

**ANKARA UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

M. Sc. THESIS

**ESTIMATION OF IMPACTS OF CLIMATE CHANGE ON IRRIGATION
WATER REQUIREMENTS OF DIFFERENT CROPS IN EMBU-KENYA.**

Godwin Samuel Odhiambo NGESA

DEPARTMENT OF FARM STRUCTURES AND IRRIGATION

**ANKARA
2014**

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THESIS APPROVAL

This thesis entitled “**Estimation of Impacts of Climate Change on Irrigation water Requirements of Different Crops in Embu-Kenya**” prepared on 7/1/2014 by Godwin Samuel Odhiambo NGESA in partial fulfillment of the requirements for the degree of **Master of Science** in the Graduate School of Natural and Applied Sciences of Ankara University, Department of Farm Structures and Irrigation and has been examined and approved by a unanimous vote of the undersigned jury members.

Supervisor : Prof. Dr. Yusuf Ersoy YILDIRIM

Jury Members:

Head of jury : Prof. Dr. Yusuf Ersoy YILDIRIM
Ankara University
Department of Farm Structures and Irrigation

Member : Prof. Dr. Ahmet ÖZTÜRK
Ankara University
Department of Farm Structures and Irrigation

Member : Doç. Dr. Zeki GÖKALP
Erciyes University Department of Biosystems Engineering

I certify the above results

Prof. Dr. İbrahim DEMİR
Director of Institute

ETHICS

I declare that this thesis complies with the rules and regulations of the Graduate School of Natural and Applied Sciences of Ankara University, the information is accurate and complete, it is in accordance with the ethics of scientific research and that all the sources of the research material used in this thesis have been properly referenced.

Date

Godwin Samuel Odhiambo NGESA

ABSTRACT

Master Thesis

ESTIMATION OF IMPACTS OF CLIMATE CHANGE ON IRRIGATION WATER REQUIREMENTS OF DIFFERENT CROPS IN EMBU-KENYA.

Godwin Samuel Odhiambo NGESA

Ankara University
Graduate School of Natural and Applied Sciences
Department of Farm Structures and Irrigation

Supervisor: Prof. Dr. Yusuf Ersoy YILDIRIM

This study aimed to determine the impacts of potential climate change on CWR of maize, beans, and sunflower in Embu district, Kenya. CROPWAT 8 was used in combination with climate scenarios from GCM models. IRSIS was used to simulate yields of the three crops under deficit irrigation conditions of 75%, 50% and 25%, respectively. The observed baseline climate is based on the 20 year-period covering, 1979-2000 and two future projections of 2046-2065 (2040s) and 2081-2100 (2080s). Beans' CROPWAT results for IPSL CM4 A2 compared to 1979-2000 showed the highest increase in CWR of 21.7 mm and 38.4 mm for 2040s and 2080s, respectively. However, in 2040s GFDL CM 2.0 A2 had the highest decrease in IWR of 25.1 mm and GFDL CM 2.0 B1 in 2080s showed the highest decrease in IWR of 23.9 mm. GFDL CM 2.0 A2 had the highest increase in CWR for maize in 2040s (36.7 mm). In 2080s, IPSL CM4 A2 had the highest increase in CWR of 60 mm compared to 1979-2000. GFDL CM 2.0 A2 model had the least IWR for maize, 113.8 mm and 116.6 mm in 2040s and 2080s respectively. IPSL CM4 A2 model had the highest CWR for sunflower in 2040s and 2080s, with an increase of 25.6 mm and 41.6 mm, respectively compared to 1979-2000. However, there was a sharp decrease in IWR in GFDL CM 2.0 A2 of 79.3 mm in 2040s, while in 2080s, GFDL CM 2.0 B1 had the greatest decrease in IWR of 80.8 mm.

7 January 2014, 83 pages

Key Words: Climate change, General Circulation Models (GCM), CROPWAT, crop water requirements (CWR), irrigation water requirement (IWR), deficit irrigation, Embu District, maize, beans, sunflower.

ÖZET

Yüksek Lisans Tezi

EMBU-KENYA'DA FARKLI BİTKİLERİN SULAMA SUYU İHTİYACINA İKLİM DEĞİŞİKLİĞİNİ
OLASI ETKİLERİNİN TAHMİN EDİLMESİ.

Godwin Samuel Odhiambo NGESA

Ankara Üniversitesi
Fen Bilimleri Enstitüsü
Tarımsal Yapılar ve Sulama Anabilim Dalı

Danışman : Prof. Dr. Yusuf Ersoy YILDIRIM

Bu çalışmanın amacı Kenya'nın Embu bölgesindeki iklim değişikliğinin mısır, kuru fasulye ve ayçiçeği bitkilerinin su tüketimi üzerindeki olası etkilerinin tahmin edilmesidir. CROPWAT 8 programında küresel iklim modellerinden istatistiksel yöntemlerle elde edilen iklim verileri kullanılmıştır. IRSIS modeli kullanılarak sırasıyla kısıntılı sulama koşulları altında (%75, %50 ve %25) üç bitkinin verimleri hesaplanmıştır. İklim veri seti gözlem yapılan 1979-2000 dönemini kapsamakta olup gelecekteki iki iklim seti 2046-2065 ve 2081-2100 dönemini kapsamaktadır. CROPWAT sonuçlarına göre fasulyenin su ihtiyacının 2046-2065 döneminde %6,2 artarken bu 2081-2100 döneminde ise %10,9 artış gösterdiği belirlenmiştir. GFDL CM 2.0 A2 modeline göre yine bu dönemlerde bitki su tüketimi değerleri 21,7 mm ve 38,4 mm daha fazla bulunmuştur. GFDL CM 2.0 A2 sonuçları kullanılarak yapılan hesaplamalarda ise bu değerler sırasıyla sulama suyu ihtiyacı (SSİ) bakımından 25.1 mm azalmanın olacağı hesaplanmıştır. GFDL CM 2.0 B1 2080'li yıllarda fasulye bitkisinin bitki su tüketimi ihtiyacı (STİ) bakımından 23,9 mm olarak en yüksek artışa sahip olacağı tahmin edilmiştir. 2040'li yıllarda GFDL CM2.0 A2 modeli, bitki STİ bakımından en yüksek artışı 36,7 mm ile mısır bitkisinde göstermiştir. Mısır için SSI GFDL CM 2.0 A2 modelinde 2040 ve 2080'li yıllarda sırasıyla 113,8 mm ve 116,6 mm ile en keskin azalışı göstermiştir. IPSL CM4 A2 modeli, ayçiçeği bitkisinde 2040 ve 2080'li yıllarda bitki STİ bakımından sırasıyla 25,6 mm ve 41,6 mm ile en yüksek artışı göstermiştir. Buna karşılık 2080'li yıllarda GFDL CM 2,0 B1 modeli en büyük azalmayı 80,8 mm ile gösterirken, GFDL CM 2.0 A2 modelinde SSİ 2040'li yıllarda 79,3 mm ile azalma göstermiştir.

Ocak 2014, 83 sayfa

Anahtar kelimeler: iklim değişikliği, Küresel iklim modelleri (GCM), CROPWAT, bitki su tüketimi, sulama suyu ihtiyacı, kısıtlı sulama Embu, mısır, fasulye, ayçiçeği.

ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to Ankara University Center for African Studies (CAS), TÜBİTAK, Yurtdışı Türkler ve Akraba Toplulukları Başkanlığı (YTB) for providing the support and opportunity to pursue my studies. I would also like to extend my heartfelt appreciation to my supervisor Prof. Dr. Yusuf Ersoy YILDIRIM for his continuous support, motivation, inspiration and guidance during my MSc. study and research. I am also deeply indebted to the immense contribution of Dr. Aggrey Ochieng' Adimo of Jomo Kenyatta University of Agriculture and Technology (JKUAT), who also made the writing of this thesis possible. The invaluable data provided by the Climate Systems Analysis Group (CSAG) of University of Cape Town was of enormous assistance throughout this study.

Finally, I would like to dedicate this study to the memory of my beloved mum, Susan Aloo and Aunt, Margaret Messo. Their absence, and the void left in my life, will forever be felt deeply. My deep appreciations go out to my family: George Ngesa, Jane Ngesa, Dan, Sara, Kevin, Mercy, Maureen, Nancy, Caro and Nelson for their support and encouragements. I would also like to thank Milda for her constant prayers, and well wishes. I owe everything to the ALMIGHTY LORD, I am grateful for His protection, mercy, grace and provision in abundance.

Godwin Samuel Odhiambo NGESA

Ankara, January 2014

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LIST OF ABBREVIATIONS

AEZ	Agro-ecological Zone.
ASALs	Arid and Semi-Arid Lands.
A.S.L	Above Sea Level.
CCCMA CGCM	Canadian Center for Climate Modeling and Analysis Coupled Global Circulation Models.
CORDEX	Coordinated Regional Downscaling Experiment.
CSAG	Climate System Analysis Group.
CWR	Crop Water Requirements.
ET _c	Crop evapotranspiration.
FAO	Food and Agriculture Organization of the United Nations.
GCMs	General Circulation Models.
GDP	Gross Domestic Product.
GHG	Greenhouse Gas.
GFDL CM	Geophysical Fluid Dynamics Laboratory Coupled Model.
GoK	Government of Kenya.
IFAD	International Fund For Agricultural Development.
IPCC	Inter-governmental Panel on Climate Change.
IPSL CM	Institut Pierre Simon Laplace Coupled Model.
IWR	Irrigation water requirement.
IRSIS	Irrigation Scheduling Information System.
Km	Kilometers.
KNBS	Kenya National Bureau of Statistics.
SDSM	Statistical Downscaling Model.
SD	Statistical Down Scaling.
SRES	Special Report Emission Scenario
SSA	Sub-Saharan Africa.
MM	millimeters.
MPI	Max Planck Institute.
TA	Tropical alpine.
UNITAR	United Nations Institute for Training and Research.
NCCRS	National Climate Change Response Strategy.

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EXTENDED TURKISH SUMMARY

1. GİRİŞ

Artan iklim değışiklikleri tarım ve su kaynaklarını etkileyecek ve daha fazla kuraklık ve neticesinde değışen bitki ve sulama suyu ihtiyaları ortaya ıkaracaktır. Bu nedenle önümüzdeki yıllarda etkin su kullanımı ve tasarrufunu ön plana ıkaracak tekniklere ihtiyaç duyulacaktır. Bu alıřmada mısır, fasulye ve ayıeğinde gelecekteki iklim değışikliği senaryolarının (2046–2065; 2081–2100) bitki su ihtiyalarına etkisi ile bu iklim değışikliği senaryolarının sulama ihtiyalarında ne gibi etkilerinin olacağı analiz edilmiştir. Kenya’da iklim değışikliğine karşı sulu mısır tarımı adapte edilmeye alışılan bir strateji olduėu için bu konu seçilmiştir. Bitki su ihtiyalarının hesaplanmasında FAO CROPWAT 8.0 modeli kullanılmıştır.

İklim değışikliği alınan tüm önlemlere rağmen ortaya ıkması kaçınılmaz bir süreçtir. Bu nedenle birçok bölgede ve sosyo-ekonomik ve çevresel sistemlerde iklim değışikliğine karşı uyum süreçleri adapte edilmelidir. Son yıllarda artan ekstrem iklim olayları, şiddetli kuraklıklar ve seller Kenyalıların yaşantılarında kritik roller üstlenmişlerdir. Bu tür ekstrem olaylar tarım, hidro elektrik enerji üretimi, hayvancılık, çevre, turizm ve sağlık gibi bir ok sektörü etkilemek suretiyle Kenya ekonomisinin sosyo-ekonomik yapısını da olumsuz bir şekilde etkilemiştir. İklim değışikliğinin etkisi fakir ve özellikle geliřmekte olan ülkelerde yaşayan kesim için daha ağır olacaktır. Eğer uygun adaptasyon ve azaltıcı önlemler zamanında alınmadığı takdirde bu etkiler daha da ağırlaşacaktır. Alınan önlemlerle uzun vadede iklim değışikliğinin etkileri en aza indirilebilecektir.

Problemin tanımı

Kenya’nın minimum sera gazı salınımına rağmen iklim değışikliğinden etkilenme oranı en üst düzeydedir. İklim değışikliğinin Kenya hükümete maliyeti 2030 yılı itibariyle 1-2 milyar dolara ulaşacağı tahmin edilmektedir. Buna ilaveten, la Niña kuraklıkları gibi

ekstrem iklim olayları 1999/2000 sezonunda bitkisel üretimi olumsuz etkilemiş ve 4.7 milyon Kenyalıyı açlık ve dengesiz beslenme ile yüz yüze bırakmıştır. Embu bölgesi Kenya'nın önemli tarım bölgelerinden birisi olup tarım çoğunlukla yağmura dayalı sulama olmaksızın yapılmaktadır.

General amaç

İklim değişiminin gelecekteki bitki su ihtiyacı ve sulama suyu ihtiyacı üzerine olası etkilerini araştırıp Embu bölgesinde sulu ve susuz tarımda bitkisel üretim sistemleri üzerine etkilerini incelemek.

Özel Amaçlar

1. Embu bölgesinde 1979-2000, 2046-2065 ve 2081-2100 dönemlerinde mısırın bitki su ihtiyacı ve sulama suyu ihtiyacını tespit etmek.
2. Embu bölgesinde 1979-2000, 2046-2065 ve 2081-2100 dönemlerinde fasülyenin bitki su ihtiyacı ve sulama suyu ihtiyacını tespit etmek.
3. Embu bölgesinde 1979-2000, 2046-2065 ve 2081-2100 dönemlerinde ayçiçeğinin bitki su ihtiyacı ve sulama suyu ihtiyacını tespit etmek.
4. İklim değişikliğinin etkilerini azaltmak ve uyum için tahmin edilen değerleri mevcut değerlerle karşılaştırıp analiz etmek.
5. %25, 50 ve 75 oranlarında kısıtlı sulama koşulları altında mısır, fasulye ve ayçiçeğinde IRSIs modelini kullanarak verim azalmasını tahmin etmek.

2. LİTERATÜR TARAMASI

Bu bölümde araştırma konusu ile ilgili daha önceden gerçekleştirilmiş araştırmalara yer verilmiştir. Özellikle iklim değişikliği ve etkileri, iklim parametrelerinin tahmininde kullanılan modeller, bitki su ihtiyacı ve sulama suyu ihtiyacının tahmininde kullanılan metotlar, mısır, fasulye ve ayçiçeğinde kısıtlı sulama uygulamaları hakkında kaynaklara yer verilmiştir.

3. MATERYAL VE YÖNTEM

Araştırmada kullanılan materyallerin nerelerden temin edildiği aşağıdaki çizelge 3.1'de verilmiştir.

Çizelge 3.1 Kullanılan data ve bilgilerin özeti

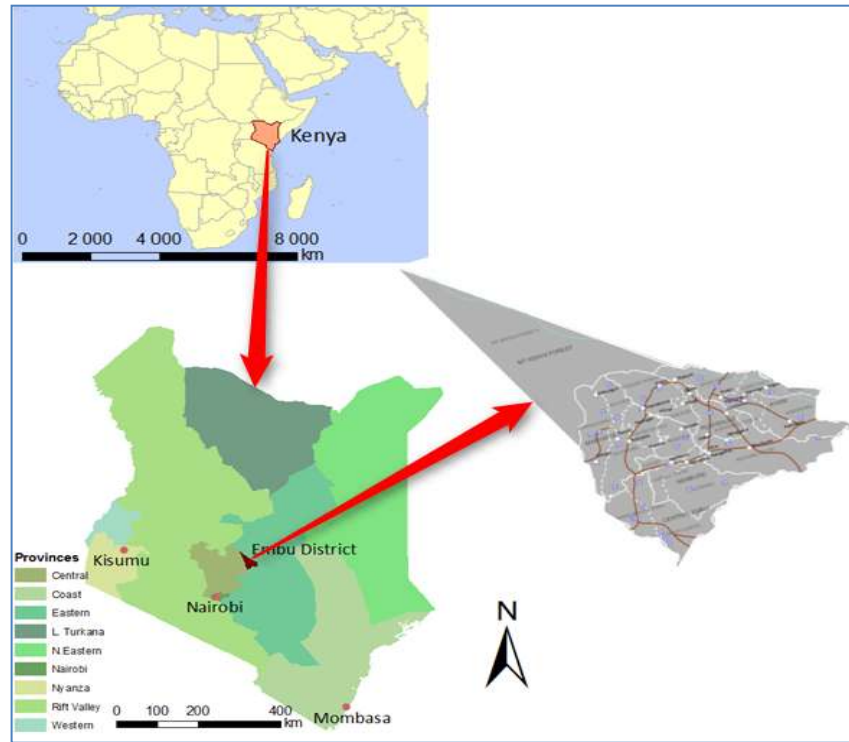
Materyal	Kaynak
Literatürler	Ankara Üniversitesi Elektronik kütüphanesi http://atoz.ebsco.com/Titles/1254
CROPWAT yazılımı	FAO
CLIMWAT yazılımı	FAO
Bitki takvimi	FAO
GMC modeli ve indirgenmiş ölçekte istatistik verileri	Cape Town Üniversitesi İklim Bilgi Portalı http://cip.csag.uct.ac.za/
IRIS yazılımı	Katholieke Universiteit Leuven (Belçika)

Çalışmada aşağıda belirtilen aşamalar gerçekleştirilmiştir:

- I. Çalışma alanı tanımlanmış ve iklim parametrelerinin zaman ve mekan boyutunda değişimi belirlenmiştir.
- II. Embu bölgesine ilişkin verilen derlenmiştir.
- III. İklim değişikliğinin Embu bölgesindeki mısır, fasulye ve ayçiçeğinin bitki su ihtiyacını etkileyeceği hipotezi kurulmuştur.
- IV. İklim senaryoları oluşturulmuştur.
- V. İklim değişikliğinin potansiyel etkileri CROPWAT modeli kullanılarak irdelenmiştir.
- VI. IRIS modeli kullanılan kısıtlı sulama uygulamaların neden olacağı verim kayıpları tahmin edilmiştir.

Araştırma alanı

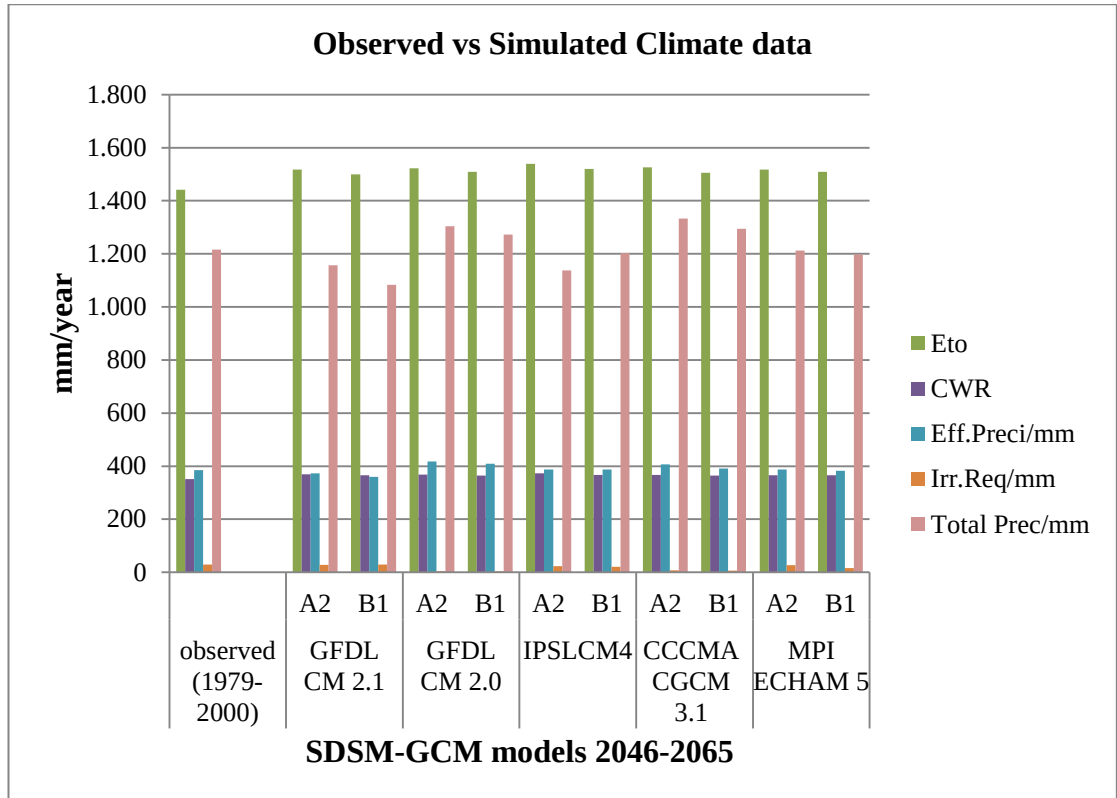
Araştırma sahası Kenya'nın Embu bölgesidir. Bölge nüfusu 516,212 olup başkenti Embu'dur. Bölge 0.5°S (enleme) ve 37.45°E (boylam) ları arasında yer almaktadır. Deniz seviyesinden yüksekliği yaklaşık 1493 metre olup toplam 5 bölgeden oluşan 708 km² lik bir yüzölçümüne sahiptir. İşlenebilir arazisi miktarı 478 km² ve toplam tarım alanı 371 km². Orman alanları ise yaklaşık 230 km² lik bir alanı kaplamaktadır. Çalışma alanı şekil 3.1'de ve toprak yapısı ise şekil 3.2'de gösterilmiştir.



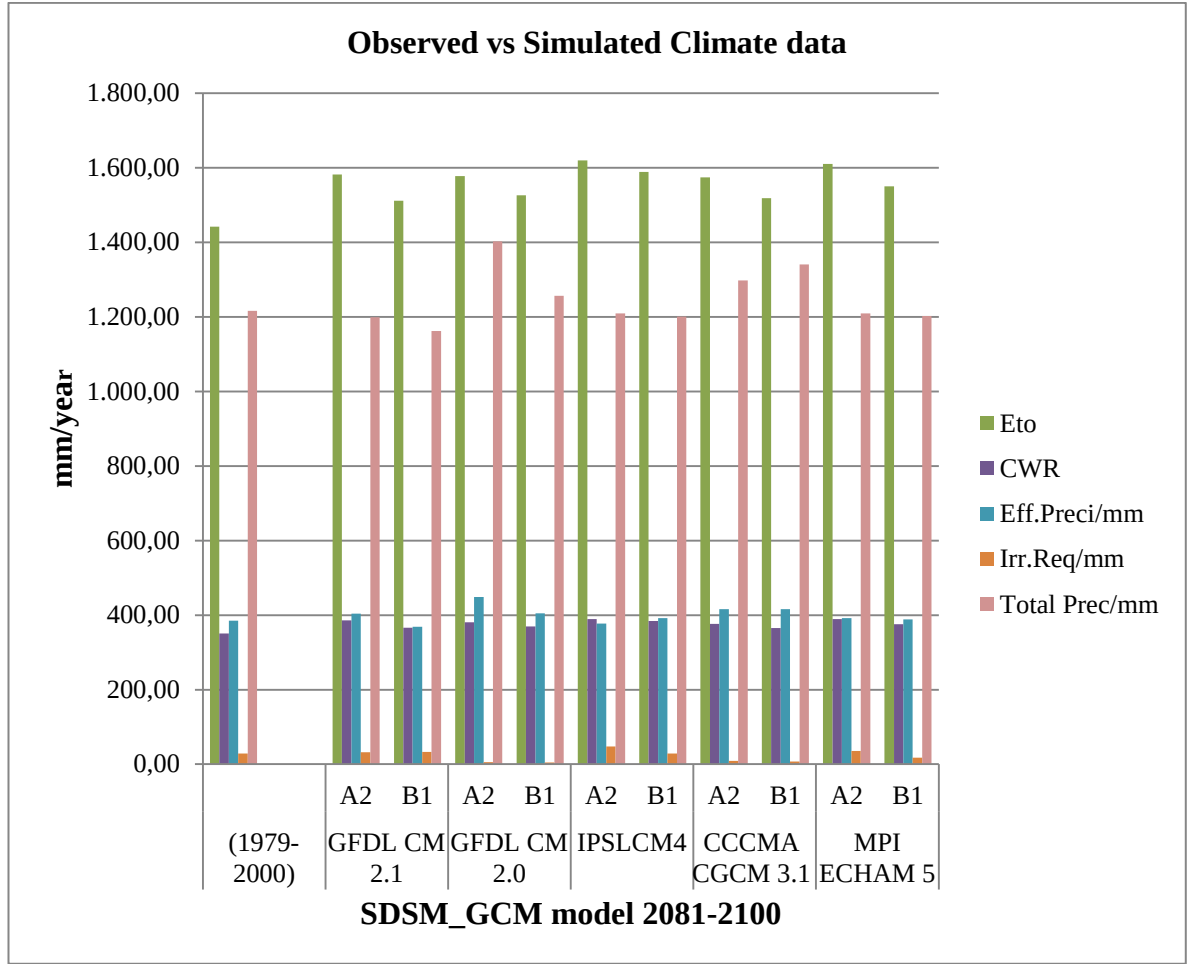
Şekil 3.1 Çalışma alanı

4. BULGULAR VE TARTIŞMA

Fasulye için iklim modelleri ve senaryolara ilişkin bitki su tüketimi (ET_o), bitki su ihtiyacı (CWR), etkili yağış (Effc. Preci.), sulama suyu ihtiyacı (Irr. Req.) ve toplam yağış (Total prec.) değerleri şekil 4.1 ve 4.2’de gösterilmiştir.

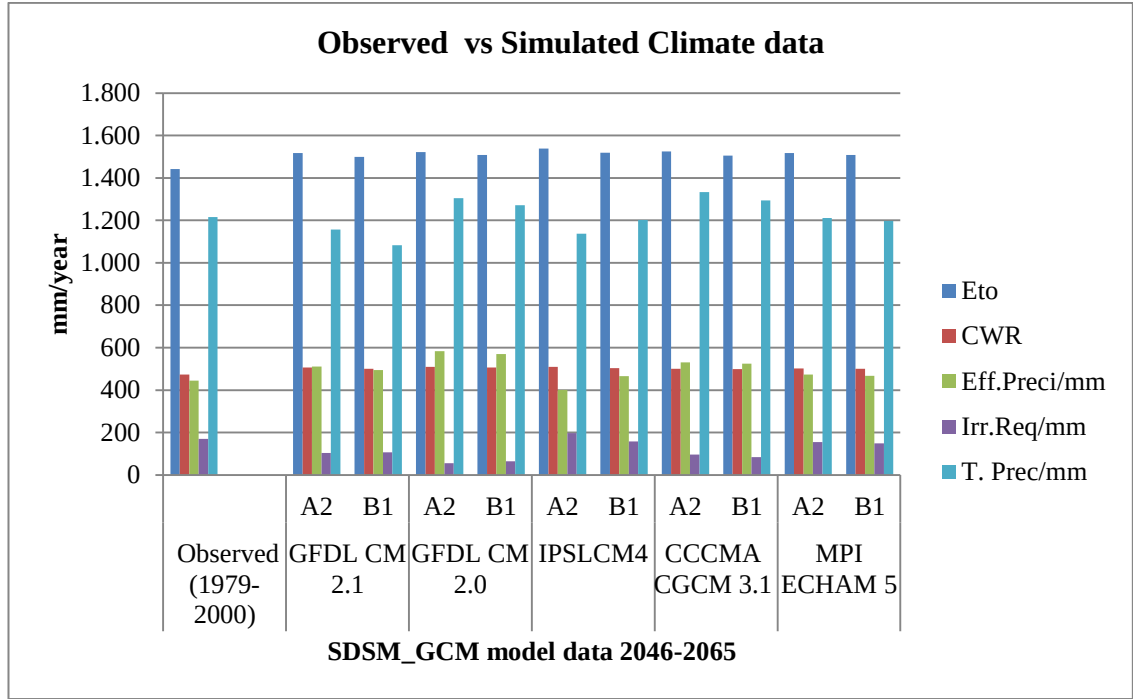


Şekil 4.1 Fasulye için gözlenen ve tahmin edilen değerler (2046-2065)

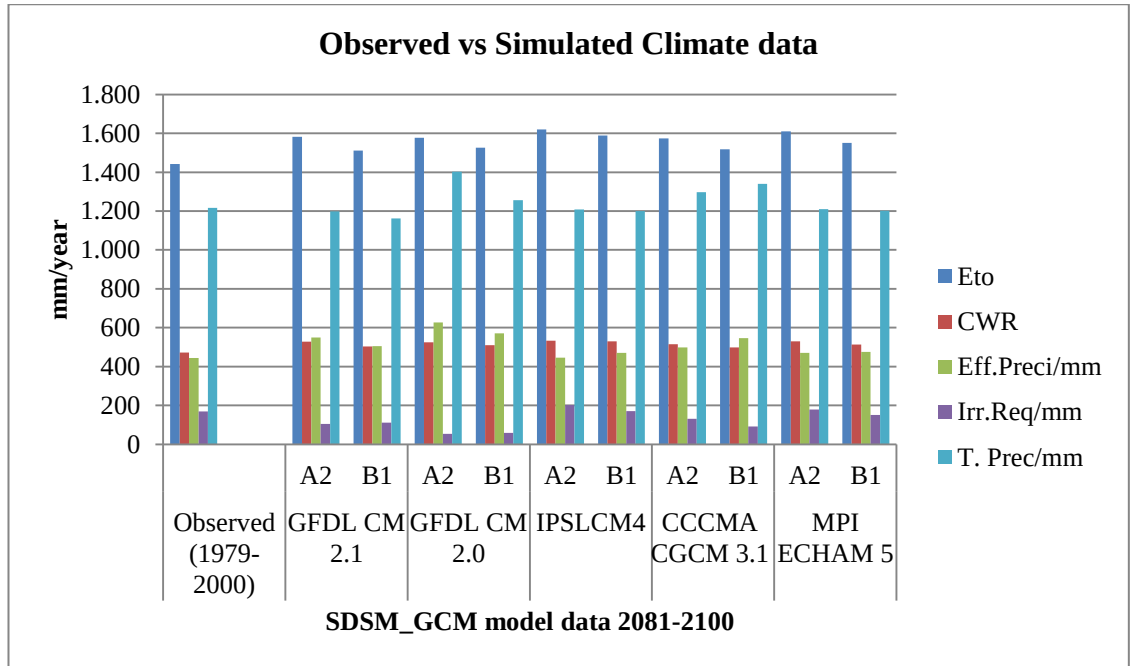


Şekil 4.2 Fasulye için gözlenen ve tahmin edilen değerler (2081-2100)

Mısır için iklim modelleri ve senaryolara ilişkin bitki su tüketimi (ET_o), bitki su ihtiyacı (CWR), etkili yağış (Effc. Preci.), sulama suyu ihtiyacı (Irr. Req.) ve toplam yağış (Total prec.) değerleri şekil 4.3 ve 4.4’de gösterilmiştir.

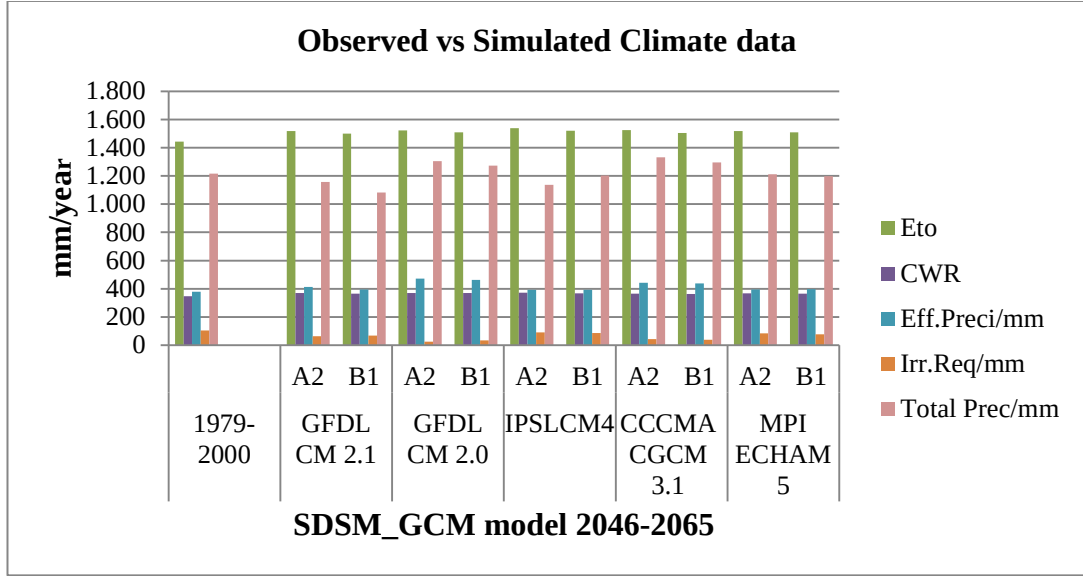


Şekil 4.3 Mısır için gözlenen ve tahmin edilen değerler (2046-2065)

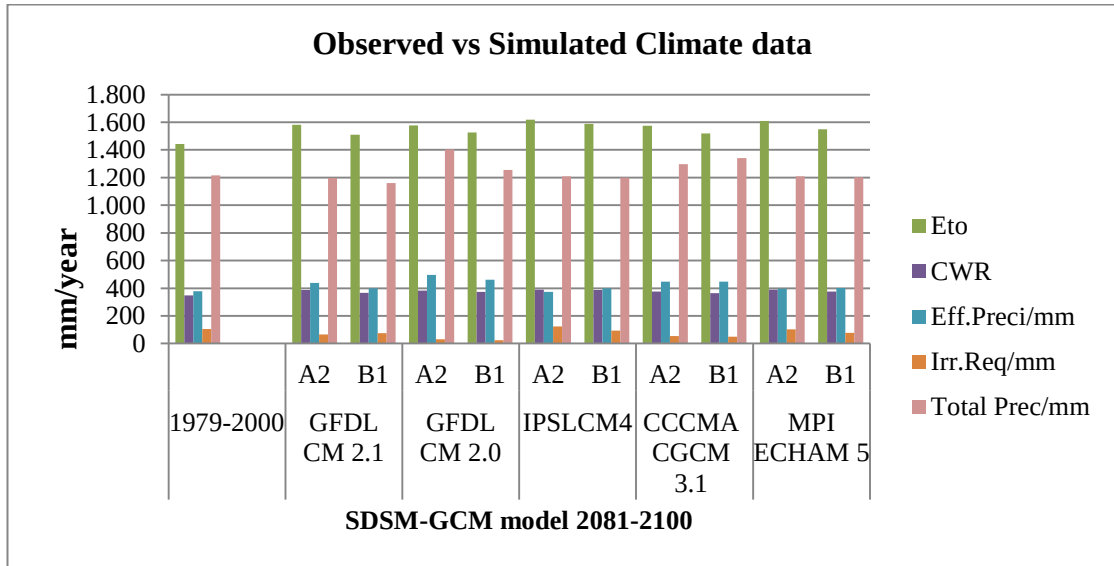


Şekil 4.4 Mısır için gözlenen ve tahmin edilen değerler (2081-2100)

Ayçiçeği için iklim modelleri ve senaryolara ilişkin bitki su tüketimi (ET_o), bitki su ihtiyacı (CWR), etkili yağış (Effc. Preci.), sulama suyu ihtiyacı (Irr. Req.) ve toplam yağış (Total prec.) değerleri şekil 4.5 ve 4.6’de gösterilmiştir



Şekil 4.5 Ayçiçeği için gözlenen ve tahmin edilen değerler (2046-2065)



Şekil 4.6 Ayçiçeği için gözlenen ve tahmin edilen değerler 2081-2100

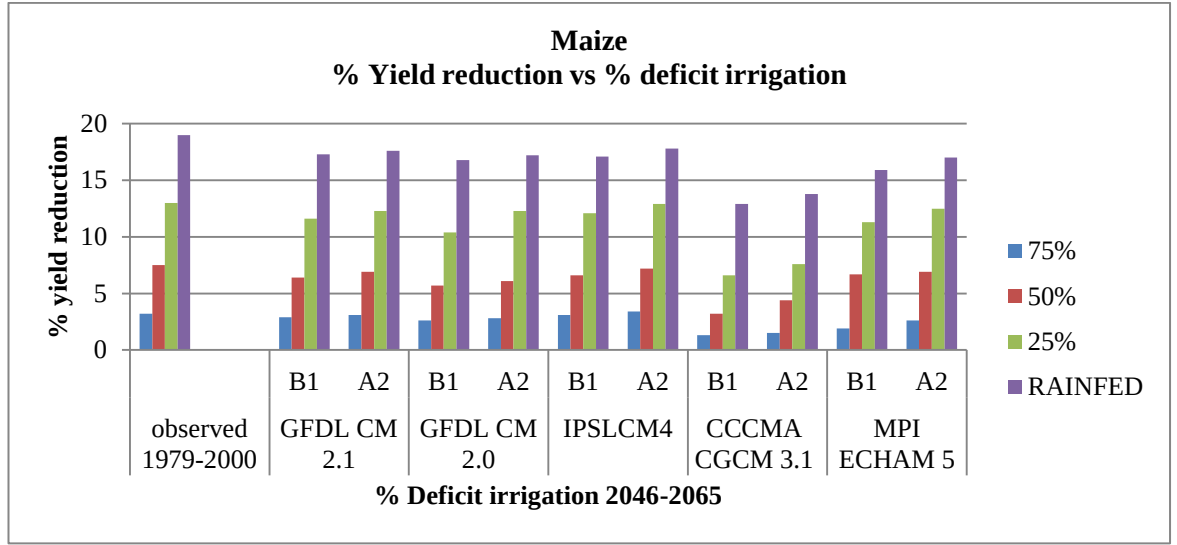
Gözlenene ve Beş farklı model ve iki farklı senaryo için tahmin edilen maksimum ve minimum sıcaklıklar çizelge 4.1’de verilmiştir.

Çizelge 4.1 Gözlenene ve tahmin edilen minimum ve maksimum sıcaklıklar

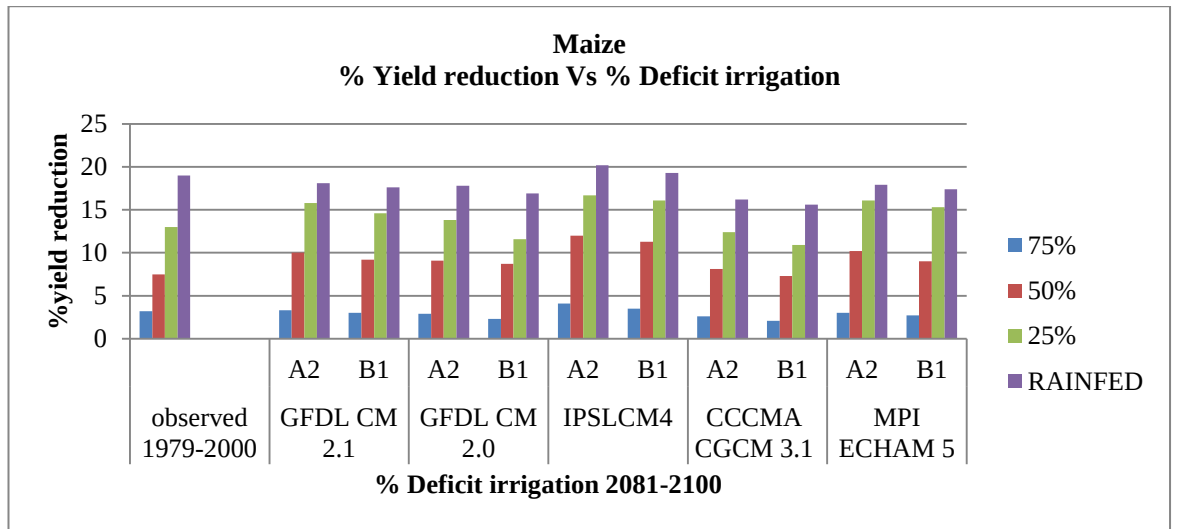
	SDSM-Model Type	Scenarios	Annual Min.Temp °C	Annual Max.Temp °C
1979-2000	observed		14.2	24.1
2046-2065	GFDL CM 2.1	A2	16.5	26.4
		B1	16	25.9
	GFDL CM 2.0	A2	16.6	26.6
		B1	16.3	26.2
	IPSLCM4	A2	16.9	27
		B1	16.4	26.4
	CCCMA CGCM 3.1	A2	16.8	26.5
		B1	16.2	26
	MPI ECHAM 5	A2	16.5	26.3
		B1	16.2	26.1
2081-2100	GFDL CM 2.1	A2	18.2	28.2
		B1	16.4	26.2
	GFDL CM 2.0	A2	18.2	28
		B1	16.7	26.6
	IPSLCM4	A2	19.1	29.1
		B1	17.5	28.6
	CCCMA CGCM 3.1	A2	18.2	27.7
		B1	16.6	26.3
	MPI ECHAM 5	A2	19	28.8
		B1	17.4	27.2

Kısıtlı sulama

Mısırdaki kısıtlı sulama uygulamaları ile ortaya çıkması beklenen verim azalışları şekil 9 ve 10'da gösterilmiştir.

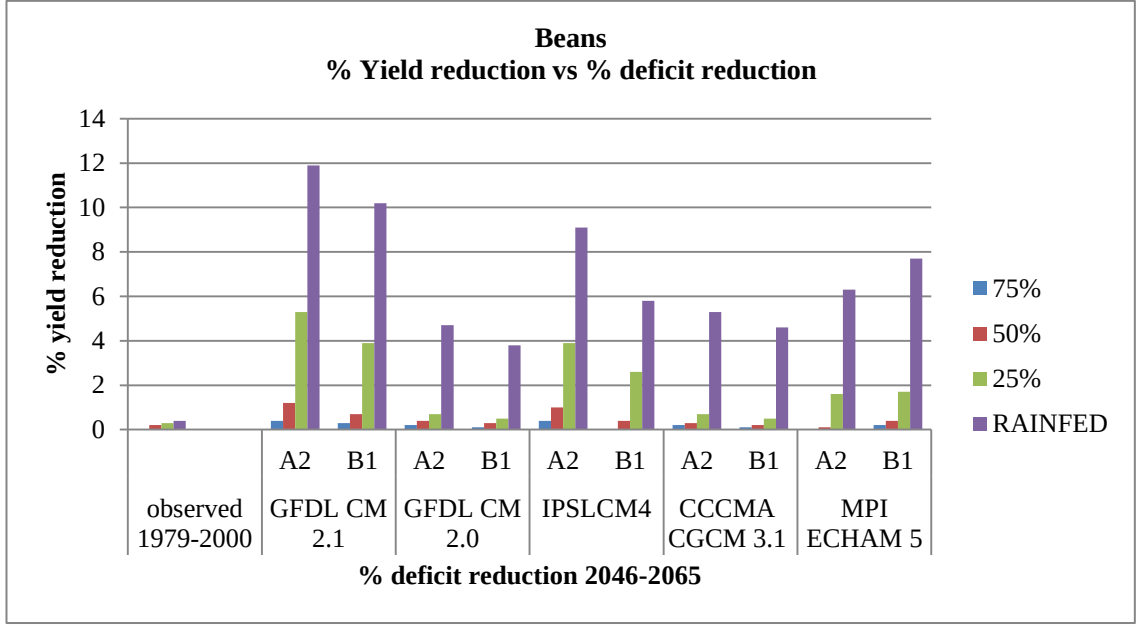


Şekil 4.7 Mısırda kısıtlı sulama ve verim kaybı (2046-2065)

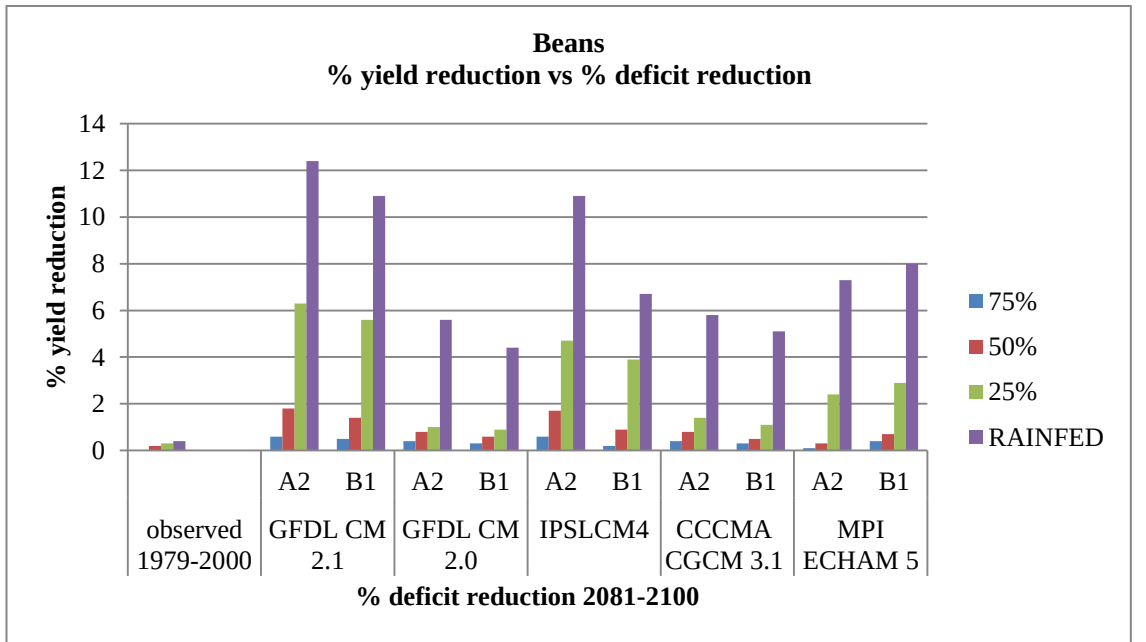


Şekil 4.8 Mısırda kısıtlı sulama ve verim kaybı (2081-2100)

Fasulyede kısıtlı sulama uygulamaları ile ortaya çıkması beklenen verim azalışları şekil 4.9 ve 4.10'de gösterilmiştir.

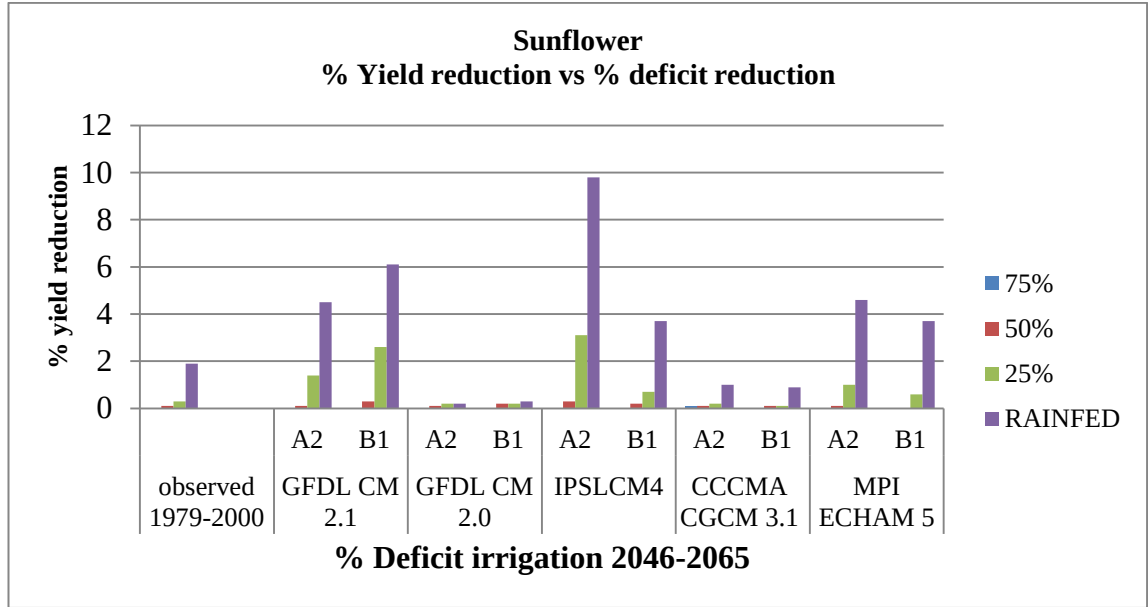


Şekil 4.9 Fasulyede kısıtlı sulama ve verim kaybı (2046-2065)

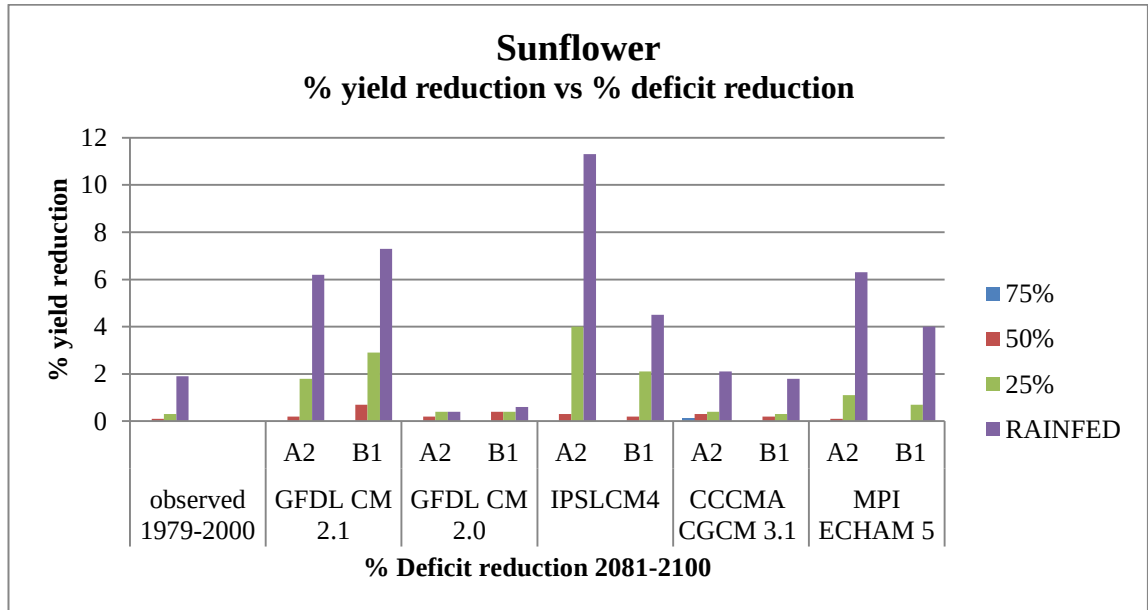


Şekil 4.10 Fasulyede kısıtlı sulama ve verim kaybı (2081-2100)

Ayçiçeğinde kısıtlı sulama uygulamaları ile ortaya çıkması beklenen verim azalışları şekil 4.11 ve 4.12’de gösterilmiştir



Şekil 4.11 Ayçiçeğinde kısıtlı sulama ve verim kaybı (2046-2065)



Şekil 4.12 Ayçiçeğinde kısıtlı sulama ve verim kaybı (2081-2100)

5. SONUÇ

Gelecekteki iki zaman periyodunda bitki su tüketimindeki artışlara rağmen beş model de mısır, fasulye ve ayçiçeği için artan bir bitki su ihtiyacı eğilimi göstermektedir. Bunun tam tersine, modeller sulama suyu ihtiyacında ise düşüş eğilimi ortaya koymaktadır. Bu eğilimler Embu bölgesinde artan yağışlara bağlanabilir. Modeller aynı zamanda üç bitki içinden özellikle mısırın her iki zaman periyodunda da en yüksek bitki su ihtiyacı sergilediğini ortaya koymuştur.

CROPWAT model 8 ile 2040 lar ve 2080 lere ilişkin elde edilen mısır, fasulye ve ayçiçeği için günlük ve mevsimlik toplam bitki su tüketimi ve bitki su ihtiyacı değerleri Kenyalı araştırmacı, planlayıcı ve politikacılar için sulu ve susuz tarım koşullarında su kaynaklarını kullanımı ve bitkisel üretime yönelik önemli veriler sunabilmektedir. Burada sunulan veriler aynı zamanda bitki su ihtiyacı kavramı ve iklim değişikliğinin etkilerinin belirlenmesindeki rolünün daha iyi anlaşılmasını sağlayacaktır. İklim değişikliğinin etkilerinin belirtilmesinde burada kullanılan yaklaşım Kenya'nın diğer bölgelerine ve hatta Afrika kıtasının tümüne uyarlanıp önleyici tedbirler konusunda gerekli adımlar atılabilir ve iklim değişikliğinin etkileri en aza indirgenmeye çalışılabilir. Bu şekilde gıda güvenliğine katkıda bulunulabilir.

IRSIS modeli ile kısıtlı sulama uygulamalarının yol açacağı verim kayıpları dikkate alındığında mısırın verim kaybı açısından diğer iki bitkiye göre daha hassas olduğu gözlenmiştir. Fasulye ve ayçiçeğinde ise %75'lik su kısıtının bile çok fazla bir ürün kaybına neden olmayacağı tahmin edilmektedir. Sonuç olarak Kenya'da iklim değişikliğine karşı en duyarlı kesim olan küçük ölçekli çiftçiler sulama teknolojileri konusunda teşvik edilip yağmura bağımlılıkları en aza indirilmelidir. Su kaynaklarının yetersizliği göz önünde bulundurulduğunda ise kısıtlı sulama uygulamaları ile daha az su ile daha fazla alanı sulayabilecekleri bildirilmelidir.

1. INTRODUCTION

Increasing climate variability can and will impact agriculture and water resources. A rapidly changing climate could possibly lead to more droughts, consequently, altering both crop and irrigation water requirements for commercial and subsistence crop production (Döll 2002). Hence, efficient water application and conservation techniques must be adopted by the crop production sector, for the future. This study was conducted to analyze the effect of future climate change scenarios on the crop water requirements of maize, beans, and sunflower, during the time series of 2040s (2046-2065) and 2080s (2081-2100) and how future climate scenarios may affect trends in the irrigation needs. This is of interest because irrigated maize production is an adaptation strategy to guard against climate change impact in Kenya (Anonymous 2012).

The FAO CROPWAT 8.0 model, was used in this study to calculate the crop water requirement (CWR) of maize, beans and sunflower. The Inter-governmental Panel on Climate Change (IPCC), has predicted that an increase in global mean temperature of less than (1° to 3° Celsius) above 1990 levels, would most likely result to beneficial impacts in some regions, and harmful ones in others. IPCC estimates annual costs to increase over time as global temperatures increase (Anonymous 2007b). The projected impacts of climate change in Africa as a result of global warming by 2020 could affect between 75 and 250 million people who will be exposed to increased water stress: reduced yields from rain-fed agriculture of up to 50 percent in some regions. Thus, attempts to increase agricultural production, and food access may be adversely affected notwithstanding (Anonymous 2007b).

Embu District in Kenya, which was the study area, is in the slopes of Mt. Kenya. A study by Anonymous (2009a) found that a large percentage of Mt. Kenya Landscape inhabitants directly depended on activities sensitive to climate, these include; livestock rearing, rainfed agriculture, extraction of forest related products, and fisheries. Also, the ability of the residents of Mt. Kenya's landscape to comprehend the risks climate change might pose on their lifestyles, could be the critical turning point for them to minimize excessive exploitation of the ecosystem services.

Mt. Kenya, the country's largest water tower, was being threatened by environmental degradation and climate change. Mt. Kenya contributes approximately a half of Tana River's flow, which produces 50 percent of the hydropower generated in Kenya (Anonymous 2007a). Mt. Kenya Landscape has not only played an important role as a source of water for irrigated agriculture, fisheries, livestock production and biodiversity conservation, but also acted as a strategic pillar to the country's economic development agenda. The government and communities within Mt. Kenya Landscape have prioritized the restoration of vegetation cover and the protection of water catchments and sources (Adimo *et al.* 2010). Improving peoples understanding of crop water requirements will be key to sustainable ecosystem-based approach of adapting to potential climate change.

A study by Williams and Funk (2011) showed that the local environment was already experiencing problems as a result of glacier retreat. The rivers were fed by the melting ice. However, earlier and shorter snow melts led to less water for the springs and rivers, making the lands drier and less productive. There were increased incidences of forest fires and reduced vegetation regeneration. Human-wildlife conflicts were on the rise: wild animals migrated downstream to search for food and water. Farmers were significantly affected, water availability was on the decline, hence, their crop production reduced sharply, directly impacting their income, food security, health and even employment (Anonymous 2009a). Natural resource management and better adaptation strategies became an important issue once pronounced evidence of climate change emerged in the region. Climate projections also showed that the impacts would be more severe in the future. Furthermore, these measures were necessary to minimize degradation of the ecosystem and the unsustainable exploitation of the natural resources as a result of population increase (Anonymous 2007a, Williams and Funk 2011).

In recent years, increased intensity and frequency of extreme climate events such as severe droughts and floods have raised the level of appreciation of the critical role played by the climate in the lives of Kenyans. These extreme events have negatively impacted the socio-economic structure of the Kenyan economy by almost affecting all sectors such as agriculture, hydropower generation, livestock production, environment, tourism and health (Anonymous 2009a, Williams and Funk 2011). These changes have caused increased demand for more specialized information and advisories. The decline

of the glaciers of Mt. Kenya was a representative sign of the impact of climate change in Kenya. It clearly indicated why the relationship between cause and effect was not particularly straightforward (Williams and Funk 2011).

Odingo (2008) illustrated that deforestation linked to human activities in the lower slopes of Mt. Kenya contributed to alteration of the ecosystem and the creation of a micro-climate within the region. Noticeably, a pattern characterized by human degradation of environment and gradual effects of climate change on ecosystem services, was emerging in the Mt. Kenya Landscape. Williams and Funk (2011) showed that coffee and tea plantations, which were the major land uses in Mt. Kenya region could be greatly affected by the year 2020. They argued that the plants are generally known to experience stress in hot conditions, based on the evidence that average Kenyan temperatures had increased by 1.0°C since 1960, a rate of increase that would probably continue.

It's important to note that future climate change will occur despite the current mitigation efforts. Adapting to climate change is therefore necessary in many regions and for certain socio-economic and environmental systems. Adaptation which is adjustment in natural and human systems to reduce vulnerability in response to actual or expected climate stimuli or their effects, which moderate harm or exploit beneficial opportunities (Anonymous 2001), is essential. There is need to integrate responses to climate change and adaptation measures into strategies for reducing vulnerability of the poor farm households and the fragile environments. Emerging insights from adaptive ecosystem management and new institutional economics suggest that building resilience in both human and ecological systems is the optimal way to deal with future surprises, or unknown risks such as those caused by climate change (Adger and Tompkins 2003).

Impacts of climate change will be greater among the poor, especially those living in developing countries. Appropriate climate change adaptation and mitigation policies, if adopted in time, could promote investments targeting the poor. In particular adaptation could increase profitability of environmentally sustainable practices even as they generate income for small producers and investment flows for rural communities. In the

long run, this would improve their resilience and the environment to climate change (Adger 2001, Smit *et al.* 2001, Adger and Tompkins 2003, Downing *et al.* 2003)

Burton *et al.* (2006) argued that since the negative impacts of climate change would not be severe everywhere, there was need to find ways of gauging and prioritizing vulnerability of societies and ecosystems by evaluating ecosystem's and society's exposure or its capacity to adapt to the effects of climate change. A study conducted by Xiaolin *et al.* (2013) demonstrated that the principle factors affecting crop water requirement (or ET_c) included the following climatic parameters; rainfall, temperature, humidity, sunshine hours, etc. Hence, they argued that any change in climatic parameters due to global warming would consequently affect the crop evapotranspiration (ET_c) or crop water requirement (CWR). In conclusion, their analysis revealed a positive correlation between ET_c /CWR and temperature, while precipitation and relative humidity showed a negative correlation.

1.1 Problem Statement

Christensen *et al.* (2007) pointed out that the current African climate was much warmer than what it was 100 years ago and that the predictions of future climate scenarios derived from GCM models based on greenhouse gas (GHG) induced climate change for the continent strongly suggested the continuation of the warming trend and a possible acceleration in many scenarios. Herero *et al.* (2010) also note that observational records showed that the African continent in the 20th century was warming at a rate of 0.05°C per decade with increased warming being observed during the June-November season compared to December-May. Herero *et al.* (2010) further revealed that five warmest years in Africa had occurred by the year 2000 since 1988, with 1988 and 1995 being the two warmest years ever recorded. This is not to say that this rate of warming is dissimilar to the globally experienced rate of warming, furthermore, the most rapid warming periods of 1910s to 1930s and the post 1970s occurred simultaneously in Africa and the rest of the world (Herero *et al.* 2010).

Even though there was less uniformity in the projections of rainfall, Christensen *et al.* (2010) argued that East Africa had a relatively stable rainfall regime, and there was a

higher likelihood of increased rainfall precipitation. The manifestation of the impacts of climate change will be noted through extreme events like floods and droughts. These extremes will exacerbate human suffering, economic decline and poverty (Anonymous 2006). Climate change poses enormous challenges to development and economic growth (Thornton *et al.* 2006). Kurukulasuriya *et al.* (2006) pointed out that there was a link between high levels of vulnerability and low adaptive capacity in many areas within Africa and their inability to adapt institutionally and financially. Most of those African countries, especially sub-Saharan Africa (SSA) countries are characterized by lack of safety nets, low per capita gross domestic product (GDP) and high poverty rates. Consequently, these areas will be adversely affected by global warming, since they are already experiencing high temperature and low precipitation, the economies are over-dependent on agriculture, and have low adoption of modern efficient technology.

Despite Kenya's minimal contribution of greenhouse gas emissions, it remains extremely vulnerable to climate change (Anonymous 2012). In an attempt to achieve a low carbon climate resilient pathway, the Government of Kenya (GoK) developed a National Climate Change Response Strategy (NCCRS) in 2010 to help understand the risk and challenges posed by climate change and thus formulate the necessary responses (Anonymous 2012). NCCRS study pointed out that unabated climate change could cost the Kenyan government approximately \$1-2 billion by the year 2030 (Anonymous 2010a). In addition, extreme climate change events like la Niña droughts of 1999/2000 adversely affected crop production and left about 4.7 million Kenyans starving and malnourished. Also, vector-borne diseases like malaria spread to places traditionally known to be non-endemic (Anonymous 2010a). Areas near large water bodies have experienced the highest increase in temperature (Anonymous 2010a). Most of the projection done on the Kenyan climate illustrated an increase of between 1°C and 3.5°C (Anonymous 2009a). Arid and Semi-arid Lands (ASALs) within the country have experienced a decline in the extreme cold temperatures (Kilavi 2008). In the recent past, Mt. Kenya has witnessed a depletion of glaciers (Anonymous 2007b, Anonymous 2009b). The glacier reduction would have an enormous impact on biodiversity, water supply and tourism within the country.

Embu district, being an important agricultural district in Kenya with strong reliance on rainfed agriculture, particularly makes it vulnerable to climate change (Yamin *et al.* 2005, Oborn 2012). Investigating the potential impacts of climate change on crop evapotranspiration (ET_c) or crop water requirement (CWR) is of utmost importance for water management and sustainable crop production (Diop 2006, Karanja 2006, Moussa *et al.* 2006). Regrettably, assessments of climate change are usually limited to mean precipitation and temperature (Anonymous 2006). This approach of assessing climate change has done little to address the ever present threat of climate change, hence, the gap can partly be filled by quantifying the impacts of climate change on crop production.

The direct implication of climate change on crop production and food security is further reinforced by the argument put forth by the IPCC which stated as follows:

"In the tropics and subtropics, where some crops are near their maximum temperature tolerance and where dry land, non-irrigated agriculture dominates, yields are likely to decrease for even small changes in climate, especially in Africa and Latin America, where decreases in overall agricultural productivity of up to thirty per cent are projected during the next century.

Therefore, there may be increased risk of hunger in some locations in the tropics and subtropics where many of the world's poorest live (Anonymous 2000)".

This study aims to use the FAO CROPWAT 8 decision tool in conjunction with GCM models to help quantify the impacts of climate change through determination of CWR for present and future scenarios of three selected crops namely maize, beans and sunflower. IRSIS was then used to simulate the crop yields under deficit irrigation conditions for the same periods. These tools have been used successfully in many projects to analyze impacts of climate change on CWR (Diop 2006, Doria *et al.* 2006, Karanja 2006, Moussa *et al.* 2006). Generally, a changing climate could cause drought, hence altering the water requirements for crops (Doria *et al.* 2006). This reinforces the need for crop production sector to be aware of efficient techniques of water application and conservation for the future. Even though, previous studies on climate change and its potential impacts on agriculture in Embu district have been done (Oborn 2012), specific

studies investigating the influence of climate change on crop water requirements and yield for the maize, beans and sunflower crops in Embu district have not yet been undertaken (Karanja 2006).

1.2 Justification

Residents of Embu district require adequate information in regard to the complex & interlinked relation of climate change and CWR and the overall influence on their farming activities with the aim of enhancing better decision making. A study conducted by Oborn (2012) illustrated that sections of Embu district, in particular, Muthatari and Kithunguriri were vulnerable to extensive dry seasons. Also, water supply for crop production was not steady as there were instances of delayed rains and even drying up of rivers which acted as water sources for irrigation. All those pointed to the need for a multi-thronged approach to help farmers adapt and mitigate these changes in climate.

The decision to use the FAO CROPWAT 8 and IRSIS decision tool was informed by studies previously conducted by Anonymous (2000), which illustrated that:

"Decreasing the vulnerability of socio-economic sectors and ecological systems to natural climate variability through a more informed choice of policies, practices and technologies will, in many cases, reduce the long term vulnerability of these systems to climate change (Anonymous 2000)".

In addition, Karanja (2006), Kurukulasuriya *et al.*(2006), Anonymous (2009), Adimo *et al.* (2010), Christensen *et al.* (2010), Oborn (2012) have argued that a comprehensive understanding of the current vulnerability is paramount in order to develop strategies that will cope with future climate change. This is largely attributed to the uncertainties associated with future climate under various scenarios (Anonymous 2001).

Climate change still remains the most important environmental issue of the twenty-first century (Adimo *et al.* 2010). This study will help to improve the understanding of crop CWR, irrigation water requirement (IWR) and how they are influenced by climate change. Furthermore, a demonstration of how yield corresponds to irrigation using the IRSIS model under deficit irrigation conditions will help disabuse the notion by small-scale farmers that irrigation requires very high amounts of water supply. The

implications of the study could be used as part of mitigation and adaptation measures. Adimo *et al.* (2010) argued that the rising temperature around the Mt. Kenya region (including Embu district) might affect crops like tea; an important cash crop for the residents. If the temperatures increase by 2 °C or more, then the regions will become less suitable for tea growing (Adimo *et al.* 2010, Anonymous 2010b). As illustrated in Figure 1 Anonymous (2010b) further stated that climate change was greatest from high to mid latitudes and over continental land masses, where large populations inhabited and heavily depended on the ecosystem services for their livelihood.

This study is a step in the right direction towards integration of basic research and application to support creation of anticipatory crop production and management strategies relevant to climate change, hence, improve the adaptation and mitigation measures already in place. The methodological approach of using the GCM model results, in combination with the FAO CROPWAT 8.0 and IRSIS decision tools in Embu district will be presented in this study. In summary, this study presents a practical and viable mechanism of linking climate change and CWR, IWR and also crop yield with the aim of enhancing mitigation and adaptation at the local levels from a crop management perspective.

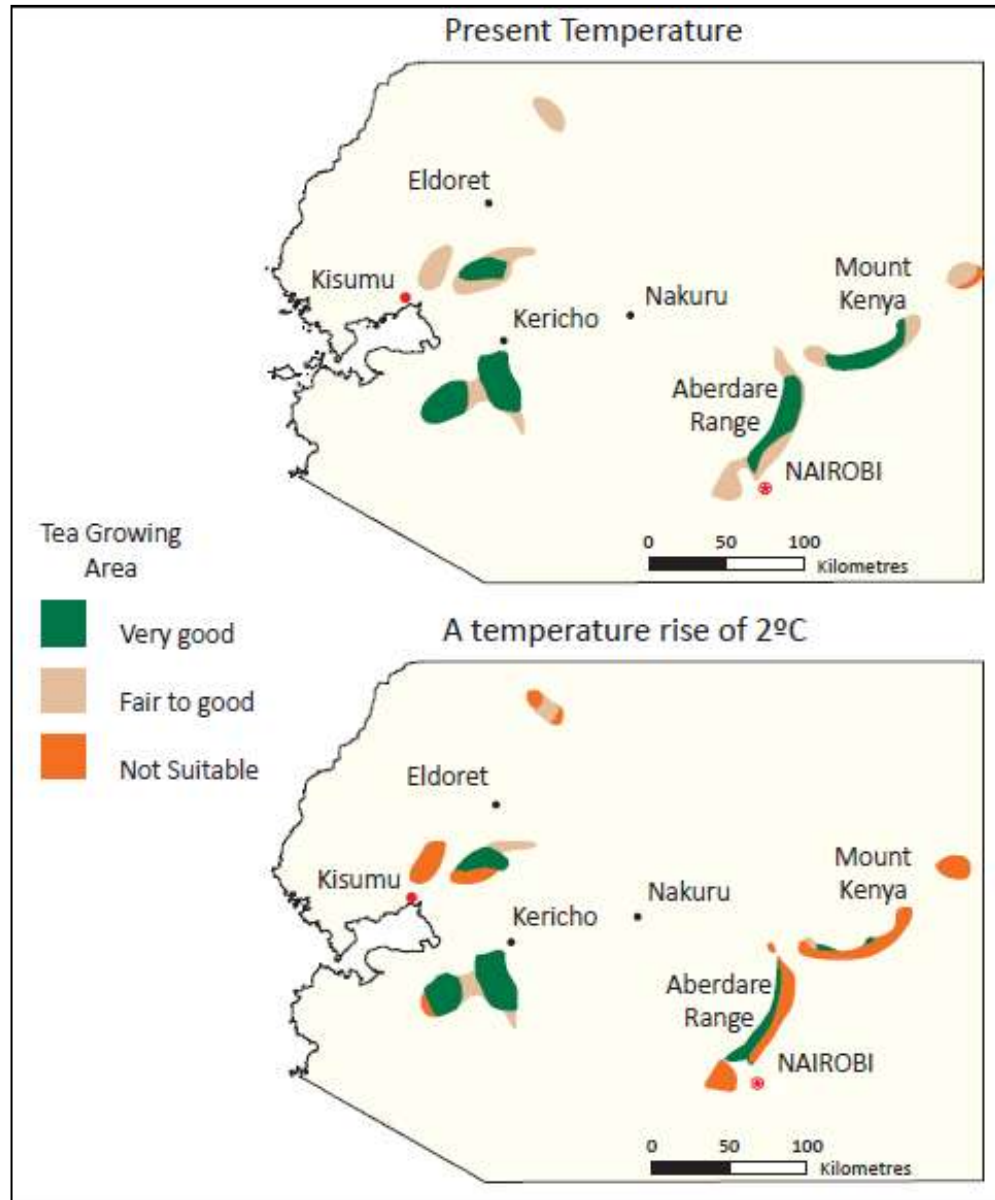


Figure 1.1 Potential impact of temperature rise of 2°C on tea growing in Kenya (Anonymous 2010b)

1.3 General Objectives

To evaluate the potential impact of climate change on future CWR and crop yield and the implication of this on the future rainfed and irrigated crop production systems in Embu district.

1.3.1 Specific Objectives

1. To determine the crop water requirement (CWR) and irrigation water requirement (IWR) for maize in the year 1979-2000, 2046-2065 and 2081-2100 for Embu district.
2. To determine the crop water requirement (CWR) and irrigation water requirement (IWR) for beans in the year 1979-2000, 2046-2065 and 2081-2100 for Embu district.
3. To determine the crop water requirement (CWR) and irrigation water requirement (IWR) for sunflower in the year 1979-2000, 2046-2065 and 2081-2100 for Embu district.
4. To analyze and compare the CWR and IWR of the base and future climate scenarios, and determine possible differences and changes to help in mitigation and adaptation to potential climate change.
5. To determine crop yield under deficit irrigation conditions of 75%, 50%, and 25% using IRSIS model for maize, beans and maize for base climate, 2040s and 2080s climate scenarios.
6. To compare rainfed and irrigated crop yield for the five GCM models under SRES scenarios; A2 and B1, for 2040s and 2080s using IRSIS.

1.4 Hypothesis

1.4.1 Null Hypothesis

Increase in temperature (maximum & minimum) and increase in precipitation as projected by statistically downscaled GCM models, causes increase in crop water requirement (CWR) and irrigation water requirement (IWR) of maize, beans and sunflower crops in Embu district.

1.5 Research Questions

1. How does increase in future maximum and minimum temperatures affect the CWR and IWR of maize, beans and sunflower in Embu district?

2. Does increase in future precipitation affect the relationship between CWR and IWR of maize, beans and sunflower with respect to increase in temperature for the same time period?
3. How do the different Special Report Emission Scenarios (SRES) of A2 & B1 affect the CWR and IWR of maize, beans and sunflower, and also the reference evapotranspiration (ET_o)?
4. Do the five models; GFDL CM 2.0, GFDL CM 2.1, IPSL CM4, CCCMA CGCM 3.1, and MPI ECHAM 5 give the same values for maximum & minimum temperature and precipitation (inputs for FAO CROPWAT 8.0 model) based on A2 & B1 scenarios for Embu district?
5. Are the models used in this study able to simulate historical observed data (Maximum & minimum temperature and precipitation) for Embu district?

1.6 Research Design

1.6.1 Non-Experimental Quantitative Design

This study used the non-experimental quantitative design and involved studying and analyzing historically observed climatic data (1979-2000); Maximum & minimum temperature, precipitation (rainfall), relative humidity, wind, and sunshine duration. In addition, correlation design was incorporated in this study mainly because of the nature of data used; only allowed interpretations involving the extent to which certain effects were related to each other and were a result of particular causes. In particular, locally observed weather and General Circulation Model (GCM) data. The ease of conducting correlation designs, allowed for its adoption into this study.

The source of the quantitative data (Future Temperature and Precipitation data for five GCM models) was from the Climate information portal (CIP) website of the University of Cape Town. A collaborative work with Coordinated Regional Downscaling Experiment (CORDEX) and United Nations Institute for Training and Research (UNITAR). Climatic, soil, and crop data were obtained from the FAO website (CLIMWAT program in particular). Some specific crop related information and data were obtained from the FAO Crop calendar website. The FAO CROPWAT model was used in the analysis of the collected data for interpretation and determination of CWR,

IWR, ET_o . On the other hand IRSIS model was used to estimate the crop yield under deficit irrigation conditions of 75%, 50% and 25%. The yields were then compared to the yields under full irrigation and rainfed conditions.

1.7 Definition of Terms

Climate change can be described as the change in the condition of climate that can be determined through statistical tests in regards to changes in the mean or the variability of its properties. It persists for longer periods, mostly decades or more (Anonymous 2010b).

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. It may be due to natural internal processes within the climate system, or variations in natural or anthropogenic external forcings (Anonymous 2010b).

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change. It is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. Vulnerability is thus the relationship between the degree of climate stress on the population (exposure), the degree of responsiveness to stress (sensitivity) and the ability of the population to adjust to climate changes (adaptive capacity) (Anonymous 2010b).

Adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides (Anonymous 2010b, Smit *et al.* 2000)

Deficit irrigation can be described as a strategy meant to optimize the use of irrigation. Generally, irrigation is applied during drought-sensitive growth stages of a selected crop. However, irrigation is greatly limited or completely avoided in cases where rainfall might provide minimum supply of water. It should be noted that water restriction is limited to drought-tolerant phenological stages, often the vegetative stages

and the late ripening period. Hence, total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle (Sam and Dirk 2009).

Irrigation Scheduling can be defined as the planning of the timing and the depth of future irrigations. The main aim is to apply the irrigation water at the right time and in the right amount (Raes *et al.* 1988). The irrigation efficiency decreases when the water supply for irrigation is untimely and is in inappropriate amounts. Limited supply results in yield reduction due to water stress (Raes *et al.* 1988). It must be noted that too much water also results into deep percolation losses which might leach the important nutrients from the root zone eventually affecting yield.

2. LITERATURE REVIEW

2.1 Introduction

Africa as a continent, specifically, Kenya is vulnerable to climate change. High temperatures and increased variability in precipitation have been reported and recorded. In an attempt to formulate adaptation strategies to climate change for small scale farmers, quantitative evaluation of impacts of climate change on crop production in the agricultural sector must be conducted (Herrero *et al.* 2010). Inter-disciplinary research studies show that global warming is a major problem for the current century. Increased anthropogenic activities are expected to enhance the greenhouse effect which will exacerbate global warming. Therefore, major changes on future precipitation and temperature are expected to occur (Mimi *et al.* 2010).

Kenyan economy has remained sensitive to variations in precipitation, just like many other sub-Saharan countries whose agricultural sector is mainly rainfed. This is largely attributed to a majority of the population depending on climate sensitive activities like agriculture production (Anonymous 2007b, Yamin *et al.* 2005). Major climatic events in Kenya, like droughts of 1991-2, 1995-6, 1998-2000 and 2004, including El-Nino rains that caused the floods of 1997-8 (Orindi and Ochieng' 2005) and the most recent droughts 2008-9 caused a lot of distress on a majority of the population that is already poor (Yamin *et al.* 2005).

The importance of agriculture to Kenya's economy is underscored by the fact that 26% of GDP and 75% of employment is contributed by the agricultural sector (Herrero *et al.* 2010). Low adoption of technology, high levels of poverty, and under-developed infrastructure systems have made rainfed agriculture in Kenya the main source of staple food and income for most of the poor in the rural regions (Herrero *et al.* 2010). Thus, scientific based studies aimed at understanding the full impacts of climate change on agriculture both at present and for future time periods must be undertaken. The outcome of such studies will provide critical data for formulating adaptation strategies to mitigate adverse impacts of climate change.

The production of maize in developing countries is estimated at approximately 100 million hectares, 70% of the total maize production in these developing countries has shown a trend which suggests that it comes from low and lower middle income countries (Anonymous 2010c). Demand for maize in developing countries has been projected to double by the year 2050, and also it's expected to have the greatest production globally, however, in the developing countries highest maize productions are expected by the year 2025 (Rosengrant *et al.* 2008). In Kenya, maize production is considered an extremely important activity mainly because it's a dominant food crop (staple food), which is wholly produced under rainfed conditions and about 1.4 million hectares is under maize (Wokabi 2001, Karanja 2006). Hence, there is an urgent need to not only understand, but to quantify the potential impacts of future climatic change on maize production. It is grown in different types of soils namely Andosols, Vertisols, Phaeozems, Cambisols, Luvisols, Nitisols, Acrisols and Ferralsols (Wokabi 2001).

The Kenyan highlands and midlands act as the main regions where there is higher productivity of common beans (Katungi *et al.* 2009). Notably, the former Rift valley, Nyanza and Eastern Provinces respectively accounted for 75 percent of the annual cultivation. A high percentage of farmers in Kenya grow the common beans once a year as a result of adverse climatic conditions, despite the fact that Kenya has two growing seasons for the crop. However, farmers in the central and eastern regions grow it twice a year, in addition, approximately 70 percent of the farmers in the eastern region grow it in the long rains (March-May). It's important to note that almost all the farmers in the two previously mentioned regions grow the crop during the short rains period (October-December) (Katungi *et al.* 2009). In this study, the potential impacts of future climate change on crop water requirements of maize, beans and sunflower in Embu district, using CROPWAT model is investigated.

It is hypothesized that an increase in global mean temperature of less than (1° to 3°C) above 1990 levels would most likely result in beneficial impacts in some regions, while, harmful effects might be experienced in other regions (Anonymous 2007b). Additionally, these future climate changes in precipitation and temperature might affect the CWR and IWR of crops (Karanja 2006). Therefore, the following literature reviews attempt to demonstrate and support the hypothesis.

2.2 Using the CROPWAT Model to Analyze the Effects of Climate Change on Rainfed Crops in Niger

In this particular study, the CROPWAT model was used to estimate future soil moisture deficit (SMD) using different climate scenarios, it further assessed the crop water requirement (CWR) including the differences in the yield of the major rainfed crops in Niger (Moussa *et al.* 2006). The study focused on two districts namely Aguié and Gaya, where SMD analysis in regard to climate change under varied cropping patterns, soil characteristics and climate conditions were conducted.

Niger is described as a landlocked country located in the Sahel and is approximately 700 km from the sea, in addition, it has a surface area of 1,267,000 km² and a total population of 10 million (Moussa *et al.* 2006). Furthermore, the climate is described as Sahelian with a long dry season and a short dry season respectively. Three sets of data were collected and used, these included meteorological data from the national meteorological service (source) which consisted of temperatures and rainfall for 1961 to 1990, and evapotranspiration for the period 1978 to 1998 for Gaya and 1978-2002 for Aguié. The soil data was obtained from the Agronomic research institute (INRAN). The National Service for Agricultural Statistics provided the vital crop data required for the study (Moussa *et al.* 2006).

Moussa *et al.* (2006) predicted the impact of climate change on the soil water availability and the crop water uptake and used MAGICC (model for the Assessment of Greenhouse-gas Induced Climate Change) and coupled it with the SCENGEN (SCEnario GENerator) developed by the IPCC (Intergovernmental Panel on Climate Change). Also, the study used the HadCM2 (Hadley center unified model 2 transient, UK) GCM to project the future climate scenarios for the year 2025, while climate data of 1961-1990 was used as the basic climate scenario.

The study results exhibited a major difference for Aguié district in relation to soil water availability and soil moisture deficit between the scenario with climate change in the year 2025 and the scenario without climate change. However, an insignificant difference was noted for Gaya district, where a decrease in rainfall maintained adequate

soil moisture which was able to support production of subsistence crops (Moussa *et al.* 2006).

The Study further recommended a paradigm shift in Niger's agricultural policy and the country's strategies for adapting to climate change and variability, as well as, changing of the cropping systems to accommodate irrigation techniques, in order to support crops not adapted to Sahelian climate conditions. Moussa *et al.* (2006) suggested in their study that in order to increase irrigation efficiency, small scale farmers needed to be organized into big units called cooperatives.

2.3 Analysis of Crop Water Use in Senegal With the CROPWAT Model

Mbaye Diop (2006) conducted a study in Senegal, whose main objective was to analyze crop water use with the FAO CROPWAT model, with the intention of assessing the potential impacts of climate change on a selected group of crops. The crops selected for the purpose of the study was done on a criteria based on the importance of the crops in the country i.e. main crops, these crops were millet and groundnuts (Diop 2006). Additionally, the study included maize which was adapted as part of a diversification strategy.

The study focused on districts chosen in the north-south gradient. Diop (2006) based the criteria for this selection on the need to represent the spatial rainfall distribution and variation. The regions selected for the study namely the Diourbel and Kaolack are located in the northern Sudanese Zone and are reported to receive an average rainfall of between 400 to 600 mm and is also located in the center of an agricultural basin. The soil is mainly sandy (Diop 2006). However, in the south, Kolda District was depicted to be representative of the sub Guinean area and had an average annual rainfall of between 900 to 1000 mm. Clay soil was said to be predominant in the region (Diop 2006).

Agriculture is an important sector in the Senegalese economy and contributes 70% of the working population and is said to contribute approximately 11% of GDP (Diop 2006). The study showed that there were seven agro-ecological zones and out of the crops grown in those zones, 96% were rainfed. The study further revealed that Millet was a staple food grown in the rural regions as the main cereal. However, millet was of

different varieties with the one cultivated in Diourbel region exhibited a 90-day cycle, while the one cultivated on Kolda had a growing cycle of 120-day. It further stated that flood irrigated crops were found along the river valleys of northern Senegal, on the northern coast (Niayes) and also in the southern region namely (Casamance) (Diop 2006).

Diop (2006) used the FAO climate and crop data to run the CROPWAT model, the study incorporated the crop coefficients from Dancette (1983) and soil data provided by the Forest Department (1982). Additionally, IPCC findings on climate change were used as part of the input data for the CROPWAT model, this was used to evaluate the impact of climate change on agriculture within Senegal. The Senegal soil map (Michel and Sall, 1983) was used to select the different types of soil.

The results of the study showed that the water use in southern part of Senegal was higher (Kolda), rainfall was abundant and soils exhibited a higher amount of organic and mineral richness compared to the northern part (Diourbel) which had less fertile soils which were relatively poor in terms of minerals content. This justified reasons why the values for actual crop evapotranspiration for crops were low in the northern region and high in the southern. Increased temperature of 1.5 degrees Celsius showed insignificant effect on millet in the northern part of the country, however it caused a significant reduction in the actual evaporation, as a consequence the yield of millet reduced in the southern part. The results reinforced the importance of using the modeling approach for evaluation of crop water use across a country, consequently the use of CROPWAT model to quantify the impact of climate change on crop water requirement (Diop 2006).

2.4 An Analysis of Climate Change Impacts on Irrigated Crop Water Requirement in the South Australian (SA) Murray-Darling Basin (MDB) Region

The study was undertaken via the support of the South Australian (SA) Murray-Darling Base (MDB) Natural resources board, the region was described as the most productive agricultural areas within SA, it's also said to occupy an area of approximately 70,000 square kilometers (Smith *et al.* 2010). The study showed that the irrigated development

in SA MDB was located close to the river Murray channel, which runs for about 640 kilometers in this specific region (Smith *et al.* 2010). SA MDB is characterized by perennial horticultural crops mainly; stone fruits, wine grapes, almonds and citrus.

The board demonstrated its commitment to support various irrigation communities in implementation of effective climate change mitigation and adaptation strategies by supporting this study, thus underscoring, the importance of understanding the threat future climate change might pose on irrigated or rainfed agriculture (Smith *et al.* 2010). The project aimed at determining the current water requirements and possible impacts of climate change scenarios that were listed on the Murray Darling Basin sustainable Yields (MDBSY) project (Chiew *et al.* 2008), the project was aimed at determining the crop water requirement for different crop types grown in the SA MDB Natural Resource Management (NRM) board region.

Smith *et al.* (2010) analyzed the Irrigation Water Requirement (IWR) for the past years of 1990-1999 and the recent climate of 2000-2009. The study further focused on the future climate scenarios developed by the MDBSY project and incorporated them in the evaluation of the possible climate conditions for the year 2030, in comparison to the year 1990. Different crops were selected (Lucerne, Almonds, Citrus, apricots, grapes, onion and potatoes) and their individual Irrigation Water Requirement (IWR) calculated and completed on an Excel spreadsheet. The Crop Water Requirements (CWR) was calculated using the United Nations Food and Agriculture Organization (FAO) single crop coefficient (K_c) methodology, also referred to as FAO-56 (Allen *et al.* 1998) a widely accepted standard procedure for CWR estimation based on its simplicity, reproducibility and good accuracy (Allen *et al.* 2007).

Chiew *et al.* (2008) description of future climate scenario was adapted in the assessment of changes in the reference Evapotranspiration and rainfall in the year 2030. Scaled historical climate data (1896 to 2006) was used in the development of future climate scenarios in 2030 based on 15 analyzed Global Climate Models (GCMs) and three global warming scenarios (Anonymous 2007b). The study argued that drought was a major climate challenge that affected rural communities. Additionally, it affected rainfall patterns which in the long run affected planting dates and crop growing cycle,

hence affecting IWR (Smith *et al.* 2010). Christensen *et al.* (2007) conducted a study and argued that rainfall changes under climate change may not be apparent for 70 + years. However, importance of observed changes could not be underestimated and its significance to the agriculture sector. Trout and Johnson (2007) argued that the weather based approach of calculating CWR and IWR presented a weak link, mainly because their studies showed difficulty in reliably estimating K_c .

The study showed that crop water use derived by $K_c * ET_{ref}$ was widely used due to its transportability between locations, it also reaffirmed the simplicity and relatively good accuracy of the method (Smith *et al.* 2010). In conclusion, the study acknowledged that climate change had the ability of altering the traditional crop planting calendar and growing cycle. In particular, rainfall remained a dominant factor that could substantially increase or reduce the IWR of any crop. However, both temperature and rainfall were noted to have considerable influence on the IWR of the crops investigated in any particular year (Smith *et al.* 2010).

2.5 Estimation of Future Crop Water Requirements for 2020 and 2050 Using CROPWAT

In this study, Doria *et al.* (2006) suggested that potential climate change had the potential of impacting water resources, as a consequence, agricultural crop production would also be affected. Indeed, a constantly changing climate could potentially lead to drought occurrences, thus, altering the water requirement for fruit production particularly of the crop production sector. They recommended adoption of efficient water application and conservation for the purposes of adapting to possible climate change scenarios.

The objective of their study was to determine or rather establish the impacts of potential climate change on daily and total CWR of a selected crop, namely; peaches located in Southern Ontario. In order to achieve this objective, CROPWAT model was used in combination with climate scenarios derived from Statistically Downscaled Models (SDSM) (Doria *et al.* 2006). A baseline climate of a 30 year period (1971-2000) of mean monthly normals was used, it included, the use of future time periods of 2020s

(2010-2039) and 2050s (2040-2069). The study used the SDSM (version 3.1) downscaling technique to downscale the climate parameters of temperature, wind speed, sunshine duration, relative humidity, precipitation (Doria *et al.* 2006).

The CROPWAT model (Anonymous 1992) was used to determine the future CWR, it involved the simulation of present and future decades' daily, and the season total of CWR and irrigation water requirement (IWR). A comparison of the results to the base climate was made, and interesting observations were noted. An increase in CWR of 6% (39 mm) per season was observed for SDSM-CGCM1 model for 2020s and 3% (20 mm) per season for both SDSM-HADCM3 A2 and B2 models for 2020s. For 2050s, an increase of 8% (56 mm) for SDSM-CGCM1 and HADCM3 A2 & B2 models for 2050s and 7% (43 mm) per season were observed. On the contrary, a decrease in the IWR compared to the present condition were observed. Specifically, a decrease of 6% (18 mm) when a 90% irrigation efficiency was assumed using the for SDSM-CGCM1 for 2020s, also a decrease of 27% (81 mm) for both for SDSM-CGCM1 and HADCM3 A2 & B2 models for 2020s was observed. As for 2050s a similar decreasing trend was observed; 2.71% (8 mm), 21% (64 mm) and 6% (59 mm) for SDSM-CGCM1 , HADCM3 A2 & HADCM3 B2 for the year 2050s (Doria *et al.* 2006).

2.6 CROPWAT Model Analysis of Crop Water Use in Six Districts in Kenya

FAO CROPWAT model was used in this study to determine the CWR of a selected crops within six Districts namely; Makueni, Migori, Laikipia, Kiambu, Vihiga and Kwale. These districts were selected from the former six provinces; Eastern, Nyanza, Rift valley, Central, Western and Coast, respectively. The criteria used for selecting these districts was based on the need to reflect diversity of the agro-ecological zones of Kenya (Karanja 2006). The objective of this study was to determine CWR, level of crop productivity in the different agro-ecological zones and also the responses of the crops to climate change and variability.

Karanja (2006) showed in his study that an increase in temperature caused a percentage increase in crop water use. CCCM scenario produced lower crop water use output compared to the GFDL3 for all the studied districts. However, within a set of temperature change scenarios, rainfall changes failed to change the amount of crop water used by crops. Karanja (2006) further argued in his study that the effect of rainfall changes could be implicit in the sense that there was a decrease in the amount of irrigation water needed following an increase in the amount of precipitation.

On the contrary, the patterns of IWR and field water supply differed from the trend mentioned above in relation to temperature. When rainfall was increased by 20% above the long term mean for each of the models, it was noted that the irrigation water required for the studied crops reduced. On the other hand, a decrease of 20% increased it (Karanja 2006). Indeed, an increase in rainfall satisfies a bigger percentage of CWR, hence, less irrigation water was required in the project. The study also showed that the field water supply was higher during climate change scenarios that were related to lower precipitation amounts of less than 20% of the original long term mean.

3. MATERIALS AND METHODOLOGY

3.1 Materials

A summary of the materials and the resources used in this study for the collection and analysis of data are shown in the Table 3.1.

Table 3.1 A summary of materials and resources

Material	Source
Research topic literature and related Material	Ankara University Electronic library (Elektronik Kaynaklar Erişim Listesi) http://atoz.ebsco.com/Titles/1254
CROPWAT software	Food and Agriculture Organization (FAO)
CLIMWAT software	Food and Agriculture Organization (FAO)
CROP Calendar	Food and Agriculture Organization (FAO)
General Circulation Model (GCM) and Statistically Downscaled Data results.	Climate Information Portal (CIP) hosted by Cape Town University. http://cip.csag.uct.ac.za/
IRSIS software	Irrigation Scheduling Information System Manual Volume 1 by Katholieke Universiteit Leuven (belgium)

3.1.1 Area of Study

Embu district is found within Embu county (Formerly Eastern Province) (Figure 3.1). The population of Embu county stands at 516212 (KNBS, 2010). Its capital town is Embu. While its population is estimated at 278196. The district has two constituencies: Manyatta and Runyenjes (Muya *et al.* 2009). The district is bordered by Mbeere district to the east and south east, Kirinyaga to the west and Meru south to the north. The district lies approximately between a 0.5°S (latitude) and 37.45°E (longitude) and is on

the windward side or the southeastern slopes of Mt. Kenya (Muya *et al.* 2009). The elevation is approximately 1493 meters a.s.l (Gachimbi 2002, Anonymous 2011). It occupies a total area of 708 km² and is divided into 5 divisions. The total arable land area is 478 km² with total available agricultural land area covering 371 km². The forest covers an estimated 230 km² (Jaetzold 2006).

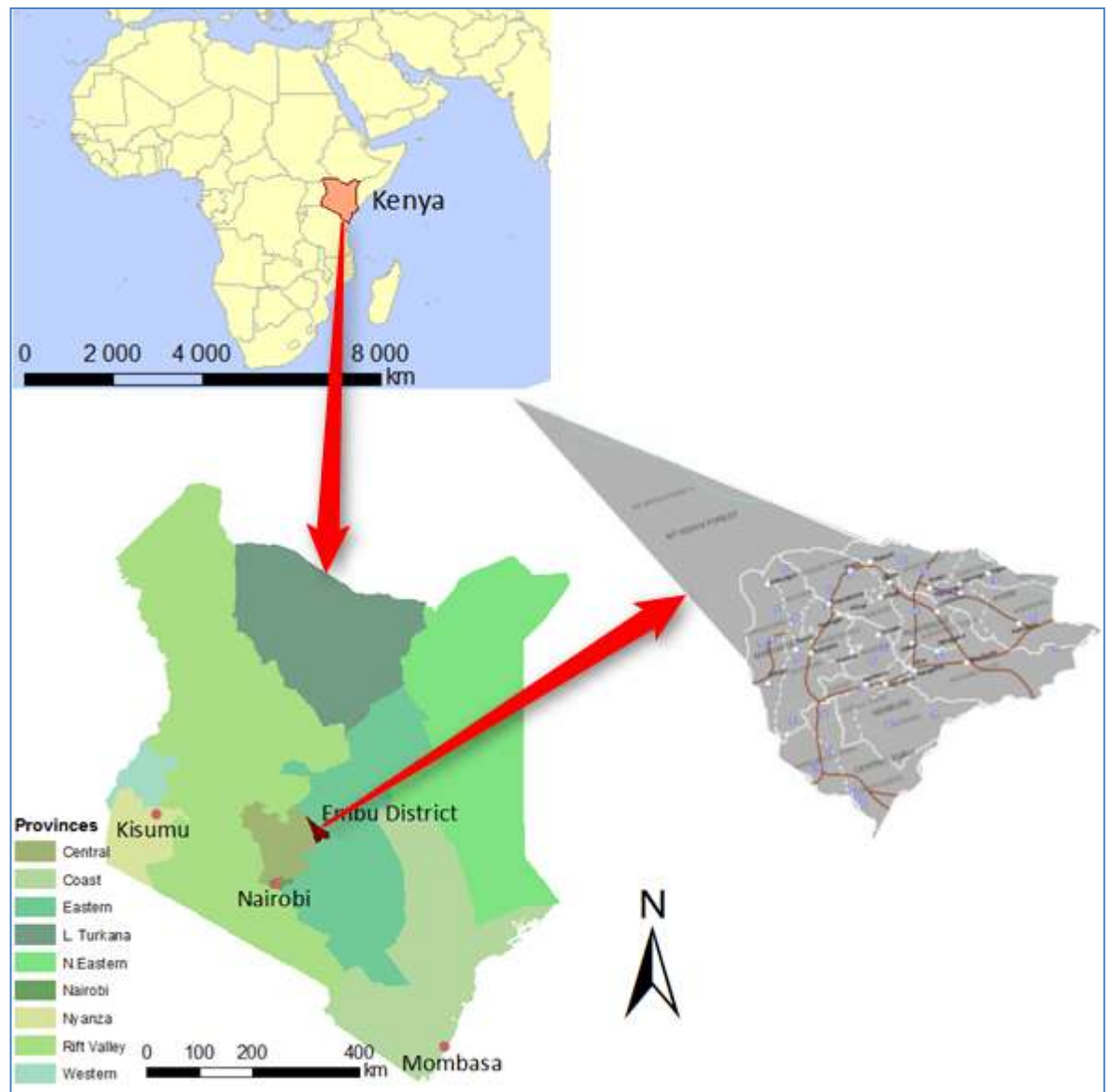


Figure 3.1 Study area of Embu District in Embu (Oborn and Enjebo 2012)

3.1.2 Topography and Soil

Mt. Kenya is an important topographical feature located in the north-western corner of Embu District. The topography is relatively more leveled towards the southeastern part of the district. Volcanic bedrock characterizes the underlying rocks which is a pathway to the uniquely varied gneisses of the basement system (Jaetzold 2006). Broad zones offer the prime location for the occurrence of the soils in this region. Furthermore, the broad zones run from southwest-northeast and exhibit certain distinctive characteristics:

heavy soils in the upper middle parts, medium to heavy in the lower middle parts, finally, light to heavy soils in the lower parts (Jaetzold 2006). MV1 and MV2 are the type of mountain soils found in Mt. Kenya. MV2 soil type is mostly associated and considered to be suitable for tea cultivation. Towards the lower ends of the region, volcanic soil type RB1, 2, 3 are more dominant. The fertility of the soil is moderate to high. However, the fertility is quickly exhausted by constant cultivation with minimum manure and fertilizer use. This is considered a general problem in the Embu region. LB1, 2 and 3 are considered foot plateau soils and are located at the boundary of Embu and Mbeere district, they have low to moderate natural fertility (Jaetzold 2006). The LB1, is the Embu district soil type, used in this study (dark red and friable clay soil).

In the uplands UU1 and UI1 soils are dominant and are associated with the hill complexes (HB3), they are mostly of low to moderate fertility. The more fertile soil types UpFC, UF1 and UUC2 are also found in the upland areas of the district. Siakago uplands area, specifically, the southern, eastern and western zones have poor soil types namely, HB3 of the hills, UQ1 (foothills) and UU1 (upland soils) (Jaetzold 2006). Figure 3.2 shows the distribution of different soil types in Embu district.

3.1.3 Explanation of the Soil Characters

1. Explanation of the first Alphabets (Jaetzold 2006).

M-Mountains (steep; slopes predominantly over 30%; relief intensity more than 300 m/km)

H-Hills (hilly to steep; slopes predominantly over 16%; relief intensity up to 300 m/km)

R-Volcanic Footridges (dissected lower slopes of major older volcanoes and older lava flows, undulating to hilly; slopes between 5 and 30%)

U-Uplands

Up-Upland / Plain Transitional Lands

L-Plateaus and High Level Structural Plains

Pd-Dissected Erosional Plains

2. Explanation of second Alphabets (Jaetzold 2006).

B-Basic and ultra-basic igneous rocks (basalts, nepheline phonolites; older basic tuffs included)

I-Intermediate igneous rocks (andesites, phonolites, syenites, etc.)

L-Limestone and calcitics Mudstones

Q-Quarzites

U-Undifferentiated Basement System rocks (predominantly gneisses)

V-Undifferentiated or various igneous rocks

3.1.4 Embu Soil description

Soil description (Jaetzold 2006).

MV1 -imperfectly drained, shallow to moderately deep, dark greyish brown, very friable, acid humic to peaty, loam to clay loam, with rock outcrops and ice in the highest parts

– dystic HISTOSOLS, lithic phase; with LITHOSOLS and rock outcrops

MV2- well drained, very deep, dark reddish brown to dark brown, very friable and smeary, clay loam to clay, with a thick acid humic topsoil; in places shallow to moderately deep and rocky

– humic ANDOSOLS, partly lithic phase

HB2- well drained, shallow to moderately deep, very dark brown, firm, stony and rocky clay loam

–LITHOSOLS; with verto-luvic PHAEOZENS, lithic phase and rock outcrops

HB3- excessively to well drained, shallow, reddish brown to dusky red, stony and rocky, friable sandy clay to clay, in places with humic topsoil
–LITHOSOLS and humic CAMBISOLS

RB1 well drained, extremely deep, dark reddish brown to dark brown, friable and slightly smeary clay, with an acid humic topsoil
–ando-humic NITISOLS; with humic ANDOSOLS

RB2- well drained, extremely deep, dusky red to dark reddish brown, friable clay, with a acid humic topsoil
–humic NITISOLS

RB3 -well drained, extremely deep, dusky red to dark reddish brown, friable clay; with inclusions of well drained, moderately deep, dark red to dark reddish brown, friable clay over rock, pisolite or petroferrous material
–eutric NITISOLS; with nitrified-chromic CAMBISOLS and chromic ACRISOLS and LUVISOLS, partly lithic, pisolite or petroferrous phase

LB1- well drained, very deep, dark red, very friable clay
–nitrified-rhodic FERRALSOLS

LB2- well drained, very deep, dark reddish brown to dark brown, friable to firm, clay; in places with a humic topsoil
–verto-eutric NITISOLS; with mollic NITISOLS

LB3 -imperfectly drained, very deep, dark grey to black, firm to very firm, bouldery and stony, cracking clay; in places with a calcareous, slightly saline deeper subsoil
–pellic VERTISOLS, stony phase and partly saline phase

UF1- well drained, very deep, dark red, friable to firm clay
– nitrified-rhodic FERRALSOLS

UI1- well drained, very deep, dusky red to dark red, friable clay

–nito-rhodic FERRALSOLS

UQ1- well drained, shallow to deep, dark red to yellowish brown, loose loamy sand to friable sandy clay loam; in places rocky and stony

–ferralic ARENOSOLS and ferralo-orthic LUVISOLS; partly lithic and stony phase

UU1- well drained, moderately deep to deep, dark red to yellowish red, friable, sandy clay loam to clay

–Rhodic and orthic FERRALSOLS; with ferralo-chromic/orthic/ferric ACRISOLS

UU3- well drained, moderately deep to deep, dark red to yellowish red, friable to firm, sandy clay to clay, often with a topsoil of loamy sand

–chromic LUVISOLS, with ferralo-chromic/orthic/ferric LUVISOLS

UUC2- well drained, moderately deep to very deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay, in many places with a topsoil of loamy sand to sandy loam

–ferralo-chromic/orthic/ferric ACRISOLS; with LUVISOLS and FERRALSOLS

UpFC- Complex of: imperfectly drained, deep black, firm, cracking, moderately calcareous clay (70%)

–pellic VERTISOLS and: well drained, shallow to deep, dark red, friable to firm, compact clay (30%)

–chromic LUVISOLS, partly lithic phase

PdUC1- Complex of: well drained, shallow, dark red to yellowish red, friable to firm, stony, loamy sand to clay

–chromic CAMBISOLS, paralithic and stony phase; with ferralic ARENOSOLS, lithic phase

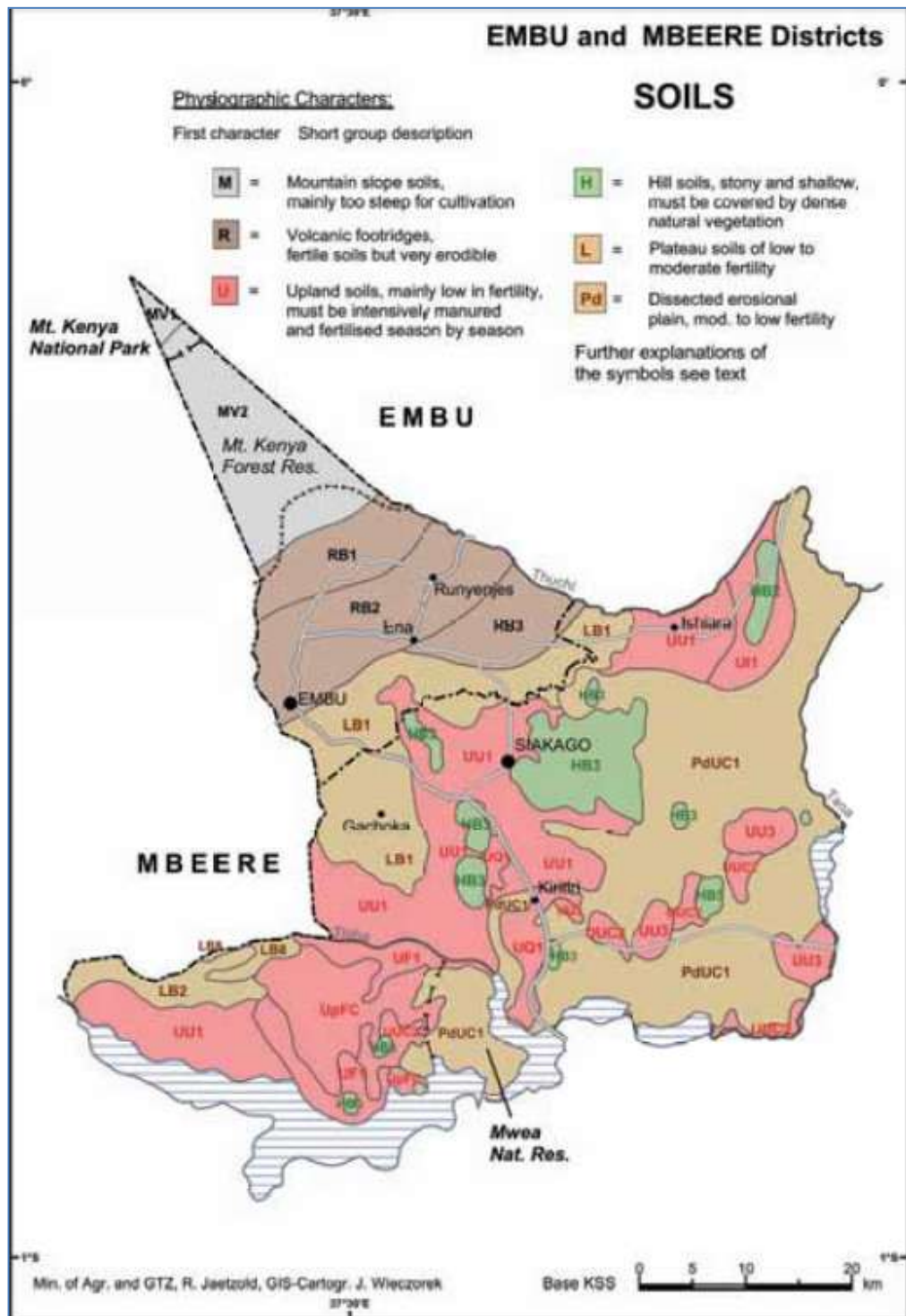


Figure 3.2 Distribution of soil in Embu and Mbeere District (Jaetzold 2006)

3.1.5 Agro-Ecological Zones (AEZ)

Agro-ecological zoning (AEZ), according to studies conducted by FAO: It was an attempt to define zones based on a combination of climatic, landform and also soil characteristics. During the definition process, a lot of emphasis was put on the climatic and edaphic requirements or needs of crops including the management system adopted for the crop. The constraints in each zone were similar, including the potential for the land use in the selected or defined zones. They played an important role during the decision making process on management strategies to be adopted for that particular zone i.e. improvement of the existing land use practices by reduction of land degradation activities or increment (Anonymous n.d).

Anonymous (n.d) further stated that AEZ, could be referred to as a set of the main applications, that guide the evaluation of land suitability and potential productivity. Figure 3.3 shows the agro-ecological zones in Embu and Mbeere district.

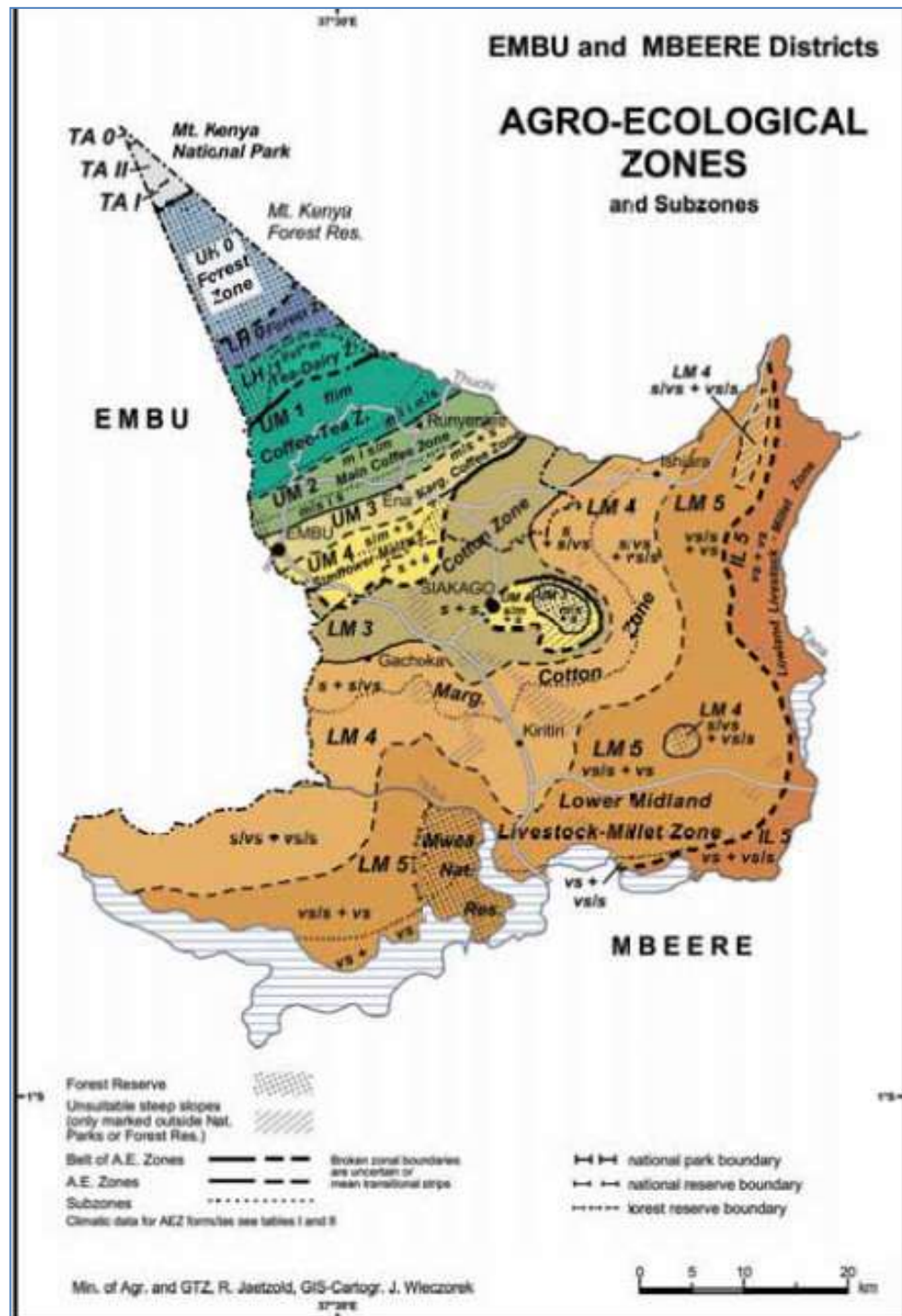


Figure 3.3 Agro-ecological zones in Embu and Mbeere district

Agro-ecological zones and subzones

Explanation of the AEZ zones in Embu district (Jaetzold 2006).

TA -TROPICAL ALPINE ZONES

TA 0 -Rocks and Glaciers (No land use, National Park)

TA (I + II)-Tropical-Alpine Moor- and Heathlands. The presence of the national park has limited the grazing potential

UH - UPPER HIGHLAND ZONES

UH 0 - Forest Zone

This zone is very wet, steep, and extremely important as a catchment area, therefore not cleared. Bamboo thickets, forest Reserve.

LH = LOWER HIGHLAND ZONES

LH 0 - Forest Zone. The same as UH 0 but many valuable timbers. Forest Reserve

LH 1 - Tea-Dairy Zone

UM = UPPER MIDLAND ZONES

UM 1 = Coffee-Tea Zone

Very good yield potential

1st rainy season, start norm. mid March: Cabbages, kales, leek, lettuce, carrots

2nd rainy season, start norm. mid Oct: same vegetables

Whole year, best planting time mid March: Passion fruit

UM 2- Main Coffee Zone

This zone has a medium cropping season and intermediate rains.

Very good yield potential is achieved during

1st rainy season, start norm, mid March: sunflower like hybrid S 301 A, some vegetables

2nd rainy season, start norm. mid Oct.: M. mat. beans (Sep. / Oct. -Jan. /Feb.)

The best planting time is mid March

UM 3 - Marginal Coffee Zone

UM 4 - Maize-Sunflower Zone

UM 4 with a short to medium and a short cropping season

Good yield potential

1st rainy season, start norm. end of March: E. mat. maize like DH 1-5, DH 8, e. mat. sorghum like Seredo, foxtail millet 1 Se 285; m. mat. beans Canad. wonder, e. mat. like Rosecoco etc.

2nd Rainy season start during mid October, maize like DH 1-5, and sunflower like Issanka are grown. Whole year, best planting time end of Oct.: Sisal, pineapples

LM = LOWER MIDLAND ZONES

LM 3 = Cotton Zone

LM 4 = Marginal Cotton Zone

LM5-Lower midland livestock millet zone

IL-INNER LOWLAND ZONES,

IL5-Innner lowland livestock millet zone

3.1.6 Crops Studied in Embu District

3.1.6.1 Maize

The production of maize in developing countries is estimated at approximately 100 million hectares, 70% of the total maize production in these developing countries has shown a trend which suggests that it comes from low and lower middle income countries (Anonymous 2010c). Demand for maize in developing countries has been projected to double by the year 2050 and also it's expected to have the greatest production globally, however, in the developing countries highest maize productions are expected by the year 2025 (Rosengrant *et al.* 2008). In Kenya, maize production is considered an extremely important activity mainly because it's a dominant food crop (staple food), which is wholly produced under rainfed conditions, about 1.4 million hectares is under maize (Wokabi 2001, Karanja 2006). Hence, there is an urgent need to not only understand but to quantify the potential impacts of future climatic change on

maize production. It is grown in different types of soils namely Andosols, Vertisols, Phaeozems, Cambisols, Luvisols, Nitisols, Acrisols and Ferralsols (Wokabi 2001)

It's important to note that different varieties of maize are grown in different parts of the country. Hybrids are commonly grown in medium elevations of approximately 1500 m, for example the Katumani hybrid is grown in Embu district (Karanja 2006).

3.1.6.2 Beans

Beans have proved to be a major source of protein in Kenya. They are also arguably one of the most important sources of income for small scale farmers in Africa (Karanja 2006). Traditionally, Kenya is considered both a major producer and consumer of the beans crop, it was on this basis of importance that this crop was selected for study. There is room to improve on the current production of this crop by managing the challenges and constraints that face the production of beans crops. In 1993, a major reduction in the beans yield levels was observed. Later in 1994 close to 70% of small scale farmers stopped the growing of bush beans during the long rains period (March to August). This decision worsened the situation to crisis levels (Karanja 2006).

A research study initiated to investigate the root cause of the crisis in bean production revealed a number of issues: decreased soil fertility, increased root rot infections and infestation of crops by bean stem maggots. Various recommendations and solutions were suggested by the scientific study, these included the use of green manure to prevent root rot, introduction of the climbing and resistant bush beans species. Additionally, by the year 1996 all farmers who had received testing seeds were encouraged to grow at least 3 varieties. The results of these concerted efforts were seen in the year 1999 where an estimated economic benefit of US\$5.4 million was achieved from the new beans varieties (Karanja 2006).

3.1.6.3 Sunflower

A study in Ghana comparing several leguminous species in biomass transfer systems revealed the high biomass transfer rate of the wild sunflower (*Tithonia diversifolia*) plant (Partey *et al.* 2011). Hence, sunflower can play a very important role in the management of soil nutrients in Embu district, especially, in regions where the soils nutrients have been exhausted due to poor farming practices. Wild Sunflower (*Tithonia diversifolia*) tends to have high concentration of important soil nutrients; Nitrogen (N), Phosphorus(P), Potassium (K) (Partey *et al.* 2011). This important characteristic of sunflower and its role in soil management practices guided the selection of the crop for this study.

Sunflower is considered as a very high value cash crop in Kenya, despite the fact that there is very limited knowledge about its farming among small scale farmers (Wangui 2012). Apart from it being a major oil crop, it's also considered as one of the main source of high quality edible vegetable oil in Kenya (Wangui 2012). On the contrary, the production of sunflower has been plummeting. This was attributed to lack of markets and market information, poor crop management practices and use of non-certified seeds (Wangui 2012). Wild sunflower (*Tithonia diversifolia*) could be grown by small scale farmers as part of the climate change adaptation strategies.

3.2 Methodology

In this study, steps used by Doria *et al.* (2006), Karanja (2006) and Adimo *et al.* (2010) were adopted. Slight modifications and adjustments were made to their methodological approach. In an attempt to capture the potential impacts of climate change on crop water requirements the following steps were adopted.

- I. Definition of the study area was done. This outlined the spatial and temporal scale of the research area.

- II. Acquisition of information about the area was done through reviews of previous literature about Embu district. This was to help capture the key issues affecting the residents.
- III. It was hypothesized that future climate change will affect crop water requirements of maize, beans and sunflower. Hence, this would impact small-scale farmers in Embu District.
- IV. Projected future climate scenarios
 - Results from Statistically Downscaled GCM models from Climate Information Portal (CIP) were used.
 - The data results (maximum, minimum and precipitation from the different GCM models were then validated, in order to determine whether the climate projections for Embu District were realistic, and if they could be used as input data for the CROPWAT 8 model.
- V. Assessing the potential impact of future climate change. The CROPWAT model was used to determine the potential impacts of climate change on crop water requirement by running the results of the future climate parameters obtained from CIP into the CROPWAT model. The soil type and characteristic for Embu District was determined from previous studies (Jaetzold 2006), then used in the CROPWAT 8 model for the three crops as of maize, beans and sunflower to determine the future CWR and IWR.
- VI. IRSIS was used to simulate deficit irrigation scheduling and also determine the yield responses of maize, beans, and sunflower to deficit irrigation for the year 1971-2000, 2046-2065, 2081-2100. Specific deficit irrigation percentages (treatments) were selected; 75%, 50%, 25% and the results compared to the full irrigation scenarios in order to determine effects of deficit irrigation on yield output with the aim of increasing conserving water.

3.2.1 CROPWAT Model 8.0

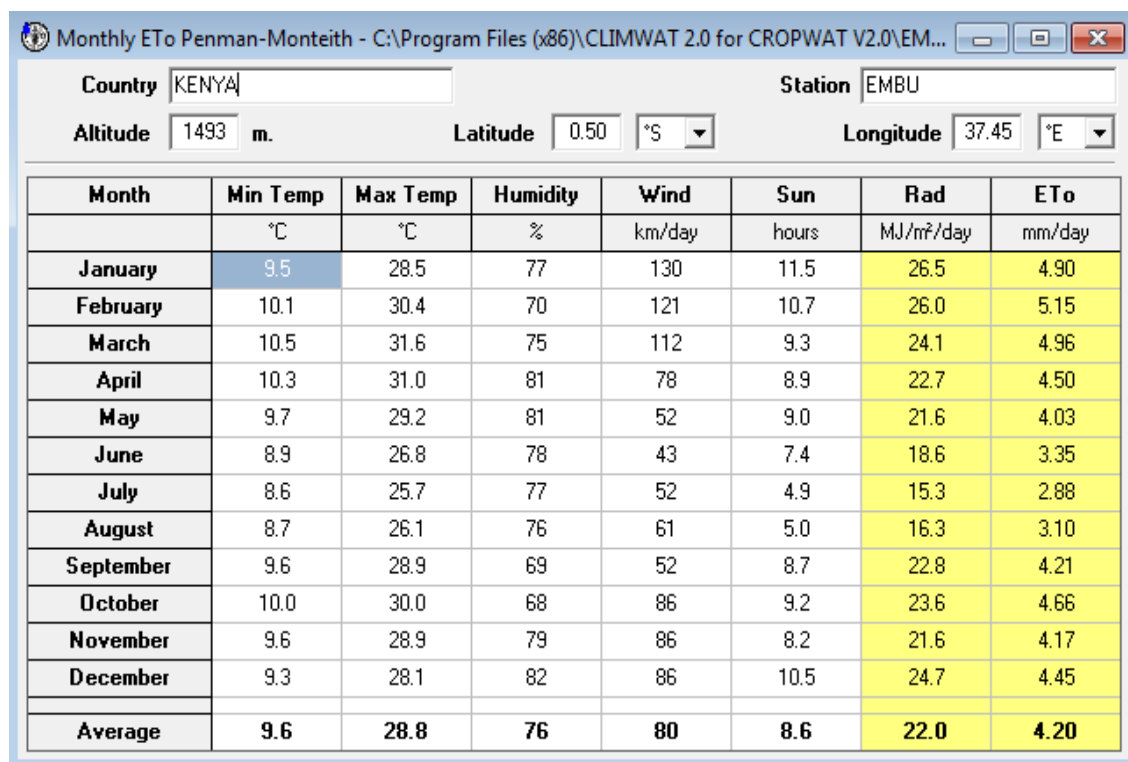
The CROPWAT model is a decision tool developed by FAO Land and Water Management Division (Anonymous 1992). Furthermore, CROPWAT 8.0 for Windows is a computer program designed to calculate CWR and IWR based on soil, climate and crop data (Figure 3.4). Additionally, the program does allow for the development of irrigation schedules for different management conditions and the calculation of scheme water supply for different crop patterns. Crop performance under rainfed and irrigated conditions can be estimated using CROPWAT 8. In addition, it can be used to evaluate farmers' irrigation practices (Anonymous 2009c). All calculation procedures used in CROPWAT 8 are based on the two FAO publications of the Irrigation and Drainage Series, namely, No. 56 "Crop Evapotranspiration-Guidelines for computing crop water requirements" and No. 33 titled "Yield response to water" (Anonymous 2009c). The main datasets used as inputs in the CROPWAT model in this study include; climatic, crop, soil and irrigation data. The climatic, crop, soil and Irrigation data are obtained from FAO CLIMWAT database and CIP.

FAO CROPWAT 8 uses a simple water balance model for the simulation of crop water stress conditions and the estimation of yield reductions using tested methodologies for the calculation of crop evapotranspiration and the responses of yield to water (Anonymous 1998, Doria *et al.* 2006). This study did not include the calculation of irrigation schedules. The CWR and IWR in this study were determined using an algorithmic equations based on estimation of potential evapotranspiration (ET_p) calculated using the Penman-Montieth equation, and crop parameters (Doria *et al.* 2006).

A 20-year period of climatological data of air temperature, solar radiation, humidity and wind speed were obtained from the FAO CLIMWAT website and used as input data in the CROPWAT 8.0 software. CROPWAT 8.0 also requires the altitude above sea level (m) and latitude (degrees north or south) of the selected site (Embu district) (Doria *et al.* 2006). In order to make adjustments to local weather parameters unique to the sites selected, altitude and latitude records are taken into account, thus, adjustments to local

average value of atmospheric pressure are possible. The data for the altitude and latitude for Embu district were obtained from the climate information portal (CIP) (Anonymous 2011).

Future climate scenarios for two time periods were selected; 2040s (2046-2065) and 2080s (2081-2100). Availability of simulated data for these two time periods guided the selection of the time periods. Limited access to simulated future regional climate data for impact assessment may affect future climate change adaptation strategies at the regional and national levels (Anonymous 2007b, Giorgi *et al.* 2009). Monthly means of maximum temperature, minimum temperature and precipitation from the 2040s and 2080s were used as input for CROPWAT 8 model and CWR determined (Doria *et al.* 2006). There were assumptions made in this study based on a similar study by Doria *et al.* (2006) i.e. sunshine duration, wind speed and relative humidity were assumed to be the same as the base line climate data (1979-2000).



Monthly ETo Penman-Monteith - C:\Program Files (x86)\CLIMWAT 2.0 for CROPWAT V2.0\EM...

Country: KENYA Station: EMBU

Altitude: 1493 m. Latitude: 0.50 °S Longitude: 37.45 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	9.5	28.5	77	130	11.5	26.5	4.90
February	10.1	30.4	70	121	10.7	26.0	5.15
March	10.5	31.6	75	112	9.3	24.1	4.96
April	10.3	31.0	81	78	8.9	22.7	4.50
May	9.7	29.2	81	52	9.0	21.6	4.03
June	8.9	26.8	78	43	7.4	18.6	3.35
July	8.6	25.7	77	52	4.9	15.3	2.88
August	8.7	26.1	76	61	5.0	16.3	3.10
September	9.6	28.9	69	52	8.7	22.8	4.21
October	10.0	30.0	68	86	9.2	23.6	4.66
November	9.6	28.9	79	86	8.2	21.6	4.17
December	9.3	28.1	82	86	10.5	24.7	4.45
Average	9.6	28.8	76	80	8.6	22.0	4.20

Figure 3.4 CROPWAT 8.0 windows interface and estimated ET_o.

3.2.3 Crop Water Requirement (CWR)

This can be defined as the amount of water required by a given crop to replenish or compensate for the evapotranspiration loss from the cropped field (Anonymous 1998). A clear distinction between crop evapotranspiration and CWR must be made despite the fact that these two values are identical. The difference is that CWR refers to the amount of water that needs to be supplied. On the other hand, irrigation water requirements depicts the difference between the CWR and the effective precipitation (PE) (Doria *et al.* 2006). Effective rainfall in the CROPWAT 8 model was estimated by the USDA SCS method which is calculated using the formulae below (Doria *et al.* 2006).

$$PE = P_{tot} * \frac{125 - 0.2 P_{to}}{125} \quad \text{for} \quad P_{tot} < 250 \text{ mm} \quad (\text{Eq.1})$$

$$PE = 125 + 0.1 * P_{tot} \quad \text{for} \quad P_{tot} > 250 \text{ mm} \quad (\text{Eq.2})$$

Where:

PE = Effective rainfall, mm

P_{tot} = Total rainfall, mm

The reference evapotranspiration (ET_o) formulae adopted for this study relied heavily on the guidelines of Anonymous (2006b). The formulae is illustrated below.

$$ET_{crop} = K_c \times ET_o \dots \dots \dots \text{Equation 1}$$

where

ET_{crop} = Crop Evapotranspiration.

ET_o = Reference Evapotranspiration.

K_c = Crop coefficient.

ET_{crop} illustrated in equation 1 is normally calculated from crops grown in optimal management and environmental conditions (Anonymous 2006b, Karanja 2006). However, the crops in this study were not grown under optimal management and environmental conditions, hence, the need to use a water stress coefficient factor (K_s) to adjust the ET_c as illustrated in equation 2.

$$ET_a = K_s \times ET_{crop} \dots \dots \dots \text{Equation 2}$$

where

ET_a = Actual Crop Evapotranspiration.

K_s = Water Stress Coefficient.

The CROPWAT model was used to calculate the ET_o , ET_c , CWR, PE and IWR for the three crops selected for this Study (maize, beans, sunflower). The crop parameters; Water Stress Coefficient (K_s), Crop coefficient (K_c), yield response factor (K_y), and Critical depletion level were obtained from FAO irrigation and drainage paper 56. Length of growing season (Anonymous 2010c). Climatic data from three time periods 1979-2000, 2045-2065, 2081-2100 were input into the CROPWAT model. The results from the CROPWAT model for the time series 2040s and 2080s, Statistical Downscaled Models (SDSM), were then compared to the end results of base line climate 1979-2000.

3.2.4 Regional Downscaling

Global Climate Models (GCMs) provide future climate projections on rather coarse scales of 1000 km by 1000 km representing large scales of very different landscape characteristics, flood potential, vulnerability to floods or any other extreme event (Anonymous n.d). Regional Climate Models (RCM) offer a solution to this challenge if run on GCMs and applied to specific regions. It can be argued that RCMs enable detailed impact and adaptation assessment and planning which is mandatory for vulnerable regions. Even though GCMs provide projections of future climate behavior (change), impacts of changing climate, and adaptation strategies necessary to mitigate these potential adverse effects will be felt more at regional or national levels (Anonymous n.d, Anonymous 2007b Giorgi *et al.* 2009,).

3.2.5 Statistical Downscaled Model (SDSM)

Monthly mean average normal data of a 20-year period for Embu district weather station was retrieved from the FAO CLIMWAT, CIP and were used as the baseline data. The time period for the baseline data used was (1979-2000). Only weather stations

with a minimum of 15-year period weather station data for Embu district were used to compile the historical observed data for Embu district (Anonymous 2003, Anonymous 2011). The data were used for simulation using the statistical Downscaling technique. It is beyond the scope of this research to statistically downscale this climatic historical data, hence, this paper focused on using the already statistically downscaled model data results of five GCM models from CIP whose main objective is to provide regional downscaled SDSM model data for researchers for the purposes of climate change impact analysis and formulation of adaptation strategies at regional levels (Anonymous 2011). The five SDSM-GCM models selected for this study included GFDL CM 2.1, GFDL CM 2.0, IPSL CM4, CCCMA CGCM 3.1, MPI ECHAM 5. Only models with the complete climatic data for maximum temperature, minimum temperature and rainfall for the future time periods of 2046-2065 and 2081-2100 were selected. Those five models have been named above. The projected three climatic data parameters mentioned above were used as input into the CROPWAT 8 model.

3.3 GCM Models Used

In this section, the models used will be discussed briefly. This study will not cover the technical aspects of these models.

3.3.1 MPI-ECHAM 5

The model was developed by the Max Planck Institute for Meteorology (MPI-M) and used as a prototype for the IPCC fourth assessment report (AR4) simulations (Anonymous 2007 b, Jungclaus *et al.* 2006). In a research study done by Jungclaus *et al.* (2006), they showed that the simulation of the critical climate variables like sea surface temperature (SST) and sea-ice were stable and realistic using this model. Additionally, they showed global-scale heat and freshwater transports agreeing with observed data and reduced flux adjustments as a result of improved compatibility of the atmospheric and ocean heat budgets.

3.3.2 GFDL CM 2 (Geophysical Fluid Dynamics Laboratory Coupled Model, 2.X).

This is a type of a coupled atmosphere-ocean general circulation model (AOGCM) developed by the Geophysical Fluid Dynamics laboratory of NOAA from the United States of America and was used for simulation purposes in the IPCC AR4 report (Delworth *et al.* 2006, Randall *et al.* 2007). Delworth *et al.* (2006) stated that, "the models were designed to simulate atmospheric and oceanic climate and variability from diurnal time scale through multi-century climate change". This was mainly attributed to challenges in computational limitations. There are two versions of the models used in this study namely, CM 2.0 and CM.2.1. The main difference between the two models are on a fundamental principle i.e. the atmospheric component uses a different dynamical core approach, tuning of the clouds and certain details of the ocean and land components were also used differently. It's important to note that both models did not use flux adjustments (Delworth *et al.*, 2006). They demonstrated that the two models (control simulation) had stable and realistic climate when integrated over multiple centuries. In particular, El-Niño Southern Oscillation (ENSO) simulation showed remarkable improvement compared to the previous GFDL model (Delworth *et al.* 2006).

It's important to note that CM 2.0 model was evaluated as an ENSO forecast model with relatively good skill as opposed to CM 2.1, however the latter has reduced temperature and salinity biases compared to the former mainly due to improved simulations of surface wind stress in CM 2.1 (Delworth *et al.* 2006). Both models were adopted for purposes of simulation in the IPCC AR4 report and demonstrated ability to simulate main feature of the observed warming in the 20th century (Delworth *et al.* 2006, Randall *et al.* 2007). That study conducted by Delworth *et al.* (2006) showed that CM 2.0 and CM 2.1 had a climate sensitivity of 2.9 and 3.4 K, respectively.

3.3.3 CCCMA CGCM 3.1 (Canadian Center for Climate Modeling and Analysis Coupled Global Circulation Models)

This model was also used in the IPCC AR4 and demonstrated ability to simulate current and future climate projects, it had an equilibrium climate sensitivity of 3.4°C (Flato 2005, Randel *et al.* 2007). Randel *et al.* (2007) explained in his study that, "Equilibrium climate sensitivity is defined as the global mean temperature response of an atmospheric climate model run with a simple (slab) ocean to a doubling of CO_2 ". The study further stated that, "it was a measure of the climate system annual mean temperature change in response to a doubling of CO_2 after it has attained equilibrium". The difference in the range of climate projections by the AOGCMs are as a result of difference in climate model sensitivity. A study conducted by Meehl (2007) estimated that the most probable climate sensitivity value was around 3.0°C .

3.3.4 IPSL CM4 (Institut Pierre Simon Laplace)

Climate as we know it, is mostly a product of complex interaction between many different subsystems (Marti *et al.* 2010). IPSL CM4 being one of the several GCM models used in the IPCC-AR4 report, it incorporates components of ocean, sea ice, land vegetation, carbon cycle, atmospheric chemistry, atmospheric aerosols and oceanic tracers (Anonymous 2007b, Randel *et al.* 2007). A study conducted by Marti *et al.* (2010) explained that IPSL CM4 model incorporated or rather coupled four aspects of the earth system namely, LMDZ for atmospheric dynamics and physics, OPA for ocean dynamics, LIM for sea ice dynamics and thermodynamics and ORCHIDEE for the land surface. LMDZ is an atmospheric general circulation model that was developed at (Laboratoire de Meteorologie Dynamique) (Marti *et al.* 2010). ORCHIDEE (Organizing and Hydrology in Dynamic Ecosystems) on the other hand is a land surface model used to simulate the water and energy cycles of vegetation and soil, the terrestrial carbon cycle and finally the composition and distribution of vegetation (Martin *et al.* 2010). The study by Martin *et al.* (2010) showed how sensitive the IPSL model was to atmospheric resolution i.e. changes in atmospheric resolution led to improved representation of storm track and the North Atlantic Oscillation. Additionally, better representation of

wind structure caused an improved northward salt transportation, the deep water formation including the Atlantic meridional overturning circulation.

It's important to point out the critical role these models mentioned above played in the preparation of the IPCC Third Assessment Report (TAR) and the fourth Assessment report (AR4) (Anonymous 2007b). Another important factor used in these models for simulation, is the greenhouse gas scenarios as was described in the IPCC Special Report on Emission Scenario (SRES). These were used in the models for purposes of future climate simulations (projections) for the time period 2040s (2046-2065) and 2080s (2081-2100) (Anonymous 2007b). In particular, the two SRES scenarios used included, A2 and B1 (Anonymous 2007b).

In order to determine the CWR, ETo, and IWR for maize, beans and sunflower using CROPWAT 8.0 model, results of the five selected downscaled GCM models for 2040s and 2080s were run separately in the CROPWAT model. The CROPWAT input data was based on the type of crop, the time period from the SDSM- GCM models e.g. 2046-2065, the climate parameter (minimum temperature, maximum temperature and precipitation), the emission scenario e.g. A2 (Figure 3.5).

Monthly ETo Penman-Monteith - C:\Program Files (x86)\CLIMWAT 2.0 for CROPWAT V2.0\EM...							
Country	KENYA			Station	EMBUA22046GFDL2.0		
Altitude	1493	m.	Latitude	0.50	°S	Longitude	37.45 °E
Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m ² /day	mm/month
January	15.9	26.6	77	130	11.5	26.5	151.18
February	16.1	26.9	70	121	10.7	26.1	139.44
March	16.6	27.3	75	112	9.3	24.1	144.97
April	17.5	27.2	81	78	8.9	22.8	130.21
May	17.6	26.5	81	52	9.0	21.6	125.04
June	16.7	25.8	78	43	7.4	18.6	103.70
July	16.3	25.5	77	52	4.9	15.4	93.08
August	16.2	25.5	76	61	5.0	16.3	99.28
September	16.7	27.1	69	52	8.7	22.8	128.85
October	16.9	27.7	68	86	9.2	23.6	144.34
November	16.3	26.4	79	86	8.2	21.6	123.50
December	16.1	26.3	82	86	10.5	24.6	138.63
Average	16.6	26.6	76	80	8.6	22.0	1522.24

Figure 3.5 ET_o for SDSM-GFDL 2.0 in 2046-2065 for A2 scenario in CROPWAT 8.0 model.

After determination of the CWR, ET_o, IWR for maize, beans, sunflower for 2040s and 2080s, a comparison was made to the baseline climate 1979-2000 (CWR, ET_o, IWR) to quantify the impact of potential climate change and identify a trend.

3.4 A2 Scenario

The A2 storyline and scenario family as described by IPCC (2000) represents a very composite world. The fundamental idea is sustentation and autonomy of regional identities. Global population progressively increases as a result of gradual convergence of fertility patterns across regions. Furthermore, economic expansion is fundamentally regionally oriented and per capita economic growth including changes in technological advancement are observed to be more disintegrated and slower in comparison to other storylines (Anonymous 2000).

3.5 B1 Scenario

On the other hand, the B1 storyline and scenario family represents a more convergent world with the same global population ultimately peaking in the mid-century only to decline later, similar to the A1 storyline, except for the rapid changes in economic structures toward a service and information economy, with substantial decrease in material dependency, and the introduction of environmental friendly and resource-efficient technologies (Anonymous 2000). Remember that," The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives" (Anonymous 2000).

3.6 Validation GCM Data

In an attempt to describe GCM data validation process, Anonymous (2010d) stated:

"One of the criteria commonly used in selecting a GCM to be used in constructing regional climate scenarios for impact assessment is the performance of the GCM in simulating the present-day climate in the region. This is evaluated by comparing the model outputs with observed climate in the target region, and also over larger scales, to determine the ability of the model to simulate large scale circulation patterns".

3.6.1 Validation of Embu GCM Data

Maximum Temperature (°C)

The Embu mean monthly maximum temperature was validated by comparing the simulated 20th century data (1979-2000) generated by the five Downscaled GCM models listed below (Figure 3.6) to the mean monthly observed data for the same time period (1979-2000). The line graph showed very close relation between the simulated data and the observed data for Embu district. Hence the projected maximum

temperature data results for 2045-2065 and 2081-2100 were used as input data for CROPWAT 8.0 model.

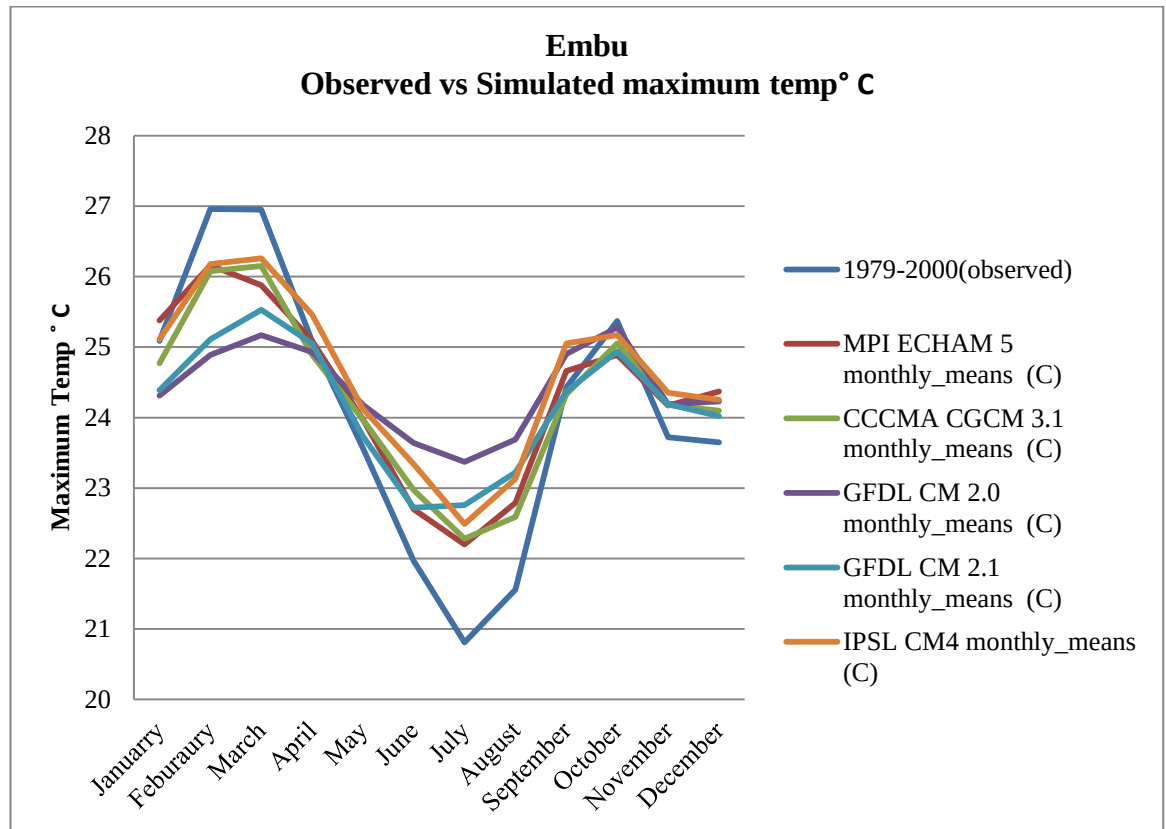


Figure 3.6 SDSM-GCM simulated mean monthly max temp °C for 1979-2000 compared to observed mean monthly max temp °C for Embu district

Minimum Temperature °C

The same validation procedure for maximum temperature mentioned above was followed for the mean monthly minimum temperature where the validation procedure entailed comparing the simulated 20th century data (1979-2000) generated by the five Downscaled GCM models mentioned previously (Figure 3.7) to the mean monthly observed data for (1979-2000). The line graph showed very close relation between the simulated data and the observed data for Embu district. Hence the projected minimum temperature data results for 2045-2065 and 2081-2100 were used as input data for CROPWAT 8.0 model.

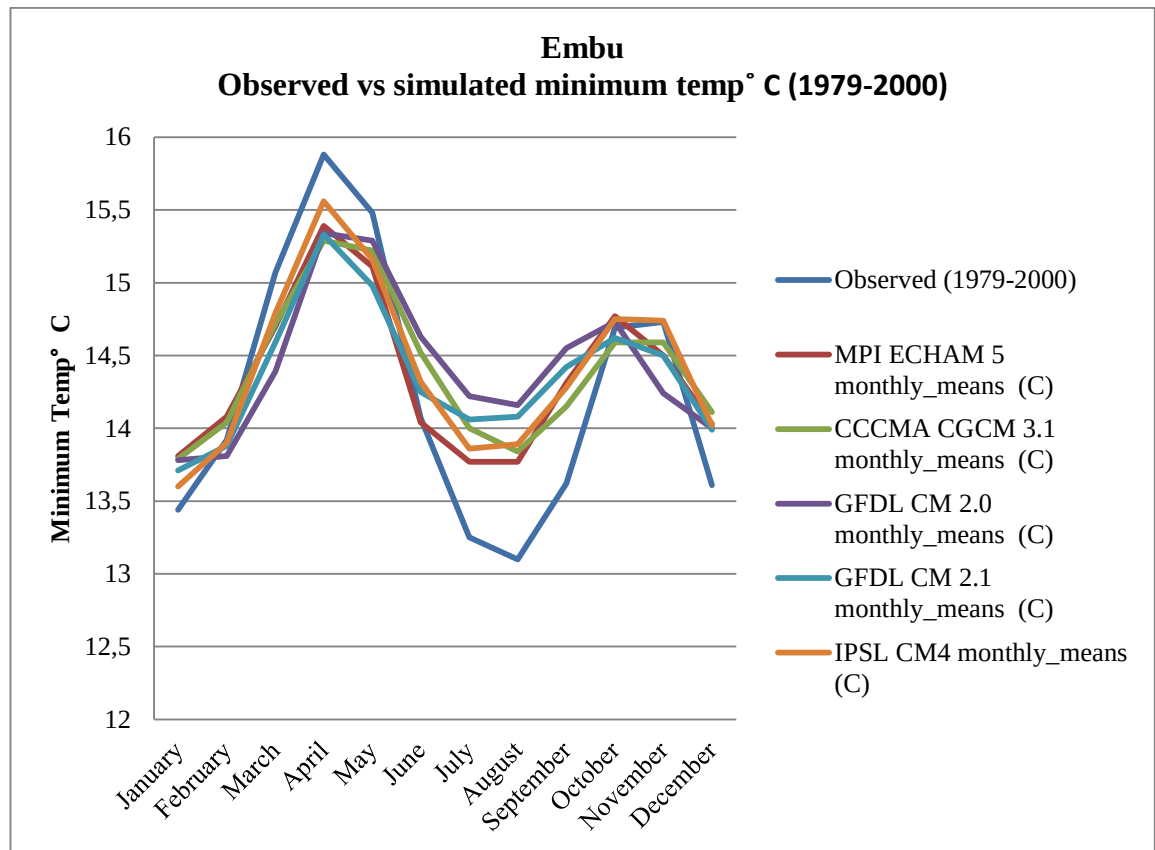


Figure 3.7 SDSM-GCM simulated vs. observed mean monthly min temp °C for 1979-2000 for Embu district

3.7 IRSIS (Irrigation Scheduling Information System)

IRSIIS was developed to offer support to scheme managers, irrigation advisers, consulting engineers, lecturers and students with the aim of solving problems related to irrigations scheduling at field level. For a given climate, crop and field (Raes *et al.* 1988). Despite having the CROPWAT model which is also used for irrigation scheduling, IRSIS was specifically used for the simulation of crop yield response under limited water supply conditions (deficit irrigation). After a comparison between the maize yield reduction results of CROPWAT model and IRSIS model under a 75%, 50%, and 25% deficit irrigation conditions, it was discovered that CROPWAT model in particular underestimated the % yield reduction values under the previously mentioned deficit irrigation conditions hence IRSIS was used to simulate the % yield reduction of maize, beans and sunflower under deficit irrigation conditions.

The objective of regulated deficit irrigation is to save on water consumption through subjection of crops to periods of moisture stress with minimal effects on yields. The stress would then lead to less evapotranspiration by closure of the stomata, reduced assimilation of carbon, and decreased biomass production. It's important to note that the reduced biomass production has very little impact on the final yield output, as the crop is able to compensate in terms of reproductive capacity (Smith and Kivumbi 2002).

3.7.1 Modeling Percentage Yield Reduction Under Deficit Irrigation

IRSIS software was used to simulate the yield response of maize, beans, and sunflower to deficit irrigation applied at 75%, 50%, and 25% of the net irrigation water requirement. The objective of applying the deficit irrigation concept was to determine the impact of deficit irrigation on yield output of the three selected crops for the previously mentioned observed and future time periods. Therefore, IRSIS was used to simulate the % yield of maize, beans, and sunflower at full irrigation i.e. based on full crop water requirement, later, the % yield reduction of the same crops were determined under deficit irrigation conditions of 75%, 50%, and 25% respectively. Since agriculture in Embu district is generally practiced under rainfed conditions (Oborn and Enjebo 2012), it was important to determine if there was any difference in yield response between irrigated conditions and non irrigated conditions (rainfed conditions). IRSIS was therefore used to determine yield output of the three crops under non-irrigation (rainfed) conditions.

3.7.2 Procedure

An assumption was made to use the same monthly climatic data used in the CROPWAT model. Hence the same ETo, rain, soil and field data were input into the IRSIS program to create different files for crop, maize, and sunflower for all the five models each having two scenarios (A2 and B1) for both observed data (1979-2000) and future climatic projected data (2046-2065 & 2081-2100). After the creation of all the necessary files (members), they were then run in order to determine the irrigation water requirements for all the three crops under every (previously mentioned) climatic scenario. The steps described in the user manual of IRSIS for irrigation scheduling and

modeling under limited water supplies were followed (Raes *et al.* 1988). Manual irrigation scheduling criteria (option) was selected for this study and was used in the IRSIS program. Yield output of all the three crops were then determined at full irrigation and recorded. The irrigation requirement of all the three crops were then reduced at 75%, 50%, and 25% respectively and the corresponding yield output determined i.e. % yield reduction was calculated. A comparison of the yield was then made for the three crops (maize, beans, sunflower) for all the five models , each with two scenarios (A2 and B1). This was done for the future projected climactic time periods of 2046-2065 and 2081-2100, then they were compared against the observed data for 1979-2000.

4. RESULTS AND DISCUSSIONS

4.1 Base climate vs. GCM Model for Beans 2040s (2046-2065) and 2080s (2081-2100)

Different trends were identified from SDSM downscaled data for Embu District from the Climate Information Portal (CIP) developed by the CSAG and from the CROPWAT 8.0 model simulation. The SDSM-IPSL CM4 A2 model exhibits the greatest increase in total ETo for beans (mean annual) in Embu District, for the time series of 2040s with a 6.7% (96.89 mm) (Figure 4.1) increase and 12.2% (177.1 mm) (Figure 4.2) increase in 2080s. The SDSM-CCCMA CGCM 3.1 A2 shows the highest increase of 9.6% (117 mm) in annual total precipitation for Embu district covering the growing season in 2040s (Figure 4.1), however SDSM-GFDL CM 2.0 A2 shows the highest increase in total annual prec. in 2080s of 15.29% (186 mm) (Figure 4.2). See appendix 2.

In the year 2040s and 2080s, SDSM-IPSL CM4 A2 exhibits the highest CWR for beans with an increase of 6.2% (21.7 mm) and 10.9% (38.4 mm) respectively, compared to the base climate and the other four models. Increased precipitation showed a corresponding decrease in irrigation water requirement as shown in the graphs below (Figure 4.1-4.2) i.e. SDSM-GFDL CM 2.0 A2 showed the greatest decrease of irrigation water requirement of 87.2% (25.1 mm) in 2040s, while in 2080s SDSM-GFDL CM 2.0 B1 showed the highest decrease in irrigation water requirement of 83% (23.9 mm) this could be attributed to the overall increase in the effective precipitation of 8.5% (32.9 mm) in 2040s and 16% (63.3 mm) in 2080s respectively for SDSM-GFDL CM 2.0 A2 model. SDSM-IPSL CM4 A2 exhibits the highest field water requirements (FWS) of 7.41 l/s/ha in 2040s and 7.42 l/s/ha in 2080s, respectively. See appendix 2.

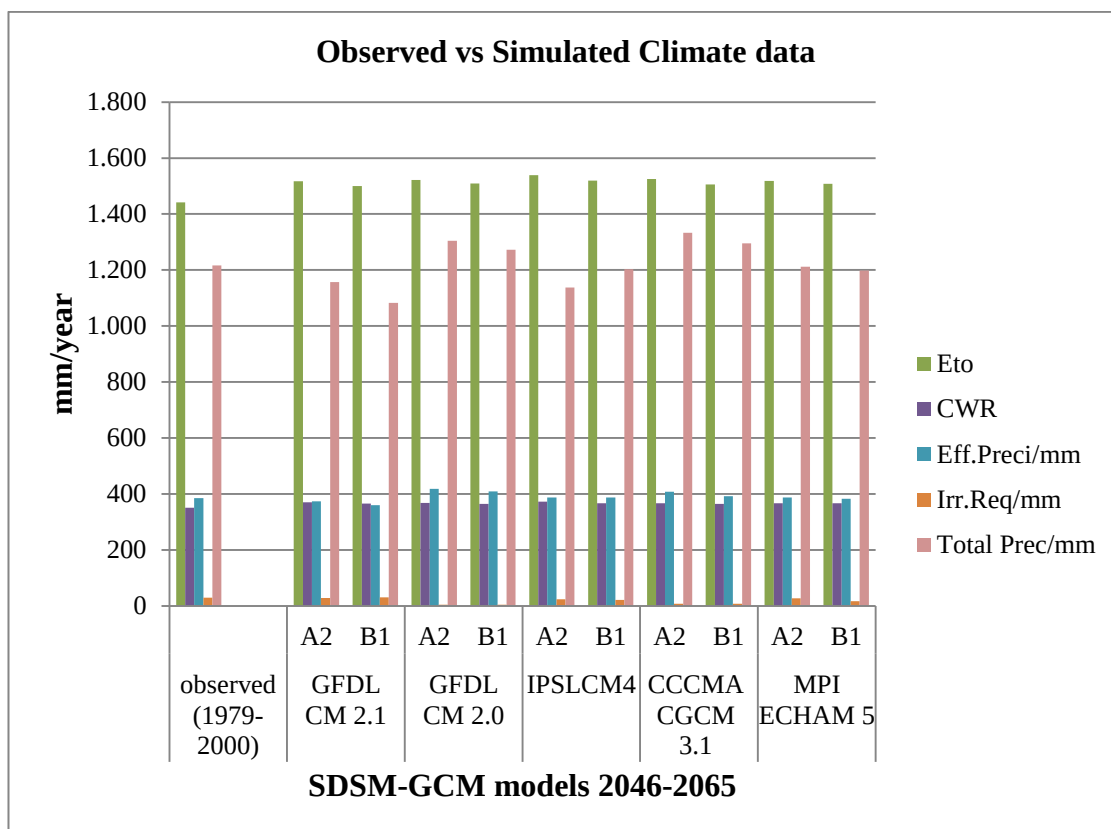


Figure 4.1 Graph showing observed vs. simulated data for beans (2046-2065)

In 2040s and 2080s there was an overall increase in ETo for all the models (Figure 4.1-4.2) compared to baseline climate (1979-2000), this can be attributed to the increasing trend of maximum and minimum temperature in 2040s and 2080s compared to 1979-2000. CWR also increased in 2040s and 2080s compared to 1979-2000 this could be as a result of the positive correlation between temperature and CWR. SRES A2 gave higher results compared to SRES B1 this might be due to higher anthropogenic activities in A2 scenario. The IPSL CM4 model gave higher results for ETo and CWR due to its high sensitivity. CCCMA CGCM 3.1 A2 simulated highest precipitation of 1,333 mm compared to the base climate hence it had the lowest irrigation water requirement due to high precipitation. The study thus revealed a negative correlation between precipitation and IWR i.e. as precipitation increased from (1979-2000) to (2046-2065) and 2081-2100. IWR showed a decreasing trend as seen in Figure 4.1 and 4.2. Beans had the lowest CWR compared to maize and sunflower due to a shorter crop cycle.

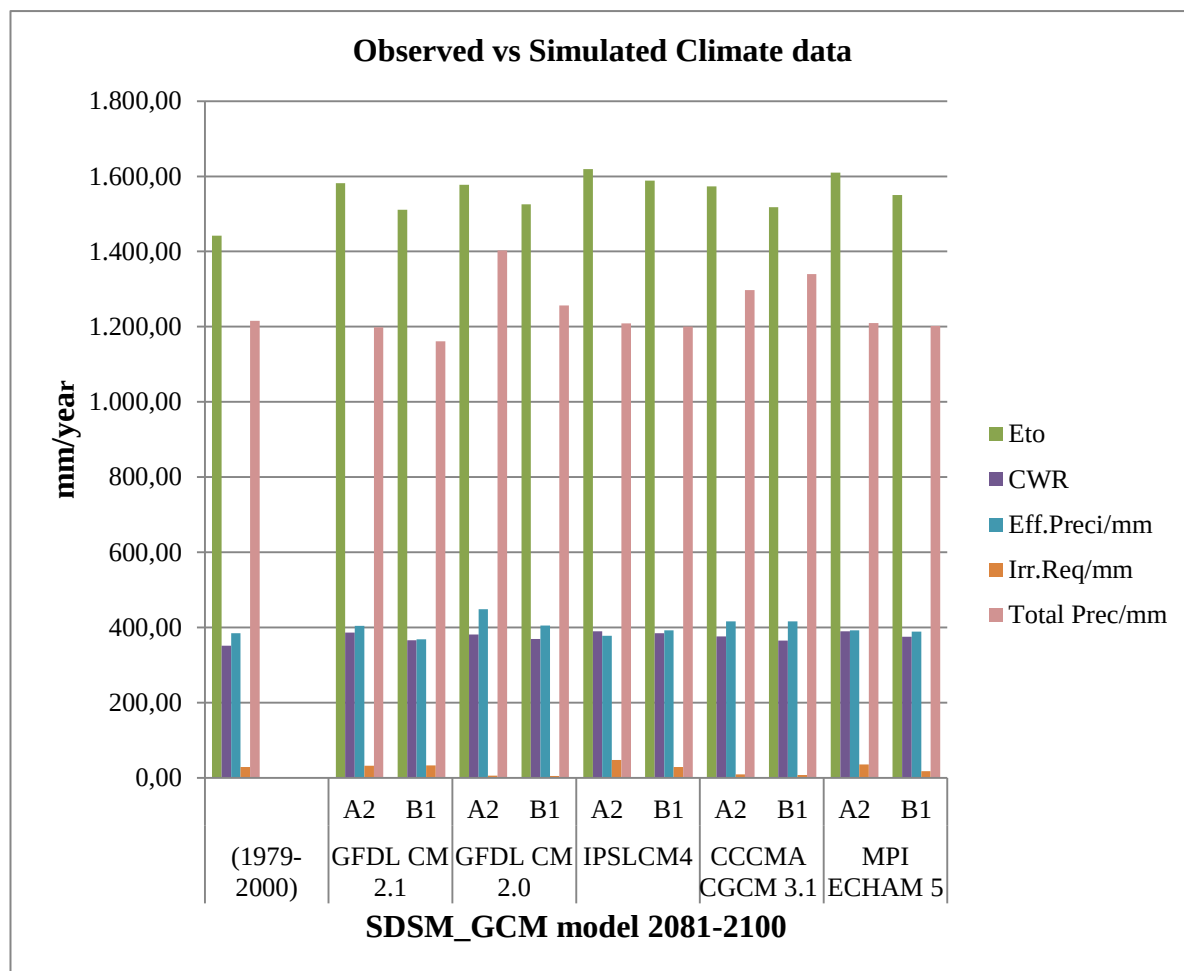


Figure 4.2 Graph showing observed vs. simulated data for beans (2081-2100)

4.2 GCM model Results Compared to Base Climate, Maize (2046-2065)

SDSM-GFDL CM 2.0 A2 exhibits the highest CWR for maize in 2040s with an increase of 7.8% (36.7 mm), but in 2080s SDSM-IPSL CM4 A2 exhibits the highest increase in CWR of 12% (60 mm) when compared to the base climate and the other four models. Increased precipitation showed a corresponding decrease in irrigation water requirement as shown in the graphs below (Figure 4.3-4.4) i.e. SDSM-GFDL CM 2.0 A2 showed the greatest decrease in irrigation water requirement of 67% (113.8 mm) in 2040s, while in 2080s SDSM-GFDL CM 2.0 A2 showed the highest decrease in irrigation water requirement of 68.7% (116.6 mm). SDSM-IPSL CM4 A2 exhibits the highest field water requirements. See appendix 1.

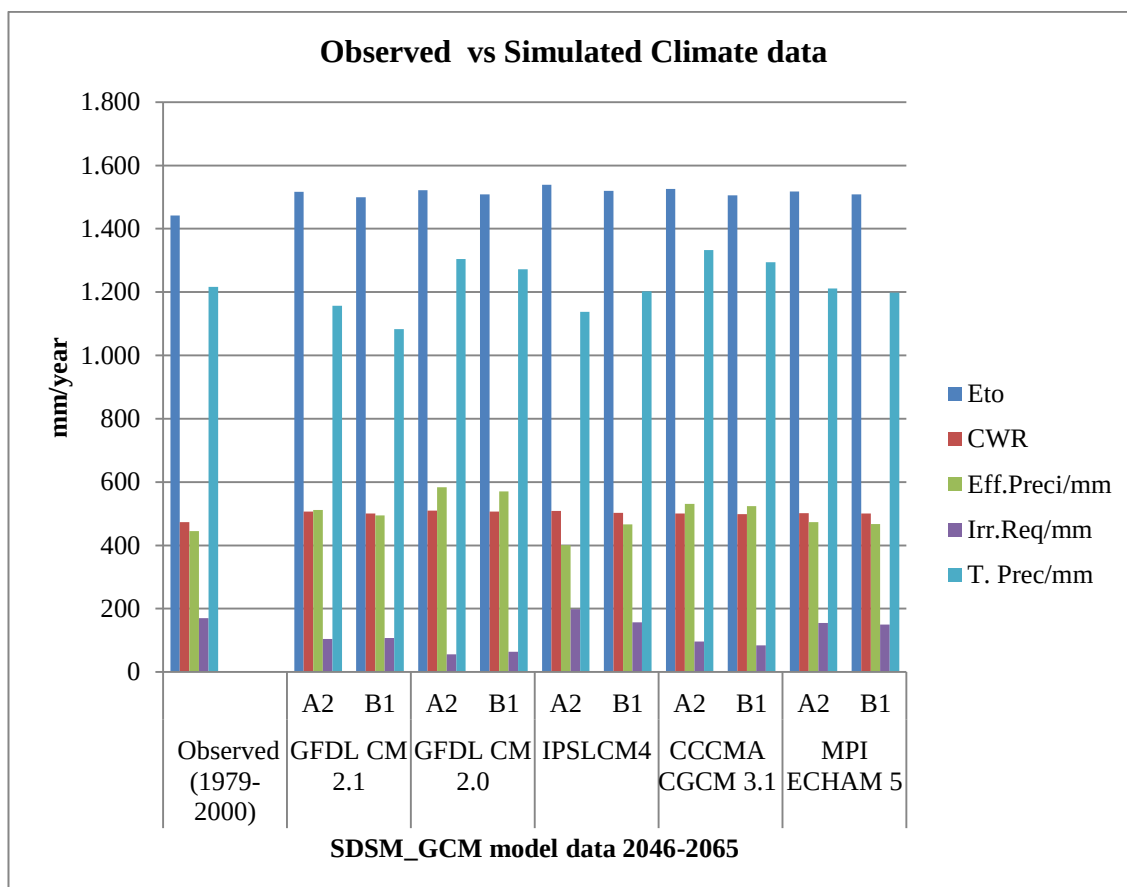


Figure 4.3 Graph showing observed vs. simulated data for maize (2046-2065)

In 2040s and 2080s there was an overall increase in ETo for all the models for maize in Embu district (Figure 4.3-4.4) compared to baseline climate (1979-2000), this can be attributed to the increasing trend of maximum and minimum temperature in 2040s and 2080s compared to 1979-2000. CWR also increased in 2040s and 2080s compared to 1979-2000 this could be as a result of the positive correlation between temperature and CWR. SRES A2 gave higher results compared to SRES B1 this might be due to higher anthropogenic activities in A2 scenario. The IPSL CM4 model gave higher results for ETo and CWR due to its high sensitivity. CCCMA CGCM 3.1 A2 simulated highest precipitation of 1,333 mm compared to the base climate hence it had the lowest irrigation water requirement due to high precipitation. The study thus revealed a negative correlation between precipitation and IWR i.e. as precipitation increased from (1979-2000) to (2046-2065) and 2081-2100. IWR showed a decreasing trend as seen in Figure 4.3 and 4.4. Maize had the highest CWR compared to beans and sunflower because of a longer crop cycle.

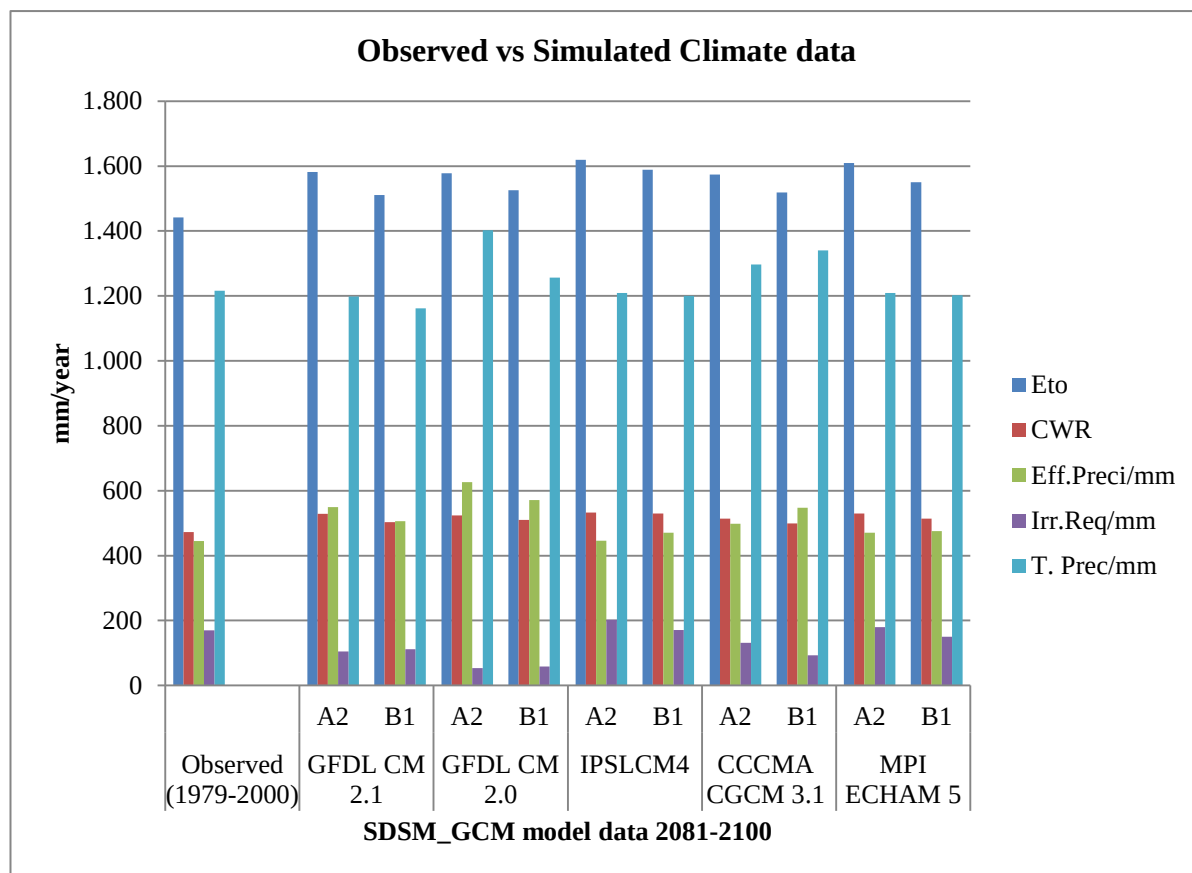


Figure 4.4 Graph showing observed vs. simulated data for maize 2081-2100

4.3 GCM Model Results Compared to Base Climate Sunflower 2046-2065

Results, for the sunflower crop, when data was input into the CROPWAT 8.0 model, showed that SDSM-IPSL CM4 A2 had the highest CWR for both 2040s and 2080s time series with an increase of 7.4% (25.6 mm) and 12% (41.6 mm) respectively when compared to the base climate data and the other four models. Increased precipitation showed a corresponding decrease in irrigation water requirement as shown in Figure 4.5-4.6. The SDSM-GFDL CM 2.0 A2 had the least irrigation water requirement in 2040s exhibiting a decrease of 75.4% (79.3 mm). In 2080s SDSM-GFDL CM 2.0 B1 showed the least irrigation water requirement, a decrease of 76.8% (80.8 mm). See appendix 3.

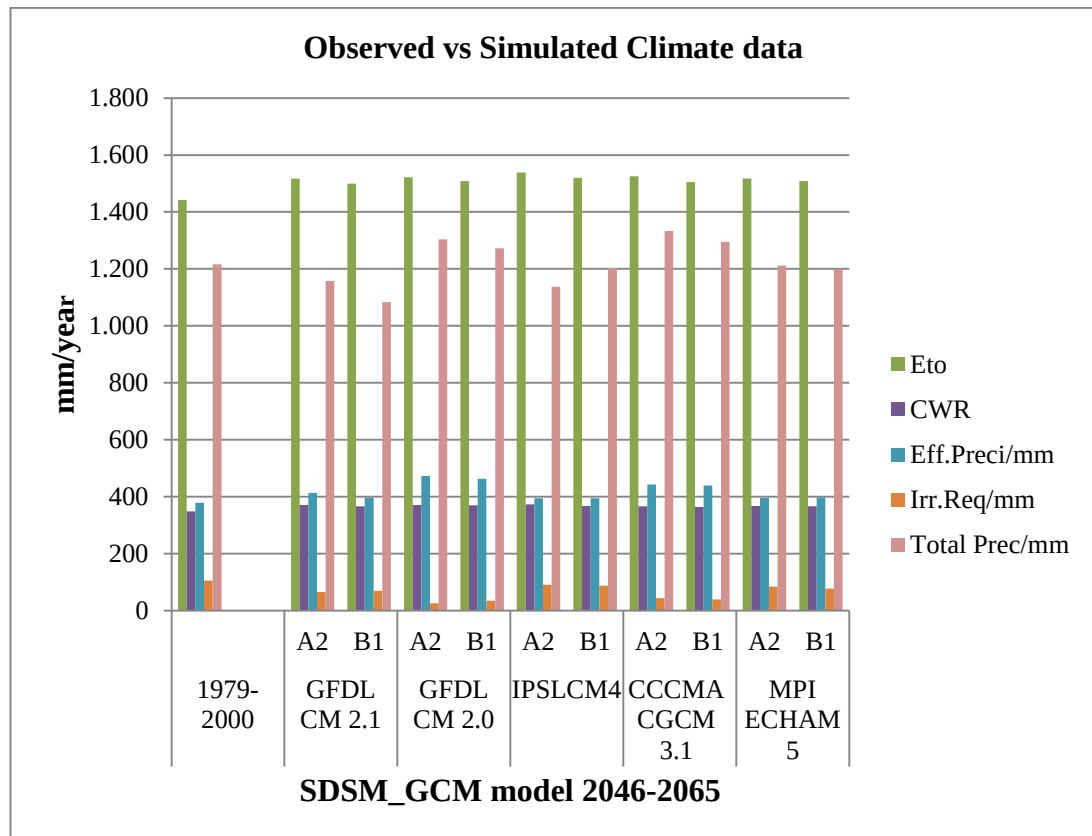


Figure 4.5 Graph showing observed vs. simulated data for sunflower 2046-2065

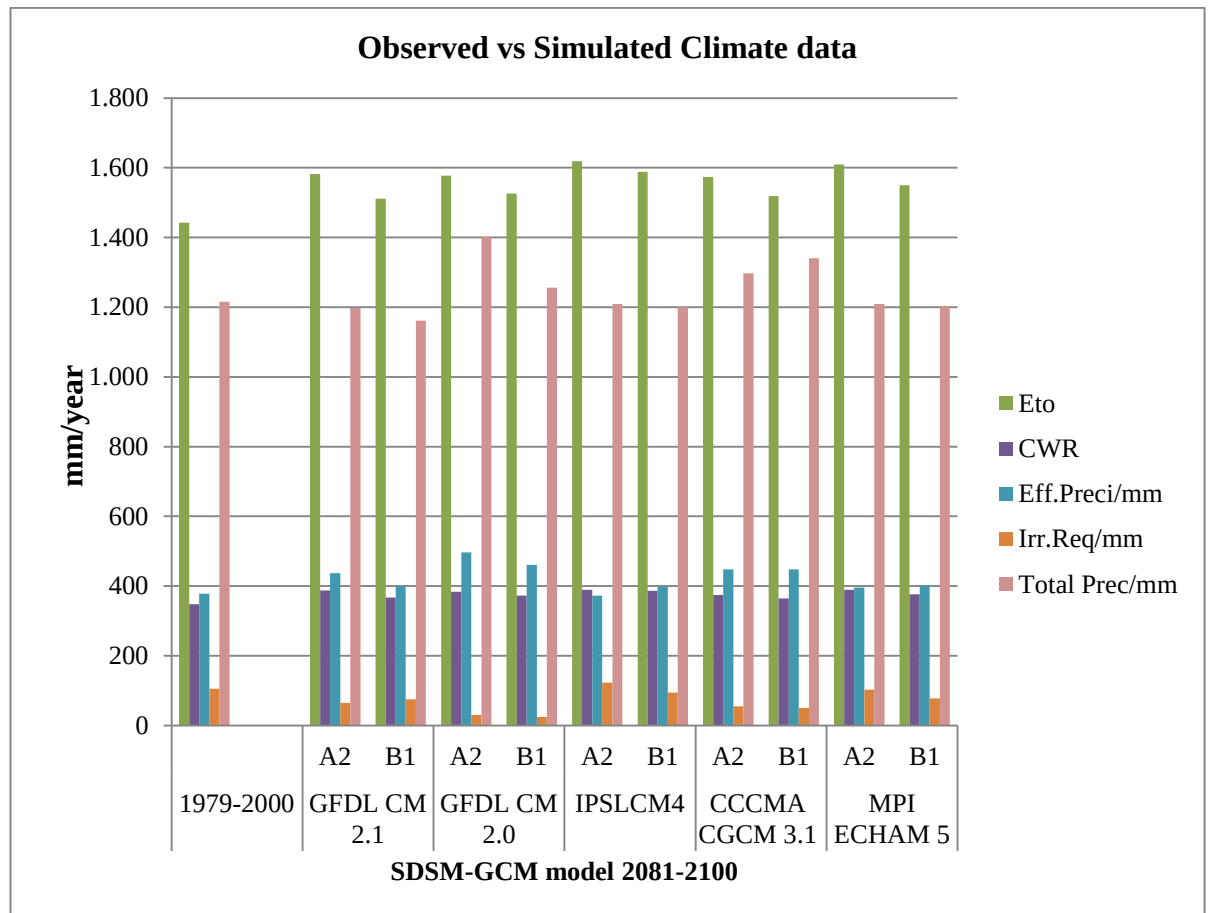


Figure 4.6 Graph showing observed vs. simulated data for sunflower 2081-2100

4.4 Maximum and Minimum Temperature (°C)

The five models used in this study generally showed an increasing trend in both maximum and minimum temperature for the two time series 2040s (2046-2065) and 2080s (2081-2100) in Embu District (Table 4.1) compared to the base climate.

Table 4.1 Observed vs. SDSM-GCM model results for max and min. temp °C for 2040s and 2080s for Embu District (Anonymous 2011).

	SDSM-Model Type	Scenarios	Annual Min.Temp °C	Annual Max.Temp °C
1979-2000	observed		14.2	24.1
2046-2065	GFDL CM 2.1	A2	16.5	26.4
		B1	16	25.9
	GFDL CM 2.0	A2	16.6	26.6
		B1	16.3	26.2
	IPSLCM4	A2	16.9	27
		B1	16.4	26.4
	CCCMA CGCM 3.1	A2	16.8	26.5
		B1	16.2	26
	MPI ECHAM 5	A2	16.5	26.3
		B1	16.2	26.1
2081-2100	GFDL CM 2.1	A2	18.2	28.2
		B1	16.4	26.2
	GFDL CM 2.0	A2	18.2	28
		B1	16.7	26.6
	IPSLCM4	A2	19.1	29.1
		B1	17.5	28.6
	CCCMA CGCM 3.1	A2	18.2	27.7
		B1	16.6	26.3
	MPI ECHAM 5	A2	19	28.8
		B1	17.4	27.2

In reference to results shown in table 4.1 SDSM-IPSL CM4 A2 exhibited the highest increase in minimum temperature of 19% (2.7°C), While SDSM-GFDL CM 2.1 B1 showed the least increase in minimum temperature of 12.7% (1.8°C) both for the 2040s time series when compared to the base climate. A similar trend was noted for the maximum temperature for the 2040s time series, where, SDSM-IPSL CM4 A2

exhibited the highest increase in maximum temperature of 12% (2.9°C). However, SDSM-GFDL CM 2.1 B1 showed the least increase in maximum temperature of 12.7% (1.8°C) when compared to the base climate.

In 2080s (2081-2100) as shown in table 4.1, SDSM-IPSL CM4 A2 model again, exhibited the highest increase in minimum temperature of 34.5% (4.9°C) while the least increase in minimum temperature was shown by SDSM-GFDL CM 2.1 B1 which was noted as 15.5% (2.2°C). SDSM-IPSL CM4 A2 exhibited the highest increase in maximum temperature of 20.7% (5°C). However, SDSM-GFDL CM 2.1 B1 showed the least increase in maximum temperature of 8.7% (2.1°C) when a comparison was done to the base climate.

4.5 Deficit Irrigation

The yield output results for maize under deficit and non-irrigation (rainfed) conditions for the future scenario (2046-2065) were compared to the observed simulated data for 1979-2000. Figure 4.7 shows the relation between deficit irrigation and % yield reduction of maize.

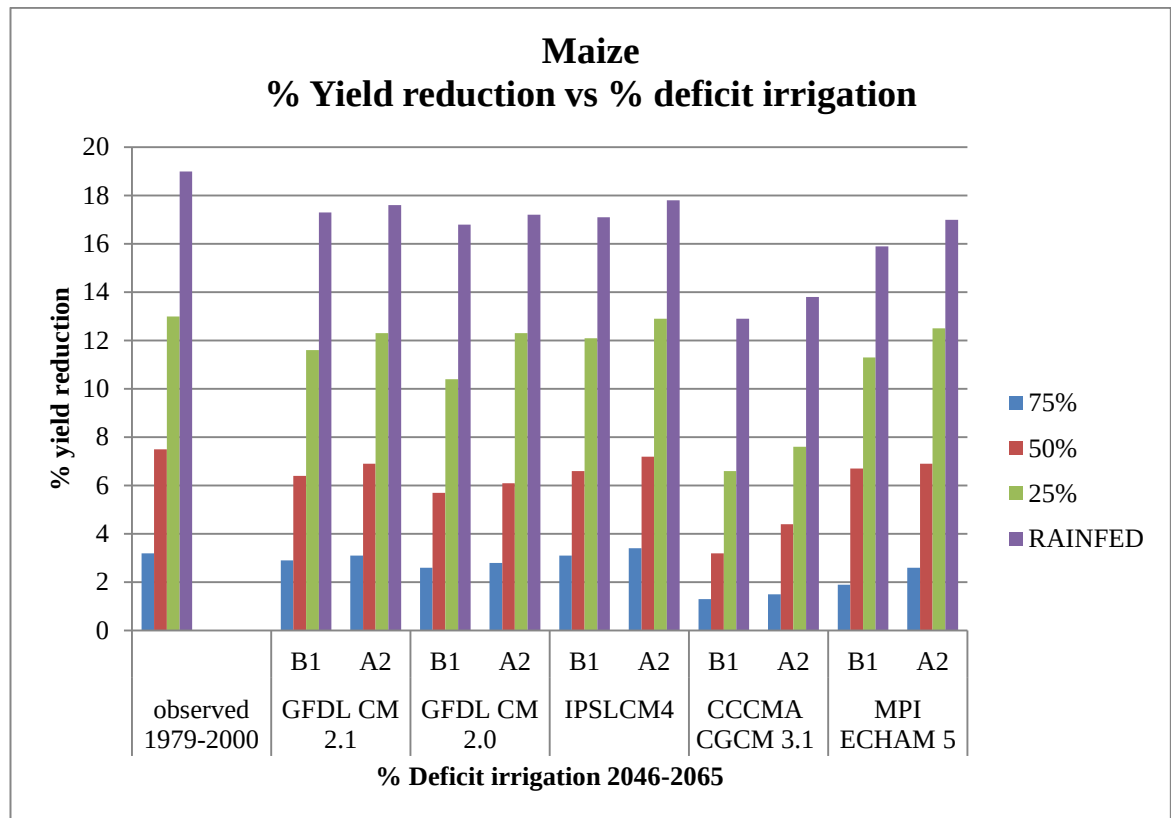


Figure 4.7 Graph showing % yield reduction vs. % deficit irrigation for maize in 2046-2065

A yield reduction of 19% was observed for maize in the year 1979-2000 under rainfed conditions (non-irrigated conditions), while 13% yield reduction was observed under a 25% deficit irrigation conditions. There was a reduction of 7.5% and 3.2% in yield percentage under 50% and 75% irrigation conditions, respectively for 1979-2000. In 2046-2065, GCM IPSL CM4 model under scenario A2, showed the greatest percentage in yield reduction of 17.8% under non-irrigation conditions (rainfed) , while, under deficit irrigation conditions of 75%, 50% and 25% showed a yield reduction of 3.4%, 7.2%, and 12.9% respectively for the year 2046-2065. Thus the study reveals that under rainfed conditions there is highest yield reduction for maize, thus farmers in Embu can transition to deficit irrigation because in 2046-2065 under 25% irrigation the yield reduction is less than 18% for all the models which means a lot of water can be conserved and used to irrigate other crops

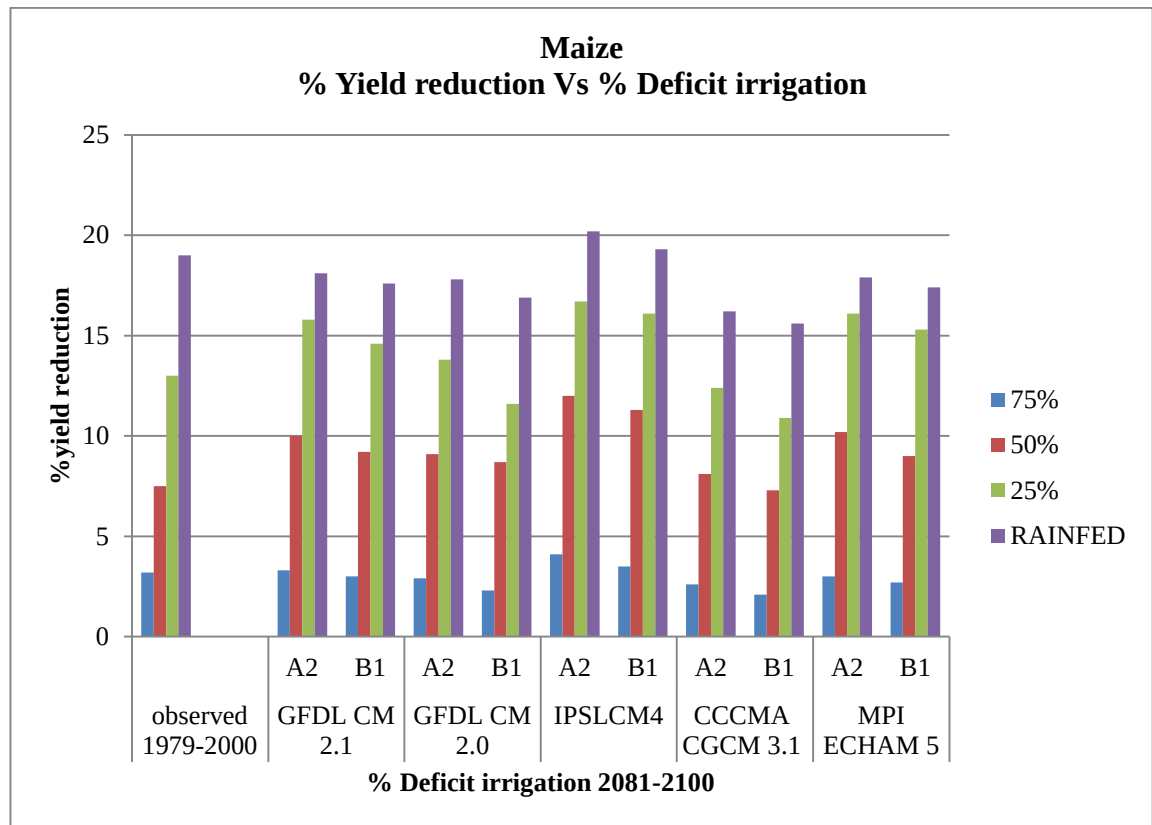


Figure 4.8 Graph showing % yield reduction vs. % deficit irrigation vs. for maize in 2081-2100

In Figure 4.8 the relationship between % deficit irrigation and % yield reduction of maize for 2081-2100 showed that GCM IPSL CM4 for A2 scenario had the highest % yield reduction of 20.2% under rainfed conditions. While, under deficit irrigation conditions of 75%, 50% and 25% showed a yield reduction of 4.1%, 12% and 16.7% respectively. The % yield reduction for maize in 2081-2100 was higher compared to both 1979-2000 and 2046-2065, this could be due to higher temperatures in 2081-2100. Rainfed conditions still show highest % yield reduction for IPSL CM4 A2 model. See appendix 4.

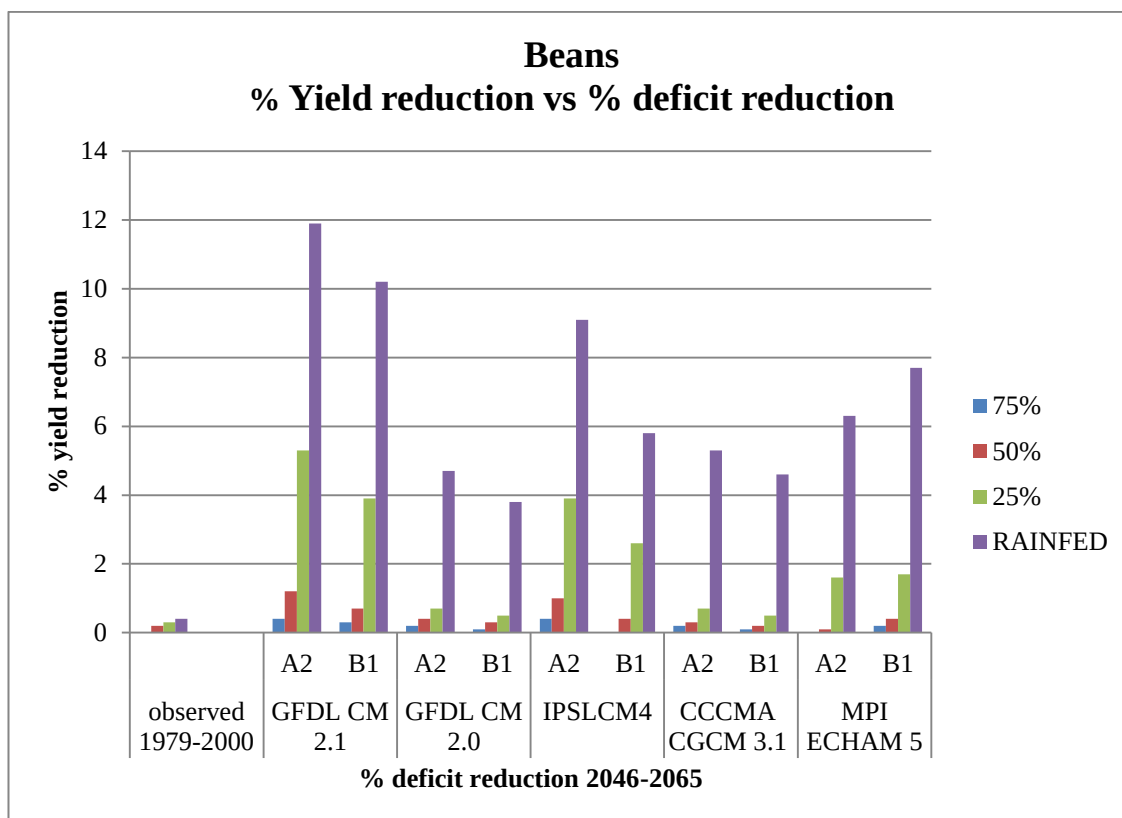


Figure 4.9 Graph showing % deficit irrigation vs. % yield reduction for beans in 2046-2065

The bar graph in Figure 4.9 shows the relationship between % deficit irrigation and % yield reduction for beans for the time series of 1979-2000 and 2046-2065. % yield reduction under rainfed conditions for beans in 1979-2000 was 0.4%. GFDL CM 2.1 A2 had the highest % yield reduction under rainfed conditions of 11.9%. Under deficit irrigation conditions GFDL CM 2.1 A2 model showed the highest sensitivity with a 0.4%, 1.2%, and 5.3% yield reduction under the 75%, 50% and 25% deficit irrigation conditions respectively. On the other hand, GFDL CM 2.0 B1 model showed the least sensitivity to both rainfed (3.8% yield reduction) and deficit irrigation (0.1%, 0.3%, and 0.5% yield reduction for 75%, 50% and 25% deficit irrigation conditions respectively) for the year 2046-2065.

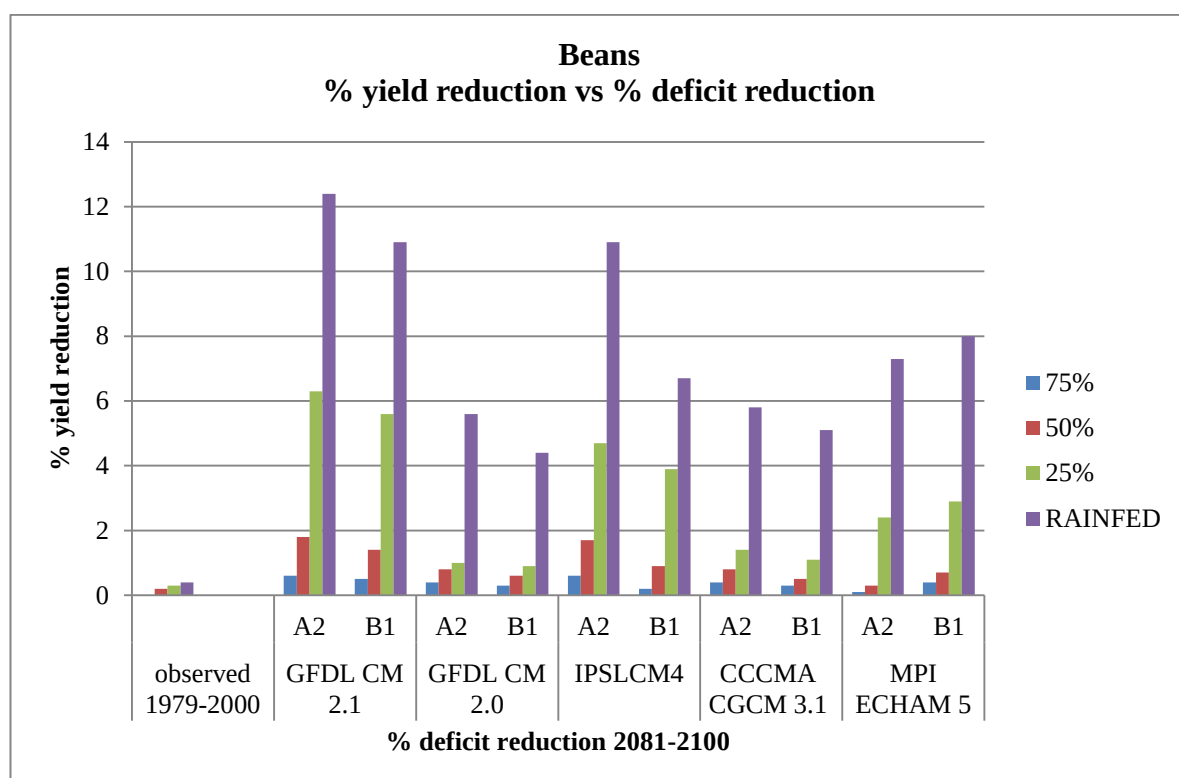


Figure 4.10 Graph showing % deficit irrigation vs. % yield reduction for beans in 2081-2100

As shown in Figure 4.10, GCM GFDL CM 2.1 in 2081-2100 had the highest % yield reduction of 12.4% under rainfed conditions and a 6.3%, 1.8% and 0.6% yield reduction under 25%, 50% and 75% deficit irrigation conditions respectively. See appendix 5. There is a sharp difference in the amount of % yield reduction for the year 1979-2000 and the future scenarios of 2040s and 2080s, the reason could be attributed to the short crop cycle of beans; since Kenya has bi-modal rainfall of between March-April-May-June (long rains) and October-November-December (short rains). At time of planting the rainfall received is sufficient for the bean crop to grow, hence explains the minimum % yield reduction. However in 2040s and 2080s climatic conditions change and there is increase in minimum and maximum temperature coupled with increase in CWR. See appendix 5.

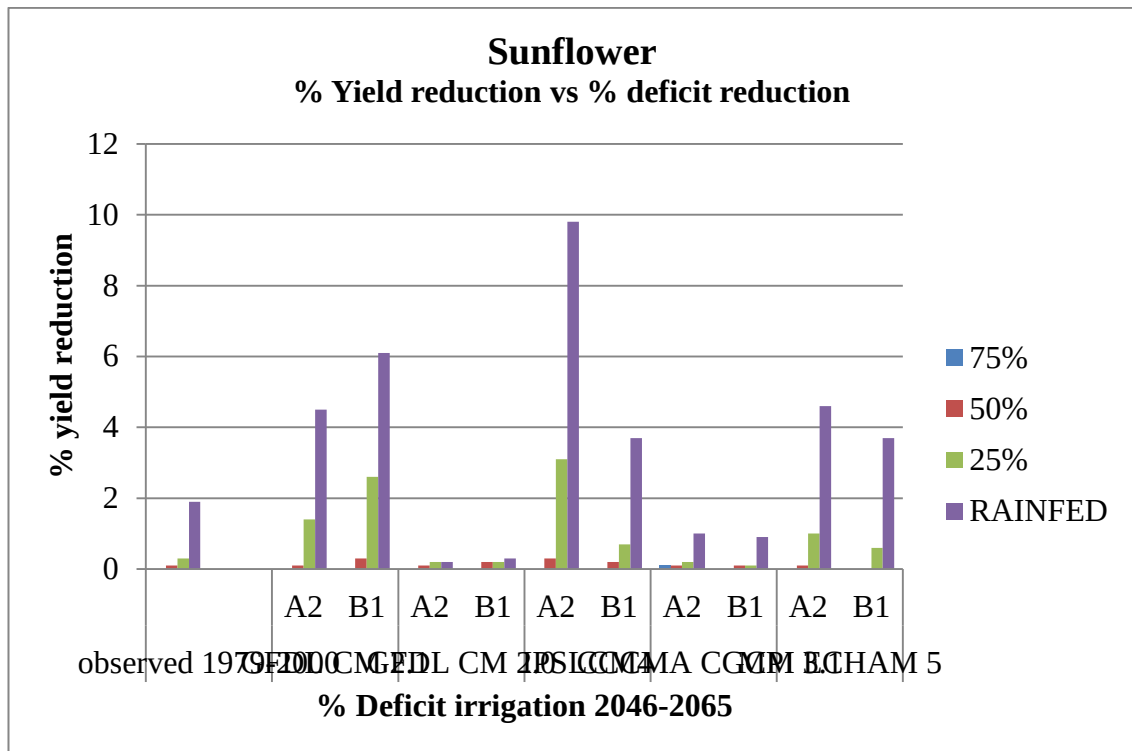


Figure 4.11 Graph showing % deficit irrigation vs. % yield reduction for sunflower in 2046-2065

As shown in Figure 4.11 GCM IPSL CM4 A2 had the highest % yield reduction of 9.8 % under rainfed conditions and 3.1% under 25% deficit irrigation conditions for 2046-2065. There was no reduction in % yield for 75% deficit irrigation conditions for all the models used for the year 2046-2065 except the CCCMA CGCM 3.1 A2 which had an almost negligible % yield reduction of 0.1%. See appendix 6.

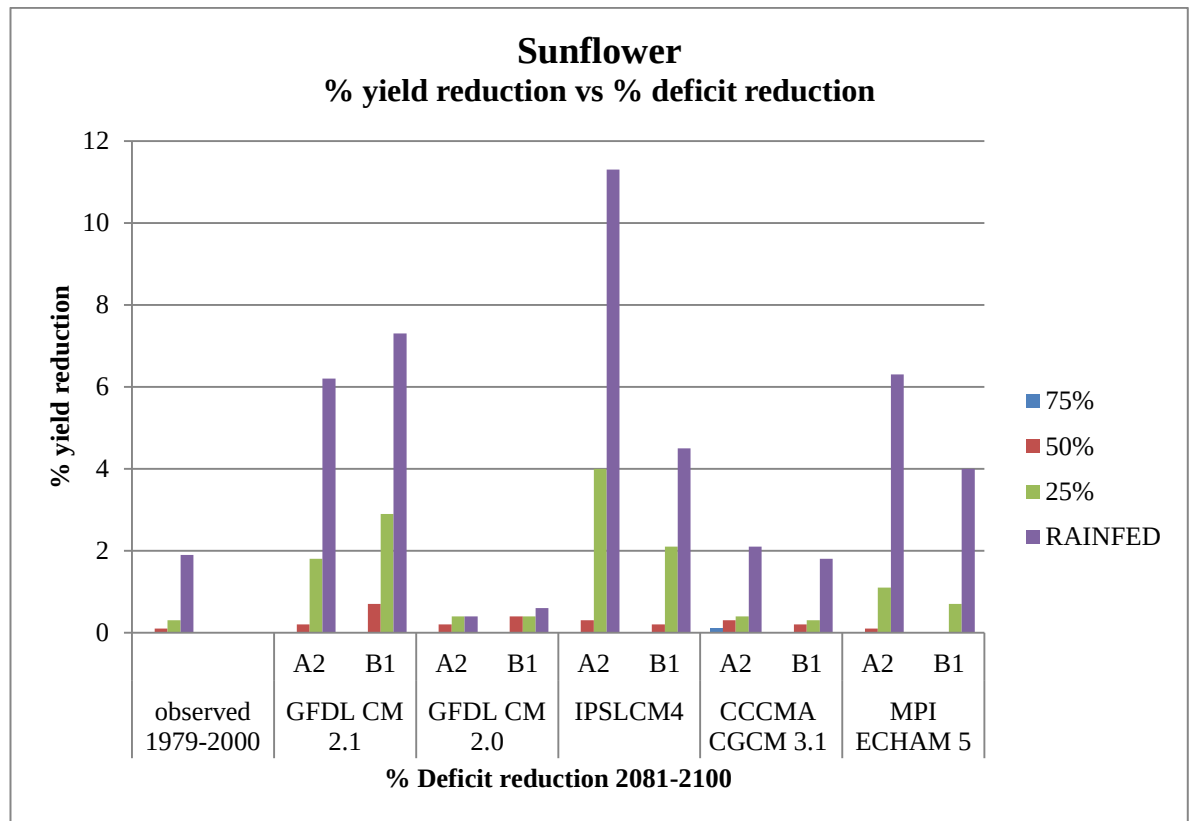


Figure 4.12 Graph showing % deficit irrigation vs. % yield reduction for sunflower in 2081-2100.

In 2081-2100, sunflower had the highest % in yield reduction for GCM IPSL CM4 A2 of 11.3% under rainfed conditions and 4% under 25% deficit irrigation condition. There was no reduction in % yield for 75% deficit irrigation conditions for all the models used in this study CCCMA CGCM 3.1 A2 which had an almost negligible % yield reduction of 0.1%. This indicated that in the future time period of 2081-2100 farmers could reduce the net irrigation water requirement for the sunflower crop without affecting its yield, hence saving on water for irrigation. See appendix 6.

5. CONCLUSION

Despite the increases in evapotranspiration in the two future time series of 2040s and 2080s as shown by the five statistical downscaled GCM models, the results from the CROPWAT 8 model when run for the three crops namely maize, beans and sunflower indicate a trend of increasing future crop water requirements. On the contrary, the irrigation water requirement showed a decreasing trend as discussed earlier. These trends could principally be attributed to the increased amounts of precipitation in Embu district, as simulated by the SDSM GCM model scenarios in the earlier mentioned future time series. The study also revealed that out of the three crops selected for this particular study, maize had the highest amount of CWR compared to beans and sunflower for both the time series of 2040s and 2080s including the base climate. Thus, according to this study increase in future maximum and minimum temperature will affect the CWR and IWR of maize beans and sunflower within Embu district. CWR for all the three crops will increase for the future time steps of 2040s and 2080s. The highest increase CWR are observed for the 2080s time step. IWR showed a declining trend for the future time steps for 2040s and 2080s when compared to baseline climate of 1979-2000. High reductions of IWR was observed in 2080s for the sunflower crop compared to maize and beans. This was as a result of increase in total precipitation in the 2080s time step.

A2 SRES scenario showed higher value results for the ETo CWR,IWR measured as projected by the five models. Furthermore, IPSL CM4 model showed the highest sensitivity when data was run through CROPWAT and IRSIS model for ETo CWR,IWR .The results from the CROPWAT model 8 representing simulated daily and seasonal total ETo and CWR for base climate and future time scenarios of 2040s and 2080s (for maize, beans and sunflower) present researchers, planners and policy makers in Kenya with a unique opportunity to allocate water resources and to accommodate more crops for agricultural production through both rainfed and irrigated agricultural systems. Furthermore, critical information presented in this study will help improve a better understanding of crop water requirement (CWR) and the role it could play in

quantification of the impacts of climate change on crop production thus improving the management and productivity of both food and cash crops.

This approach of quantifying impacts of climate change, could be adopted and replicated across different districts (including the arid and semi-arid regions) within Kenya and Africa as a continent to help formulate an interdisciplinary and multi-sectored based policy integration to address the challenge of climate change which will consequently help design comprehensive, mitigative and adaptive strategies without compromising the competing socio-economic sectors namely, domestic, industrial and agricultural. Ultimately, this could help to improve agricultural production which would help reduce food insecurity and poverty within the country. The results from IRSIS (crop yield simulation model) on irrigation scheduling with limited water supplies showed that maize crop was the most sensitive in terms of percentage yield reduction under both rainfed and limited (deficit) irrigation conditions for both observed (1979-2000) and future climatic (2046-2065 and 2081-2100) data scenarios, there was a great reduction in percentage yield under rainfed conditions hence supporting the case for adopting water efficient irrigation practices to help improve yield output of maize, beans and sunflower.

The study also revealed that regulated deficit irrigation of 75% would not negatively impact the % yield of beans and sunflower for the future climatic conditions of 2046-2065 and 2081-2100 as used in this study, furthermore, this would help save on water for irrigation for both the 2046-2065 and 2081-2100 future time series, thus, deficit irrigation would not only strike a delicate balance between adaptation to strained water resources but also maintain high yield output for maize, beans, and sunflower within Embu District in Kenya. Besides, water saved by adoption of irrigation technology could be used to irrigate other crops, thus, increase the overall food production within Embu district. End result would outweigh any possible yield reduction as a result of deficit reduction. Since the level of technology adoption within Embu district is low, this approach of irrigation scheduling using CROPWAT and IRSIS models to simulate CWR, IWR, and yield output for different crops could help farmers better schedule and manage their irrigated farms with the aim of improving crop yield and using limited

water resources more efficiently. Thus, it could be replicated in other Kenyan Districts and hence contribute towards a more food secure Kenya. The study acknowledged that rainfed agriculture practiced within Embu district was leading to higher yield losses compared to simulated irrigation conditions, thus, farmers must be assisted to transition from rainfed agriculture to deficit irrigated agriculture through the adoption of the simple irrigation models like CROPWAT and IRSIS to help them adapt to a changing climate within Embu district. This transition will help solve many challenges the farmers face like low annual produce, low income, poor nutrition and food scarcity

In conclusion, the results strongly suggest that climate change has the ability to alter the CWR and IWR. In particular, rainfall was a prepotent factor that could significantly increase or reduce IWR of any crop. However, it must be noted that both temperature and rainfall played a considerable role in influencing the IWR and CWR of maize, beans and sunflower as investigated in this study. GCM models used in this study projected an average increase in temperature of about 1°C for Embu district and did result in beneficial impacts for the three main crops studied i.e. increase in precipitation for 2040s and 2080s hence reduction in IWR. Agricultural policies within Kenya should be more proactive in encouraging small scale farmers, who are more vulnerable to climate change to adopt low technology irrigation techniques and reduce their over-dependence on rainfed agriculture systems in order to improve crop yield, which will eventually boost income and food supply within the country.

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APPENDICES

Appendix 1 GCM models CROPWAT data for 2040s and 2080s (Scenario A2 and B1) maize

Appendix 2 GCM models CROPWAT data for 2040s and 2080s (scenario A2 and B1) beans

Appendix 3 GCM models CROPWAT, and deficit irrigation for 2040s and 2080s (Scenario A2 and B1) sunflower

Appendix 4 IRSIS Deficit irrigation data for 2040s and 2080s (scenario A2 and B1) maize

Appendix 5 IRSIS Deficit irrigation data for 2040s and 2080s (scenario A2 and B1) beans

Appendix 6 IRSIS Deficit irrigation for 2040s and 2080s (scenario A2 and B1) sunflower

GCM models CROPWAT data for 2040s and 2080s (scenario A2 and B1) maize

Climate change results for different GCM models for 2040s and 2080s (scenario A2 and B1) MAIZE									
	Model Type	scenarios	Ann. Min.Temp°C	Annual Max. Temp°C	ET _o	CWR	Irr.Req/mm	l/s/ha	T. Prec/mm
1979-2000	observed		14.2	24.1	1,442.04	473	169.8	7.31/0.15	1,216
2040	GFDL CM 2.1	A2	16.5	26.4	1,517	507.1	104.1	7.31	1,157.20
		B1	16	25.9	1,499.80	500.4	107.4	7.31	1,083
	GFDL CM 2.0	A2	16.6	26.6	1,522.16	509.7	56	7.31	1,304.20
		B1	16.3	26.2	1,508.90	506.5	64.4	7.31	1,272.10
	IPSLCM4	A2	16.9	27	1,538.93	509	197.9	7.31/0.14	1,137.10
		B1	16.4	26.4	1,519.52	502.8	157.4	7.31/0.13	1,202.30
	CCCMA CGCM 3.1	A2	16.8	26.5	1,525.58	501	95.8	7.31	1,333.00
		B1	16.2	26	1,505.44	498.3	84	7.31	1,294.70
	MPI ECHAM 5	A2	16.5	26.3	1,517.92	502	155.4	7.31/0.13	1211.8
		B1	16.2	26.1	1,508.50	500.8	149.7	7.31/0.13	1,197.90
	Model Type	scenarios	Ann. Min.Temp°C	Annual Max.Temp°C	ET _o	CWR	Irr.Req/mm	l/s/ha	T. Prec/mm
	observed		14.2	24.1	1,442.04	473	169.8	7.31/0.15	1,216
2080	GFDL CM 2.1	A2	18.2	28.2	1,581.94	528.3	104.8	7.31	1,198.50
		B1	16.4	26.2	1,511.04	502.7	111.7	7.31	1,161.50
	GFDL CM 2.0	A2	18.2	28	1,577.62	524.2	53.2	7.31	1,402.50
		B1	16.7	26.6	1,526	510.4	58.2	7.31	1,256.10
	IPSLCM4	A2	19.1	29.1	1,619.14	533.1	202.8	7.32/0.15	1,208.90
		B1	17.5	28.6	1,588.39	529.8	170.6	7.31/0.13	1,200.40
	CCCMA CGCM 3.1	A2	18.2	27.7	1573.57	514.2	131.3	7.32	1297.2
		B1	16.6	26.3	1,518.24	499	92.5	7.31	1,340.10
	MPI ECHAM 5	A2	19	28.8	1,609.84	529.9	179.7	7.32/0.14	1,209.30
		B1	17.4	27.2	1,550.13	513.7	150.5	7.31/0.13	1202.1

GCM models CROPWAT data for 2040s and 2080s (scenario A2 and B1) beans

Climate change results for different GCM models for 2040s and 2080s (scenario A2 and B1) beans									
	Model Type	scenarios	Ann. Min.Temp°C	Annual Max.Temp°C	ET _o	CWR	Irr Req/mm	l/s/ha	Total Prec/mm
1979-2000	observed		14.2	24.1	1,442.04	351	28.8	7.4	1,216
2040	GFDL CM 2.1	A2	16.5	26.4	1,517	370	28.2	7.4	1,157.20
		B1	16	25.9	1,499.80	365.8	29.9	7.4	1,083
	GFDL CM 2.0	A2	16.6	26.6	1,522.16	368.2	3.7	7.4	1,304.20
		B1	16.3	26.2	1,508.90	364	3.7	7.4	1,272.10
	IPSLCM4	A2	16.9	27	1,538.93	372.7	23.3	7.41	1,137.10
		B1	16.4	26.4	1,519.52	367.2	21	7.4	1,202.30
	CCCMA CGCM 3.1	A2	16.8	26.5	1,525.58	366.4	7.1	7.4	1,333.00
		B1	16.2	26	1,505.44	364	7	7.4	1,294.70
	MPI ECHAM 5	A2	16.5	26.3	1,517.92	366.1	26.9	7.4	1211.8
		B1	16.2	26.1	1,508.50	366.2	16.2	7.4	1,197.90
	Model Type	scenarios	Ann. Min.Temp°C	Annual Max.Temp°C	ET _o	CWR	Irr Req/mm	l/s/ha	Total Prec/mm
	observed		14.2	24.1	1,442.04	351	28.8	7.4	1,216
2080	GFDL CM 2.1	A2	18.2	28.2	1,581.94	386.2	32.1	7.41	1,198.50
		B1	16.4	26.2	1,511.04	366.1	33.1	7.4	1,161.50
	GFDL CM 2.0	A2	18.2	28	1,577.62	380.7	5.2	7.41	1,402.50
		B1	16.7	26.6	1,526	369.2	4.9	7.4	1,256.10
	IPSLCM4	A2	19.1	29.1	1,619.14	389.4	47.4	7.42	1,208.90
		B1	17.5	28.6	1,588.39	384.5	28.5	7.41	1,200.40
	CCCMA CGCM 3.1	A2	18.2	27.7	1573.57	376.2	9.1	7.41	1297.2
		B1	16.6	26.3	1,518.24	365.2	6.9	7.4	1,340.10
	MPI ECHAM 5	A2	19	28.8	1,609.84	389.3	35.5	7.41	1,209.30
		B1	17.4	27.2	1,550.13	375.5	17.4	7.41	1202.1

GCM models CROPWAT, and deficit irrigation for 2040s and 2080s (scenario A2 and B1) sunflower

Climate change results for different GCM models for 2040s and 2080s (scenario A2 and B1) sunflower									
	Model Type	scenarios	Ann. Min.Temp°C	Annual Max.Temp°C	ET _o	CWR	Irr Req/mm	l/s/ha	Total Prec/mm
1979-2000	observed		14.2	24.1	1,442.04	347.8	105.2	7.48	1,216
2040	GFDL CM 2.1	A2	16.5	26.4	1,517	370.5	65	7.49	1,157.20
		B1	16	25.9	1,499.80	365.6	68.8	7.48	1,083
	GFDL CM 2.0	A2	16.6	26.6	1,522.16	371	25.9	7.48	1,304.20
		B1	16.3	26.2	1,508.90	369.4	34.1	7.48	1,272.10
	IPSLCM4	A2	16.9	27	1,538.93	373.4	90.7	7.49	1,137.10
		B1	16.4	26.4	1,519.52	367.6	87	7.49	1,202.30
	CCCMA CGCM 3.1	A2	16.8	26.5	1,525.58	366.3	43.5	7.49	1,333.00
		B1	16.2	26	1,505.44	364.2	39.1	7.49	1,294.70
	MPI ECHAM 5	A2	16.5	26.3	1,517.92	366.8	84.3	7.49	1211.8
		B1	16.2	26.1	1,508.50	366.3	77.6	7.49	1,197.90
	Model Type	scenarios	Ann. Min.Temp°C	Annual Max.Temp°C	ET _o	CWR	Irr Req/mm	l/s/ha	Total Prec/mm
	observed		14.2	24.1	1,442.04	347.8	105.2	7.48	1,216
2080	GFDL CM 2.1	A2	18.2	28.2	1,581.94	387.6	65.2	7.49	1,198.50
		B1	16.4	26.2	1,511.04	366.8	75	7.48	1,161.50
	GFDL CM 2.0	A2	18.2	28	1,577.62	383.4	29.9	7.49	1,402.50
		B1	16.7	26.6	1,526	372.3	24.4	7.49	1,256.10
	IPSLCM4	A2	19.1	29.1	1,619.14	389.4	122.9	7.5	1,208.90
		B1	17.5	28.6	1,588.39	386.5	94.3	7.49	1,200.40
	CCCMA CGCM 3.1	A2	18.2	27.7	1573.57	374.9	54.8	7.49	1297.2
		B1	16.6	26.3	1,518.24	364.4	49.9	7.49	1,340.10
	MPI ECHAM 5	A2	19	28.8	1,609.84	388.9	102.7	7.5	1,209.30
		B1	17.4	27.2	1,550.13	376.1	78.2	7.49	1202.1

IRSIS Deficit irrigation data for 2040s and 2080s (scenario A2 and B1). % yield reduction for maize

	Model Type	scenarios	75%	50%	25%	RAINFED
1979-2000	observed 1979-2000		3.2	7.5	13	19
2040	GFDL CM 2.1	B1	2.9	6.4	11.6	17.3
		A2	3.1	6.9	12.3	17.6
	GFDL CM 2.0	B1	2.6	5.7	10.4	16.8
		A2	2.8	6.1	12.3	17.2
	IPSLCM4	B1	3.1	6.6	12.1	17.1
		A2	3.4	7.2	12.9	17.8
	CCCMA CGCM 3.1	B1	1.3	3.2	6.6	12.9
		A2	1.5	4.4	7.6	13.8
	MPI ECHAM 5	B1	1.9	6.7	11.3	15.9
		A2	2.6	6.9	12.5	17
	model type	scenarios	75%	50%	25%	RAINFED
	observed 1979-2000		3.2	7.5	13	19
2080	GFDL CM 2.1	A2	3.3	10	15.8	18.1
		B1	3	9.2	14.6	17.6
	GFDL CM 2.0	A2	2.9	9.1	13.8	17.8
		B1	2.3	8.7	11.6	16.9
	IPSLCM4	A2	4.1	12	16.7	20.2
		B1	3.5	11.3	16.1	19.3
	CCCMA CGCM 3.1	A2	2.6	8.1	12.4	16.2
		B1	2.1	7.3	10.9	15.6
	MPI ECHAM 5	A2	3	10.2	16.1	17.9
		B1	2.7	9	15.3	17.4

IRSIS Deficit irrigation data for 2040s and 2080s (scenario A2 and B1). % yield reduction for beans

	Model Type	scenarios	75%	50%	25%	RAINFED
1979-2000	observed 1979-2000		0	0.2	0.3	0.4
2040	GFDL CM 2.1	A2	0.4	1.2	5.3	11.9
		B1	0.3	0.7	3.9	10.2
	GFDL CM 2.0	A2	0.2	0.4	0.7	4.7
		B1	0.1	0.3	0.5	3.8
	IPSLCM4	A2	0.4	1	3.9	9.1
		B1	0	0.4	2.6	5.8
	CCCMA CGCM 3.1	A2	0.2	0.3	0.7	5.3
		B1	0.1	0.2	0.5	4.6
	MPI ECHAM 5	A2	0	0.1	1.6	6.3
		B1	0.2	0.4	1.7	7.7
	Model Type	scenarios	75%	50%	25%	RAINFED
	observed 1979-2000		0	0.2	0.3	0.4
2080	GFDL CM 2.1	A2	0.6	1.8	6.3	12.4
		B1	0.5	1.4	5.6	10.9
	GFDL CM 2.0	A2	0.4	0.8	1	5.6
		B1	0.3	0.6	0.9	4.4
	IPSLCM4	A2	0.6	1.7	4.7	10.9
		B1	0.2	0.9	3.9	6.7
	CCCMA CGCM 3.1	A2	0.4	0.8	1.4	5.8
		B1	0.3	0.5	1.1	5.1
	MPI ECHAM 5	A2	0.1	0.3	2.4	7.3
		B1	0.4	0.7	2.9	8

IRSIS Deficit irrigation for 2040s and 2080s (scenario A2 and B1). % yield reduction for SUNFLOWER.

	Model Type	scenarios	75%	50%	25%	RAINFED
1979-2000	observed 1979-2000		0	0.1	0.3	1.9
2040	GFDL CM 2.1	A2	0	0.1	1.4	4.5
		B1	0	0.3	2.6	6.1
	GFDL CM 2.0	A2	0	0.1	0.2	0.2
		B1	0	0.2	0.2	0.3
	IPSLCM4	A2	0	0.3	3.1	9.8
		B1	0	0.2	0.7	3.7
	CCCMA CGCM 3.1	A2	0.1	0.1	0.2	1
		B1	0	0.1	0.1	0.9
	MPI ECHAM 5	A2	0	0.1	1	4.6
		B1	0	0	0.6	3.7
	Model Type	scenarios	75%	50%	25%	RAINFED
	observed 1979-2000		0	0.1	0.3	1.9
2080	GFDL CM 2.1	A2	0	0.2	1.8	6.2
		B1	0	0.7	2.9	7.3
	GFDL CM 2.0	A2	0	0.2	0.4	0.4
		B1	0	0.4	0.4	0.6
	IPSLCM4	A2	0	0.3	4	11.3
		B1	0	0.2	2.1	4.5
	CCCMA CGCM 3.1	A2	0.1	0.3	0.4	2.1
		B1	0	0.2	0.3	1.8
	MPI ECHAM 5	A2	0	0.1	1.1	6.3
		B1	0	0	0.7	4

CURRICULUM VITAE (CV)

Name : Godwin Samuel Odhiambo Ngesa
Place of birth : Kisumu East, KENYA
Date of birth : 1984
Marital status : Single
Foreign Languages : Swahili, English, Turkish, Spanish

EDUCATION

Secondary : Kanga High School, KENYA 1999-2002
Undergraduate: Jomo Kenyatta University of Agriculture and Technology
(JKUAT).Faculty of Engineering 2004-2009
Bsc. Soil, Water and Environmental Engineering
Post graduate : Ankara University, Institute of Science, Department of Irrigation
and Drainage Engineering 2010-2013
Msc. Irrigation and Drainage Engineering

EMPLOYMENT

1. Institution: E.C Philips and Sons
Date/Place: 2012, Alaska, United States of America
Position: Quality control Technician