded as the highest mean value of crude fat from treatment 100kg NPK which was observed to be significantly higher than other treatments. However, 2.3% was recorded as the lowest value which was obtained from treatment 400kg NPK for figure 4.76.

4.8.3 Ash Content

Figure 4.75 shows the ash content of *Corchorus olitorus* as influenced by water and fertilizer treatment. At the end of the trial, the highest mean value of 27.30% of ash was recorded from treatment with 400kg NPK which was significantly higher than the mean values from other treatments. The ash content of plants with treatment 300kg NPK recorded a mean value of 25.25%, which was significantly higher than mean values obtained from treatments 300kg NPK and 400kg NPK. 18.76% was obtained as the mean value of ash content for treatments of 300kg NPK which was significantly higher than treatment 100kg NPK which recorded the least mean value of 12.98%.

Figure 4.76 shows treatment 400kg NPK recording the highest mean value of 23.06% which was significantly higher than treatment 300kg NPK with mean value of 19.56%. However, 10.54% was recorded as the lowest value for treatment 100kg NPK

4.8.4 Carbohydrate Content

Figure 4.75 shows the carbohydrate content of *Corchorus olitorus* as influenced by water and fertilizer treatment. At the end of the trial, the highest mean value of 29.58% of carbohydrate content was recorded from treatments with 400kg NPK which was significantly higher than the mean values from other treatments. The carbohydrate content of plants with treatments 300kg NPK recorded a mean value of 20.19%, which was significantly higher than mean values obtained from treatments 200kg NPK and 100kg NPK. 18.99% was obtained as the mean value of ash content for treatments of 200kg NPK which was significantly higher than treatments 100kg NPK which recorded the least mean value of 11.44%.

The highest mean value of 23.02% of carbohydrate content was obtained from treatments with 400kg NPK which was observed to be significantly higher than other treatments. Treatments with 300, 200, 100kg NPK had values of 15.77, 12.40 and 8.96% respectively for figure 4.76.

4.8.5 Crude Fibre Content

Figure 4.75 shows the crude fibre of *Corchorus olitorus* as influenced by water and fertilizer treatment. At the end of the first trial, the highest mean value of 0.25% of crude fibre was recorded from treatments with 100kg NPK which was not significantly higher than the mean value of treatments 200kg NPK with a mean value of 0.23%. However, it was significantly higher than treatment 200kg NPK and 100kg NPK, which had mean values of 0.13% and 0.11% respectively. The crude fibre content of plants with treatments 400kg NPK and 300kg NPK, did not show any significant difference.

0.19% of crude fibre was recorded as the highest mean value of crude fibre from treatment 100kg NPK in the second trial which was significantly higher than treatments 400 and 300kg NPK with mean values of 0.18 and 0.19% respectively. However, treatment 200kg NPK had mean value of 0.16 (figure 4.76).

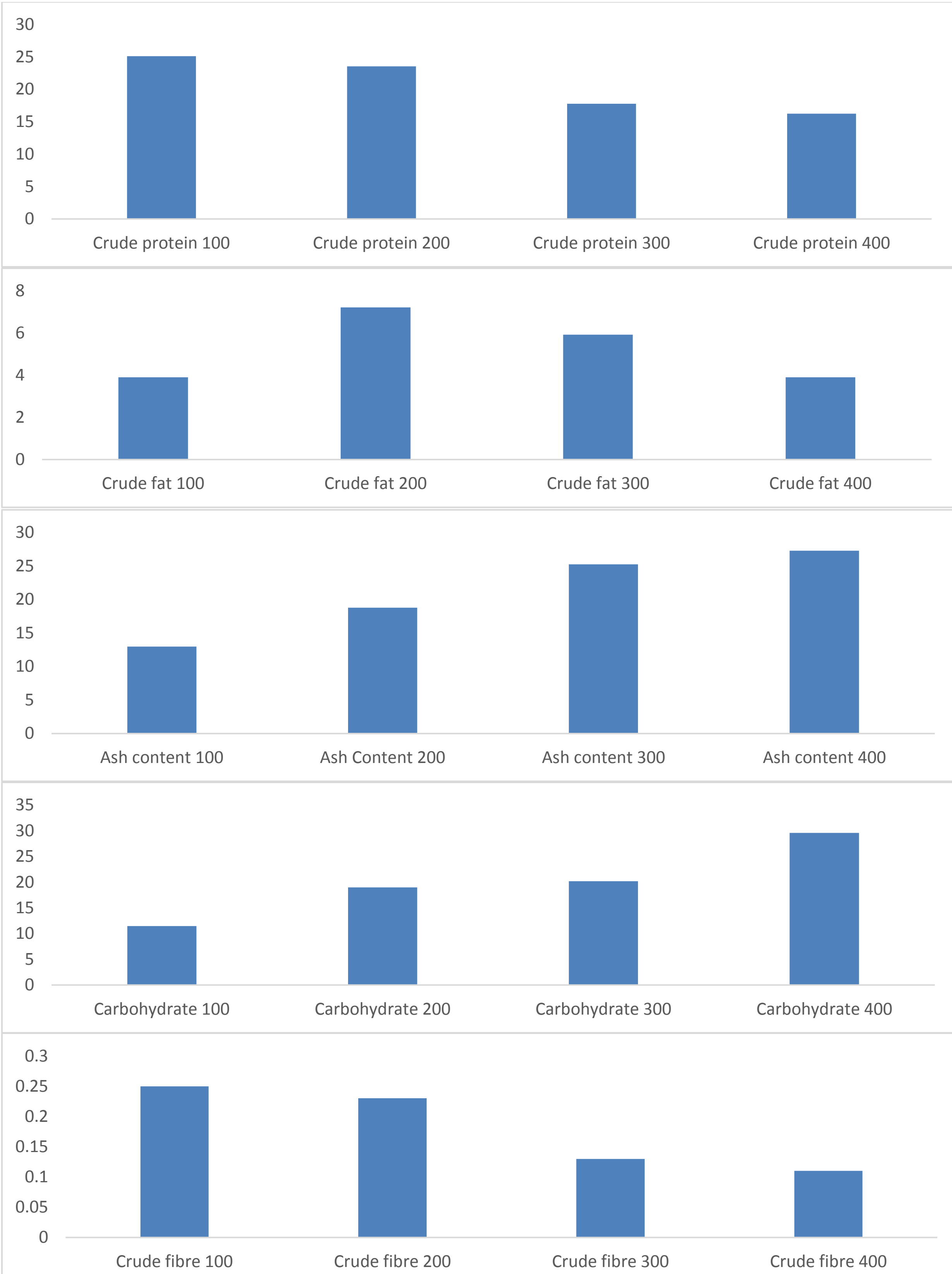


Figure 4.75: Proximate analysis parameters at different fertilizer application (First Trial)

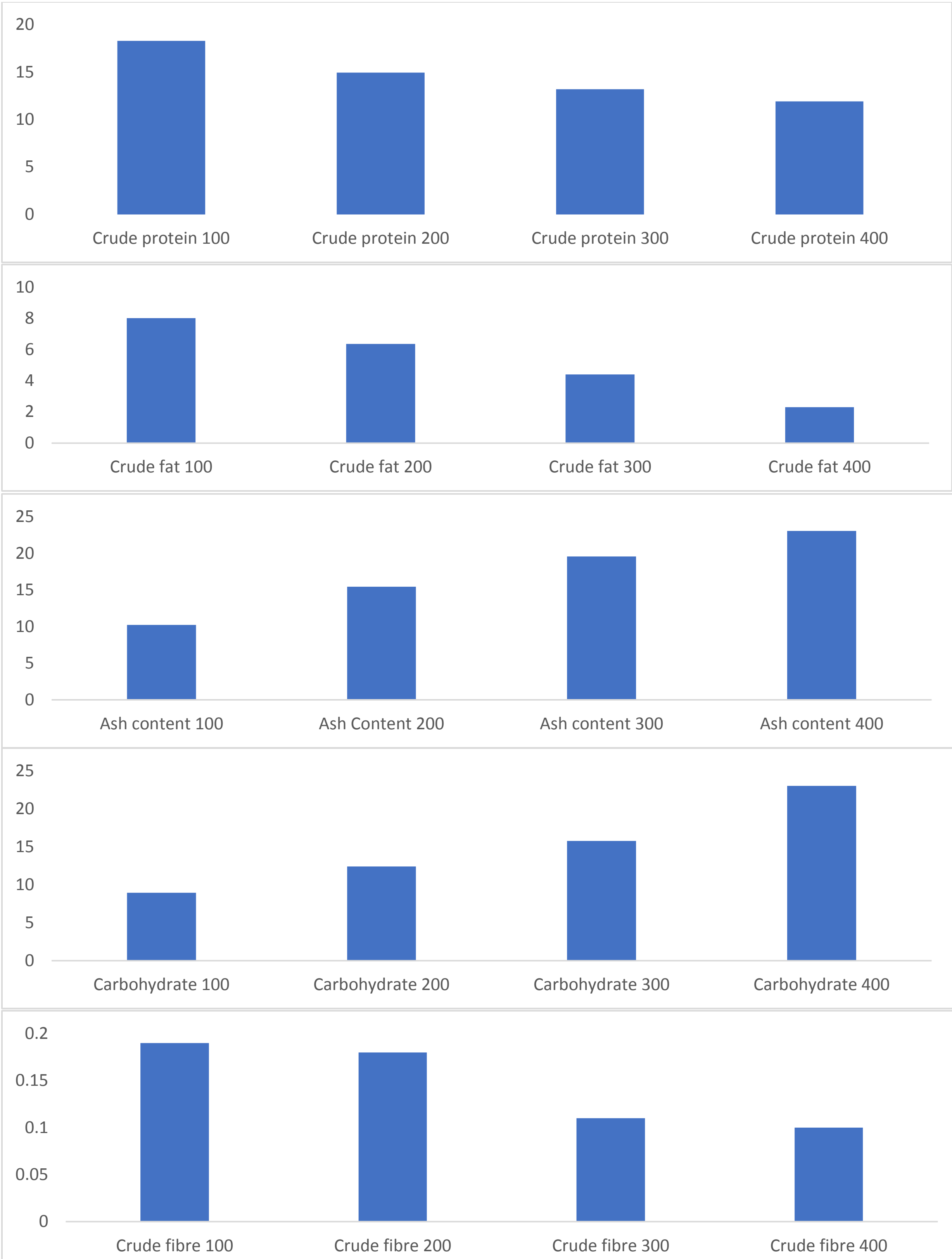


Figure 4.76: Proximate analysis parameters at different fertilizer application (Second Trial)

4.8 DISCUSSION

4.8.1 Seed Planting and Germination

Tillage practice is an important factor usually not emphasised in the cultivation of crops. The seeds were planted using broadcasting method. During the initial planting trial, adequate amount of water was applied to the soil after the soil was tilled for seed germination to occur at the right time. After planting of seeds occurs, maintaining a proper soil moisture level for proper plant growth becomes critical. It was observed that the soil was not properly tilled. Germination of the seed occurred after six to seven days of planting. The application of water on the soil led to the compaction of the soil after evaporation must have occurred. Evaporation of water from the surface of the soil brought about the drying of the soil which resulted in an increase in temperature and the formation of a hard pan at the surface of the soil. The hard pan stopped the penetration of the seeds into the soil. A continuous application of water to the surface of the soil resulted in no significant change because the hard pan formed resisted the infiltration of the water into the soil. This undesirable scenario led to water runoff which means that water applied to the surface of the soil is wasted. The increase in the temperature of the soil as result of water no penetrating into the soil is also undesirable for seed germination. The planting process was repeated with the soil well prepared, friable and properly tilled with all stones and tiny sticks removed. Proper water infiltration and permeability was experienced after proper tillage which resulted in water application efficiency during the seed sprouting period. Adequate water application during the seed germination period led to the cooling of the soil thereby reducing soil temperature, evaporation and making the soil soft for the seeds to penetrate the soil for sprouting to occur. The application of water to the surface of the soil was strictly monitored to avoid flooding because too much water on the surface of the soil will inhibit sprouting or flush away the seeds from the surface of the soil. Due to proper tillage practice the seed began to sprout after three days of planting. The significance of proper tillage practices observed from this study was similar to what was stated by Rahman *et al.* (2004).

4.8.2 Temperature, Evapotranspiration and Growing Degree Days Dynamics

Table 4.3-4.7 showed a maximum and minimum temperatures for both field and greenhouse trials. The temperatures recorded from the field were higher than the temperatures obtained from the greenhouse. The temperature from the field recorded a maximum value of 36.6°C while maximum temperature obtained from greenhouse was 35.3°C. The substrate temperature recorded a maximum value from the field (39.5°C) compared to 34-37°C recorded for greenhouse. Potential evapotranspiration of *Corchorus olitorus* recorded a maximum value of 4.41mm on the field compared to 4.18mm in the greenhouse. The amount of heat energy absorbed by the plant from germination to maturity recorded a maximum value of 1397.2 in the field compared to 1374.1 recorded from the greenhouse. Regression equations with R^2>0.99 were developed to predict possible outcomes of evapotranspiration and growing degree days in fig. 4.59-4.63. Table 4.8 shows the actual evapotranspiration with respect to the amount of water applied. The maximum cumulative amount of water applied (182.98mm) was recorded for water application of 8mm compared to the least cumulative water application of 55.79mm for water application depth at 2mm. It was observed that 4mm and 6mm water application depth recorded values of 103.46mm and 152.74mm respectively. The Kc values recorded from crop initial stage to maturity for a 10 weeks' period were 0.431, 0.439, 0.464, 0.607, 0.610, 0.813, 0.888, 0.981, 0.885 and 0.615. Figure 4.63 shows the relationship between actual evapotranspiration and time. Regression equations with R^2>0.99 were developed to predict possible outcomes of actual evapotranspiration.

4.8.3 Plant Growth Parameters

Inorganic fertilizer (NPK 15-15-15) improved most of the growth parameters significantly (Plant Height, Length of Leaves, Width of Leaves, Number of Leaves, Number of Branches, Stem Diameter) but it was not total significant when considering the petiole in *Corchorus olitorus.* The application of the fertilizer above 200kg/ha in the greenhouse with 8mm depth of water application (2ETo) i.e (2ET, 200kg NPK) adversely affected the growth of the plant. This situation was not experienced during the field experiment. The improvement experienced in the growth parameters because of the application of inorganic fertilizer at different rates is because of the increase in the nitrogen uptake enhanced by water supply and its related in photosynthesis and the assimilation of gases e.g carbon(iv)oxide with the help of leave chlorophyll resulting in improved growth (Bationo *et al*., 2006; Ertek, 2014). The result obtained from the plant with 8mm depth of water application (2ETo) with no fertilizer application showed reduced values of growth parameters which can be credited to insufficient nitrogen in the soil. The results shown in figure 4.73, indicated a strong relationship between water supply and root depth (primary and secondary roots). In water stressed plants, the secondary roots were longer than the primary roots for both 2mm and 4mm irrigation regimes having mean values of 33.4, 32.4cm and 12.0, 22.4cm respectively. However, primary roots for 6mm and 8mm irrigation regimes were greater than mean values of secondary roots with values 31.4, 34.0cm and 27.5 and 29.4cm respectively. Also, primary roots of plants with fertilizer application were higher than those without fertilizer but this did not occur in all cases. The result shows that the influence of water to plant root depth was more significant than fertilizer uptake. This shows that when increased in root depth is prioritised during crop propagation, the influence of water supply should not be underestimated (Li, et al., 2007; Behera et al., 2010; Ofelia et al., 2013) using *Jatropha curcas* L. as study crop.

4.8.4 Chlorophyll Content

The results from figure 4.51-4.54 reveals the chlorophyll content of the top leaves in the field during the dry season were higher than the chlorophyll content of the top leaves planted in the greenhouse while the chlorophyll content of the bottom leaves in the field was lower than the chlorophyll content of the bottom leaves in the greenhouse in most cases. This shows that the consequence of subjecting plants to water stress is an increase of chlorophyll content of the leaves to compensate for the inability of the chlorophyll present to absorb enough light for the manufacture of food. The effect predominantly occurs at the top leave of the plant. This results in the restrictions on proper development of several parts experienced during growth on stressed plants. From the results obtained it can be deduced that the top leave plays a very significant role in food production for the plant and chlorophyll content is affected predominately by the availability of solar or light radiations. The result obtained from the study was not similar to Skukla et al. (2012) on soya bean and Symsia et al. (2017) but was similar with Sairam (1994) on stress tolerant wheat.

4.8.5 Water and Fertilizer Use

The results from Table 4.9 and 4.10 which showed the response factor values indicate that plant water consumption (ET) have a greater effect on yield of *Corchorus olitorus* than the application of fertilizer. Considering the response factor of ET-fertilizer on the nutrient uptake due to application of irrigation water, a significant effect can be noticed. Increase in irrigation water applied to the crops directly leads to a yield increase by easily dissolving the fertilizer and making absorption by the crop easy in the field. It can be observed that an increase in irrigation water and increase in fertilizer applied to the crops increased yield of the crop till a threshold is attained after which an increase in irrigation water and fertilizer will result in a reduction in yield of the crop. This adverse effect of increase in fertilizer and irrigation water was not well noticed during the planting period in the field trials but this was conspicuous in the greenhouse experiment. This was because a single plant was planted in one pot and the fertilizer applied by the side while the plants are spaced in the field and the fertilizer applied by the side of the plants, also the pot confines the movement of water so that the water will be retained within an area of soil while the water can flow spatially in the field without any restriction though it takes time for this to occur.

The results from figure 4.65-4.68, show that the fertilizer uptake decreased by $y = -1169.2x^6 + 4097.7x^5 - 5741.5x^4 + 4087.1x^3 - 1545.6x^2 + 291.97x - 20.688$, $R^2 = 0.5793$ units when water needed decreased by 1 unit for field experiment and $y = -1719.6x^6 + 598.7x^5 - 8272.9x^4 + 5724.6x^3 - 2048.2x^2 + 348.08x - 20.544$, $R^2 = 0.5646$ units for greenhouse experiment. This means that a deficit in water supplied will result to a corresponding reduction in the yield of the crop. This invariably means that the usefulness of fertilizers applied to the soil can be easily assessed by plant with the help of water. This helps us to understand that water and fertilizer are two factors that cannot be discussed isolating one from the other. The consideration of water as a limiting factor, the desired level of plant development and yield cannot be attained through the application of fertilizer. An increase in yield is usually obtained by adequate supply of water and the right quantity of fertilizer. However, fertilizer application exceeding the optimum amount results in a reduction in yield which will lead to farmer incurring losses after sales. The results from figure 4.65 also show models developed to predict yield reduction with respect to evapotranspiration reduction, $y = 28.263x^5 - 69.51x^4 + 65.037x^3 - 29.477x^2 + 7.1939x - 0.0219$, $R^2 = 0.9863$, shows how the yield reduces due to evapotranspiration loss. The R^2 value which is greater than 0.9 shows the model is highly reliable. Model, $y = -15498x^6 + 47210x^5 - 58089x^4 + 36834x^3 - 12652x^2 + 2225.4x - 155.82$, $R^2 = 0.4025$, shows the nitrogen uptake reduction and evapotranspiration reduction relationships. The model predicts how unit decrease in water needed affects the nitrogen uptake of plants. Figure 4.67 shows models developed to predict yield reduction with respect to evapotranspiration reduction for greenhouse, $y = 29.929x^4$ -

$69.119x^3 + 56.627x^2 - 18.642x + 2.7213$, $R^2 = 0.9111$. The developed model shows a high level of reliability. Model, $y = -15948x^6 + 48465x^5 - 59430x^4 + 37511x^3 - 12809x^2 + 2236.9x - 155.19$, $R^2 = 0.3726$, shows the nitrogen uptake reduction and evapotranspiration reduction relationships for greenhouse, similar to models developed by Ertek (2014).

The fresh weight of the crop was increased by 14.1% and 12.8% with fertilizer application (NPK 15-15-15) during the field experiment in 2016 and 2017 respectively. A similar trend was also experienced in the greenhouse with the fresh weight of the crop increasing by 49.6% and 32.1%. This reveals that fertilizer application significantly helps in increased crop development. The yield of the crop planted in the field was increased by 20% and 18.7% with the application of NPK 15-15-15 fertilizer in 2016 and 2017 respectively. This trend continued in the greenhouse with the yield of the crop increasing by 32% and 49%. Maximum yield for profitability can be achieved by applying the approximate amount of water i.e considering the crop water requirement and the right quantity of fertilizer taking into consideration that when the amount of fertilizer is more than required proper development of the crop become impeded, this invariably means loss to farmers. The amount of nutrient available in the soil used for cultivation of the crop is directly proportional to the nutrient amount absorbed by the crop. The nitrogen uptake by the crop increases as the amount of water increases. Most importantly, this phenomenon was clearly observed in the plants harvested from the experiment carried out in the greenhouse. However, similar occurrence was experienced in the field but there were slight variations. Thus, plants with the least amount of fertilizer uptake was experienced from plants with deficit water application.

The results from table 4.9 and 4.10 show he fertilizer use efficiency (FUE) increases as nitrogen uptake of the plant and crop water requirement of the plant increases. Plants where the same quantity of water is applied, and fertilizer applied at different rate experiences growth and development till a point is reached where increase in fertilizer becomes harmful to the plant. Fertilizer use efficiency (FUE) and water use efficiency (WUE) values can be used as a determinant in knowing the most suitable fertilizer and water levels needed in achieving the optimum yield for profitability. High values obtained from the ratio of WUE: FUE represents high amount of crop yield. Hence, to appreciate the effect of water and fertilizer on crop yield, WUE and FUE should not be evaluated distinctly (Ertek, 2014).

The conducted study shows that when water level was kept constant and the fertilizer rate increased, an increase in yield was experienced. However, when fertilizer and water rates were increased there was a linear relationship varying on the fertilizer or water level. However, an unfavourable effect on the yield is experienced at a level of water and fertilizer application. This makes it very important to understand the synergetic relationship between fertigation and irrigation on crop yield. The synergetic relationship of ET–yield response factor (KyET), fertilizer–yield response factor (KyF), and ET–fertilizer response factor (KFET) can be decided by proper application. However, these synergetic effects can be determined by considering the response factor of one with the other. These response factors can also be used in analyzing the economic benefits or demerits that can be derived because of increase or decrease in 1 unit of water or fertilizer. ET–fertilizer response factor (KFET) showed the optimum water and fertilizer requirement for maximum yield and profitability to prevent wastages experienced during crop cultivation (Ertek, 2014). These wastages can be monetary and environmental impact considerations. The monetary consideration can be seen in situations where a lot of money is spent purchasing water and fertilizer. Agriculture is a business, so profitability of the venture becomes paramount. Environmental impact looks into the effect of excessive application of fertilizer and water on the soil. Excessive water application can result in the washing down of the nutrients in the soil (leaching), erosion of the soil can also be experienced. When fertilizer is applied beyond the recommended or optimum amount the excess is washed down by the water and this will result in the contamination of the groundwater which provide nutrient for bacteria enrichment. Adequate knowledge of these helps in reducing yield losses experienced from fertilizer and water deficits (Nwangburuka *et al*., 2012; Ertek, 2014; Bationo *et al*., 2016).

4.8.6 Stress Tolerance Index

This index was consistent in identifying plants that were subjected to water stress under different conditions. The maximum yield obtained from field experiments with adequate water supply (rainy season) was 15.6 t/ha while the average yield on non-stressed plants was 13.1/ha. High values of STI represent high yield and a signal in understanding that the plant in question expresses lower level of stress compared to when the STI values was low. When STI values approaches 1, it indicates that the plant is well watered and when STI values approaches 0, it shows that the plant is stressed. The level of stress increases as the STI value approaches zero and also the level of stress reduces as STI values approaches 1. The result showed that plants with water application of 8mm (2ETo) had higher values of STI ranging from 0.321-0.461 and 0.367-0.649 in field and greenhouse experiments compared to those of water application of 6mm (3/2ETo), 4mm (1ETo) and 2mm (1/2ETo) ranging from 0.067-0.382 and 0.088-0.527 in field and greenhouse experiments as shown in table 4.14. It was observed that the STI values can be used to explained how stressed a plant is but it cannot be used to interpret the effect of fertilizer application and the plant. The result obtained from the study was similar to what was stated by Fernandez (1995).

4.8.7 Leaf Relative Water Content

The average LRWC of *Corchorus olitorus* obtained from field experiment at different irrigation regimes shows that a mean value of 49.75%, 55.76%, 61.07% and 66.09% for 2016, and 50.57%, 56.70%, 59.87% and 65.81% for 2017 at 2, 4, 6, 8mm irrigation regimes respectively. The results from the greenhouse was higher in most cases when compared to field results. The obtained mean values are 51.92%, 53.22%, 62.75% and 70.82% for first trial and 52.30%, 52.96%, 64.08% and 71.48% for second trial as shown in figure 4.77. The leaf relative water content increases as the amount of water applied to the plant increase. LRWC was higher in the greenhouse than in the field. This is because in the latter the temperature is higher which result in an increase in the rate of evapo-transpiration i.e loss of water from the leaves and the soil also becomes drier. However, because of this situation water is also retained in the soil which will not be available to the plant. The variation in leaf relative water content can also be attributed to the difference in the thickness of the leaves which also affects the stomata conductance of the leaf when considering a particular experiment. When the leaf relative water content is high, it leads to a high stomata resistance which aids in decreasing water loss indicating an activity that controls the loss of water in the plant. The results obtained did not show any fertilizer application effect to the plant relative leaf water content which implies that fertilizer application does not affect relative leaf water content. The LRWC of non-stressed plant s were higher than stressed plants but not as high as results from Dorota *et al*., (2016).

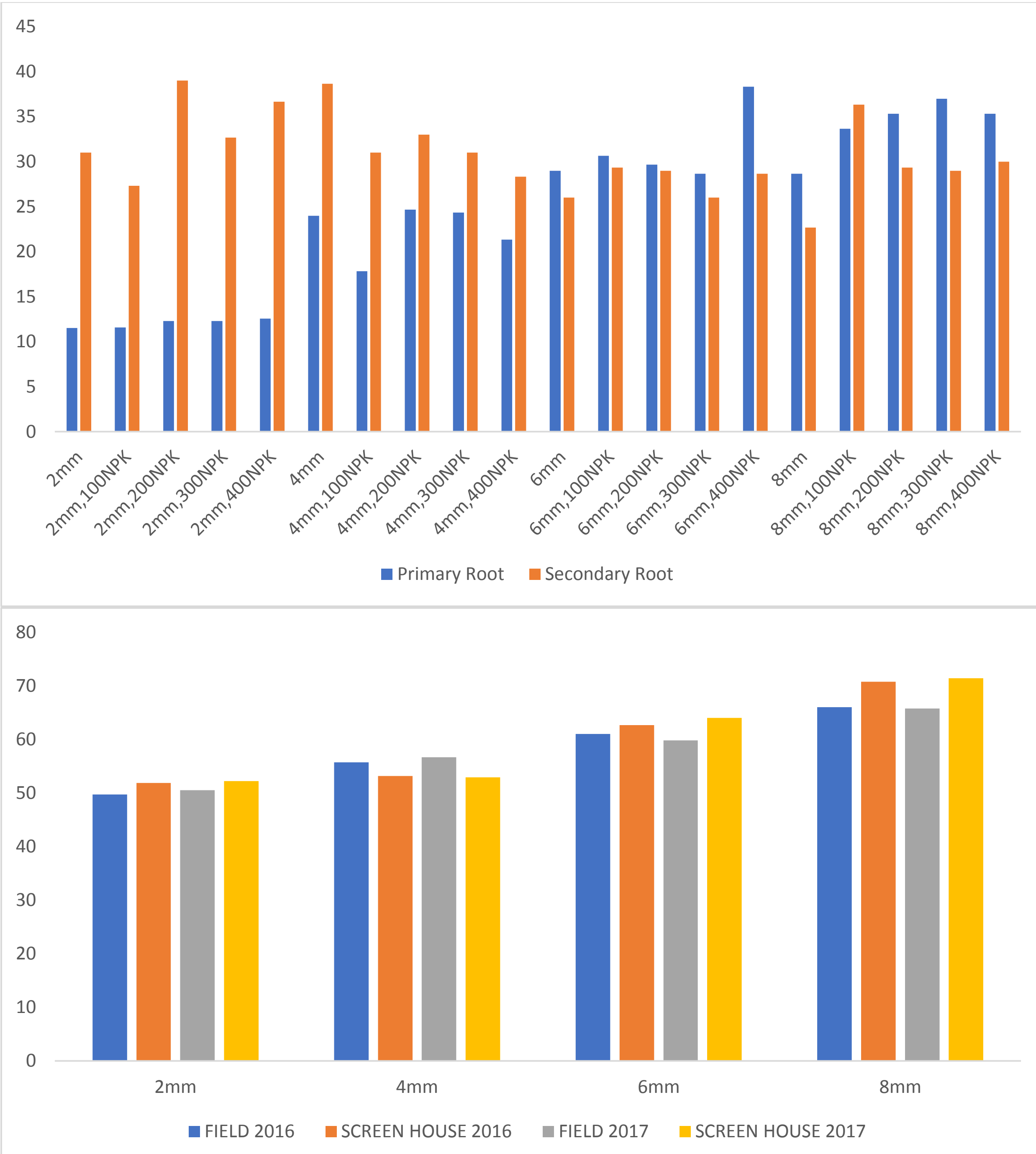


Figure 4.77: Graph of Primary and Secondary Root of *Corchorus olitorus* and average relative leave water content of *Corchorus olitorus* at different irrigation regimes

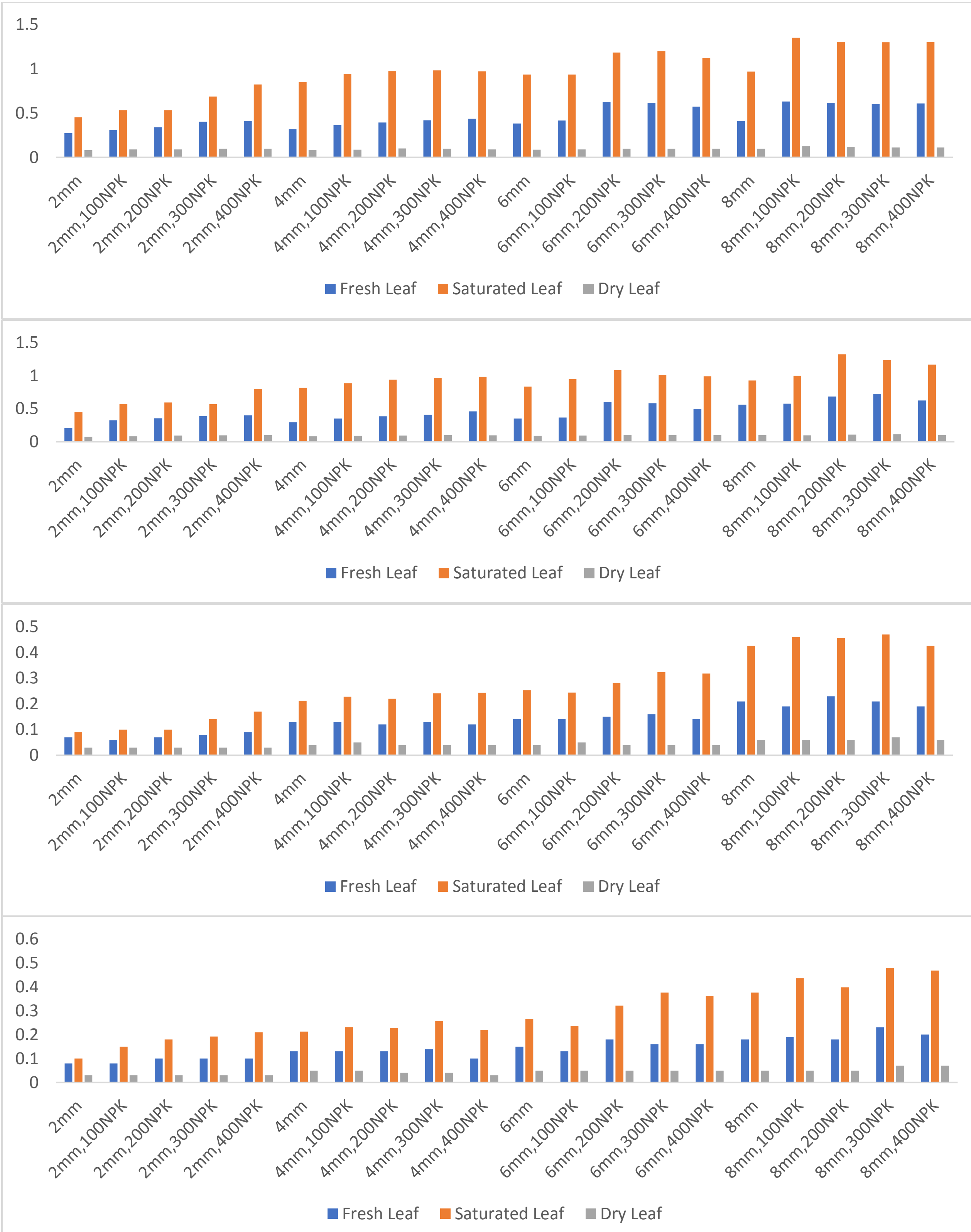


Figure 4.78: Graph of fresh leaf, saturated leaf and dry leaf for 2016 and 2017 in greenhouse and field

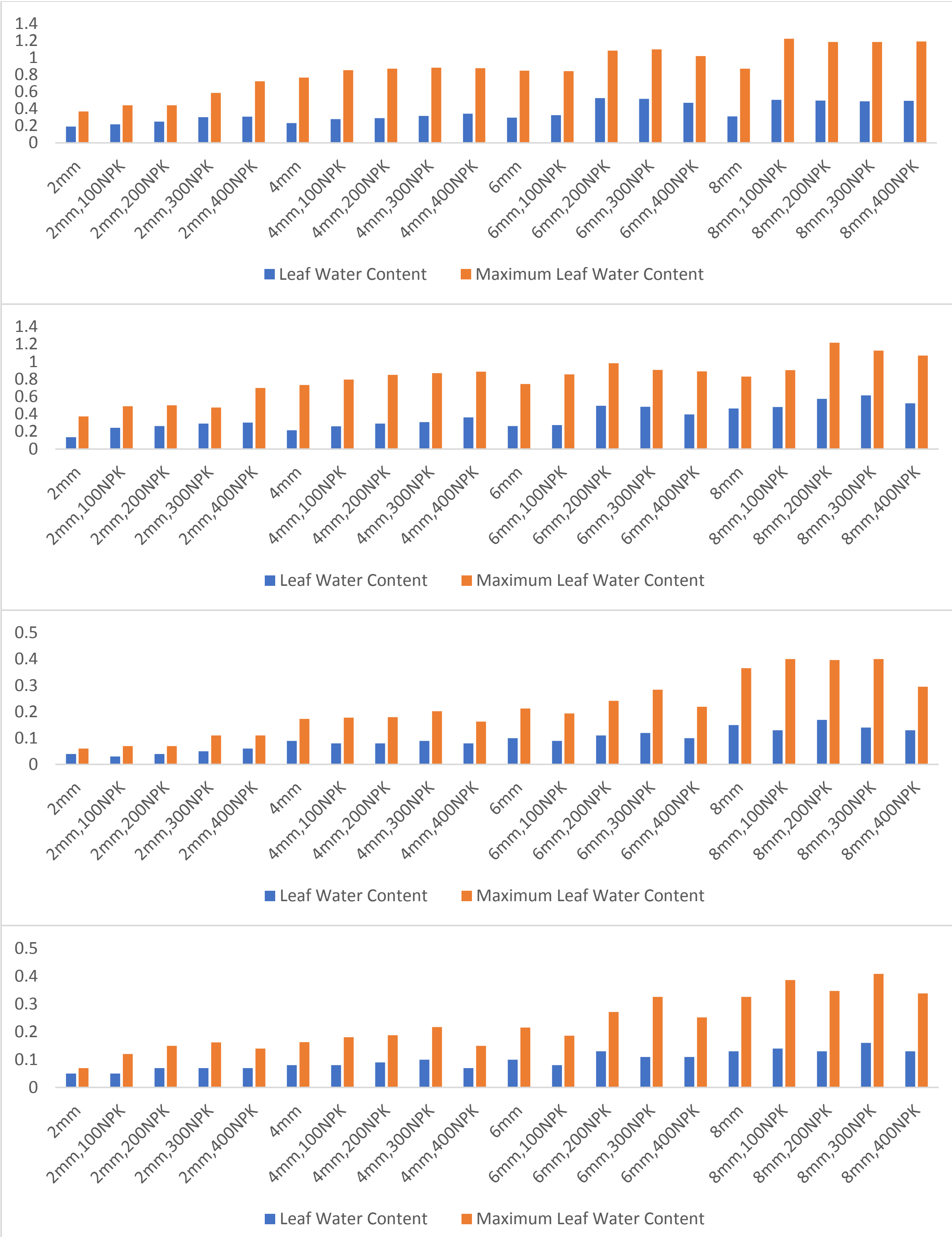


Figure 4.79: Graph of leaf water content and maximum leaf water content for greenhouse and field for 2016 and 2017

Figure 4.78 and 4.79 show the graph of fresh, saturated and dry mean weight of the leaves, and the maximum leaf water content obtained. An increase in weight was observed as water supply and fertilizer application increased but got to a peak where increase in fertilizer application affects the mean weight of fresh, saturated and dry leaves. These difference in weight will in turn affect the thickness of the leave which played a significant role in affecting the relative leaf water content. This situation also occurs for the maximum leaf water content. It should be noted that in field condition, the similar occurrences cannot be substantiated but an increase in water and fertilizer application increases the mean weight of fresh, saturated and dry leaves (Arve *et al*., 2011).

4.8.7 Plant Nutrient Composition

The study from figure 4.75 and 4.76 reveal that an increase in the amount of fertilizer applied to the soil reduces the crude protein content of the plant. The essential part of protein with regards to its nutritional value is the amino- acid. Hence, it can also be said that an increase in the amount of fertilizer reduces the concentration of amino-acid in the plant which helps in maintaining optimum performance of the body, repair and formation of cells. The results obtained show that an increase in the amount of fertilizer applied to the soil led to the reduction of crude fat content in the plant. Fat deficiency leads to poor energy supply, reduction in absorption rate of nutrients and a poor maintenance of body temperature. Ash content retention increased as the amount of fertilizer added to the soil increased showing increase in inorganic materials i.e minerals in the soil. An increase in fertilizer applied to the soil, increased the amount of carbohydrate in the plant showing an increase in the supply of energy (Tracy and Micheal, 2014). Crude fiber content of the plant increased as the amount of fertilizer applied to the soil reduced. This shows that the plant residue obtained after extraction of nutrient after digestion increases as the fertilizer applied reduces. This plays a significant role in determining the succulence of the plant (Bationo *et al*., 2006).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The study shows that the soil textural class was homogeneous when considering different layers of the soil: 0-15cm to 15-30cm. The soil textural class was observed to be a loamy sand soil. Proper tillage practice and watering has shown to be essential activities to be carried out for proper and early germination of the crop. Calibration of the process-based model before usage is necessary in achieving the desired goals and a necessity in simulating crop outputs in any climate and location at any given time. The CropWAT Model was used in calculating evapotranspiration using meteorological characteristics of the study area. Crop growth coefficient at different stages was simulated, however the result obtained shows that this simulation model is reliable because the results obtained was close to that which was obtained from the field indicating the level of precision of the model. The CropWAT Model was also used in the prediction of the gross and net irrigation requirement considering the crop water requirement of the crop. The results obtained after taking proper cognizance of standard procedures show that the process- based model (CropWAT Model) and empirical models performed well in determining or simulating crop water and nutrient dynamics on crop growth parameters.

The simplicity and ease of assessment of the process-based model (CropWAT) due to its required readily available minimum input data has made its usage easy and friendly. This makes it also useful for planning and decision making for researchers, farmers, water administrators, managers and policy makers. This research work has shown the possibility and applicability of using this process-based model (CropWAT) in solving problems concerning future climate change challenges. It is also suited in developing strategies concerning agricultural water management for different application and objectives. Generally, many factors affect crop yield, but the simulation models used do not consider the effect of pest and diseases and the effect on saline water. Therefore, this model should not be considered under conditions with pest, diseases and saline water. Since irrigation is necessary in the dry season for maximum crop yield, deficit agriculture has really shown to be a disaster. Hence, for maximum yield to be sustainable, adequate monitoring of soil moisture content is necessary for proper management of irrigation water. The fact that water plays a significant role in plant growth and morphology is known. This is also affected by undesirable stresses experienced mechanically or from nutrient level. The use of the CropWAT model has truly shown to be useful in research concerning irrigation strategies considering different water deficit environmental conditions. Empirical models with coefficient of determination (R^2) of 1 were produced considering plant growth parameters in relation to evapotranspiration in mm and growing degree days in ^{0}C. The relationship between plant growth parameters and time was determined using statistical model with varying levels of coefficient of determination (R^2). The results obtained show that CropWAT model can adequately be used to simulate crop yield reduction occurring due to water stress undesirable effect on the plant.

The developed simple empirical models provide an important information in understanding the relationship and interactions between the amount of water applied to the crop and the nitrogen uptake. The varied water supplied to the plant, considering level of evapotranspiration affected the level of nitrogen uptake by the plant. This also affected the level of plant growth and in turn its profitability. These are limiting factors that need to be properly addressed for plant growth to be maximised. The research work has shown that the balance between the amount of water supplied and nitrogen uptake can be understood and maintained targeting maximum yield.

The study showed strong relationship between moisture content of the soil and maximum plant root depth, and survival of plant and moisture content of the soil. Crops with the highest quantity of water added to the soil, had the highest root depth and the roots were spread out to hold the plant firmly to avoid the plant from dying. Crops with the lowest quantity of water added to the soil, had the lowest root depth and the roots were thinner covering a smaller space, thereby making it hard for the plant to be held firmly in the soil and plant death eventually.

It is of great importance that the measurement and estimation of plant growth parameters were simplified by using a reduced number of variables for its determination, using its relationship with the accumulated actual evapotranspiration in mm calculated using a dynamic weighing lysimeter and accumulative growing degree days in ^{0}C, considering the maximum, minimum temperature and a base temperature for *Corchorus olitorus*.

5.2 RECOMMENDATIONS

Irrigation efficiency should be improved by moving away from the traditional or conventional methods to more efficient surface method like drip irrigation or sub-subface method such as the use of perforated pipes.

The irrigation amount to the soil should be marched with the amount of actual evapotranspiration experienced by the crop. This will greatly help in reducing the level of wastages incurred during crop cultivation to maximise profit.

Proper knowledge of the application, calibrations and utilization of the process-based model (CropWAT) to obtain the desired simulated results should be encouraged.

CropWAT model and the empirical models produced should not be used for simulating plant growth parameters when considering the effect of pest and diseases, and the effect of salinity on the crop.

The right amount of fertilizer should be applied to the soil to guarantee nitrogen use efficiency which in turn reduces the cost incurred from cultivation of the crop and reducing pollution occurring due to ground water contamination.

It will be of great importance that other undesirable factors that contribute to unprofitable yield gaps in crop production are identified.

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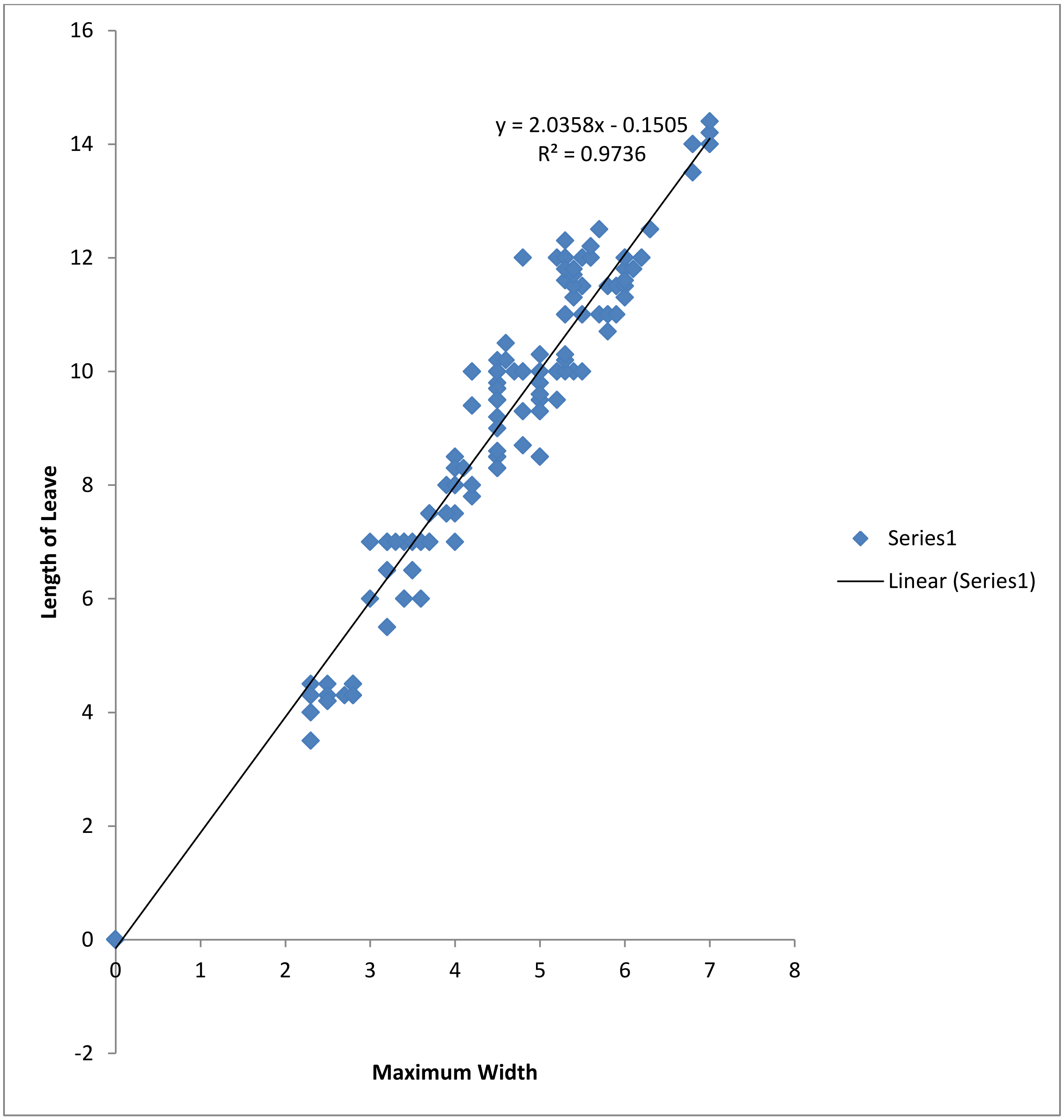
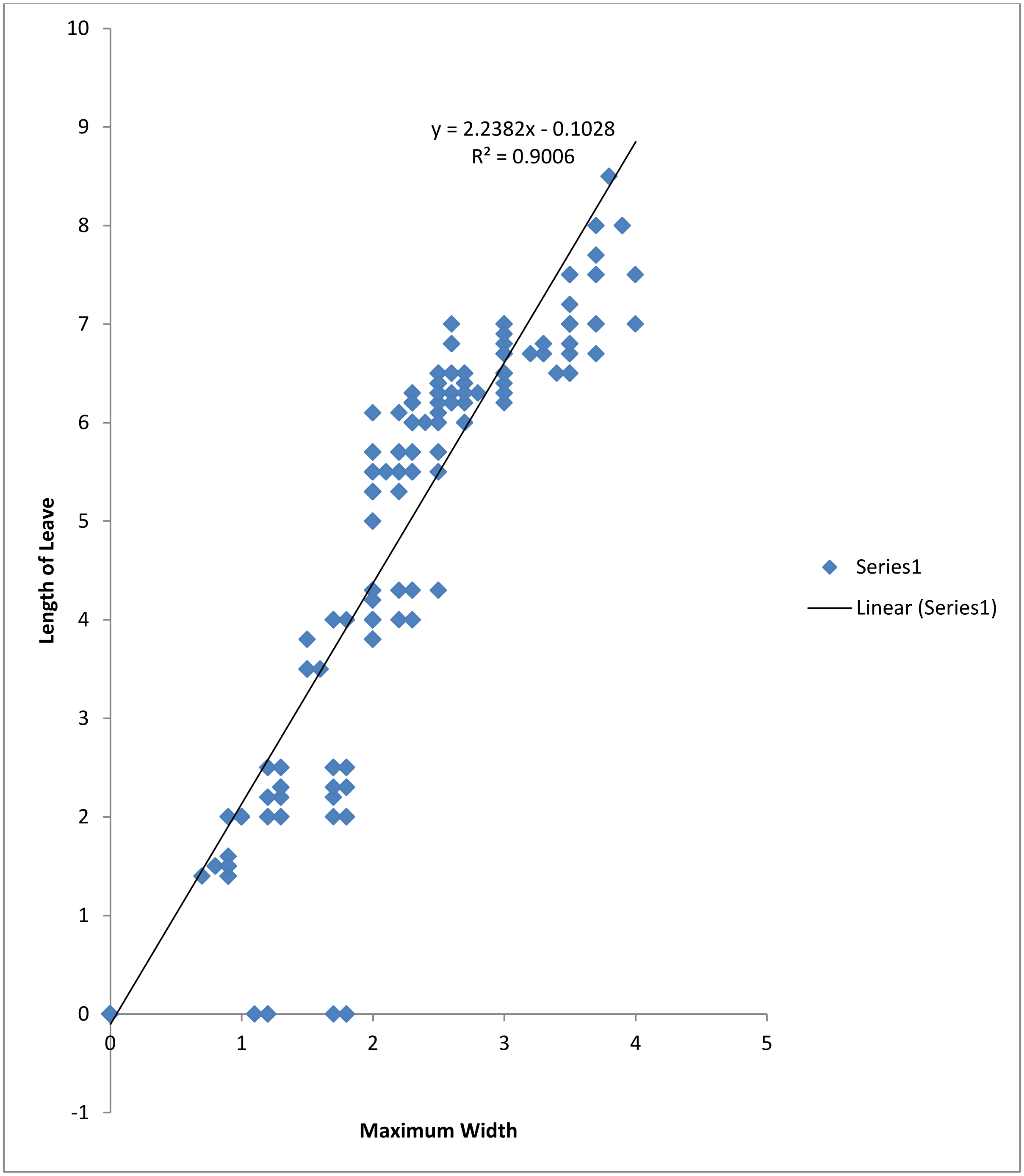
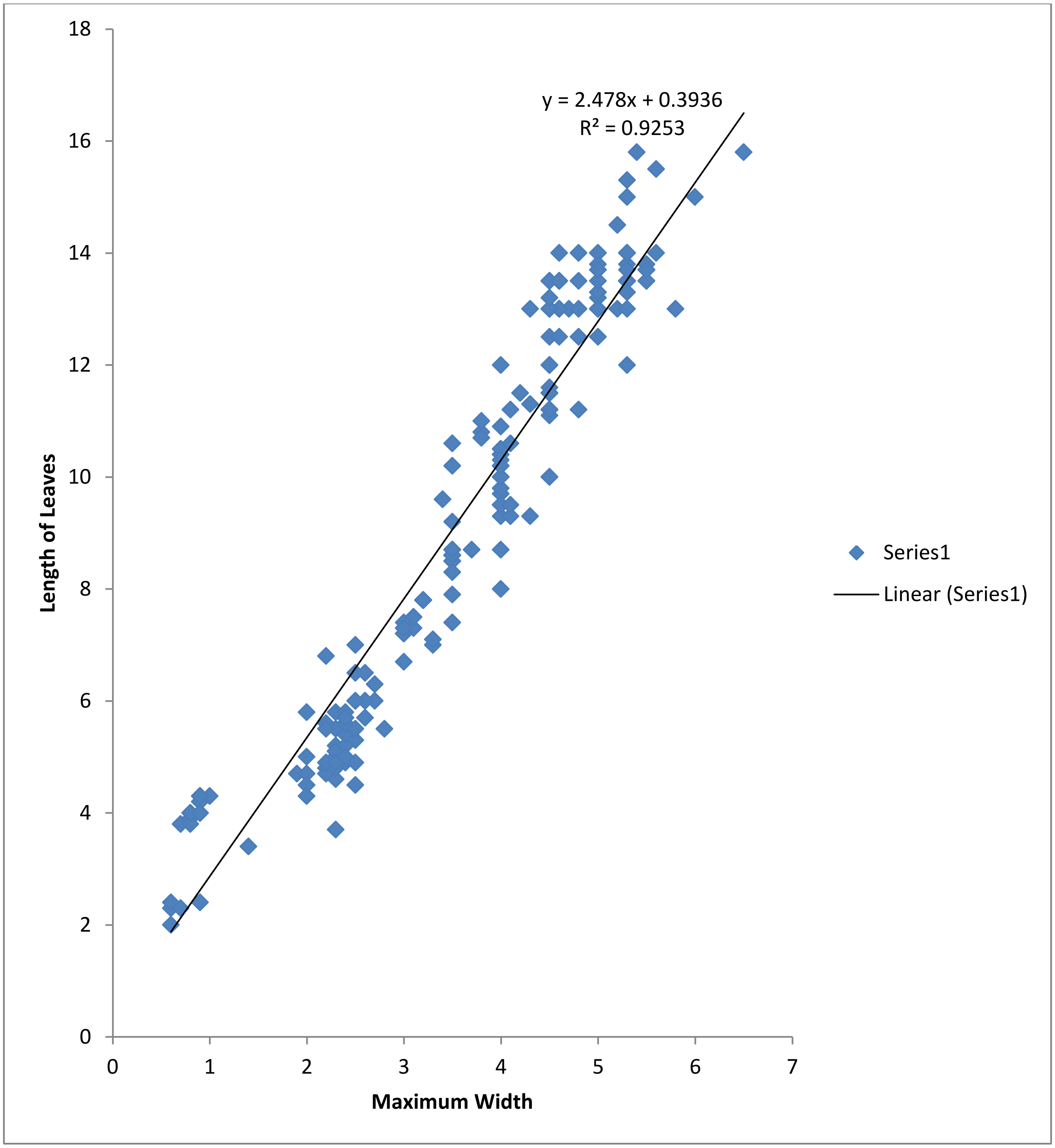
APPENDICES



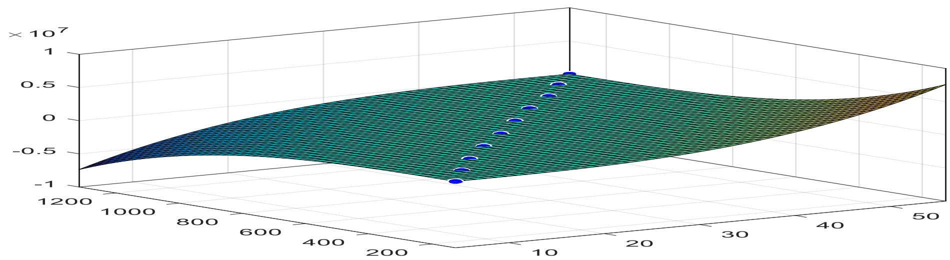
Appendix 1: Graph of Length of Leave vs Maximum Width



Appendix 2: Graph of Length of Leave vs Maximum Width Field Dry Season



Appendix 3: Graph of Length of Leave vs Maximum Width Field Rain



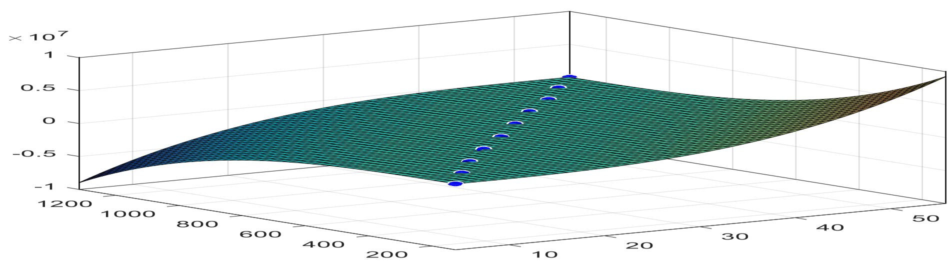
Linear statistical model:

PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where mean x = 29.95±17.76 and y value is 726.8±405.3

where: p00 = 8.609, p10 = -420.4, p01 = 428.6, p20 = -7181, p11 =1.465e+04, p02 =-7466

p30 =   3.023e+05, p21 = -9.055e+05, p12 =   9.043e+05, p03 = -3.011e+05



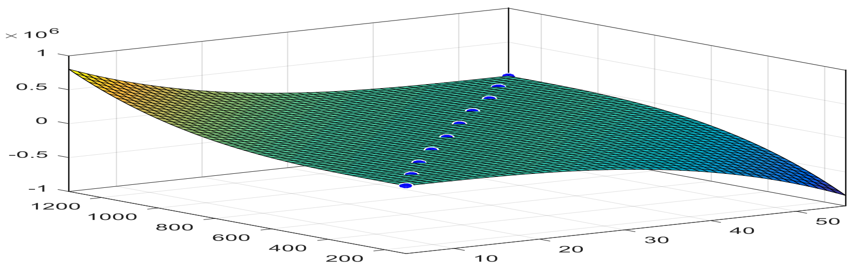
Linear model:

PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x is 29.95±17.76 and y is 726.8±405.3

where: p00 = 8.971, p10 = -553.2, p01 = 558.9, p20 = -7728, p11 =1.572e+04, p02 = -7990, p30 =   3.693e+05, p21 = -1.105e+06, p12 =   1.103e+06, p03 = -3.668e+05

Appendix 4: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 2mm and 2mm 100 NPK for field



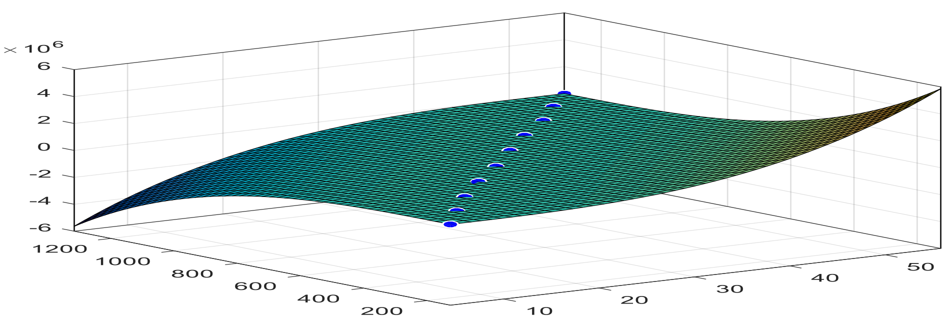
Empirical model Poly33:

PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76, and y = 726.8±405.3

p00 = 14.45, p10 = 67.09, p01 = -63.65, p20 = -252.4, p11 = 462.9, p02 = -211.1

p30 = -3.333e+04, p21 = 9.996e+04, p12 = -9.99e+04, p03 = 3.328e+04



Model:

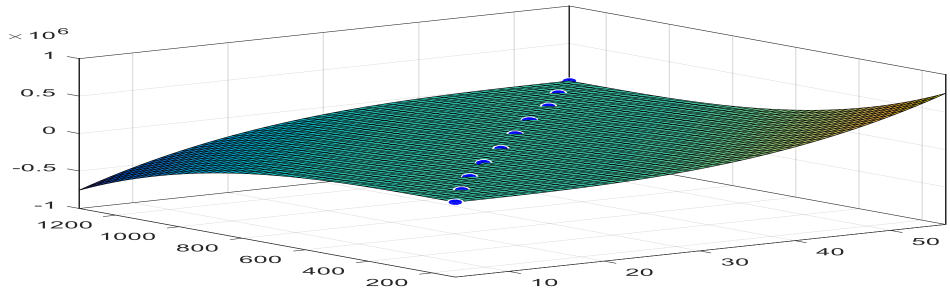
PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 726.8±405.3

p00 =10.64, p10 = -368.5, p01 = 373, p20 = -2618, p11 = 5335, p02 = -2714

p30 = 2.338e+05, p21 = -6.975e+05, p12 = 6.937e+05, p03 = -2.3e+05

Appendix 5: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 2mm 200 NPK and 2mm 300 NPK for field

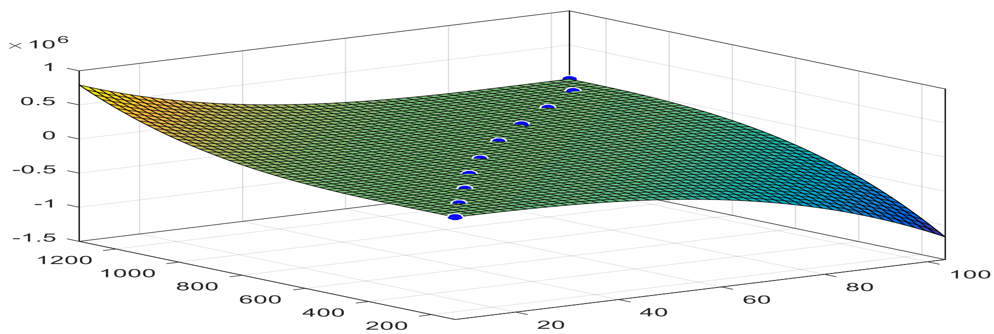


PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 726.8±405.3

p00 = 14.04, p10 = -77.2, p01 = 80.94, p20 = -2339, p11 = 4709, p02 = -2369

p30 = 3.066e+04, p21 = -9.143e+04, p12 = 9.1e+04, p03 = -3.023e+04



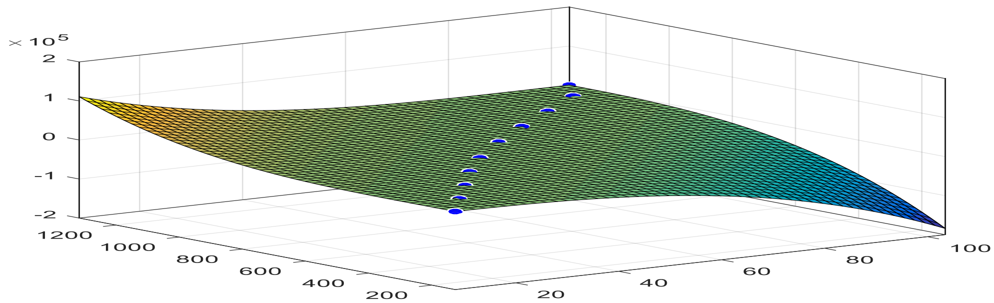
PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 726.8±405.3

p00 = 6.621, p10 = -1211, p01 = 1234, p20 = -1.601e+04, p11 = 3.264e+04

p02 = -1.661e+04, p30 = -4.04e+04, p21 = 1.221e+05, p12 = -1.212e+05, p03 = 3.95e+04

Appendix 6: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 2mm 400 and 4mm for field



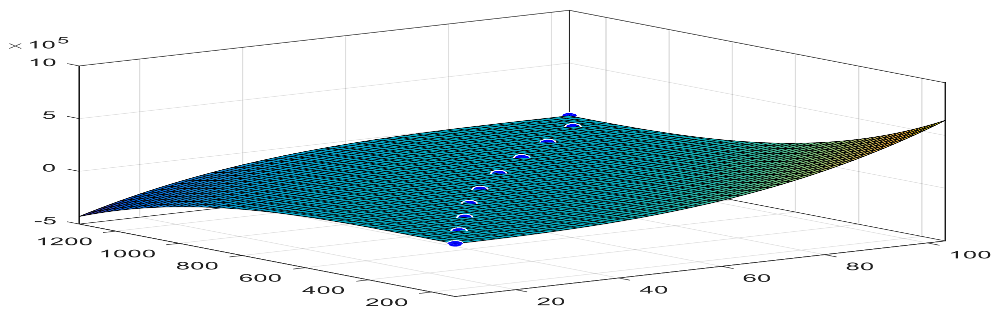
Statistical model:

PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 726.8±405.3

p00 = 5.879, p10 = -360.1, p01 = 381.2, p20 = -3333, p11 = 6899, p02 = -3552

p30 = -6013, p21 = 1.825e+04, p12 = -1.815e+04, p03 = 5896



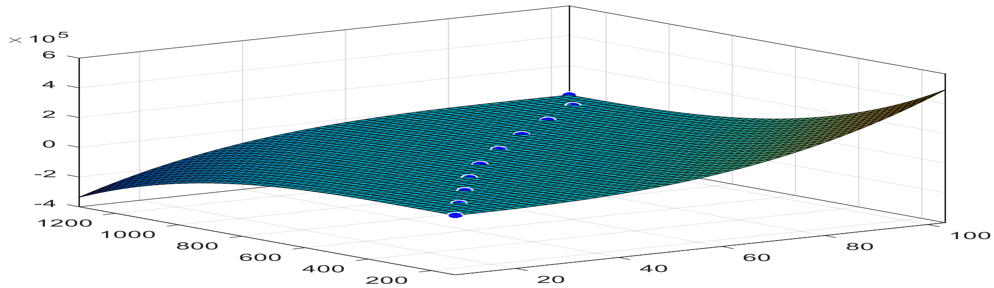
PHH = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 726.8±405.3

p00 = 17.56, p10 = 678.2, p01 = -673.1, p20 = 9311, p11 = -1.893e+04, p02 = 9616

p30 = 2.207e+04, p21 = -6.672e+04, p12 = 6.618e+04, p03 = -2.153e+04

Appendix 7: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 4mm 100 NPK and 4mm 200 for field

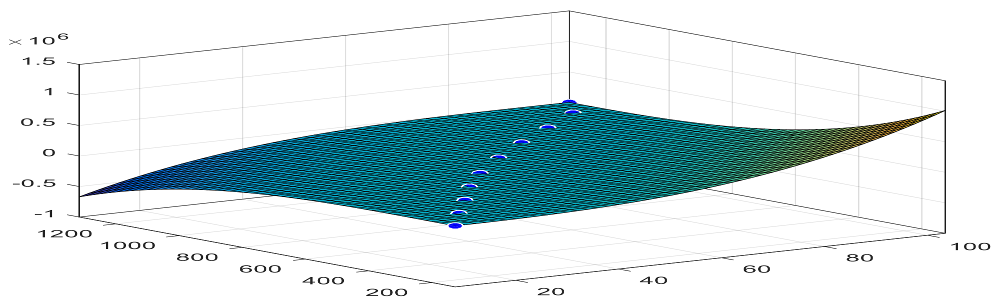


PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56. and y = 726.8±405.3

p00 = 12.5, p10 = 416.6, p01 = -405.5, p20 = 6692, p11 = -1.357e+04

p02 = 6880, p30 = 1.721e+04, p21 = -5.18e+04, p12 = 5.121e+04, p03 = -1.662e+04

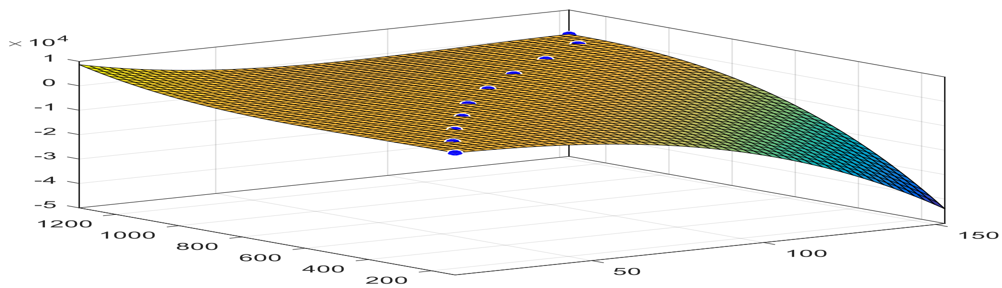


PHH(x,y) axis = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 726.8±405.3

p00 = 23.55, p10 = 1140, p01 = -1142, p20 = 1.493e+04, p11 = -3.04e+04, p02 = 1.547e+04, p30 = 3.461e+04, p21 = -1.047e+05, p12 = 1.04e+05, p03 = -3.385e+04

Appendix 8: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 4mm 300 NPK and 4mm 400 for field

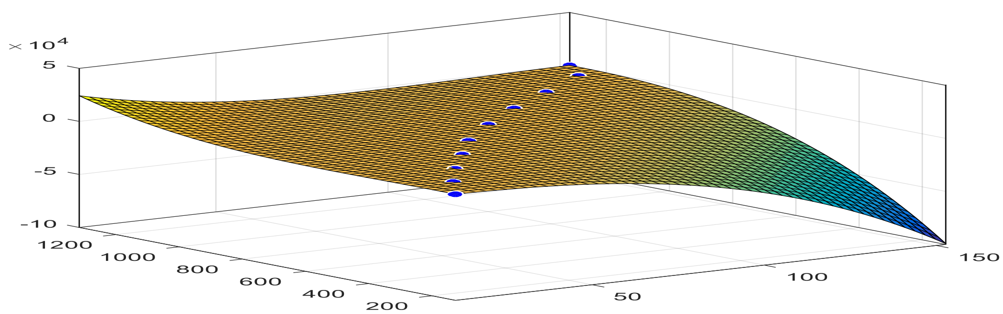


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97, and y = 726.8±405.3

p00 = 4.12, p10 = -302.8, p01 = 333.5, p20 = -1787, p11 = 3784, p02 = -1978

p30 = -1145, p21 = 3365, p12 = -3048, p03 = 812.8

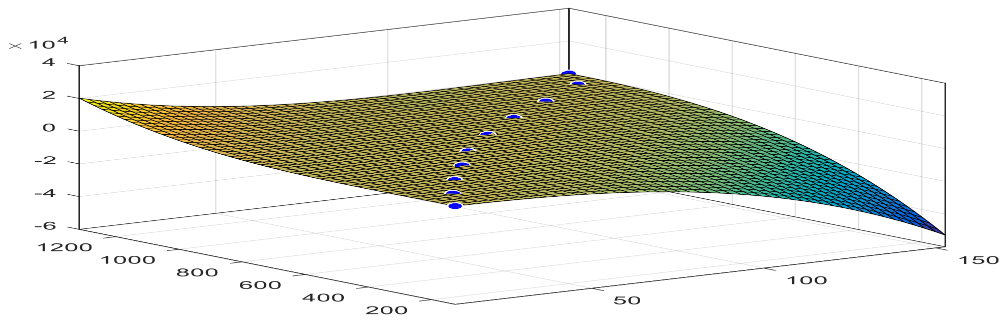


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97, and y = 726.8±405.3

p00 = -5.993, p10 = -614.8, p01 = 659.8, p20 = -3758, p11 = 7904, p02 = -4114, p30 = -2652, p21 = 7866, p12 = -7244, p03 = 2000

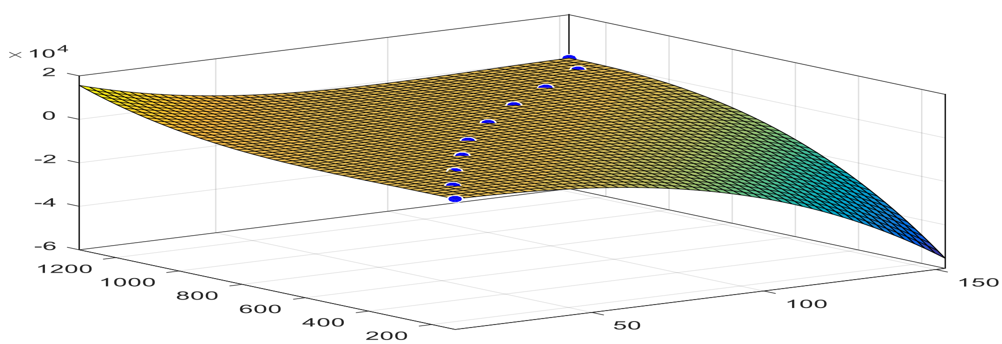
Appendix 9: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 6mm and 6mm 100 NPK for field



PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97 and y = 726.8±405.3

p00 = 16.51, p10 = -187.4, p01 = 211.1, p20 = -1556, p11 = 3232, p02 = -1668, p30 = -1598, p21 = 4702, p12 = -4391, p03 = 1280



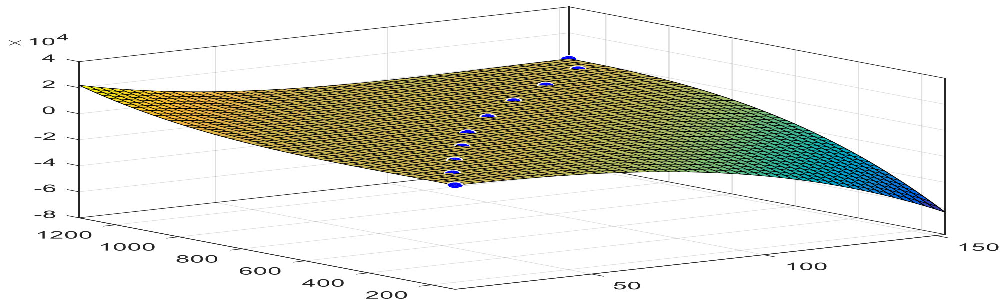
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97 and y = 726.8±405.3

p00 = 7.146, p10 = -314.3, p01 = 347.3, p20 = -1961, p11 = 4131, p02 = -2151

p30 = -1539, p21 = 4537, p12 = -4186, p03 = 1172

Appendix 10: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 6mm 200 NPK and 6mm 300 NPK

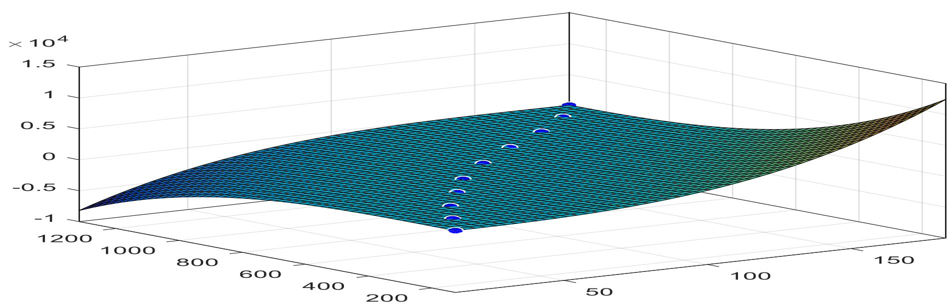


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97 and y = 726.8±405.3

p00 = 8.282, p10 = -307.3, p01 = 340.9, p20 = -1961, p11 = 4136, p02 = -2157

p30 = -1871, p21 = 5458, p12 = -5032, p03 = 1430



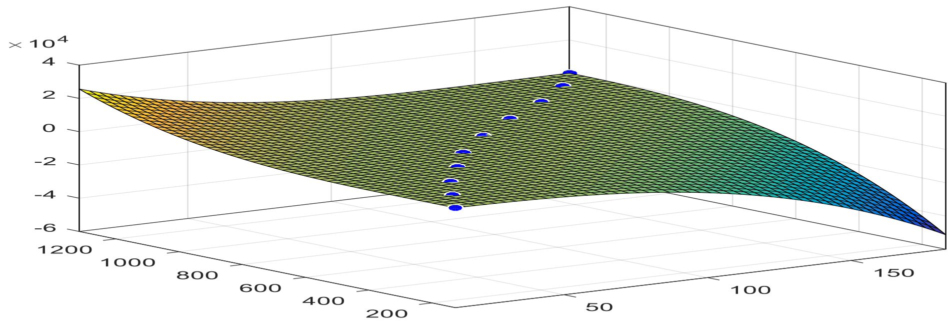
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45 and y = 726.8±405.3

p00 = 20.37, p10 = 1.363, p01 = 16.23, p20 = 111.8, p11 = -223, p02 = 115.9

p30 = 456.8, p21 = -1322, p12 = 1256, p03 = -390.3

Appendix 11: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 6mm 400 and 8mm for field

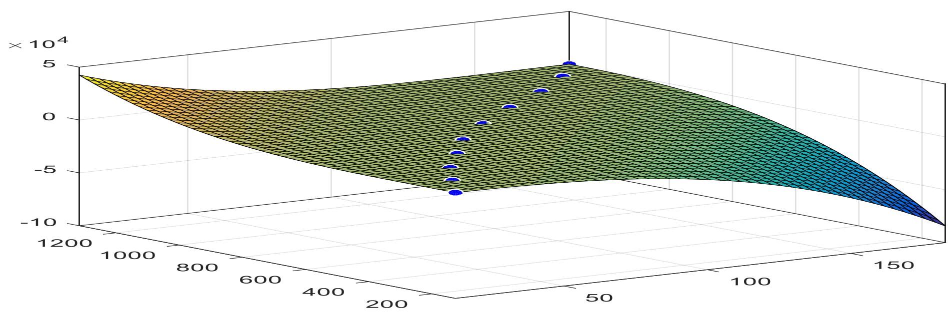


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45 and y = 726.8±405.3

p00 = 17.2, p10 = -125.8, p01 = 151.5, p20 = -988.5, p11 = 2068, p02 = -1072

p30 = -1659, p21 = 4848, p12 = -4589, p03 = 1391



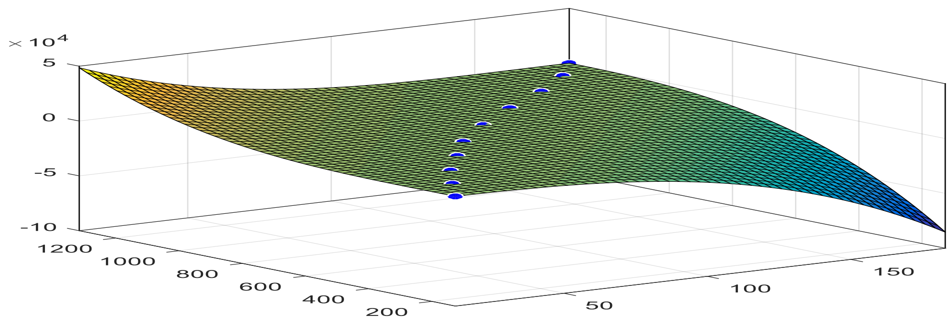
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45 and y = 726.8±405.3

p00 = 16.79, p10 = -205.5, p01 = 238.1, p20 = -1607, p11 = 3355, p02 = -1737

p30 = -2732, p21 = 7992, p12 = -7580. p03 = 2305

Appendix 12: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 8mm 100NPK and 8mm 200 NPK

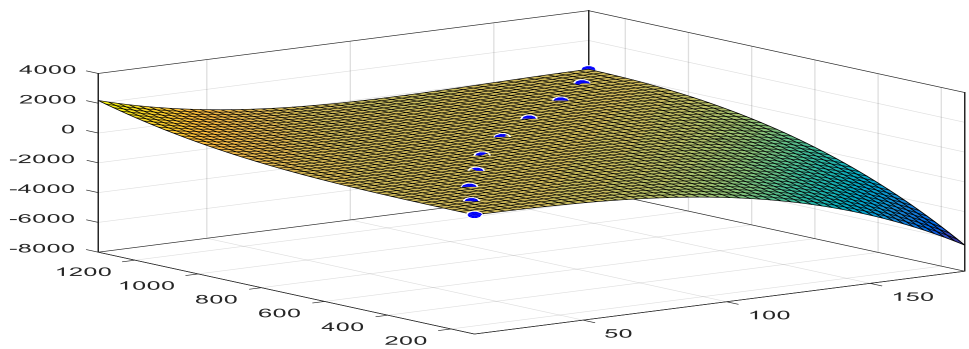


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45 and y = 726.8±405.3

p00 = 21.73, p10 = -125.7, p01 = 154.5, p20 = -1265, p11 = 2644, p02 = -1373

p30 = -2951, p21 = 8526, p12 = -8035, p03 = 2450



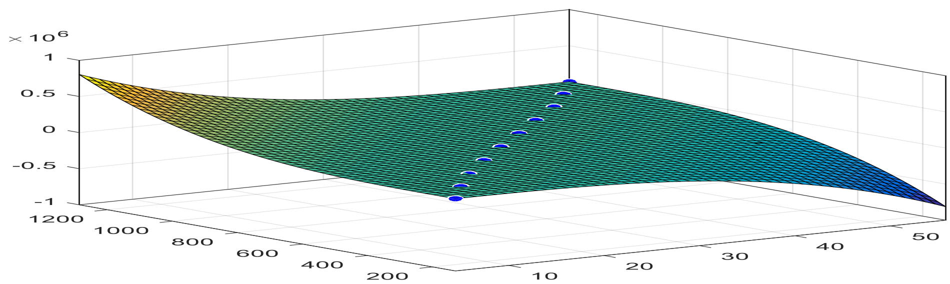
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45 and y = 726.8±405.3

p00 = 23.9, p10 = -4.856, p01 = 27.95, p20 = -176.8, p11 = 377.6, p02 = -196.4

p30 = -235.3, p21 = 577.9, p12 = -446, p03 = 101.4

Appendix 13: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 8mm 300 NPK and 8mm 400 NPK

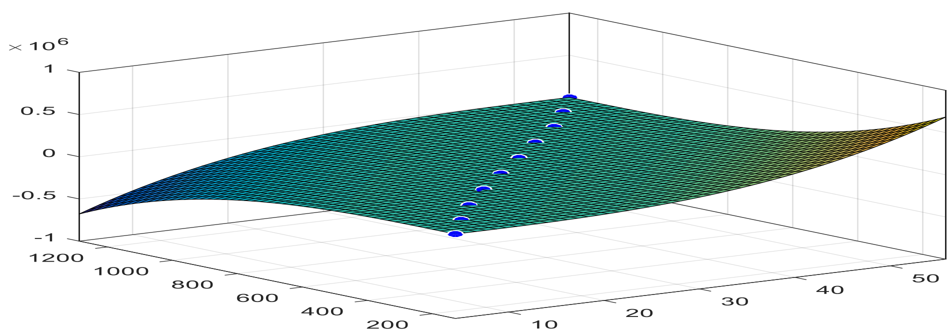


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 707.9±388.8

p00 = 32.17, p10 = 50.21, p01 = -45.9, p20 = 166.5, p11 = -389, p02 = 216.1

p30 = -3.17e+04, p21 = 9.572e+04, p12 = -9.628e+04, p03 = 3.226e+04



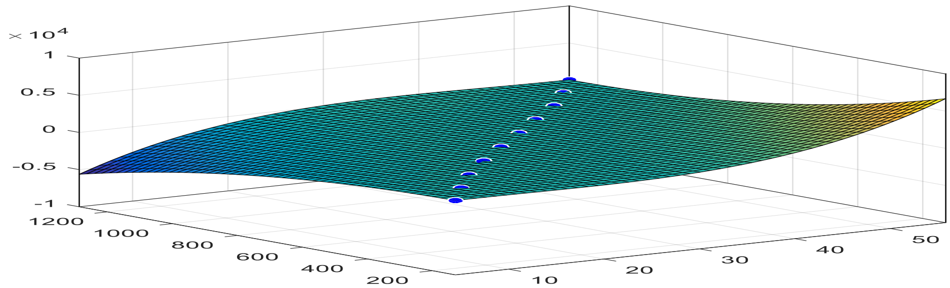
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 707.9±388.8

p00 = 33.86, p10 = -169.2, p01 = 188.9, p20 = -325.2, p11 = 605.8, p02 = -286.9

p30 = 2.751e+04, p21 = -8.144e+04, p12 = 8.037e+04, p03 = -2.645e+04

Appendix 14: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 2mm and 2mm 100 NPK Greenhouse

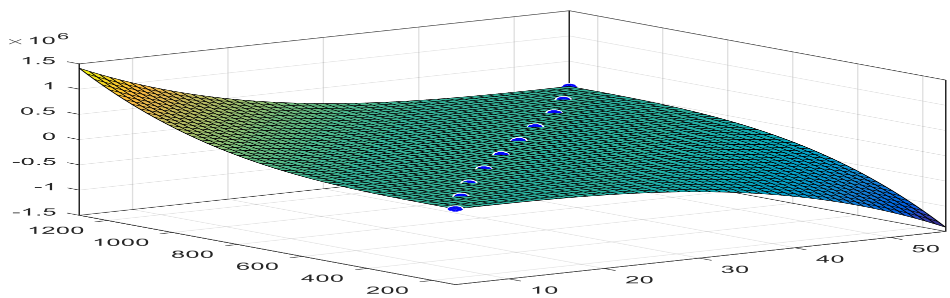


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76, and y = 707.9±388.8

p00 = 39.9, p10 = -16.65, p01 = 26.14, p20 = 17.88, p11 = -101.2, p02 = 73.51

p30 = 489, p21 = -953.9, p12 = 509.2, p03 = -40.09



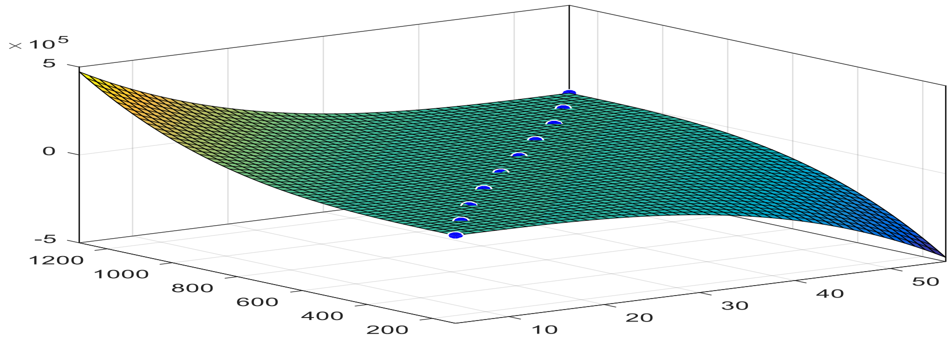
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 707.9±388.8

p00 = 38.37, p10 = 6.181, p01 = 3.248, p20 = 1059, p11 = -2210, p02 = 1142,

p30 = -5.507e+04, p21 = 1.671e+05, p12 = -1.689e+05, p03 = 5.687e+04

Appendix 15: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 2mm 200 NPK and 2mm 300 NPK Greenhouse

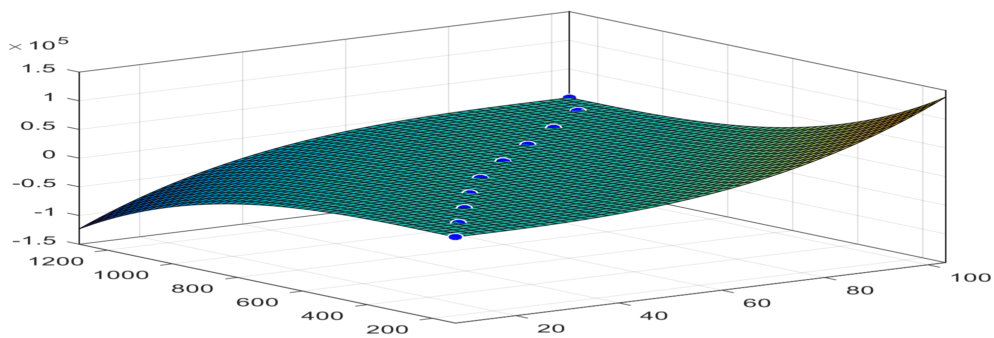


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 707.9±388.8

p00 = 47.97, p10 = 356.5, p01 = -357.9, p20 = 186.5, p11 = -464.6, p02 = 265.5

p30 = -1.986e+04, p21 = 5.75e+04, p12 = -5.546e+04, p03 = 1.784e+04

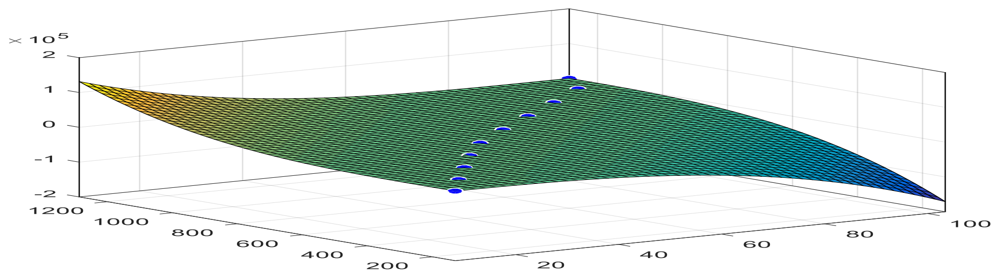


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 707.9±388.8

p00 = 13.84, p10 = -273.1, p01 = 327.8, p20 = 393.6, p11 = -587.6, p02 = 220.1, p30 = 5645, p21 = -1.645e+04, p12 = 1.58e+04, p03 = -5032

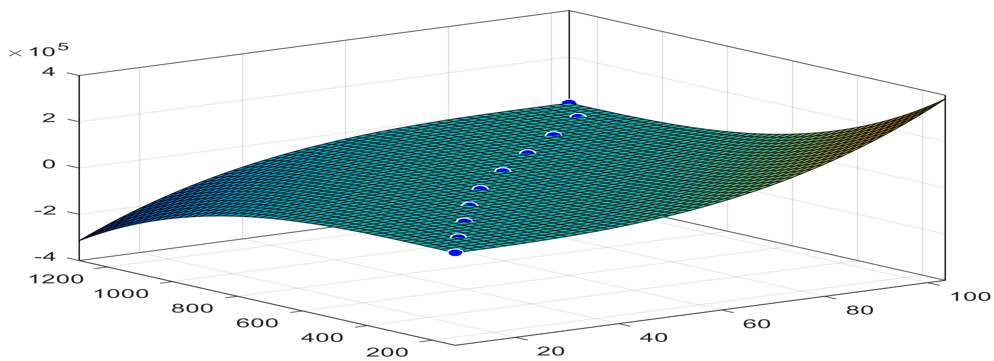
Appendix 16: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 2mm 400 NPK and 4mm Water Depth Greenhouse



PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 707.9±388.8

p00 = 37.28, p10 = -161.8, p01 = 182.9, p20 = -1621, p11 = 3316, p02 = -1697, p30 = -6360, p21 = 1.873e+04, p12 = -1.816e+04, p03 = 5793



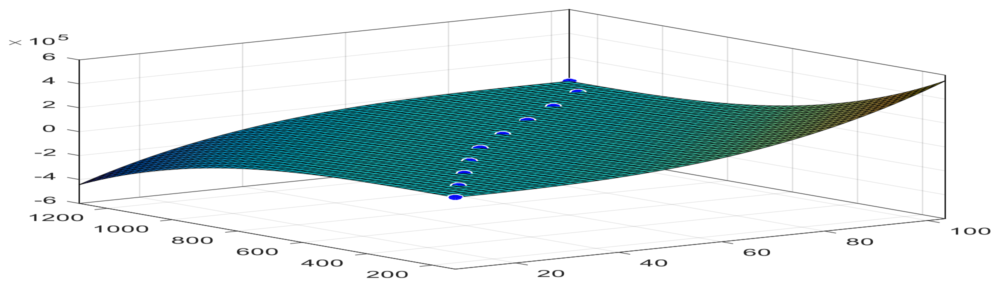
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56, and y = 707.9±388.8

p00 = 25.74, p10 = -90.4, p01 = 138.1, p20 = 2639, p11 = -5187, p02 = 2560,

p30 = 1.461e+04, p21 = -4.323e+04, p12 = 4.225e+04, p03 = -1.366e+04

Appendix 17: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 4mm 100 NPK and 4mm 200 NPK Greenhouse

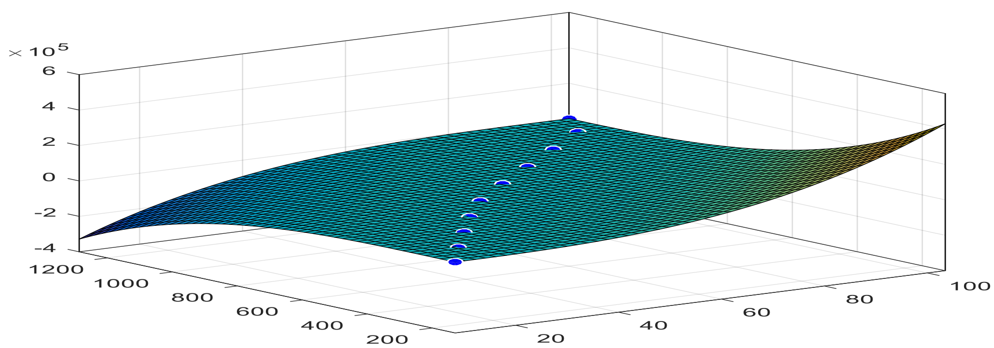


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56, and y = 707.9±388.8

p00 = 23.52, p10 = -17.89, p01 = 70.9, p20 = 4270, p11 = -8453, p02 = 4197,

p30 = 2.08e+04, p21 = -6.168e+04, p12 = 6.036e+04, p03 = -1.952e+04



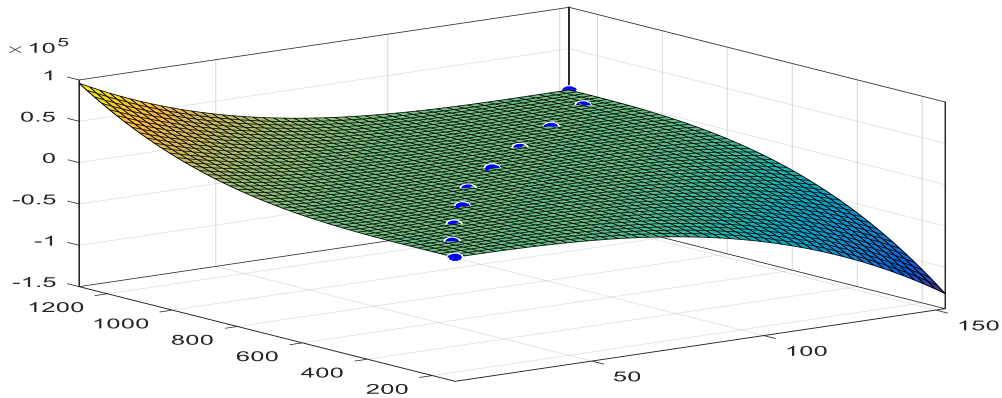
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56, and y = 707.9±388.8

p00 = 34.39, p10 = 181.8, p01 = -151.2, p20 = 4246, p11 = -8514, p02 = 4266,

p30 = 1.566e+04, p21 = -4.667e+04, p12 = 4.584e+04, p03 = -1.485e+04

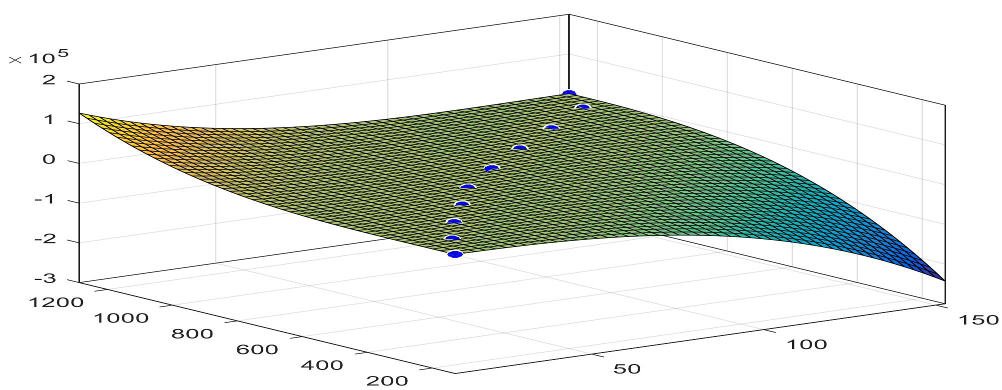
Appendix 18: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 4mm 300 NPK and 4mm 400 NPK Greenhouse 1



PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97 and y = 707.9±388.8

p00 = 55.39, p10 = 19.14, p01 = -23.3, p20 = -1248, p11 = 2427, p02 = -1203, p30 = -4874, p21 = 1.446e+04, p12 = -1.401e+04, p03 = 4455

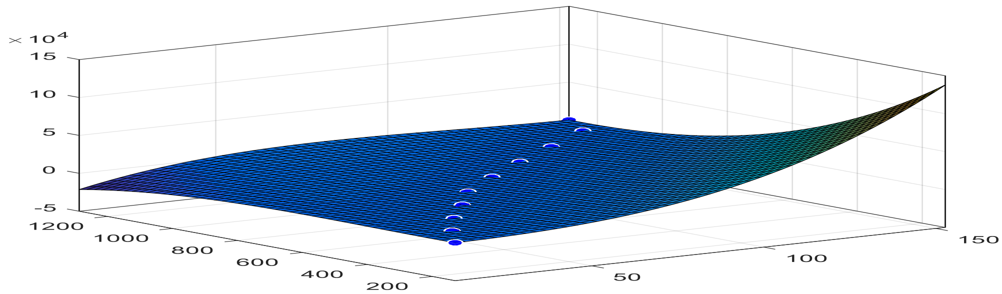


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97, and y = 707.9±388.8

p00 = 16.83, p10 = -763.7, p01 = 816.2, p20 = -5240, p11 = 1.09e+04, p02 = -5625, p30 = -8034, p21 = 2.351e+04, p12 = -2.21e+04, p03 = 6605

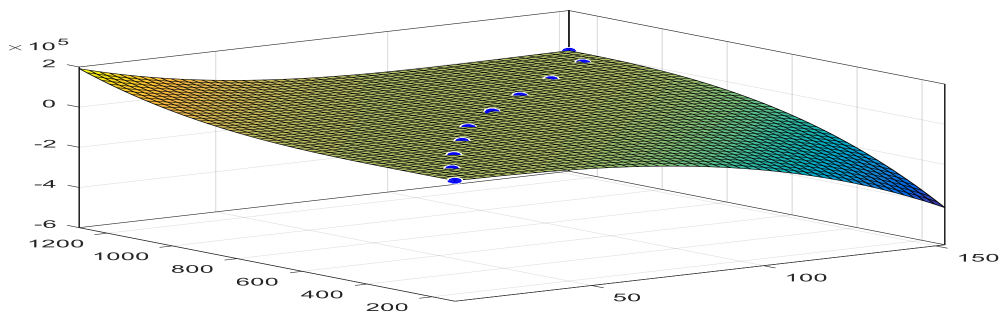
Appendix 19: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 6mm and 6mm 100 NPK Greenhouse



PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97, and where y = 707.9±388.8

p00 = 116, p10 = 1103, p01 = -1143, p20 = 5909, p11 = -1.261e+04, p02 = 6609, p30 = 3872, p21 = -1.048e+04, p12 = 8580, p03 = -1918



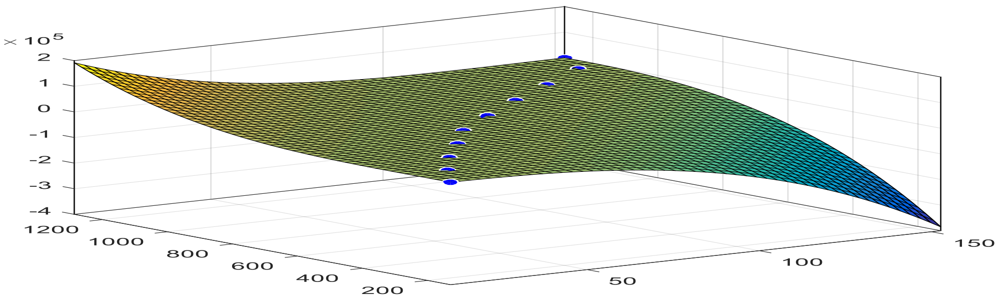
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97 and y = 707.9±388.8

p00 = -25.74, p10 = -1660, p01 = 1768, p20 = -1.042e+04, p11 = 2.181e+04

p02 = -1.13e+04, p30 = -1.33e+04, p21 = 3.868e+04, p12 = -3.589e+04, p03 = 1.046e+04

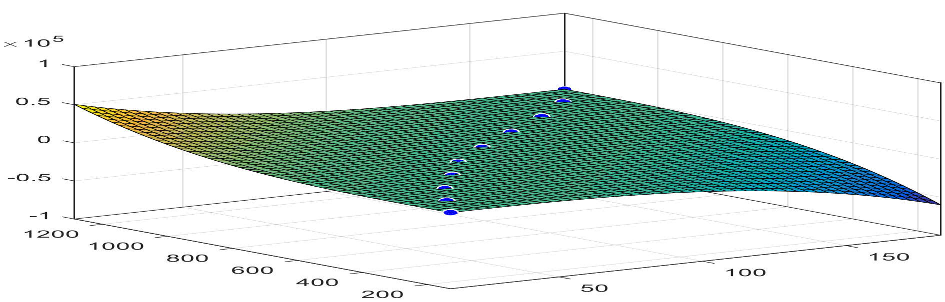
Appendix 20: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 6mm 200 NPK and 6mm 300 NPK



PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97, and y = 707.9±388.8

p00 = -8.811, p10 = -1346, p01 = 1423, p20 = -8846, p11 = 1.847e+04,p02 =-9553, p30 = -1.261e+04, p21 = 3.674e+04,p12 = -3.429e+04, p03 = 1.012e+04

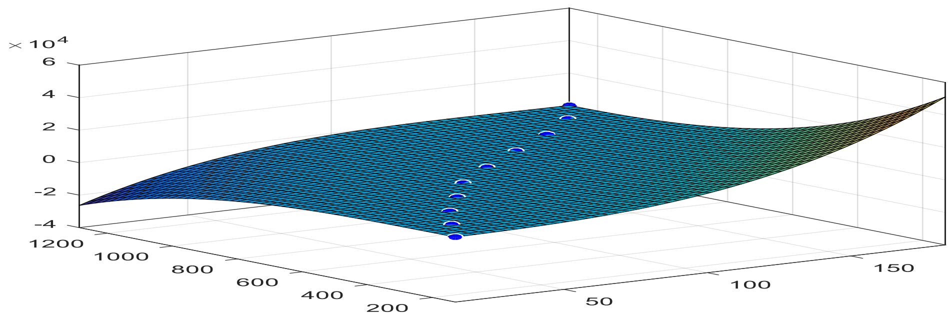


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45, and y = 707.9±388.8

p00 = 64.96, p10 = 132.8, p01 = -134.1, p20 = -7.44, p11 = -114.4, p02 = 89.24, p30 = -2374, p21 = 6968, p12 = -6727, p03 = 2156

Appendix 21: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 6mm 400 NPK and 8mm Water Depth Greenhouse

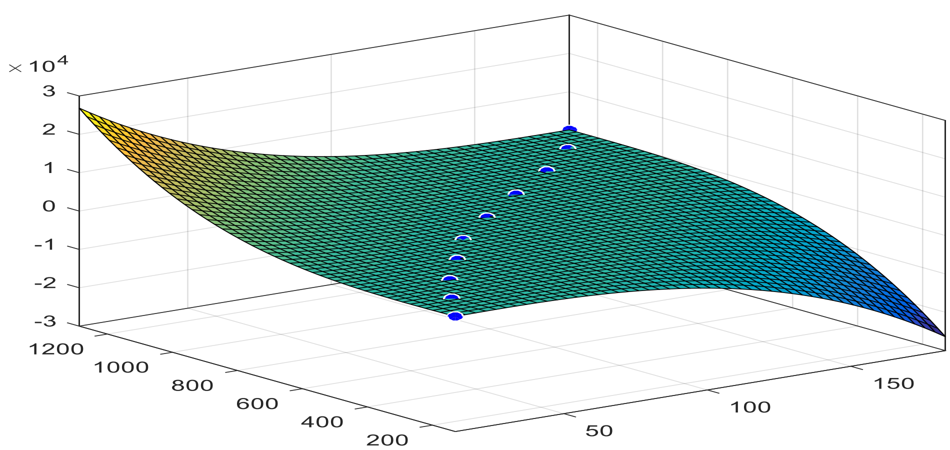


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45, and where y is normalized by mean 707.9±388.8

p00 = 89.41, p10 = 233.6, p01 = -233.9, p20 = 880.7, p11 = -2040, p02 = 1112

p30 = 1836, p21 = -4926, p12 = 4351, p03 = -1229

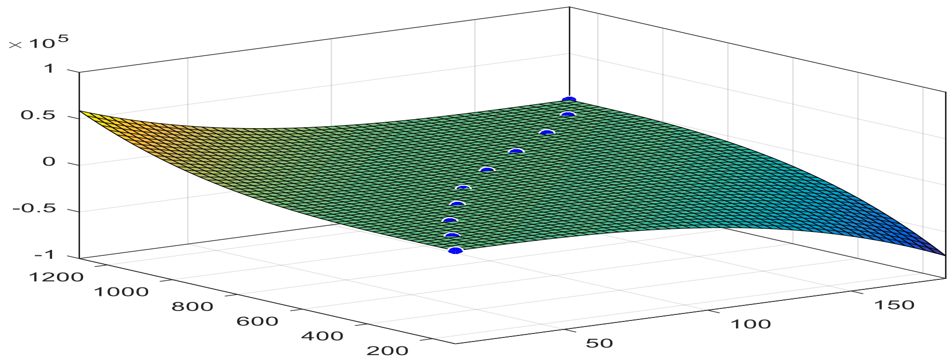


PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45, and y = 707.9±388.8

p00 = 73.16, p10 = 155.4, p01 = -156.5, p20 = 242.4, p11 = -653.9, p02 = 373.9, p30 = -1087, p21 = 3338, p12 = -3346, p03 = 1120

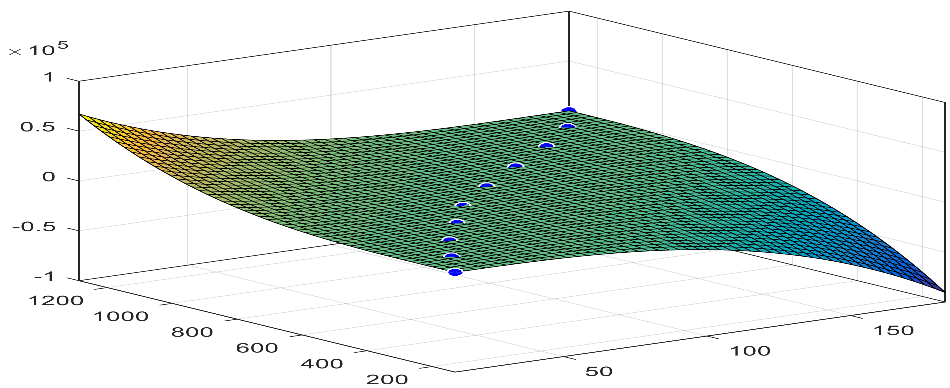
Appendix 22: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 8mm 100 NPK and 8mm 200 NPK



PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45, and y = 707.9±388.8

p00 = 65.06, p10 = 104.8, p01 = -107, p20 = -296.9, p11 = 491.5, p02 = -228, p30 = -2891, p21 = 8474, p12 = -8141, p03 = 2581



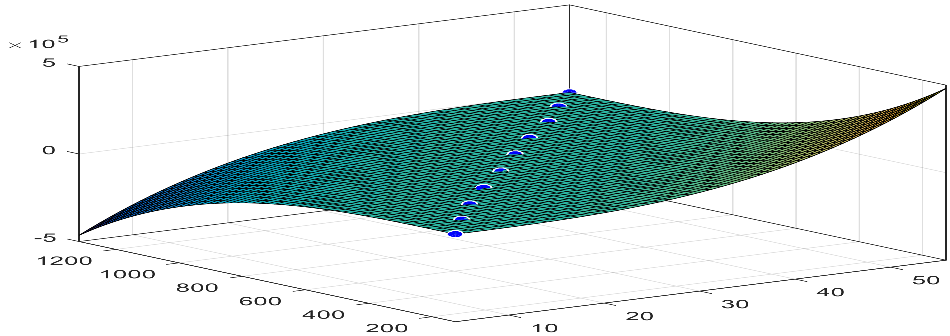
PHH(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45, and y = 707.9±388.8

p00 = 69.89, p10 = 157.2, p01 = -166.1, p20 = -514.4, p11 = 945.6, p02 = -472

p30 = -3532, p21 = 1.008e+04, p12 = -9405, p03 = 2885

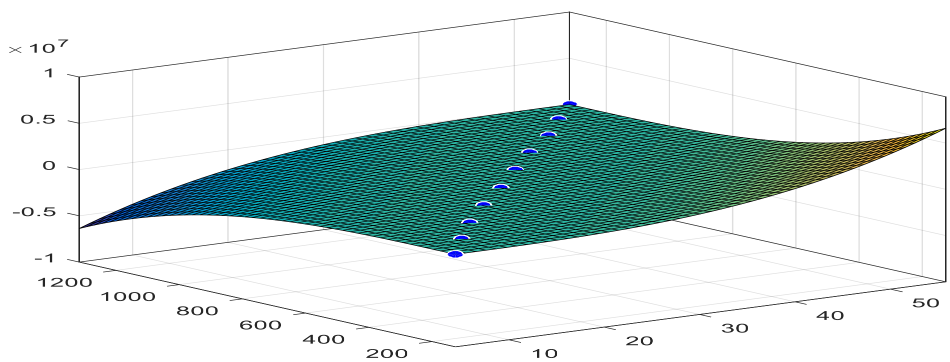
Appendix 23: Graph of Plant Height in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 300 NPK and 8mm 400 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.7 and y = 726.8±405.3

p00 = 8.748, p10 = 82.91, p01 = -80.72, p20 = -281.7, p11 = 558.3, p02 = -278.4, p30 = 1.869e+04, p21 = -5.686e+04, p12 = 5.762e+04, p03 = -1.944e+04

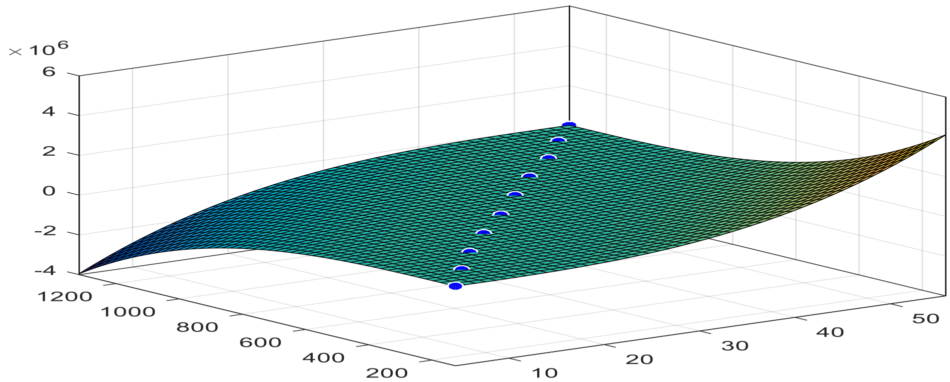


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 5.443, p10 = -303.2, p01 = 305.1, p20 = -3971, p11 = 8127, p02 = -4155, p30 = 2.628e+05, p21 = -7.863e+05, p12 = 7.845e+05, p03 = -2.609e+05

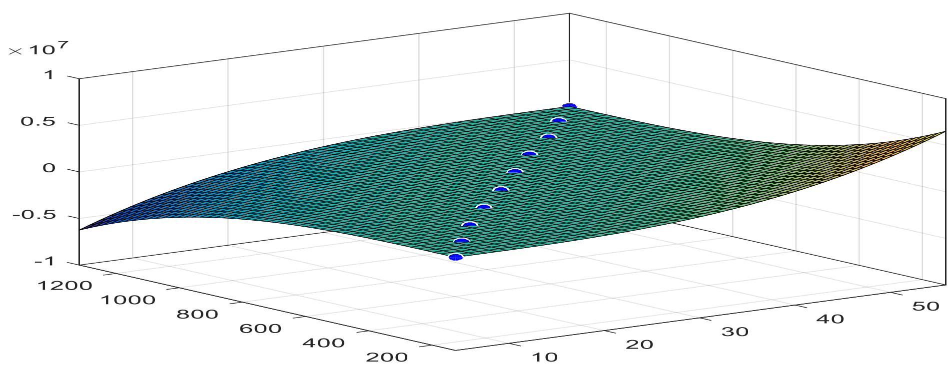
Appendix 24: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm and 2mm 100 NPK for field



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 6.99, p10 = -160.1, p01 = 164.9, p20 = -1617, p11 = 3300, p02 = -1682, p30 = 1.631e+05, p21 = -4.88e+05, p12 = 4.869e+05, p03 = -1.619e+05

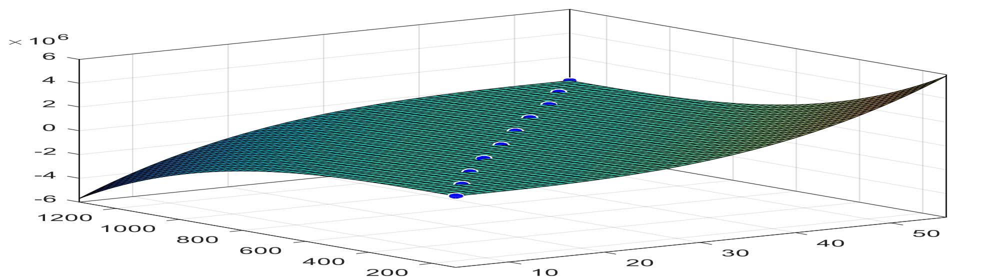


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 726.8±405.3

p00 = 5.546, p10 = -376.3, p01 = 381.1, p20 = -2182, p11 = 4483, p02 = -2299, p30 = 2.59e+05, p21 = -7.732e+05, p12 = 7.694e+05, p03 = -2.553e+05

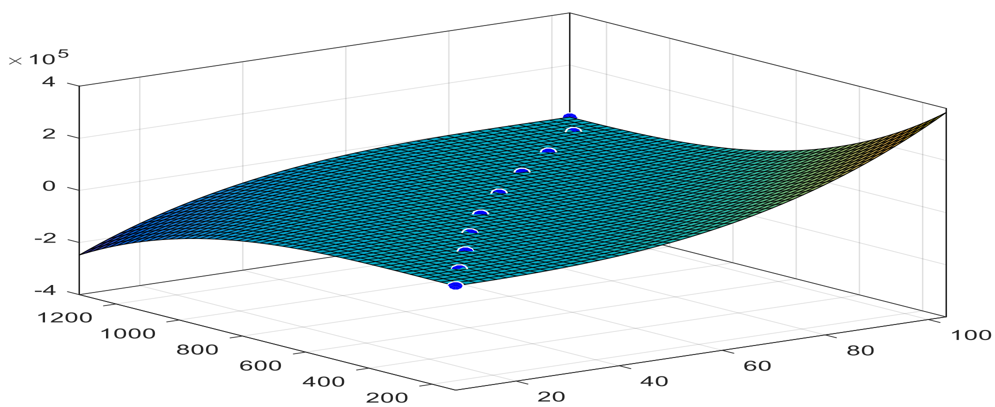
Appendix 25: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm 200 NPK and 2mm 300 NPK for field



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 726.8±405.3

p00 = 6.632, p10 = -361.9, p01 = 367.5, p20 = -4379, p11 = 8969, p02 = -4588, p30 = 2.351e+05, p21 = -7.028e+05, p12 = 7.004e+05, p03 = -2.328e+05

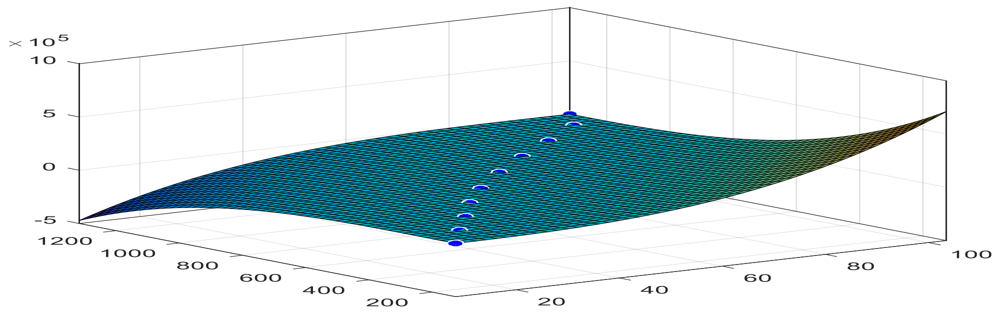


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6± 33.56 and y = 726.8±405.3

p00 = 13.75, p10 = 501.6, p01 = -506.4, p20 = 5990, p11 = -1.226e+04, p02 = 6261, p30 = 1.299e+04, p21 = -3.929e+04, p12 = 3.896e+04, p03 = -1.266e+04

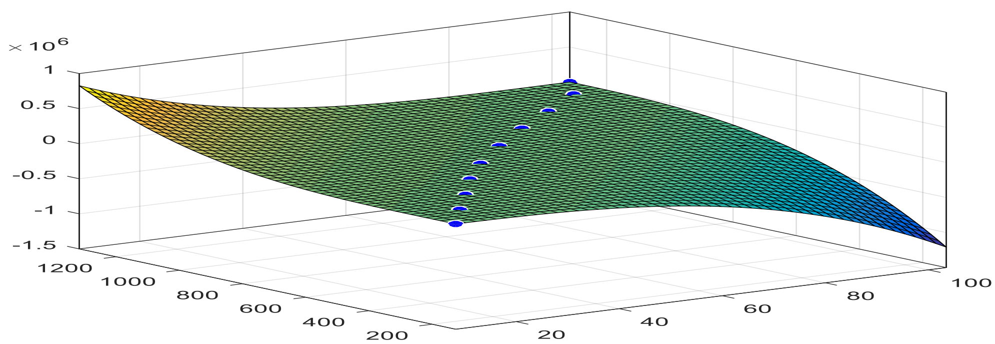
Appendix 26: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm 400 NPK and 4mm Water Depth for field



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 726.8±405.3

p00 = 14.49, p10 = 813.1, p01 = -820.1, p20 = 1.038e+04, p11 = -2.119e+04, p02 = 1.08e+04, p30 = 2.438e+04, p21 = -7.362e+04, p12 = 7.3e+04, p03 = -2.374e+04

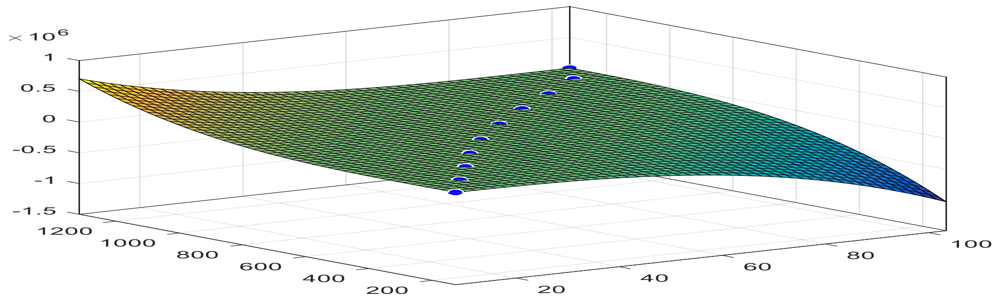


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 726.8±405.3

p00 = -0.394, p10 = -1238, p01 = 1258, p20 = -1.606e+04, p11 = 3.274e+04, p02 = -1.667e+04, p30 = -4.197e+04, p21 = 1.267e+05, p12 = -1.257e+05, p03 = 4.094e+04

Appendix 27: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 4mm 100 NPK and 4mm 200 NPK

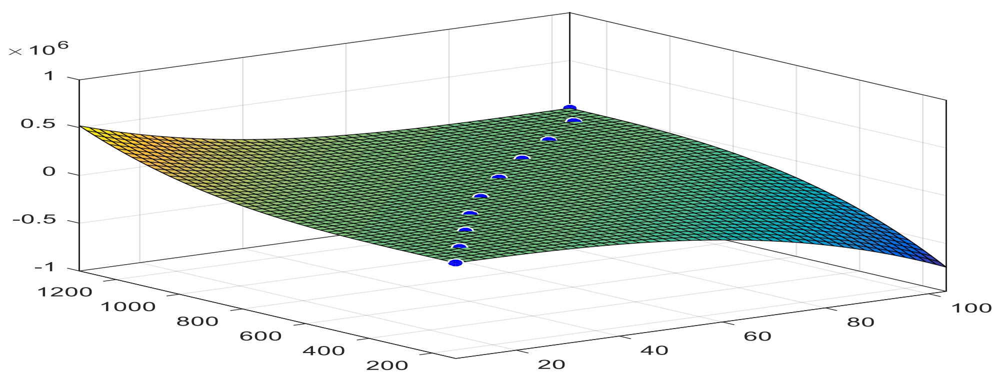


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 726.8±405.3

p00 = -0.303, p10 = -1085, p01 = 1104, p20 = -1.378e+04, p11 = 2.811e+04

p02 = -1.431e+04, p30 = -3.577e+04, p21 = 1.08e+05, p12 = -1.071e+05, p03 = 3.49e+04

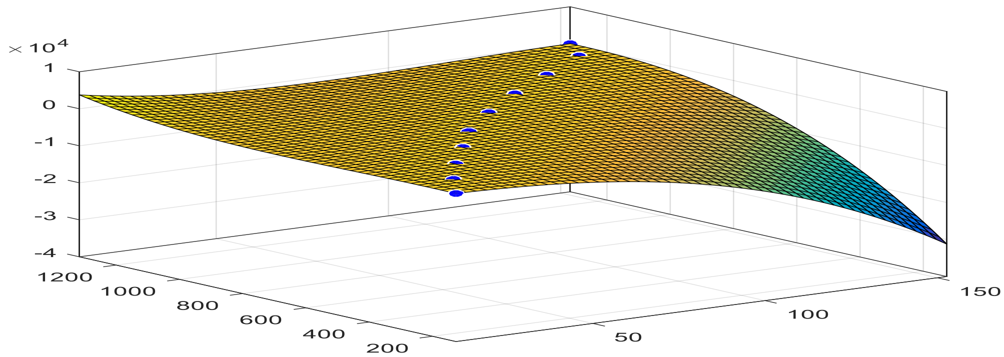


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 54.6±33.56 and y = 726.8±405.3

p00 = 3.387, p10 = -733.1, p01 = 746.7, p20 = -9468, p11 = 1.93e+04, p02 = -9819, p30 = -2.618e+04, p21 = 7.896e+04, p12 = -7.829e+04, p03 = 2.551e+04

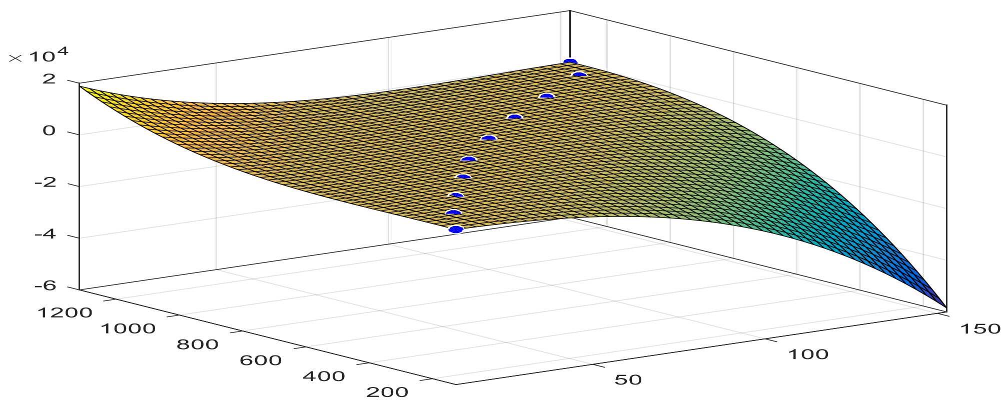
Appendix 28: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 4mm 300 NPK and 4mm 400 NPK for field



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = -6.935, p10 = -302.2, p01 = 325.9, p20 = -1411, p11 = 3006, p02 = -1577, p30 = -725.7, p21 = 2187, p12 = -1992, p03 = 514

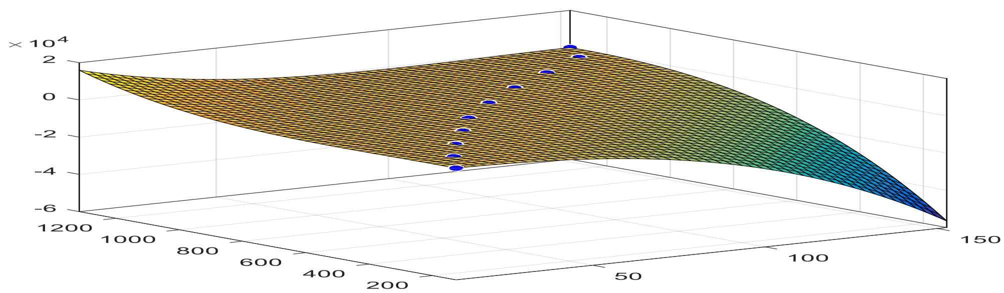


LAA(x,y) axis= p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = -7.136, p10 = -360.2, p01 = 383.2, p20 = -1922, p11 = 4048, p02 = -2107, p30 = -1635, p21 = 4903, p12 = -4610, p03 = 1325

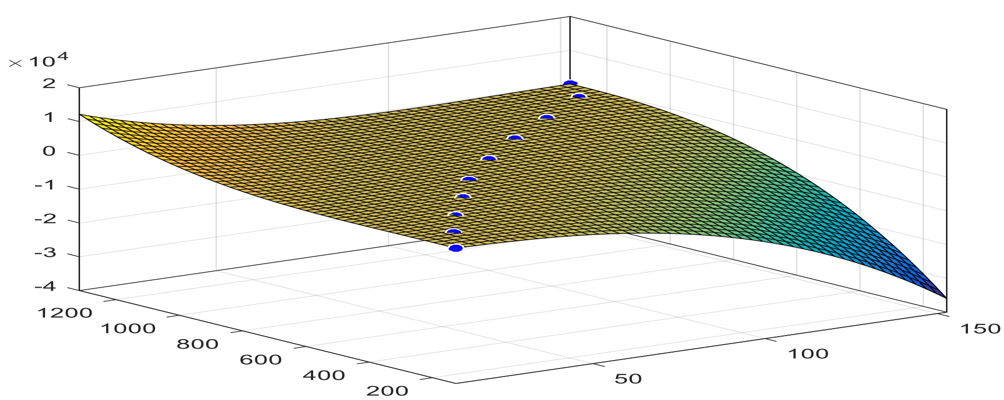
Appendix 29: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm and 6mm 100 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97 and y = 726.8±405.3

p00 = -8.632, p10 = -388.6, p01 = 414.1, p20 = -2000, p11 = 4222, p02 = -2201, p30 = -1527, p21 = 4583, p12 = -4283, p03 = 1209

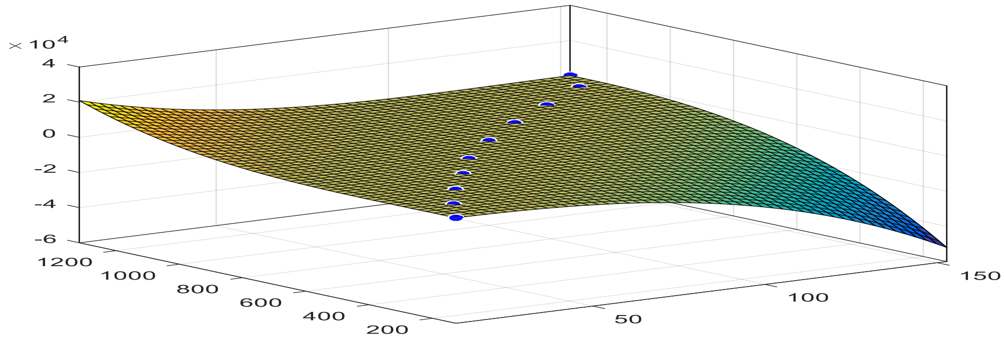


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = -3.375, p10 = -257.6, p01 = 277.2, p20 = -1140, p11 = 2423, p02 = -1268, p30 = -1004, p21 = 3031, p12 = -2868, p03 = 828.8

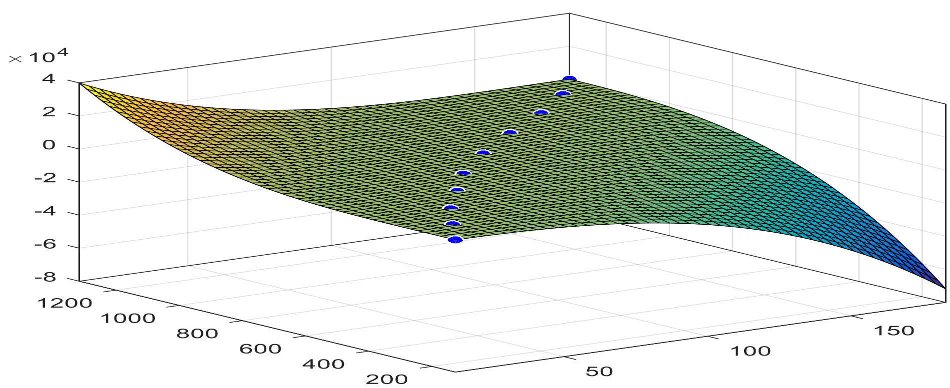
Appendix 30: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm 300 NPK and 6mm 400 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97 and y = 726.8±405.3

p00 = -0.1127, p10 = -263.1, p01 = 279.6, p20 = -1461, p11 = 3055, p02 = -1582, p30 = -1532, p21 = 4626, p12 = -4417, p03 = 1314

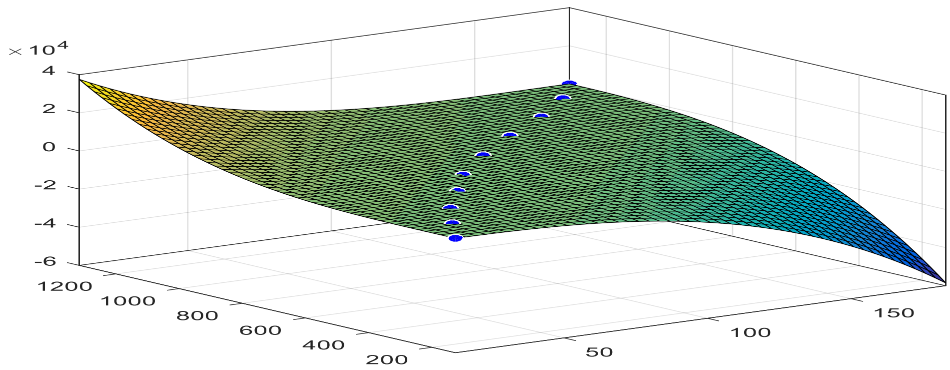


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 4.894, p10 = -166.5, p01 = 181.4, p20 = -1135, p11 = 2365, p02 = -1224, p30 = -2349, p21 = 6999, p12 = -6764, p03 = 2106

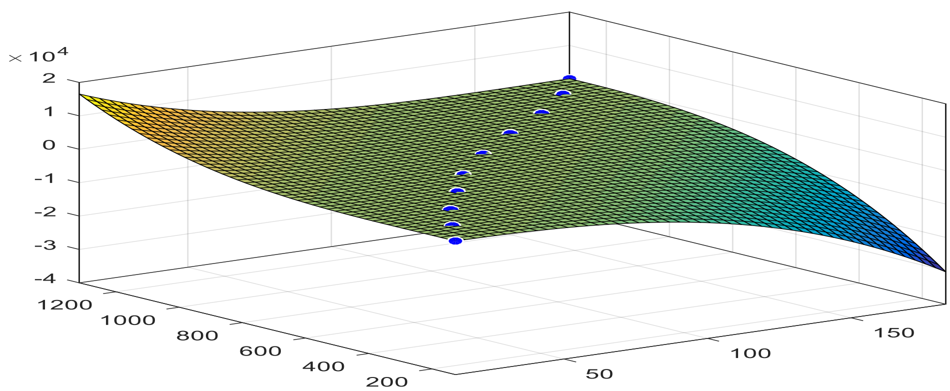
Appendix 31: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm 400 NPK and 8mm Water Depth



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 8.164, p10 = -84.27, p01 = 94.8, p20 = -596.7, p11 = 1245, p02 = -646.4, p30 = -2048, p21 = 6055, p12 = -5853, p03 = 1843

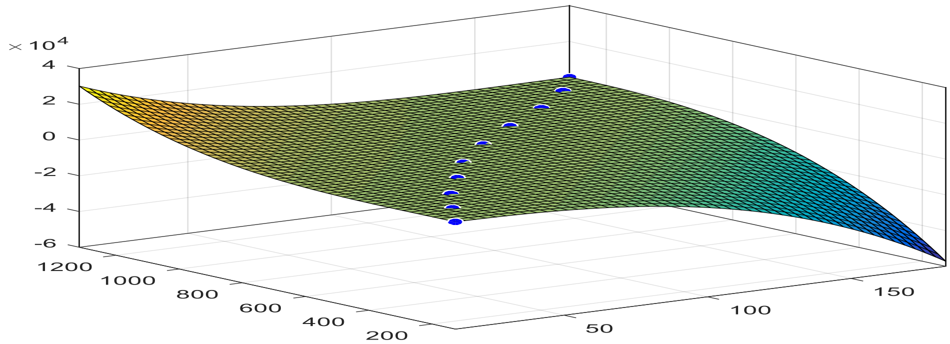


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 11.1, p10 = -61.59, p01 = 67.25, p20 = -507.9, p11 = 1045 p02 = -538.9, p30 = -945.1, p21 = 2915, p12 = -2874, p03 = 905.4

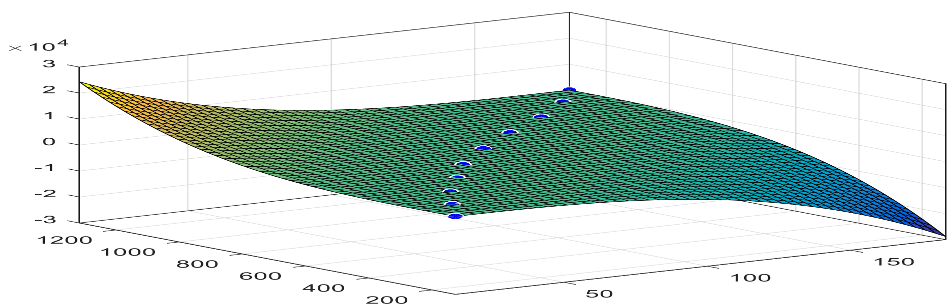
Appendix 32: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 100NPK and 8mm 200 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 92±60.45 and y = 726.8±405.3

p00 = 9.443, p10 = -125.7, p01 = 135.9, p20 = -1016, p11 = 2099, p02 = -1084, p30 = -1816, p21 = 5465, p12 = -5298, p03 = 1645

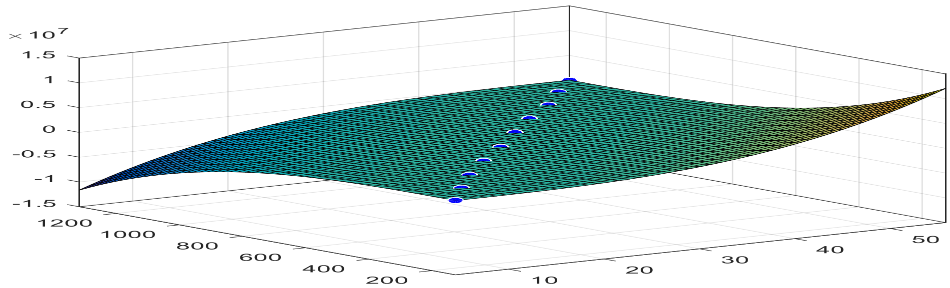


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 13.85, p10 = 28.77, p01 = -24.98, p20 = 89.6, p11 = -175, p02 = 81.41, p30 = -1129, p21 = 3372, p12 = -3320, p03 = 1081

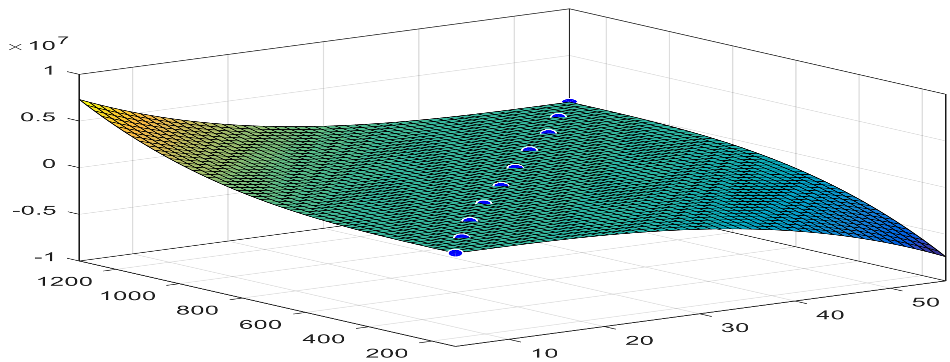
Appendix 33: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 300NPK and 8mm 400 NPK for field



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 20.03, p10 = -899.6, p01 = 911.4, p20 = -6183, p11 = 1.27e+04, p02 = -6515, p30 = 4.836e+05, p21 = -1.442e+06, p12 = 1.433e+06, p03 = -4.748e+05

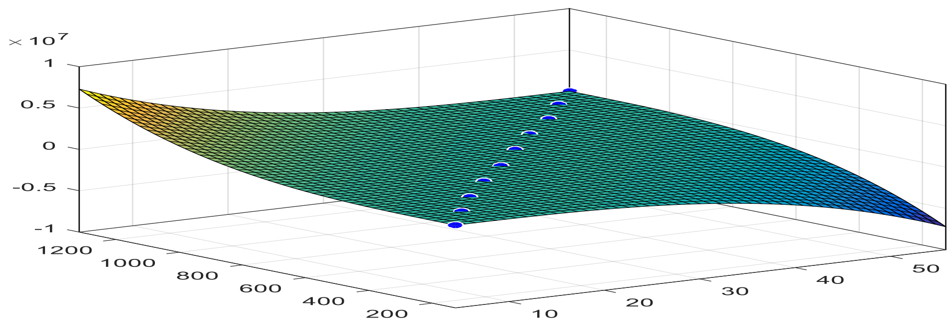


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 35.54, p10 = 512.8, p01 = -501.3, p20 = 1.353e+04, p11 = -2.759e+04, p02 = 1.405e+04, p30 = -2.951e+05, p21 = 8.893e+05, p12 = -8.937e+05, p03 = 2.995e+05

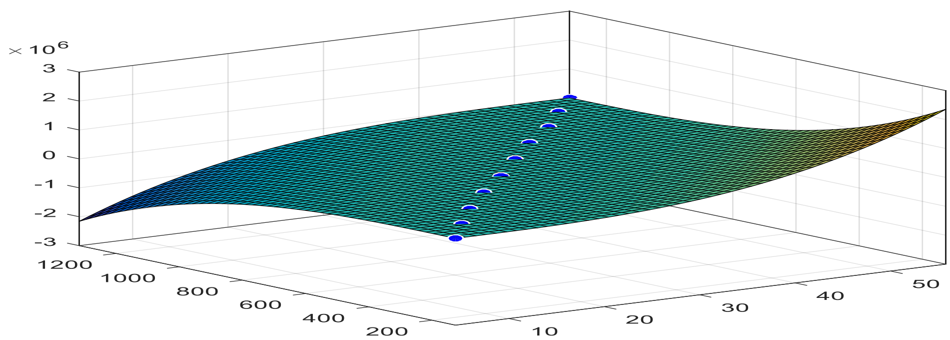
Appendix 34: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm and 2mm 100 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 726.8±405.3

p00 = 38.82, p10 = 556.4, p01 = -538, p20 = 2.29e+04, p11 = -4.657e+04, p02 = 2.366e+04, p30 = -2.88e+05, p21 = 8.738e+05, p12 = -8.842e+05, p03 = 2.984e+05

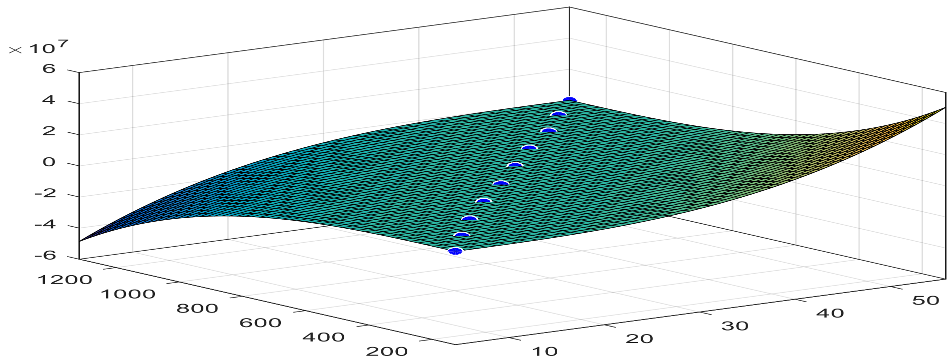


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 29.95±17.76 and y = 726.8±405.3

p00 = 36.15, p10 = -139.7, p01 = 158.8, p20 = 5523, p11 = -1.118e+04, p02 = 5651, p30 = 9.412e+04, p21 = -2.764e+05, p12 = 2.703e+05, p03 = -8.803e+04

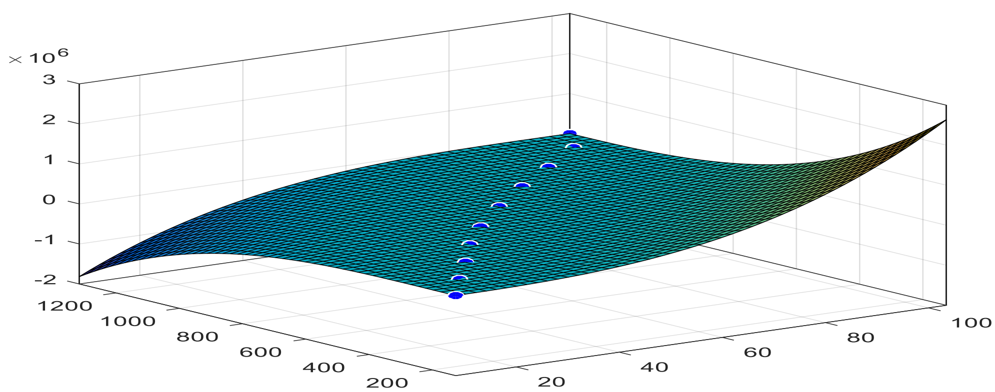
Appendix 35: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm 200 NPK and 2mm Water Depth 300 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 14.41, p10 = -3293, p01 = 3333, p20 = -2.171e+04, p11 = 4.467e+04, p02 = -2.294e+04, p30 = 2.012e+06, p21 = -6.01e+06, p12 = 5.984e+06, p03 = -1.987e+06

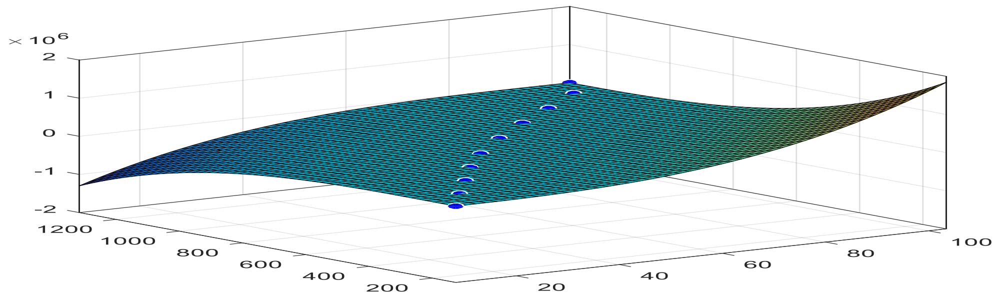


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 30.12, p10 = 2332, p01 = -2324, p20 = 3.446e+04, p11 = -6.998e+04, p02 = 3.553e+04, p30 = 9.213e+04, p21 = -2.776e+05, p12 = 2.75e+05, p03 = -8.947e+04

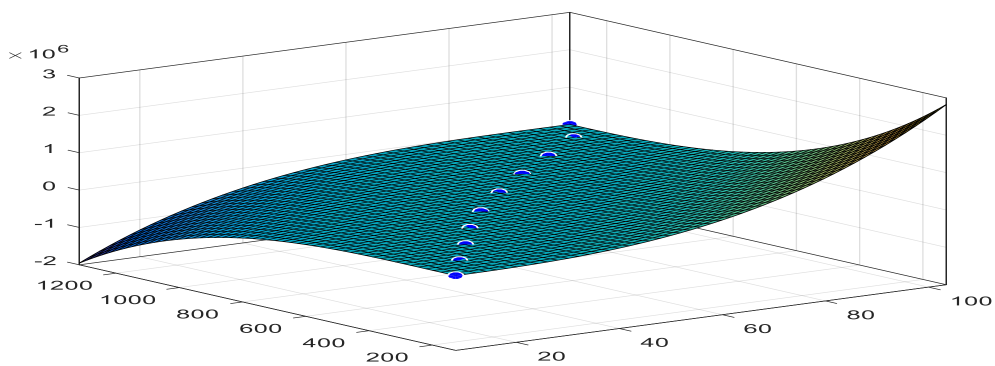
Appendix 36: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm 400 NPK and 4mm Water Depth



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6± 33.56 and y = 726.8±405.3

p00 = 28.63, p10 = 1424, p01 = -1411, p20 = 2.226e+04, p11 = -4.515e+04, p02 = 2.29e+04, p30 = 6.514e+04, p21 = -1.961e+05, p12 = 1.942e+05, p03 = -6.324e+04

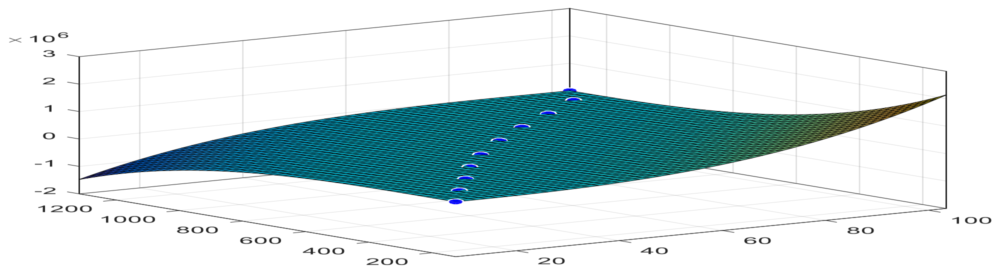


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 41.3, p10 = 2552, p01 = -2556, p20 = 3.624e+04, p11 = -7.371e+04, p02 = 3.746e+04, p30 = 9.88e+04, p21 = -2.978e+05, p12 = 2.951e+05, p03 = -9.607e+04

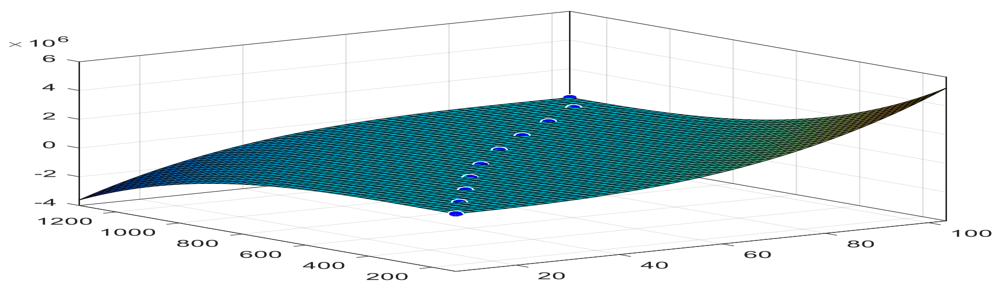
Appendix 37: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 4mm 100 NPK and 4mm 200 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 43.27, p10 = 1949, p01 = -1946, p20 = 2.77e+04, p11 = -5.635e+04, p02 = 2.864e+04, p30 = 7.476e+04, p21 = -2.253e+05, p12 = 2.232e+05, p03 = -7.266e+04

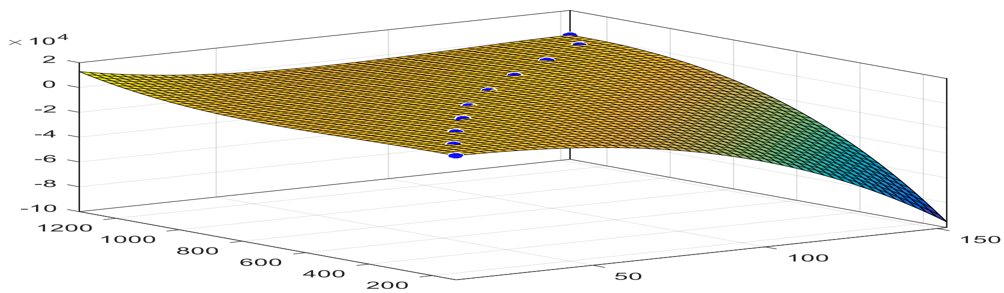


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 40.03, p10 = 4793, p01 = -4813, p20 = 6.816e+04, p11 = -1.386e+05, p02 = 7.043e+04, p30 = 1.829e+05, p21 = -5.516e+05, p12 = 5.468e+05, p03 = -1.781e+05

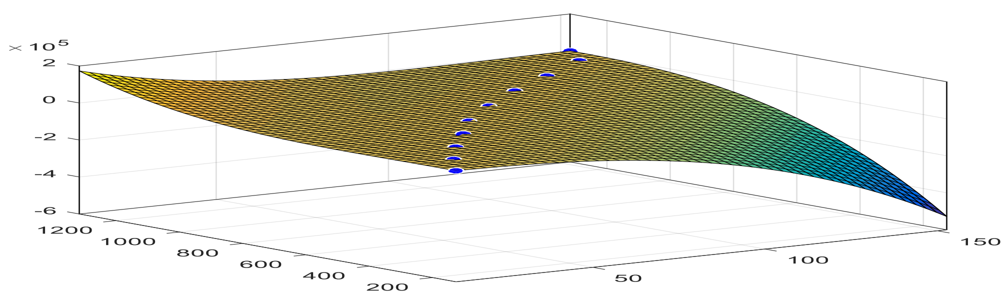
Appendix 38: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 4mm 300 NPK and 4mm 400 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97 and y = 726.8±405.3

p00 = 40.95, p10 = -489.8, p01 = 510.2, p20 = -4395, p11 = 8994, p02 = -4605, p30 = -2198, p21 = 6847, p12 = -6418, p03 = 1765

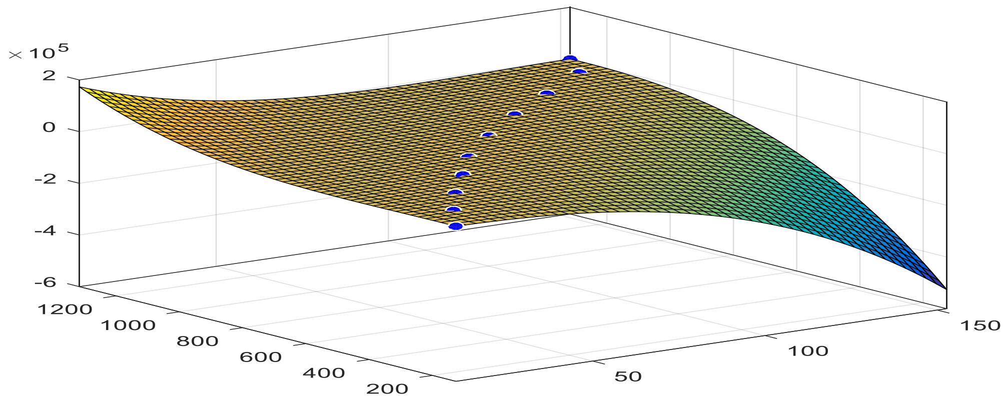


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = -12.9, p10 = -2483, p01 = 2589, p20 = -1.743e+04, p11 = 3.618e+04, p02 = -1.869e+04, p30 = -1.476e+04, p21 = 4.46e+04, p12 = -4.226e+04, p03 = 1.233e+04

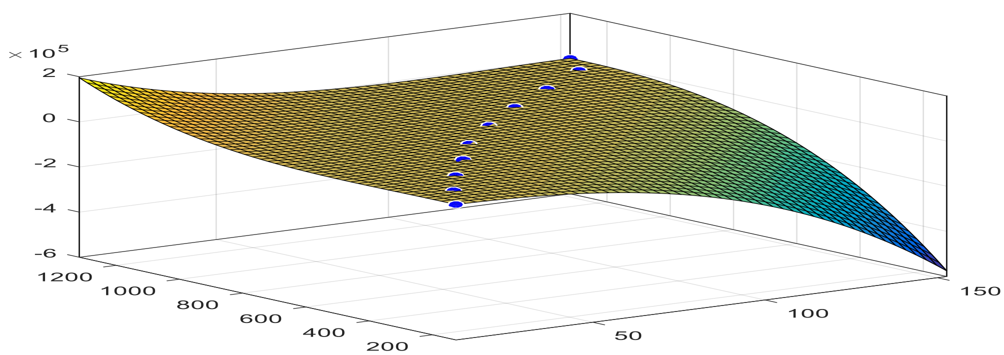
Appendix 39: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm and 6mm 100 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = -14.44, p10 = -2492, p01 = 2601, p20 = -1.73e+04, p11 = 3.594e+04, p02 = -1.857e+04, p30 = -1.471e+04, p21 = 4.446e+04, p12 = -4.213e+04, p03 = 1.23e+04

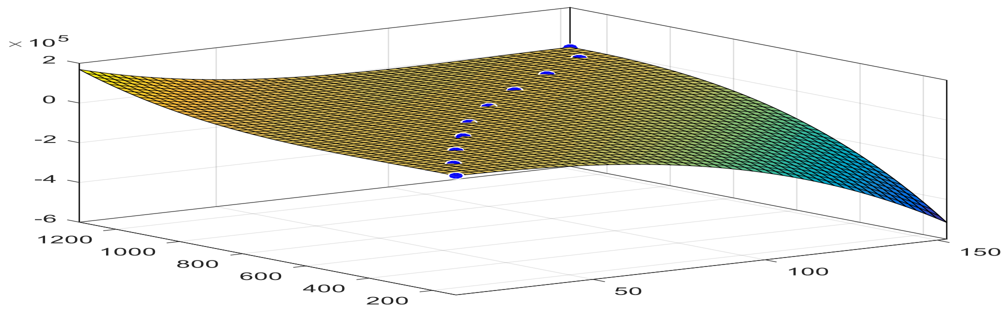


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

where x = 78.15±50.97, y = 726.8±405.3

p00 = -13.7, p10 = -2647, p01 = 2761, p20 = -1.857e+04, p11 = 3.853e+04, p02 = -1.99e+04, p30 = -1.62e+04, p21 = 4.896e+04, p12 = -4.648e+04, p03 = 1.363e+04

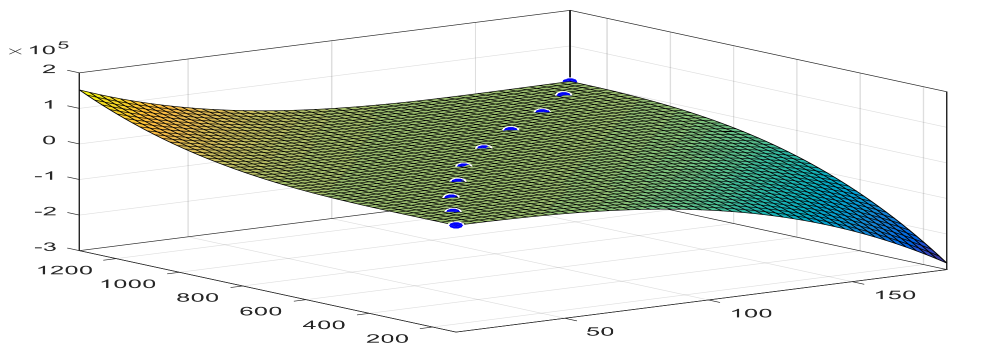
Appendix 40: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm 200 NPK and 6mm 300 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97, y = 726.8±405.3

p00 = -16.57, p10 = -2476, p01 = 2584, p20 = -1.706e+04, p11 = 3.545e+04, p02 = -1.833e+04, p30 = -1.445e+04, p21 = 4.359e+04, p12 = -4.124e+04, p03 = 1.201e+04

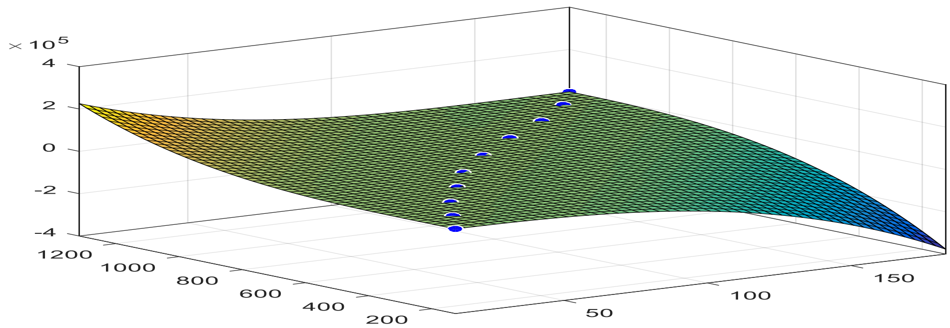


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 91.42, p10 = -215.3, p01 = 215.8, p20 = -4852, p11 = 9825, p02 = -5037, p30 = -9457, p21 = 2.767e+04, p12 = -2.613e+04, p03 = 7931

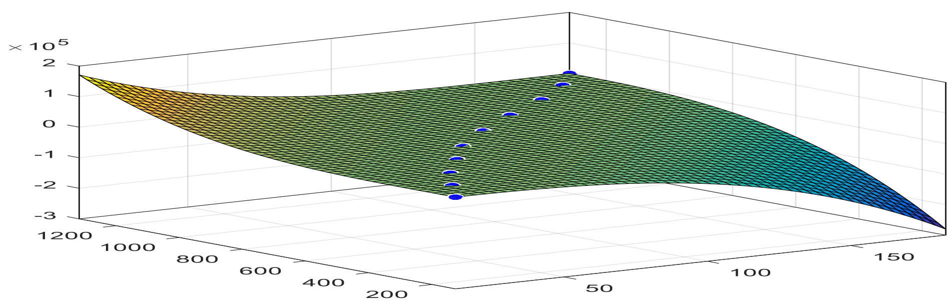
Appendix 41: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm 400 NPK and 8mm Water Depth



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8± 405.3

p00 = 134.9, p10 = -61.07, p01 = 65.28, p20 = -5003, p11 = 1.009e+04, p02 = -5183, p30 = -1.335e+04, p21 = 3.864e+04, p12 = -3.635e+04, p03 = 1.108e+04

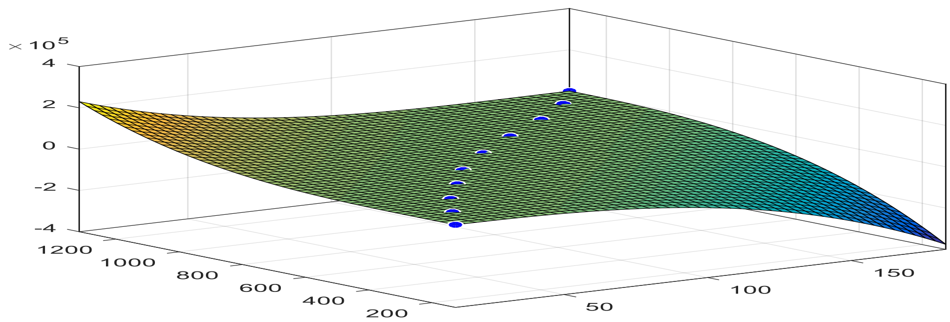


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 87.94, p10 = -229.8, p01 = 254.1, p20 = -3490, p11 = 7097, p02 = -3650, p30 = -9727, p21 = 2.86e+04, p12 = -2.741e+04, p03 = 8529

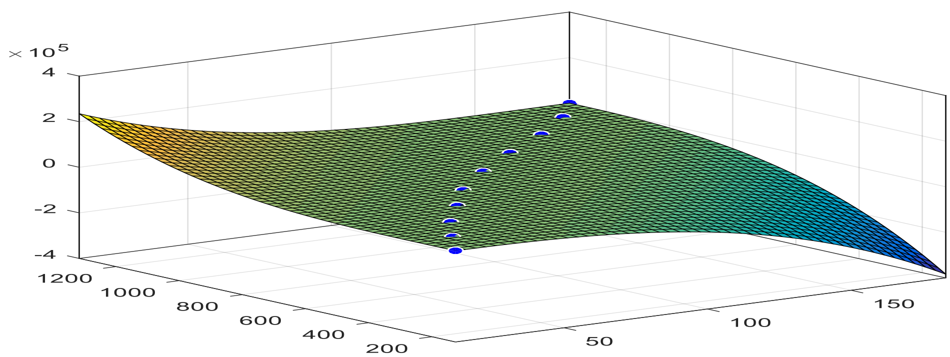
Appendix 42: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 100 NPK and 8mm 200 NPK



LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 100.7, p10 = -223, p01 = 235.1, p20 = -4667, p11 = 9448, p02 = -4845, p30 = -1.313e+04, p21 = 3.85e+04, p12 = -3.679e+04, p03 = 1.143e+04

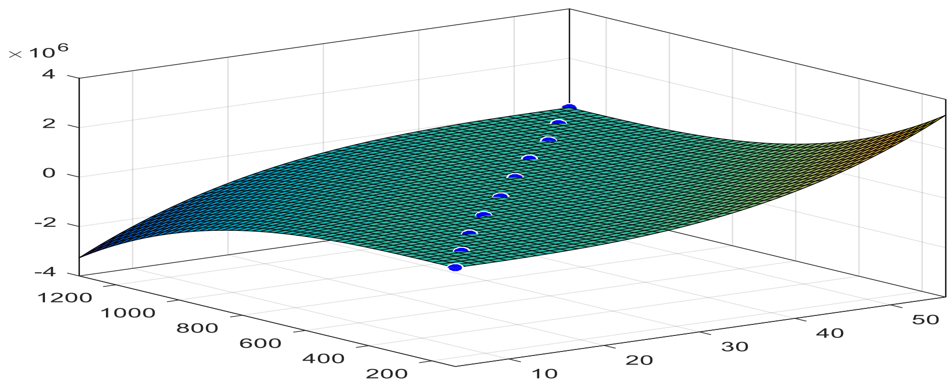


LAA(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 108.6, p10 = -18.69, p01 = -22.33, p20 = -4784, p11 = 9575, p02 = -4890, p30 = -1.347e+04, p21 = 3.948e+04, p12 = -3.762e+04, p03 = 1.165e+04

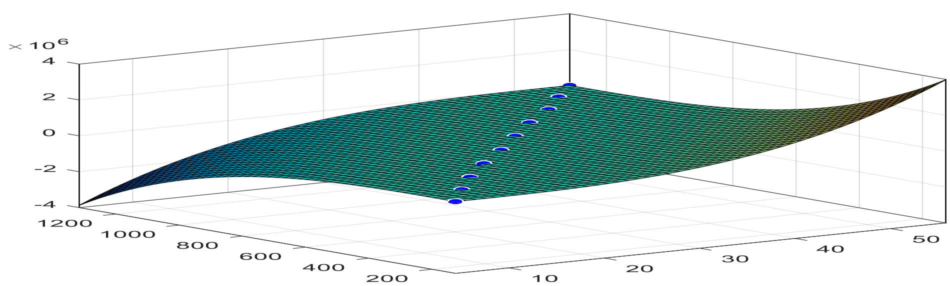
Appendix 43: Graph of Leaf Area in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 300 NPK and 8mm 400 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8± 405.3

p00 = 5.873, p10 = -181.8, p01 = 186, p20 = -3388, p11 = 6907, p02 = -3517, p30 = 1.34e+05, p21 = -4.013e+05, p12 = 4.008e+05, p03 = -1.335e+05

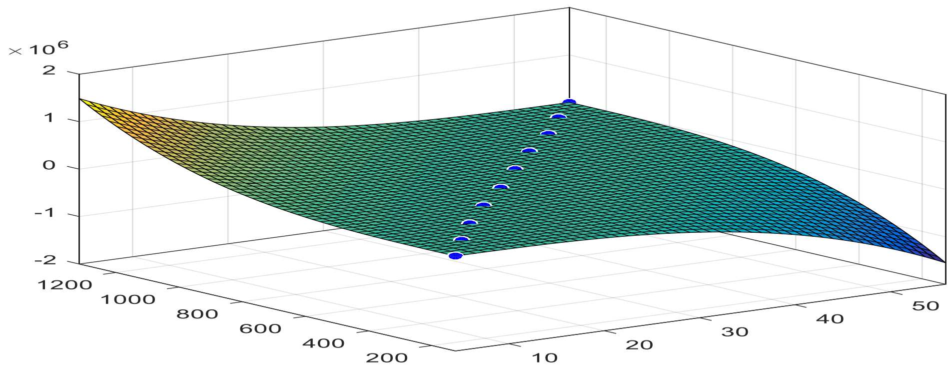


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 6.067, p10 = -242.9, p01 = 245.8, p20 = -3530, p11 = 7176, p02 = -3644, p30 = 1.592e+05, p21 = -4.764e+05, p12 = 4.752e+05, p03 = -1.581e+05

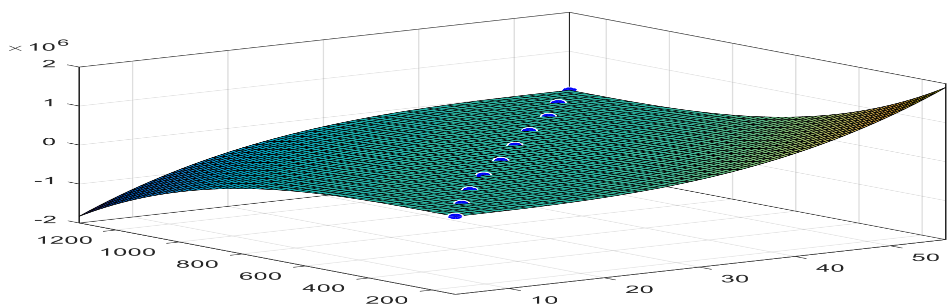
Appendix 44: Graph of Growth Index in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 2mm Water Depth and 2mm 100 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 9.051, p10 = 96.05, p01 = -94.18, p20 = 489, p11 = -1030, p02 = 540.5, p30 = -6.144e+04, p21 = 1.84e+05, p12 = -1.837e+05, p03 = 6.114e+04

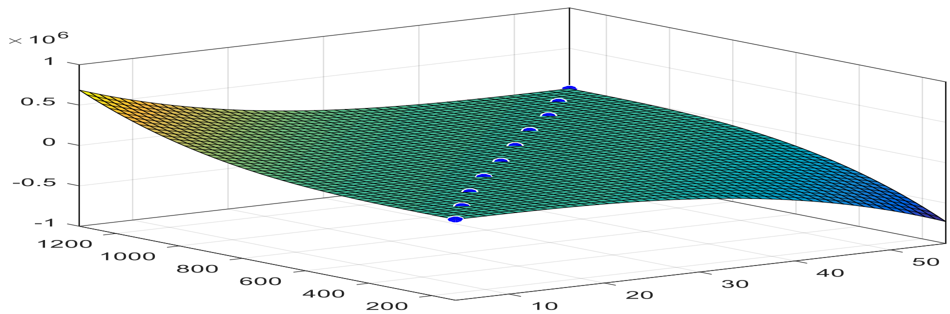


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 7.116, p10 = -127.8, p01 = 130.2, p20 = -726, p11 = 1474, p02 = -746.6, p30 = 7.615e+04, p21 = -2.267e+05, p12 = 2.251e+05, p03 = -7.449e+04

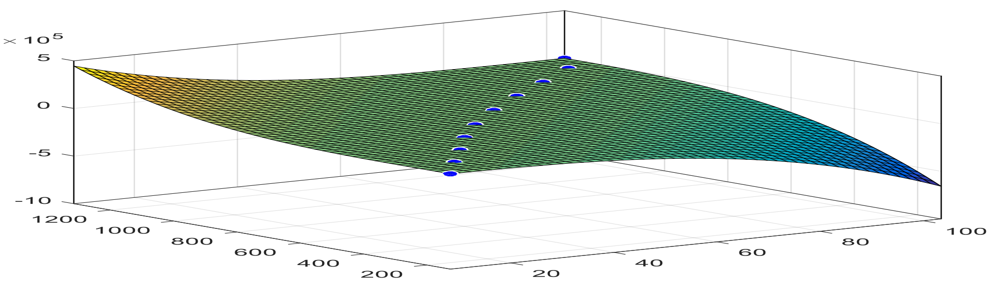
Appendix 45: Graph of Growth Index in cm (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 2mm 200 NPK and 2mm 300 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 8.871, p10 = 21.04, p01 = -18.98, p20 = -628.3, p11 = 1244, p02 = -616.3, p30 = -2.86e+04, p21 = 8.576e+04, p12 = -8.568e+04, p03 = 2.852e+04

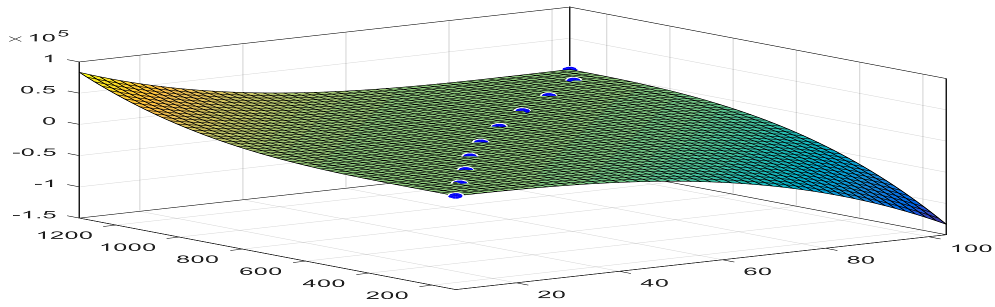


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 3.72, p10 = -689.3, p01 = 703.4, p20 = -8996, p11 = 1.834e+04, p02 =-9338, p30 = -2.27e+04, p21 = 6.861e+04, p12 = -6.813e+04, p03 = 2.221e+04

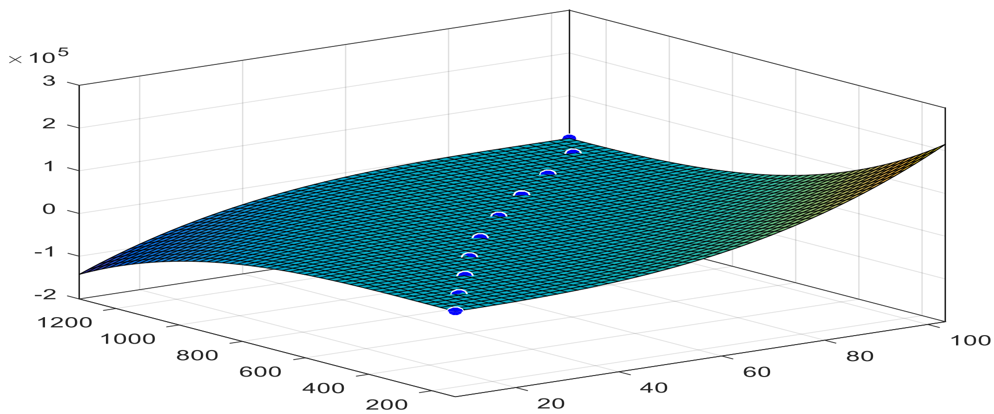
Appendix 46: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm 400 NPK and 4mm Water Depth



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 3.792, p10 = -230.3, p01 = 242.6, p20 = -2238, p11 = 4622, p02 = -2375, p30 = -4428, p21 = 1.343e+04, p12 = -1.335e+04, p03 = 4346

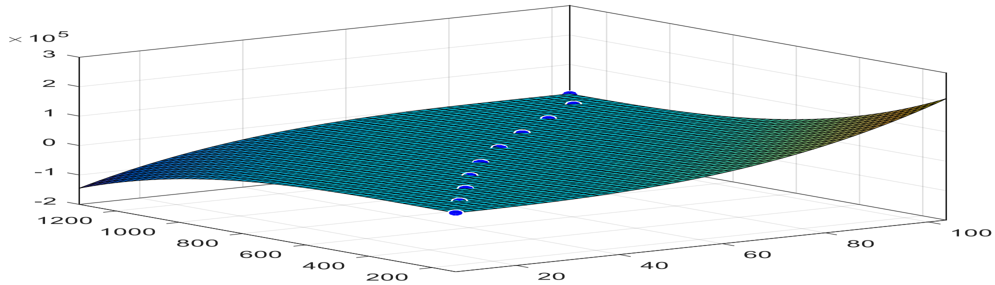


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 9.101, p10 = 218.4, p01 = -213, p20 = 3181, p11 = -6451, p02 = 3271, p30 = 7374, p21 = -2.229e+04, p12 = 2.21e+04, p03 = -7183

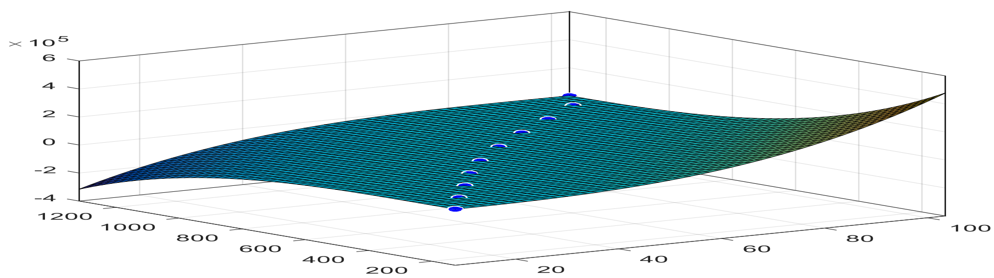
Appendix 47: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 4mm 100 NPK and 4mm 200 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 7.132, p10 = 164.7, p01 = -157.3, p20 = 2880, p11 = -5826, p02 = 2950, p30 = 7435, p21 = -2.235e+04, p12 = 2.206e+04, p03 = -7150

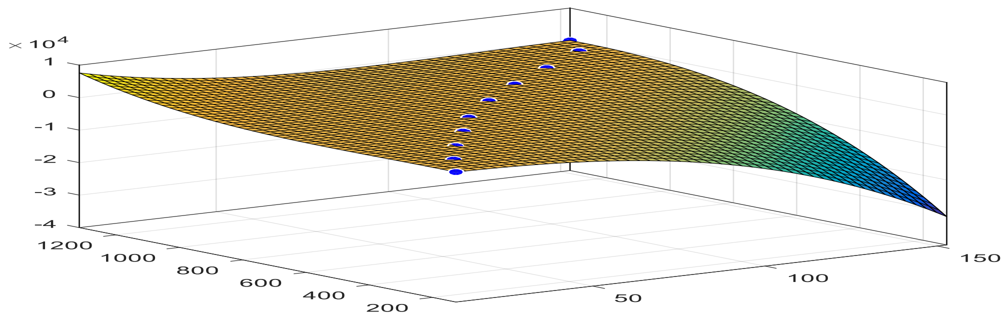


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56, y = 726.8±405.3

p00 = 12.72, p10 = 533, p01 = -532.3, p20 = 7081, p11 = -1.442e+04, p02 = 7331, p30 = 1.632e+04, p21 = -4.936e+04, p12 = 4.899e+04, p03 = -1.594e+04

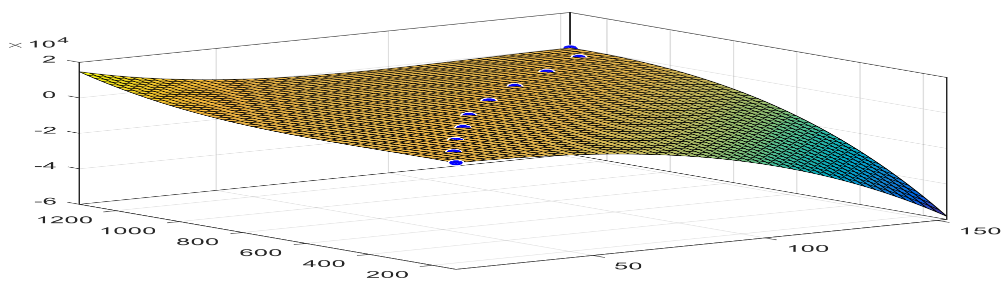
Appendix 48: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 4mm 300 NPK and 3mm 400 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = 1.798, p10 = -200.9, p01 = 219.4, p20 = -1181, p11 = 2497, p02 = -1304, p30 = -834.8, p21 = 2475, p12 = -2279, p03 = 629.2

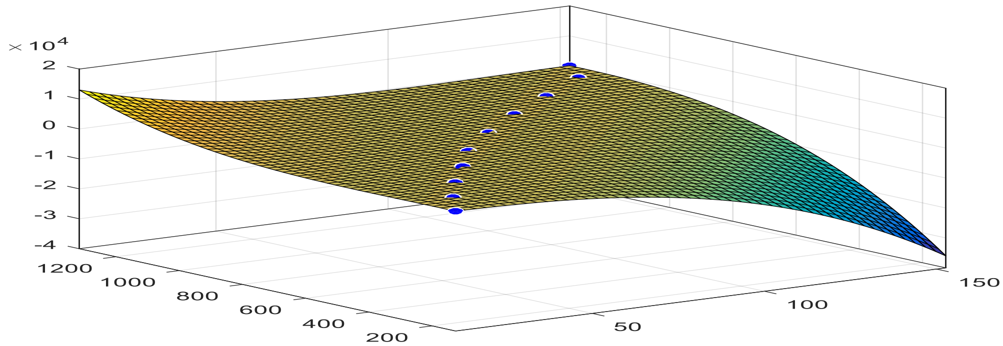


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = -3.378, p10 = -359.2, p01 = 385, p20 = -2173, p11 = 4571 p02 = -2379, p30 = -1560, p21 = 4643, p12 = -4294, p03 = 1195

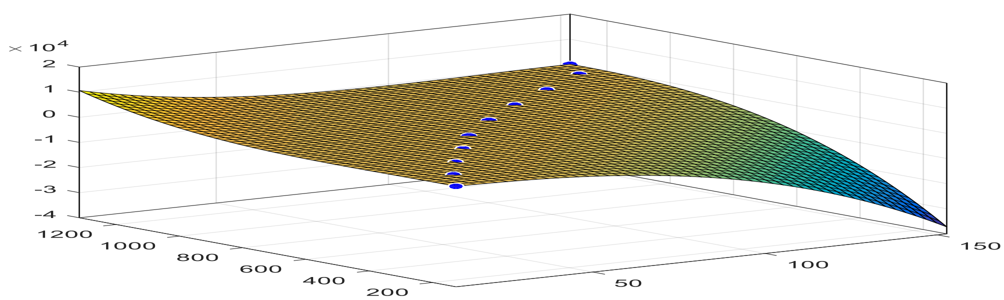
Appendix 49: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm and 6mm Water Depth and 100 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 +p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = 7.641, p10 = -151.5, p01 = 166.9, p20 = -1107, p11 = 2308, p02 = -1194, p30 = -1060, p21 = 3141, p12 = -2945, p03 = 857.4

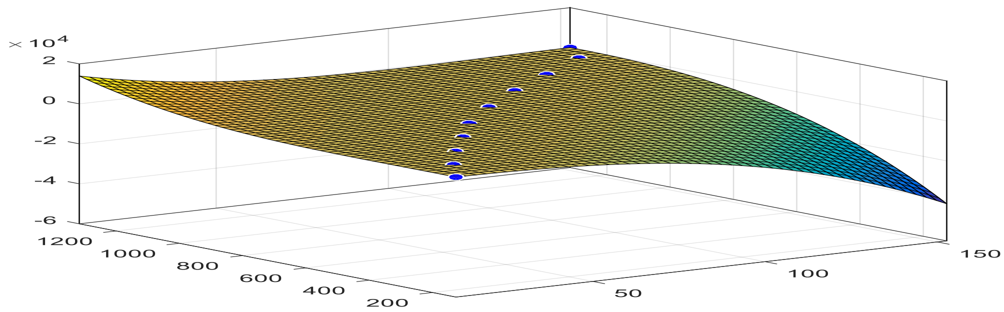


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97, y = 726.8± 405.3

p00 = 2.894, p10 = -215.9, p01 = 236.1, p20 = -1310, p11 = 2759, p02 = -1437, p30 = -1028, p21 = 3050, p12 = -2833, p03 = 800

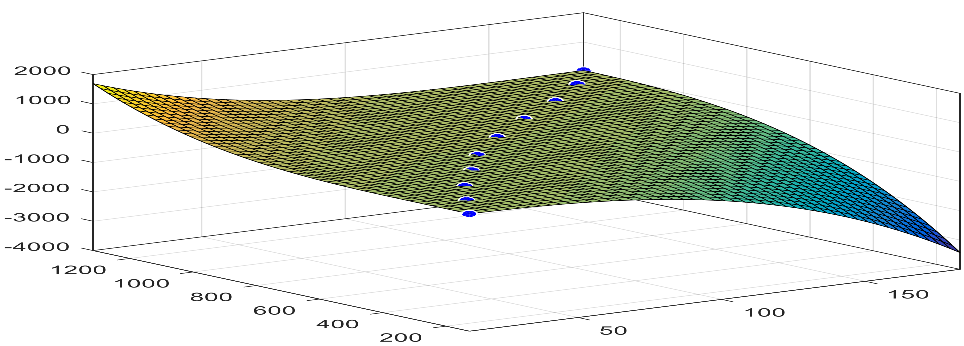
Appendix 50: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm 200 NPK and 6mm 300 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = 3.543, p10 = -213.3, p01 = 233.9, p20 = -1325, p11 = 2792, p02 = -1455, p30 = -1207, p21 = 3549, p12 = -3291, p03 = 938.5

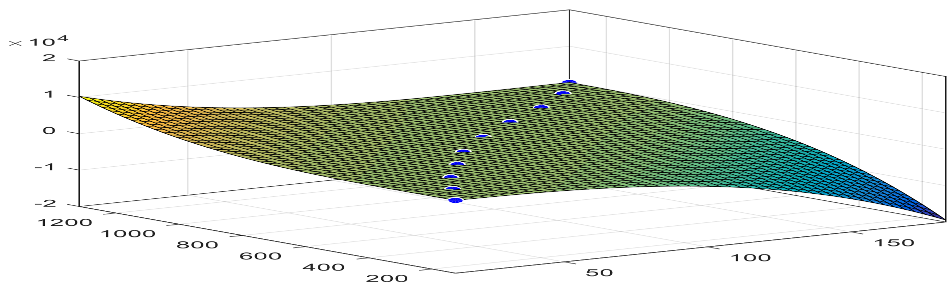


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 11.96, p10 = -12.02, p01 = 22.19, p20 = -69.16, p11 = 146.5, p02 = -75.29, p30 = -102.3, p21 = 312.8, p12 = -308.8, p03 = 97.87

Appendix 51: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm 400 NPK and 8mm Water Depth

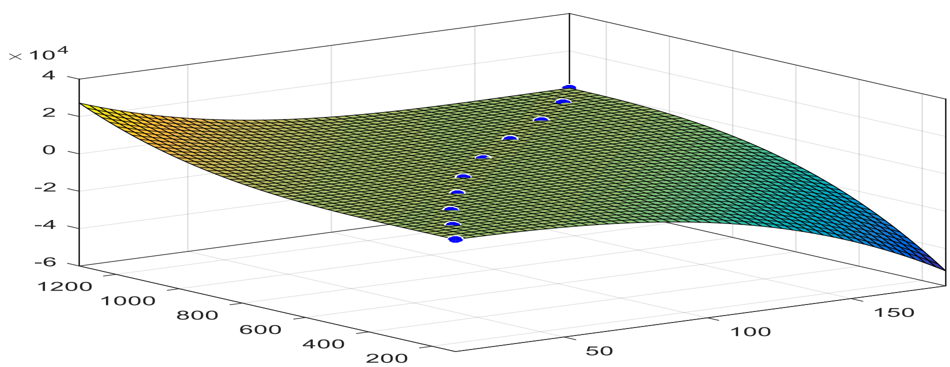


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 11.38, p10 = -41.63, p01 = 53.56, p20 = -340.4, p11 = 709.9, p02 = -366.9

p30 = -638.7, p21 = 1873, p12 = -1785, p03 = 547.5

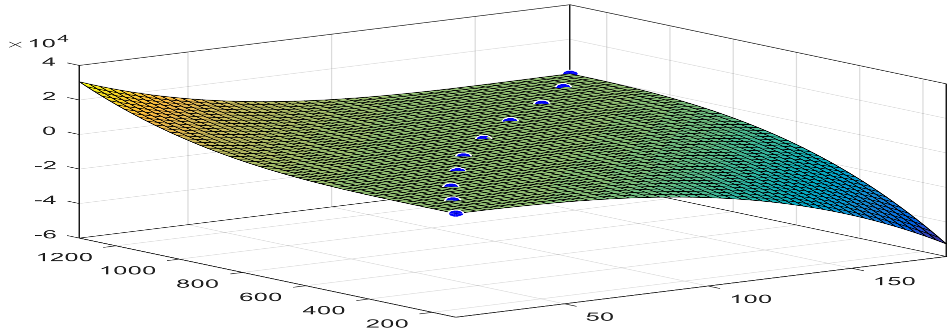


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 10.35, p10 = -113.9, p01 = 131.4, p20 = -927.2, p11 = 1932, p02 = -999.7, p30 = -1704, p21 = 4992, p12 = -4748, p03 = 1453

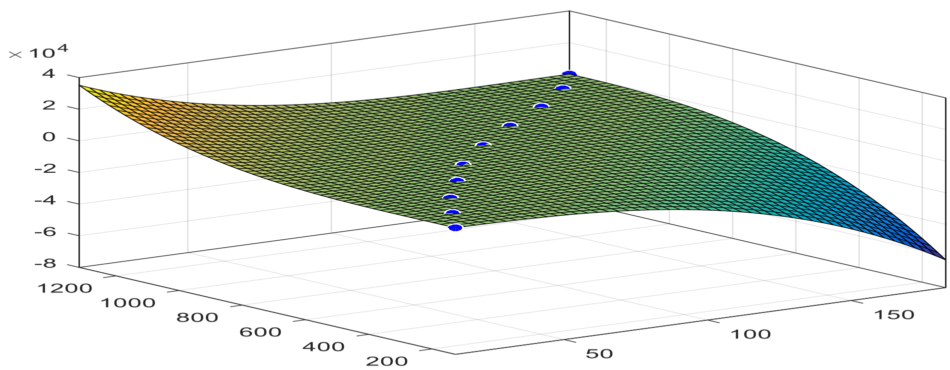
Appendix 52: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 100 NPK and 8mm 200 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 12.67, p10 = -74.54, p01 = 90.23, p20 = -749.2, p11 = 1562, p02 = -809.9, p30 = -1823, p21 = 5288, p12 = -5008, p03 = 1537

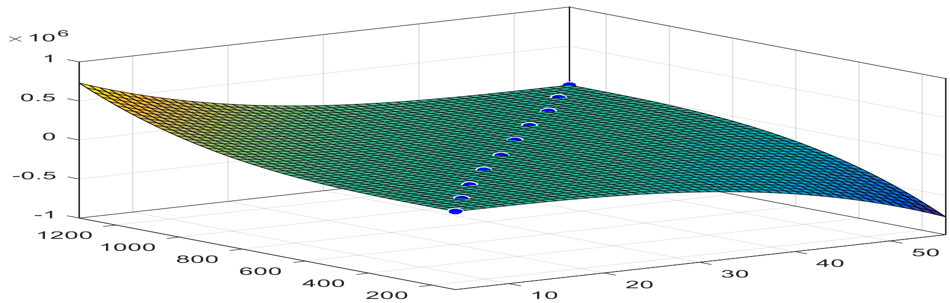


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 15.38, p10 = -74.25, p01 = 89.77, p20 = -962.2, p11 = 1984, p02 = -1022, p30 = -2139, p21 = 6207, p12 = -5868, p03 = 1796

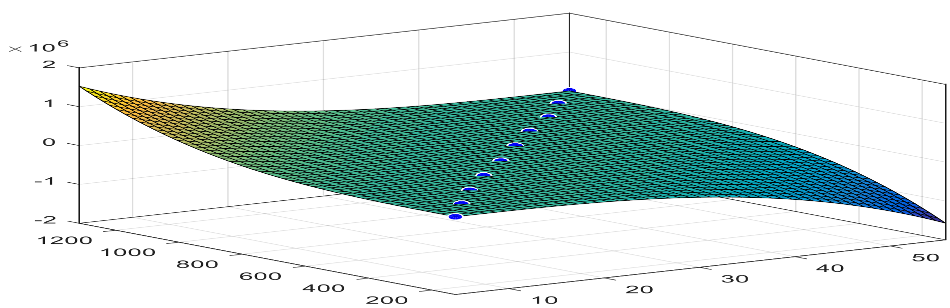
Appendix 53: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 300 NPK and 8mm 400 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 18.71, p10 = -4.353, p01 = 8.275, p20 = -469.2, p11 = 931.1, p02 = -465.4, p30 = -3.028e+04, p21 = 9.091e+04, p12 = -9.093e+04, p03 = 3.03e+04

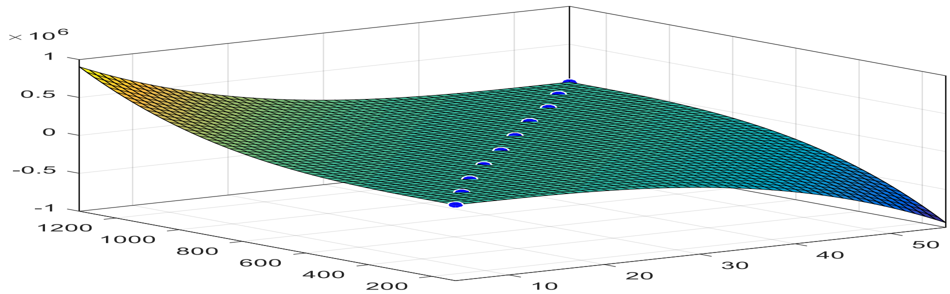


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 21.89, p10 = 151.5, p01 = -147.3, p20 = 1520, p11 = -3149, p02 = 1623, p30 = -6.275e+04, p21 = 1.878e+05, p12 = -1.874e+05, p03 = 6.236e+04

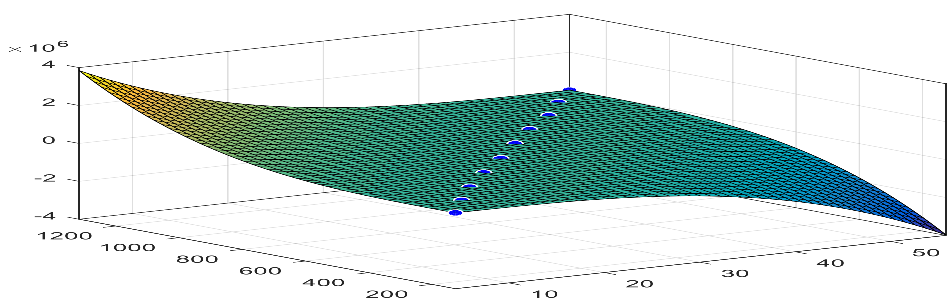
Appendix 54: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm and 2mm 100 NPK for greenhouse



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 24.5, p10 = 75.7, p01 = -71.35, p20 = 546.5, p11 = -1155, p02 = 601.9, p30 = 3.728e+04, p21 = 1.117e+05, p12 = -1.115e+05, p03 = 3.713e+04

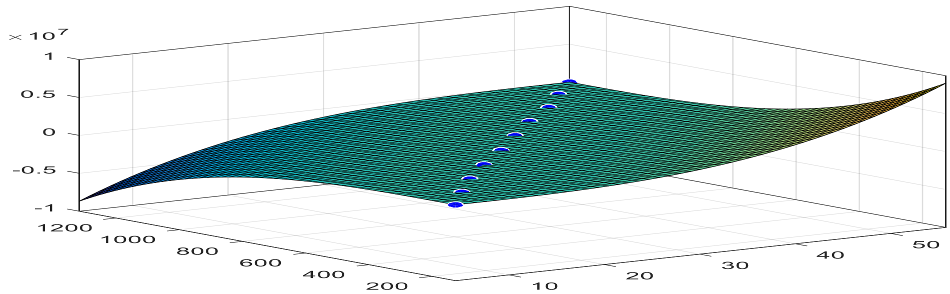


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 24.47, p10 = 218.4, p01 = -214.9, p20 = 2890, p11 = -5940, p02 = 3044, p30 = -1.58e+05, p21 = 4.735e+05, p12 = -4.731e+05, p03 = 1.576e+05

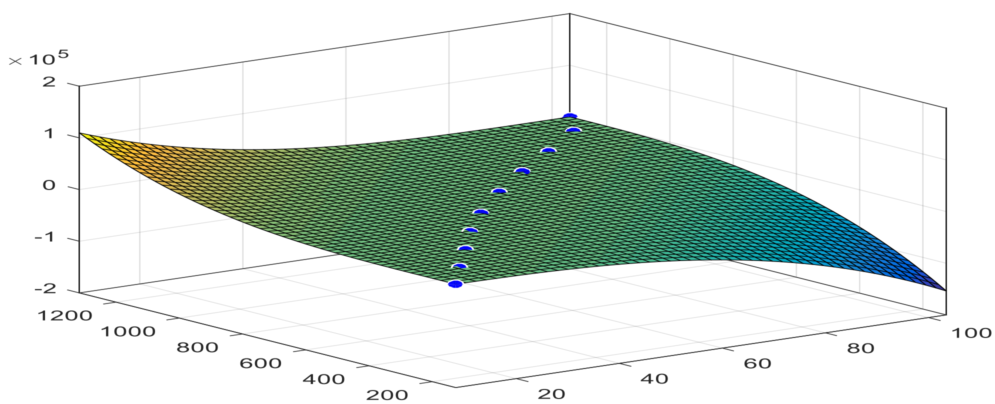
Appendix 55: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm 200 NPK and 2mm 300 NPK greenhouse



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 29.95±17.76 and y = 726.8±405.3

p00 = 21.23, p10 = -545.8, p01 = 556.6, p20 = -2932, p11 = 6018, p02 = -3086, p30 = 3.599e+05, p21 = -1.075e+06, p12 = 1.07e+06, p03 = -3.55e+05

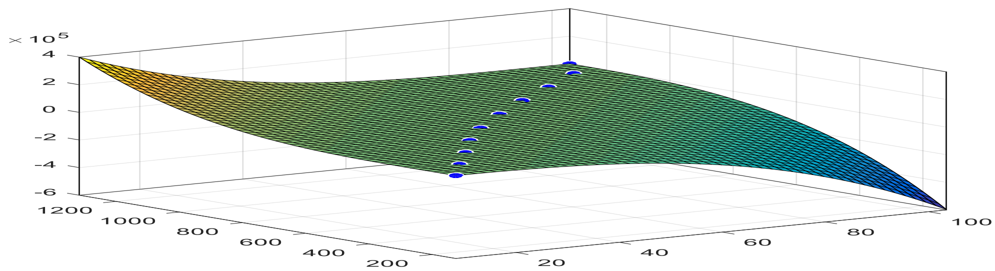


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 12.06, p10 = -227.4, p01 = 248.5, p20 = -1723, p11 = 3602, p02 = -1869, p30 = -5388, p21 = 1.631e+04, p12 = -1.63e+04, p03 = 5364

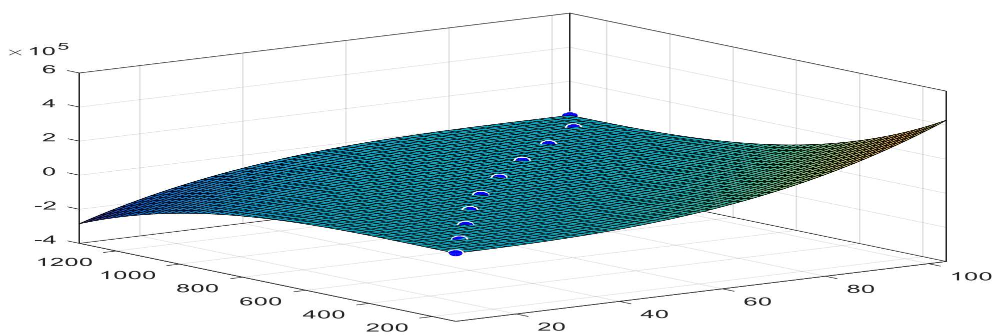
Appendix 56: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 2mm 400 NPK and 4mm Water Depth



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 15.73, p10 = -706.3, p01 = 727.5, p20 = -8420, p11 = 1.721e+04,p02 =-8788, p30 = -2.054e+04, p21 = 6.2e+04, p12 = -6.145e+04, p03 = 1.998e+04

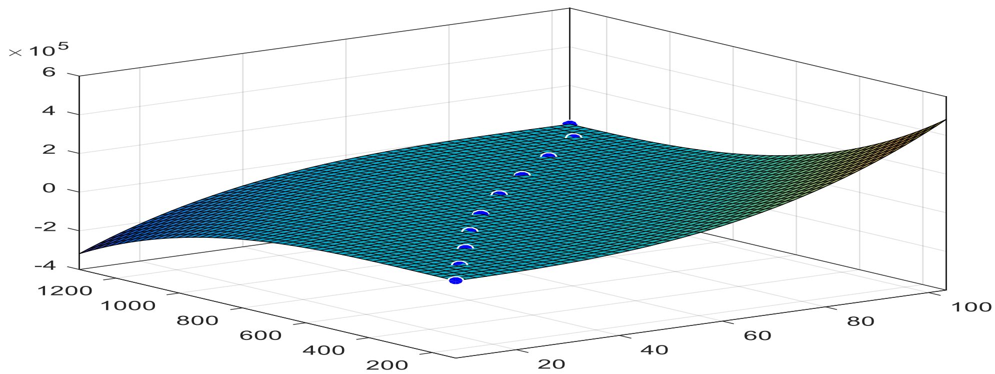


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 24.45, p10 = 435.8, p01 = -428.3, p20 = 6276, p11 = -1.276e+04, p02 = 6475, p30 = 1.469e+04, p21 = -4.444e+04, p12 = 4.414e+04, p03 = -1.438e+04

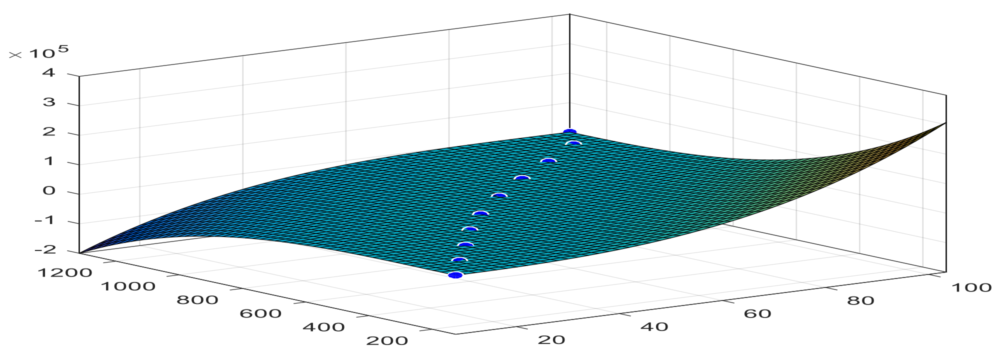
Appendix 57: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 4mm 100 NPK and 4mm 200 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 25.19, p10 = 511.6, p01 = -504.6, p20 = 7185, p11 = -1.46e+04, p02 = 7406, p30 = 1.642e+04, p21 = -4.98e+04, p12 = 4.955e+04, p03 = -1.617e+04

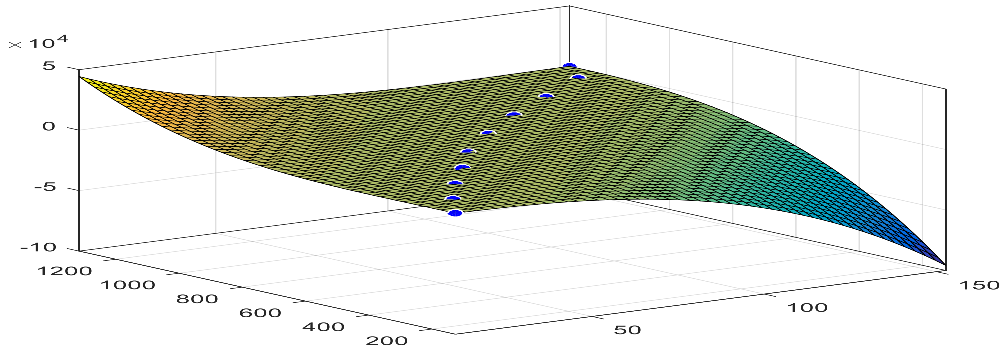


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 54.6±33.56 and y = 726.8±405.3

p00 = 25.56, p10 = 365.4, p01 = -359.5, p20 = 4772, p11 = -9688, p02 = 4910, p30 = 1.03e+04, p21 = -3.144e+04, p12 = 3.145e+04, p03 = -1.031e+04

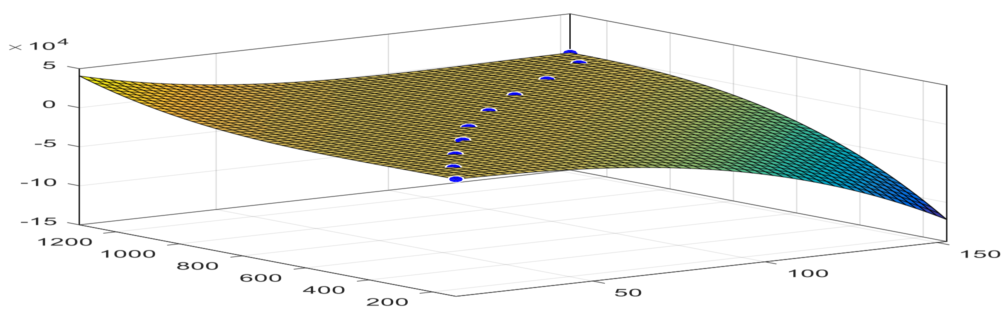
Appendix 58: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^{o}C (z axis) for 4mm 300 NPK and 3mm 400 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = 20.43, p10 = -287.3, p01 = 302.7, p20 = -2361, p11 = 4853, p02 = -2492, p30 = -2970, p21 = 8949, p12 = -8606, p03 = 2623

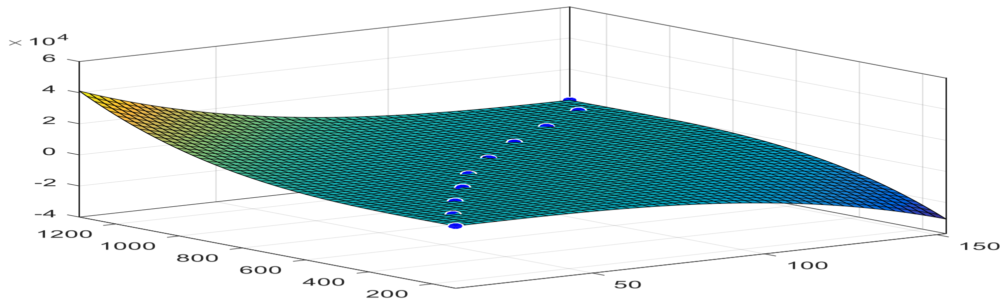


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = 5.901, p10 = -612.2, p01 = 650.2, p20 = -3957, p11 = 8255, p02 = -4278, p30 = -3430, p21 = 1.033e+04, p12 = -9772, p03 = 2848

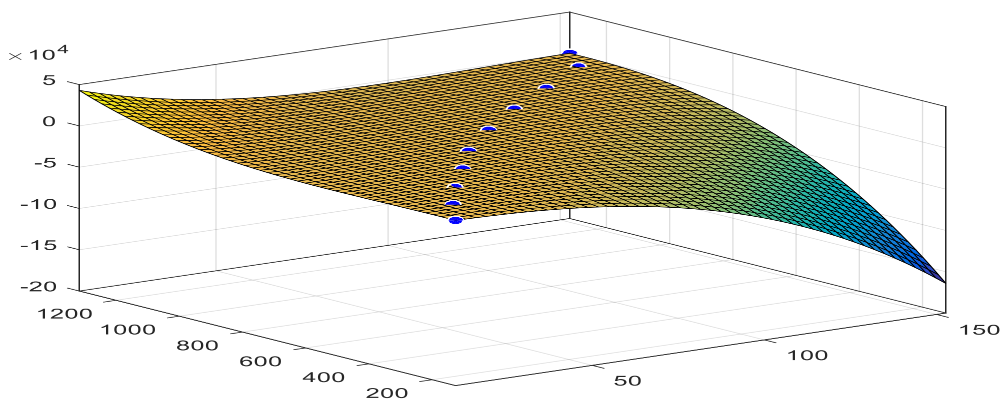
Appendix 59: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm and 6mm 100 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = 45.26, p10 = 215, p01 = -215.1, p20 = 902.5, p11 = -1999, p02 = 1073, p30 = -1434, p21 = 4516, p12 = -4802, p03 = 1737

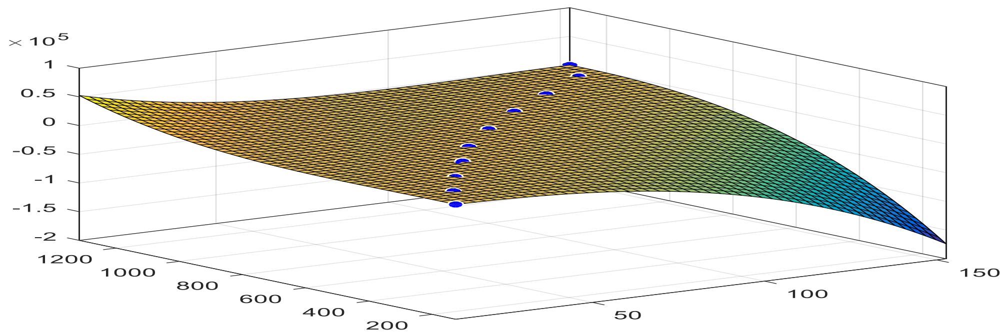


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15±50.97 and y = 726.8±405.3

p00 = -9.537, p10 = -981.8, p01 = 1041, p20 = -6060, p11 = 1.269e+04, p02 = -6593, p30 = -4375, p21 = 1.315e+04, p12 = -1.228e+04, p03 = 3464

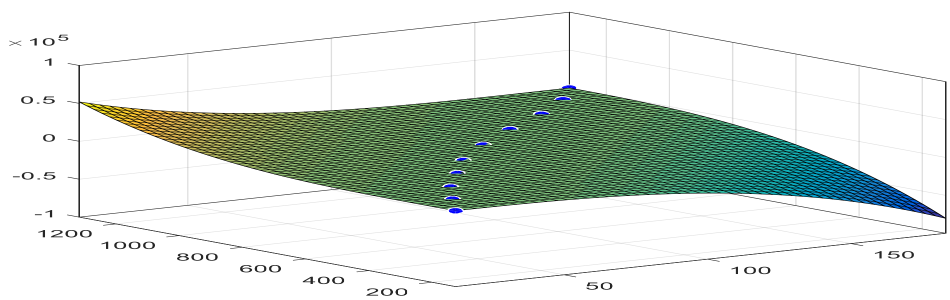
Appendix 60: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm 200 NPK and 6mm 300 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 78.15± 50.97 and y = 726.8±405.3

p00 = -6.621, p10 = -946.9, p01 = 999.1, p20 = -5988, p11 = 1.252e+04, p02 = -6497, p30 = -4794, p21 = 1.439e+04, p12 = -1.351e+04, p03 = 3872

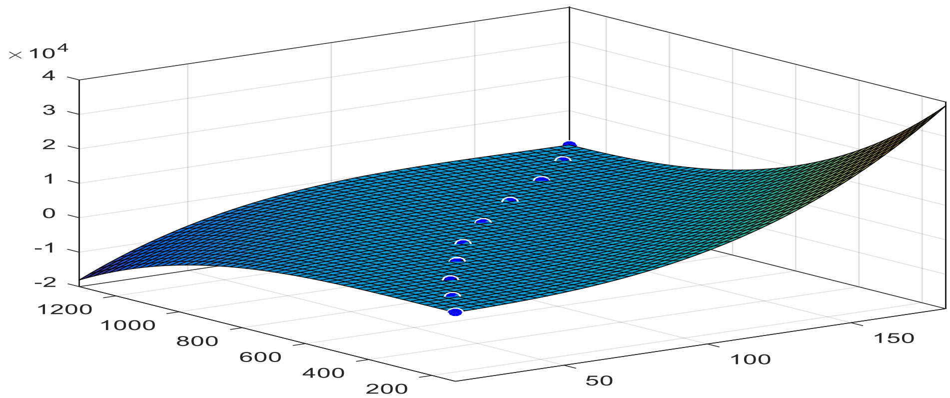


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 35.91, p10 = -19.61, p01 = 25.66, p20 = -824.5, p11 = 1639, p02 = -831, p30 = -2873, p21 = 8414, p12 = -8054, p03 = 2518

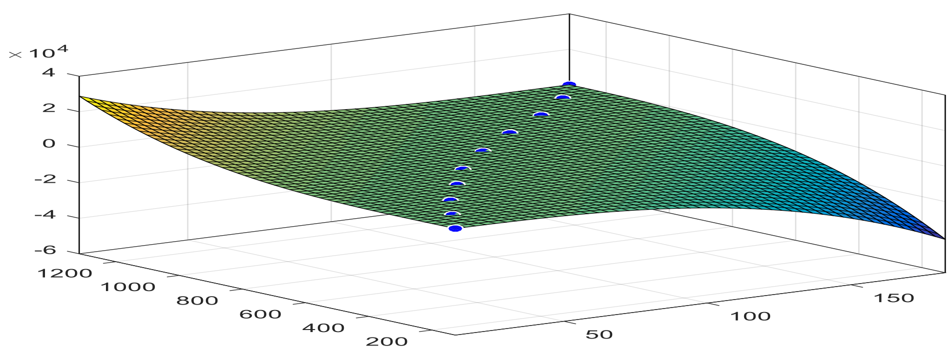
Appendix 61: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 6mm 400 NPK and 8mm Water Depth



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92± 60.45 and y = 726.8±405.3

p00 = 55.16, p10 = 198.5, p01 = -203.3, p20 = 777.3, p11 = -1746, p02 = 936.7, p30 = 1280, p21 = -3587, p12 = 3303, p03 = -972.5

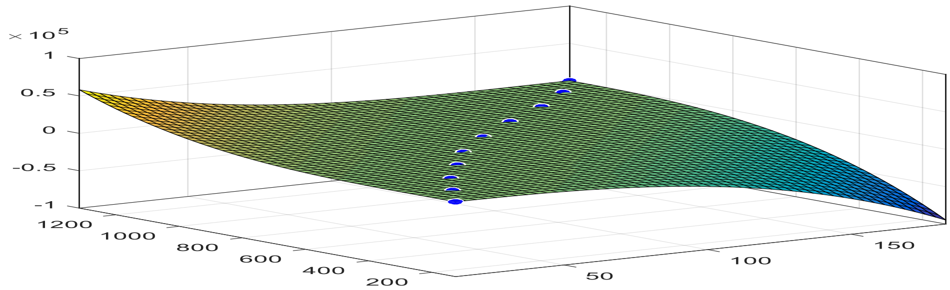


GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 41.85, p10 = 41.51, p01 = -38.27, p20 = -312.9, p11 = 565.3, p02 = -273.4, p30 = -1505, p21 = 4466, p12 = -4320, p03 = 1369

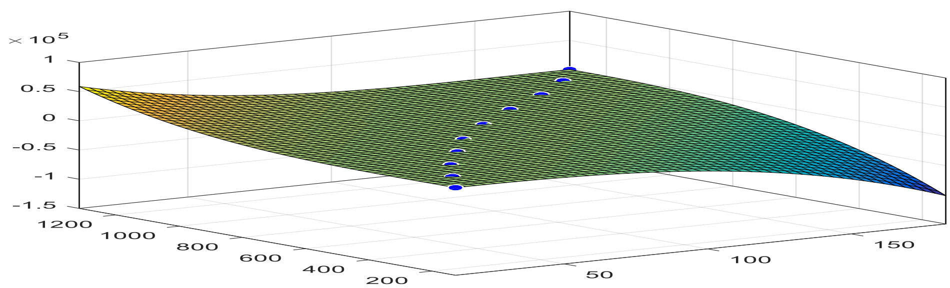
Appendix 62: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 100 NPK and 8mm 200 NPK



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 36.62, p10 = -53.97, p01 = 60.53, p20 = -1164, p11 = 2344, p02 = -1198, p30 = -3307, p21 = 9719, p12 = -9307, p03 = 2898



GII(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3

x = 92±60.45 and y = 726.8±405.3

p00 = 38.78, p10 = -55.92, p01 = 60.52, p20 = -1481, p11 = 2997, p02 = -1538, p30 = -3521, p21 = 1.025e+04, p12 = -9685 p03 = 2960

Appendix 63: Graph of Growth Index in cm^2 (x axis), Actual Evapotranspiration in mm (y axis) and Growing Degree Days in ^oC (z axis) for 8mm 300 NPK and 8mm 400 NPK

(a)

(b)

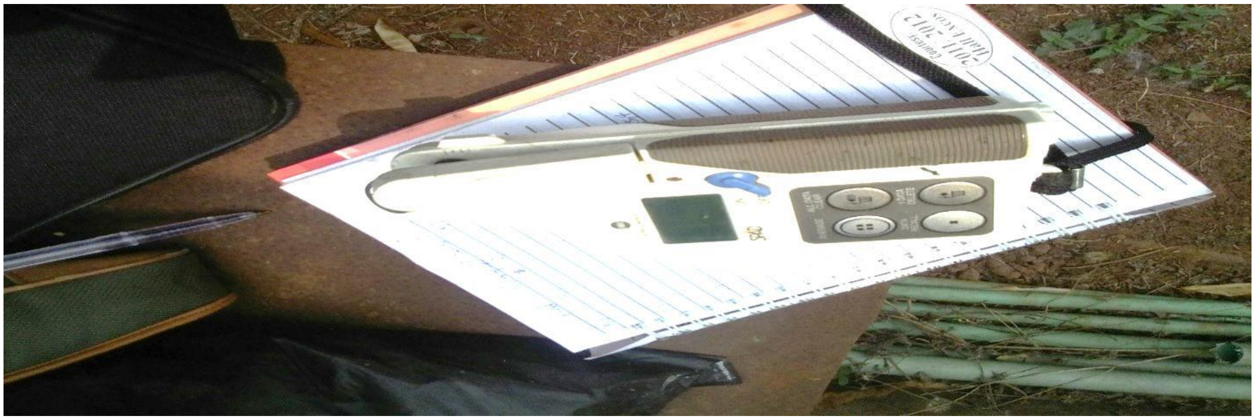
Appendix 64: (a) Infiltration Test Using Double Ring Infiltrometer (b) Hydraulic Conductivity Test

(a)

(b)

(c)

Appendix 65: Soil Field Capacity Test Using Tension Table (b) Soil Moisture Test Using a Moisture Meter (c) Soil Sample in a Core



(a)

(b)

(c)

Appendix 66: (a) SPAD Meter (b) Lux Meter (c) Meteorological Station

(a)

(b)

(c)

Appendix 67: Soil Samples Weighed at Different Growth Stage for Evapotranspiration Using the Micro-Dynamic Weighing Lysimeter Method

(a)

(b)

(c)

Appendix 68: *Corchorus olitorus* cultivation in Field and Greenhouse

(a)

(b)

(c)

Appendix 69: (a), (b) and (c) Experimental site using split plot design, Installation of tanks, pipes and emitters for Irrigation purposes

(a) 2mm

(b) 2mm 100 NPK

(c) 2mm 200 NPK

Appendix 70: Root of (2mm), (2mm 100 NPK), (2mm 200NPK)

(a) 2mm 300 NPK

(b) 2mm 400 NPK

(c) 4mm

Appendix 71: Root of (2mm 300 NPK), (2mm 400 NPK), (4mm)

(a) 4mm 100 NPK

(b) 4mm 200 NPK

(c) 4mm 300 NPK

Appendix 72: Root of (4mm 100 NPK), (4mm 200 NPK), (4mm 300NPK)

(a) 4mm 400 NPK

(b) 6mm

(c) 6mm 100 NPK

Appendix 73: Root of C5 (4mm 400 NPK), D1 (6mm), D2 (6mm 100NPK)

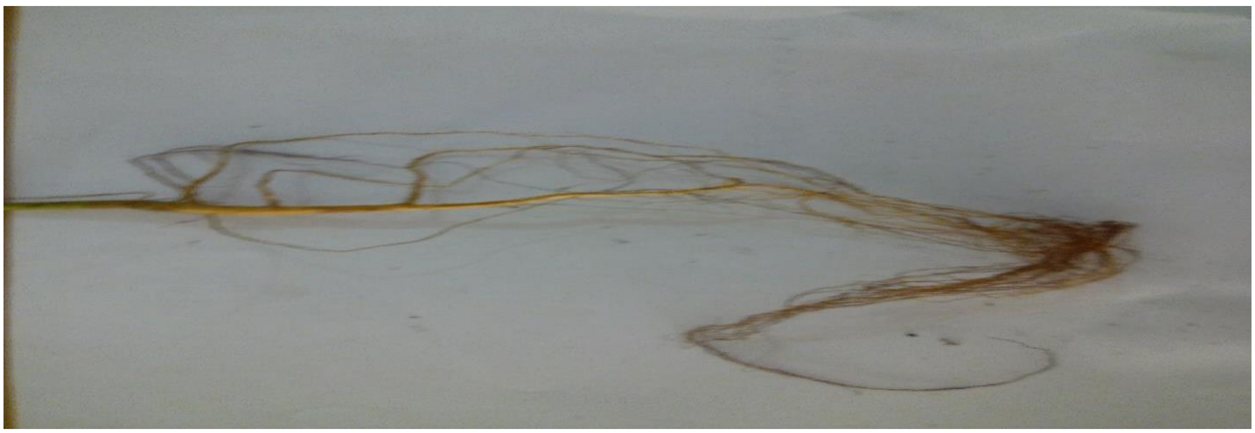
(a) 6mm 200 NPK

(b) 6mm 300 NPK

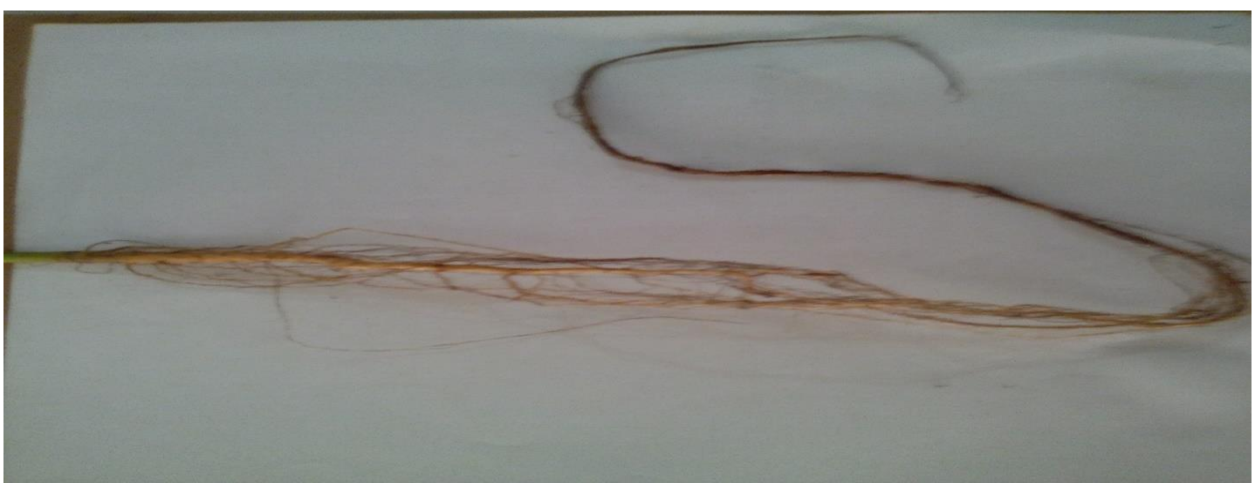
(c) 6mm 400 NPK

Appendix 74: Root of (6mm 200 NPK), (6mm 300 NPK), (6mm 400NPK)

(a) 8mm

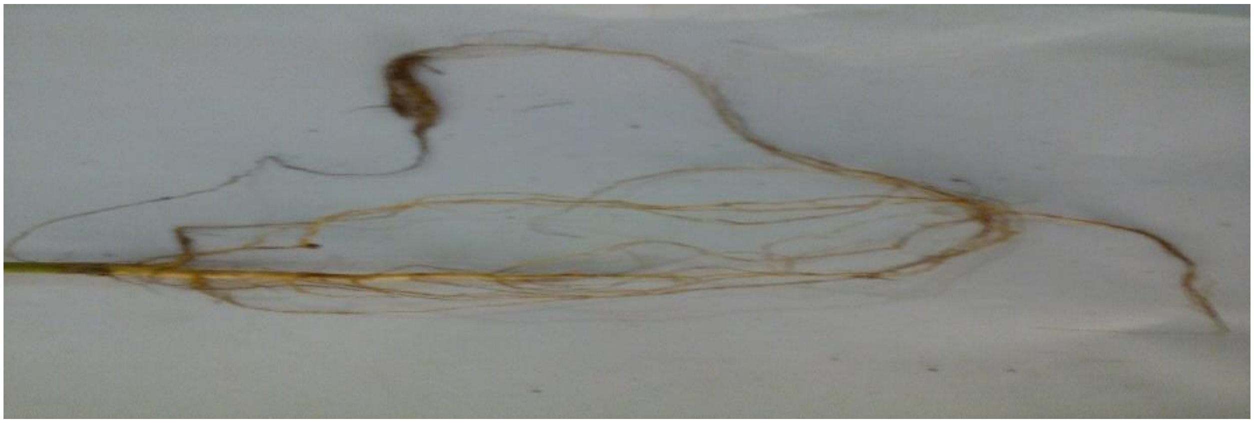


(b) 8mm 100 NPK



(c) 8mm 200 NPK

Appendix 75: Root of (8mm), (8mm 100 NPK), (8mm 200 NPK)



(a) 8mm 200 NPK

(b) 8mm 300 NPK

(c) 8mm 400 NPK

Appendix 76: Root of (8mm 200 NPK), (8mm 300 NPK), (8mm 400NPK)

	Screen	Field	Screen	Field	Screen	Field	Screen	Field	Screen	Field	Screen	Field
	0mm	0mm	2mm	2mm	4mm	4mm	6mm	6mm	8mm	8mm	pH	pH
0kg/ha	37.0	38-41	37.0	38-41	36.0	38-41	34.0	38-41	34.0	38-41	6.0	7.0
100kg/ha	37.0	38-41	37.0	38-41	36.0	38-41	34.0	38-41	34.0	38-41	5.5	7.0
200kg/ha	37.0	38-41	37.0	38-41	36.0	38-41	34.0	38-41	34.0	38-41	5.0	6.5
300kg/ha	37.0	38-41	37.0	38-41	36.0	38-41	34.0	38-41	34.0	38-41	5.0	6.5
400kg/ha	37.0	38-41	37.0	38-41	36.0	38-41	34.0	38-41	34.0	38-41	5.0	6.5

Appendix 77: (a) Temperature and pH of the soil in greenhouse and Field