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UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA

PROGRAMAS MULTIDISCIPLINARIOS DE POSGRADO EN CIENCIAS AMBIENTALES

AND

COLOGNE UNIVERSITY OF APPLIED SCIENCES

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

WATER QUALITY IMPACT ON RICE PRODUCTION. CASE STUDY: BLUE CREEK, BELIZE

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

DEGREE AWARDED BY

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

AND

MASTER OF SCIENCE

TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

IN THE SPECIALIZATION: RESOURCES MANAGEMENT

DEGREE AWARDED BY COLOGNE UNIVERSITY OF APPLIED SCIENCES

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Abstract

The rice industry in Belize has seen many changes since its establishment. Currently, the nation is self-sufficient in rice production by the implementation of mechanized, irrigated and high-input farm systems; of which a large portion is performed in northern Belize. Such production systems may directly or indirectly have effects on the environment in the longer run. Hence, the objectives of this research was to analyze the water quality impacts on rice production, be it on the soil structure like on plant's growth and development. At the same time, simulate the rice production under current conditions via AquaCrop – crop modeling program, to determine its reliability for future experiments. As a result, the water implemented for irrigation is classified as C4-S1, high saline content with low sodium levels: which is considered inadequate for agriculture use, unless specific conditions are met, such as well drained soils, excess water availability for leaching, saline tolerant crops, etc. Soils were determined as calcareous and clayey with high levels of calcium and magnesium. Under specific agronomic practices and said water and soil quality, yield observed was of 6.67 tons/ha, a reduced yield from previous years. The simulated yield was of 6.14 ton/ha, an 8% difference from observed data. The use of AquaCrop seems reliable for simulating rice yields under the production conditions of the study area. In order to improve rice production in Blue Creek, Belize, it is necessary to implement water treatments via blending or alternating water sources available during plant phases that suffer less salinity stress; soil amendments through the incorporation of organic matter before planting for improvement of soil structure.

Resumen

La industria del arroz en Belice ha visto varios cambios desde su establecimiento. Actualmente, el país es auto suficiente en la producción de arroz debido a implementación de sistemas mecanizados, irrigados y de los altos insumos; de los cuales, una gran parte ocurre en el norte de Belice, principalmente la comunidad de Blue Creek. Dichos sistemas, pueden tener efectos directos e indirectos al ambiente a largo plazo. Debido a esto, el objetivo de este trabajo es de analizar agua de riego y su impacto en la producción de arroz, ya sea en la estructura del suelo como el crecimiento y desarrollo del cultivo. A la misma vez, simular la producción de arroz bajo la condiciones actuales a través del programa de modelaje de cultivos – AquaCrop y determinar la confiabilidad del programa para futuros experimentos. Como resultado, el agua utilizada para el riego se clasifica como C4-S1, con un alto contenido sales y bajo contenido de sodio. Dicha agua, es considerada inadecuada para su uso agrícola, a menos que cumplan determinadas condiciones como: suelos de buen drenaje, disponibilidad excesiva de agua para lixiviación, cultivos tolerantes al a salinidad, etc. Los suelos fueron clasificados como calcáreos y arcillosos con altos niveles de calcio y magnesio. Bajo las prácticas agrícolas, calidad del agua y suelo utilizadas, el rendimiento observado fue de 6.67 ton/ha, una disminución de años anteriores. El rendimiento simulado fue de 6.14 ton/ha, un diferencia de 8% con respecto al observado. La utilización del programa AquaCrop es confiable para simular los rendimientos de arroz bajo las condiciones actuales de producción del área de estudio. Para mejorar la producción de arroz en Blue Creek, Belize, es necesario implementar tratamiento de agua a través de la mezcla de alternación de diferentes fuentes de agua durante las fases del cultivo menos susceptibles al estrés por salinidad; enmiendas al suelo por medio de la incorporación de materia orgánica antes de la siembra para mejorar su estructura.

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1. Introduction

Agriculture production has been increasing since the green revolution. This increase comes along by the growing global population which is estimated to increase to 9.15 billion people by 2050 (Alexandratos & Bruinsma, 2012). Many scientists and researchers have the question, how to feed said amount of people with the limited natural resources available? As per mentioned by FAO (2009, p. 8) in “How to feed the world in 2050”, the intensification of ecosystems for food production often cause degradation, clearly indicated by “*soil nutrient depletion, erosion, desertification, depletion of freshwater reserves, loss of tropical forest and biodiversity*”. With this in mind, many seek innovative technologies that can improve agricultural production, be it through better practice management, improved genetics, and precision farming, amongst others aiming towards a more environmentally friendly production system.

Belize is located in Central America, forming part of the Yucatan Peninsula and lying between $17^{o}30'17''$ N and $88^{o}11'12''$ W. It comprises of a multi-ethnic population with a total of 351,600 inhabitants (SIB, 2012). Belize’s population has increased 36% within the last decade and is projected to increase by 67% (590,000) by 2050 (FAOSTAT, 2014). Considering a growing nation and threats of global climate change, are valid reasons to contemplate how to feed the nation.

Belize is characterized as a subtropical region in Central America and the Caribbean. Northern Belize receives 1,500 mm of rain; meanwhile Southern Belize gets 3,800mm precipitation on a yearly average. Belize’s climate is characterized by a wet and dry season, June – November and December – May, respectively. Average annual temperatures oscillate between 10-35^{o}C, the lowest being in the mountainous areas of Belize where the highest peak rises to 1,120 m.a.s.l. during the months of December – February which is when Belize receives like 12 cold fronts. The highest temperatures are observed between July and August (BMS, 2014).

Rice production has become very important in many parts of the world; in 2010, a total of 696 million tons was produced globally. Rice is the most important food grain for human consumption in tropical areas of Latin America and the Caribbean (GRiSP, 2013). In Belize, rice production is an important staple in the daily nutrition of citizens and it is self-sustainable in its production. Being so, in 2006 a total of 13,068 tons of paddy rice was produced and in 2010 a total 22,623 tons (SIB, 2012); thereby providing annually a consumption of 34 kg/capita. In the community of Blue Creek, in any given year, is responsible for more than 50% of the rice paddy production in Belize (Trujillo 2012, Personal Interview). Rice production is performed under traditional and conventional systems, the latter being predominant at the study area which comprises of approximately 1629 hectares (Dyck, 2012).

Water availability may not be an issue in Belize, due to the vast amount of freshwater present in the region (BEST, 2012); however, the quality does affect its use for irrigation purposes. Water originating from a spring of karstic nature contains a high content of calcium and sulfates (laboratory results) which are detrimental to soil texture, structure and fertility (Martin et al., 2008). Rice production requires between 1500 – 5000 liters/kg of paddy rice, depending on soil type, local climate and rice variety (IRRI). Being so, millions of water liters are implemented in rice production.

On the other hand, conventional systems or intensive farming is carried out through the application of high-input systems that offer an increased yield (Pacini et al., 2003). These inputs include: fertilizers, herbicides, insecticides, fungicides and others than can be classified as agrochemicals. Such is the case of rice production in the study area.

The increasing effect of climate change on agriculture has significantly influenced on production and has created awareness on how to continue contributing to food security. However, despite the many attempts, not all are successful or realistic. Considering the above, crop models have been designed in making a difference. Crop modeling may be used for "*interpreting experimental results and as an agronomic research tools for research knowledge synthesis…also to use them as a decision support tools for systems*"

(Steduto, 2009, p.426). FAO developed a crop modeling program Aquacrop for "*simulating attainable yields of major herbaceous crops as a function of water consumption under rainfed, supplemental, deficit, and full irrigation condition*" (Steduto, 2008, p. 426).

Considering the above, a case study to analyze the rice production in Blue Creek, Belize has been undertaken, focusing on the water quality for irrigation purposes. It has been observed that the large sums of the valuable resource – water, along with the increasing temperatures, higher evaporation, and other climate change factors, may be influencing on rice production and its environment.

Research question

How does the water quality used for irrigation influence on rice production and its environment in Blue Creek, Belize?

Specific Questions

- What is the type and quality of the water implemented for rice production in Blue Creek, Belize?
- How can a crop modeling program aid in simulation rice plant response to water quality?
- If the water quality is of inappropriate use, what practices can be done to alleviate the problem?

General Objective

To analyze and determine the appropriate use and management of irrigation water in rice farming in the community of Blue Creek, Belize that leads to sustainable rice production.

Specific objectives:

- To determine the chemical and physical quality of water used for irrigation in Blue Creek
- To simulate rice yield response to water quality, environmental conditions and agronomic practices through a crop modeling program.

- To improve the use water and its quality through water treatment, soil amendments or different agricultural practices.

2. Literature Review

2.1 Geographical description

Belize is located in Central America, which borders Mexico on the north and west side and Guatemala on the west side. It has coastal areas along the east side. Belize comprises of 2.28 million hectares (Table 1). Although 38% of the total land area is considered potentially suitable for agricultural use, 10 to 15% may be in use in any one year. About half of this is under pasture, with the remainder in a variety of permanent and annual crops (GOB). From the agricultural area, an approximate 4,450 ha is under rice cultivation. Of these, more than half is cultivated in the northern part of Belize, which produces over 50% of the total rice consumed in Belize (Trujillo, 2012, Personal Interview).

Table 1. Land use in Belize (2009)
(Source: FAOSTAT.)

Area	’000 of hectares	Percentages
Total	2,297	
Land area	2,281	100.00
Agricultural area	152	6.66
Arable land and permanent crops	102	4.47
Arable land	70	3.07
Permanent crops	32	1,40
Permanent grasslands and pastures	50	2.19
Forest area	1,412	61.91
Other lands	717	31.42
Internal water	16	0.70

2.1.1. Climatic Features

Belize is under a tropical climate region. Belize’s yearly average temperature is approximately 27 C, bearing maximum of 34 and a minimum of 15 between the months of May-August and December-February, respectively. During the cropping season, January to April, temperatures peaked 33.6 in April and its lowest 17.9 in March. Planting period coincides with the months of lowest rainfall, hence it need for irrigation. A total of 170 mm was accumulated in the first trimester of the year, April being the lowest with 5.9 mm. The relative humidity followed a similar pattern in comparison to the accumulated precipitation, ranging from 86.4% to 73.8%, the former for January and the latter for April. The total monthly sunshine hours peaked in April, 279.8 hours; meanwhile the lowest was recorded in the last trimester of the year. Consequently, the highest evaporation rates were recorded in the months of April and May.

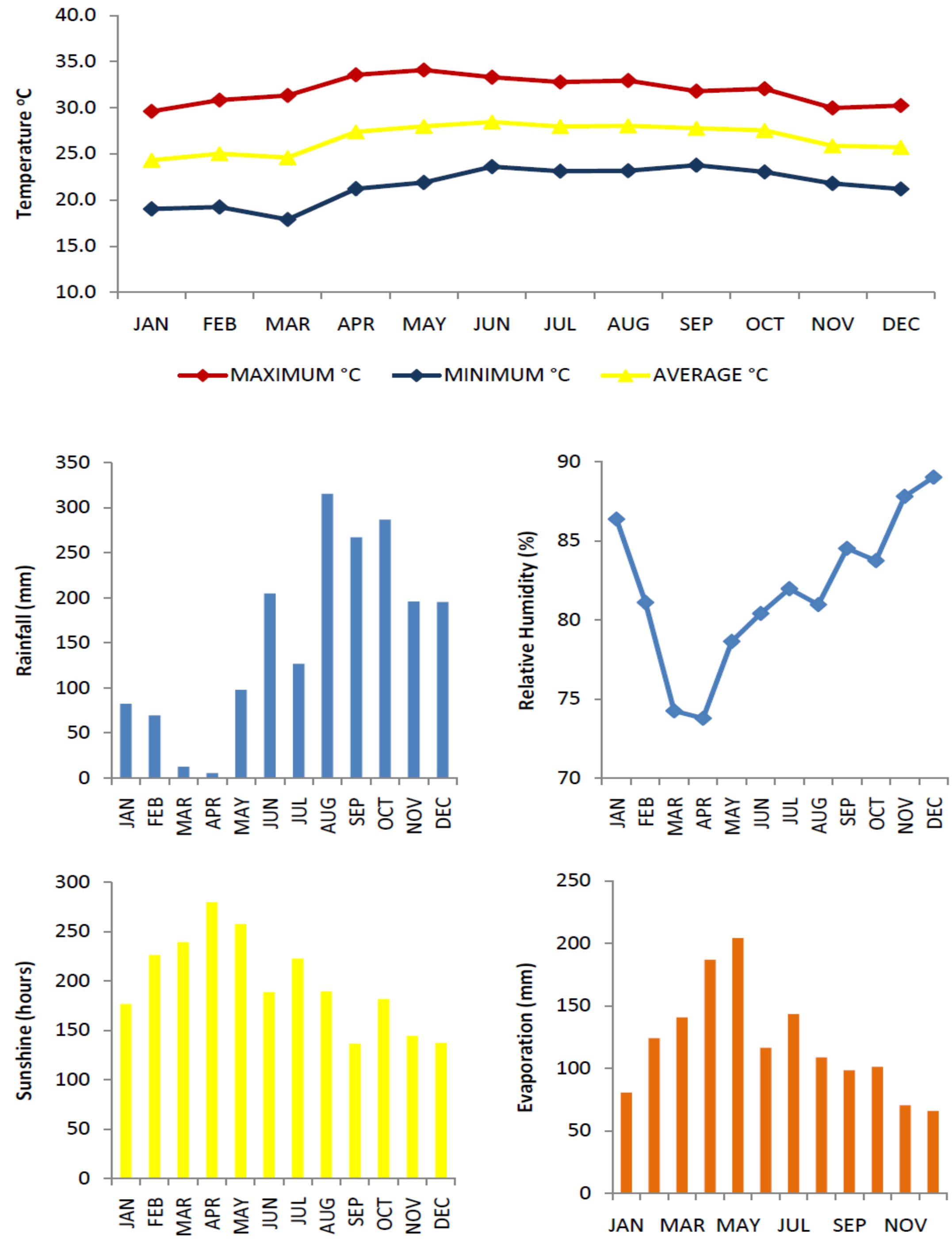


Figure 1. Annual climate parameters for Blue Creek, Belize for year 2013.
(Source: Own elaboration; data from Belize Sugar Industries)

2.1.2. Watershed description

Belize is composed of many rivers and lagoons and coast line bordering the east side. In addition, there are many springs all over the country, primarily in elevated areas. In northern Belize, there is a transboundary river between Guatemala, Mexico and Belize, sharing a main bordering river, Rio Hondo. Figure 2 illustrates the watershed that encompasses Blue Creek, Orange Walk, Belize. In the watershed, appear sources of water bodies used in agriculture, including springs and other rivers. Other rivers include Rio Bravo and the New River; both join with the main river, Rio Hondo along its path. For this research purpose, it must be known that the Rio Bravo borders the rice fields under study and that the Rio Hondo and Rio Bravo joins a couple kilometers north of the area under study.

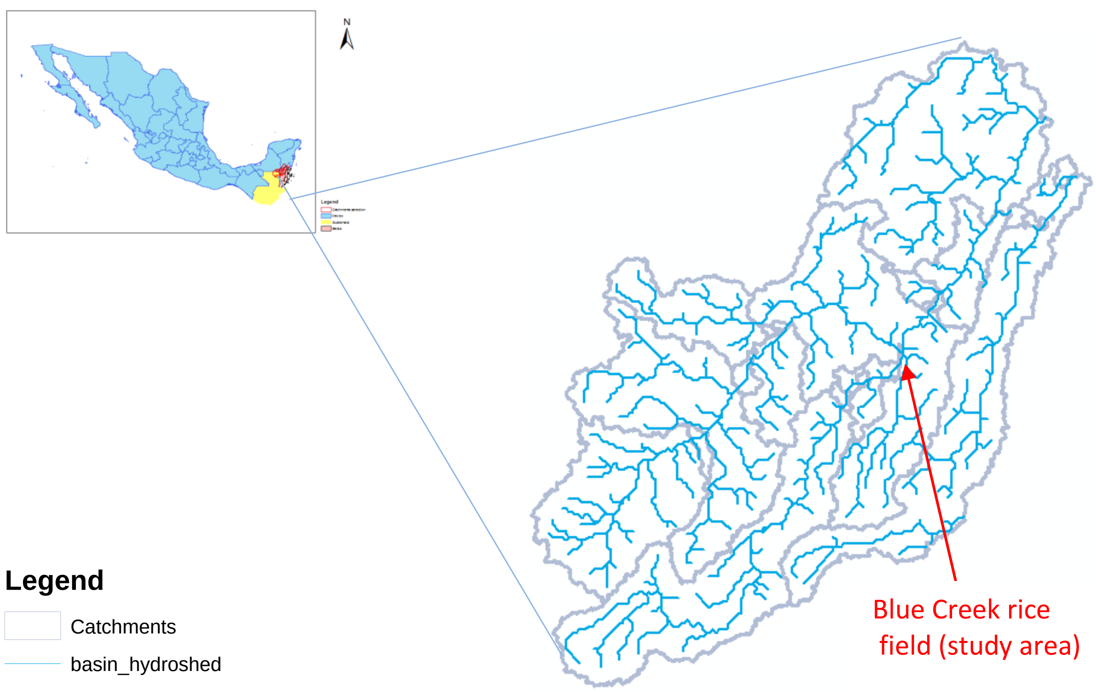


Figure 2. Transboundary watershed of Belize-Guatemala-Mexico Region
(Source: own elaboration based on BERDS, 2010)

Amongst the natural resources, water requires special management and attention given its importance in all Earth systems. Belize is recognized as the country with highest per capita water resources in the Americas (BEST, 2012) given its geographic location, low population, relatively dense forest cover and 18 different water catchment areas (BMS, 2010). A study performed by Fabro et al, 2011 showed that there is steady decline of the water resources per capita; where in 1987 it stood at 91,324 cubic meters and in 2009 at 48,019 cubic meters. Almost 95% of the freshwater supply derives from groundwater (UNSCD, 2013). According to BEST (2012), the existing groundwater aquifers and their annual recharge rate have not been quantified adequately. At the same time, Belize lacks standards to determine water quality and efficiency use for a better water management program, highlighted by the National Integrated Water Resource Management Policy in UNSCD (2013) and its need to perform a comprehensive assessment and water quality baseline development.

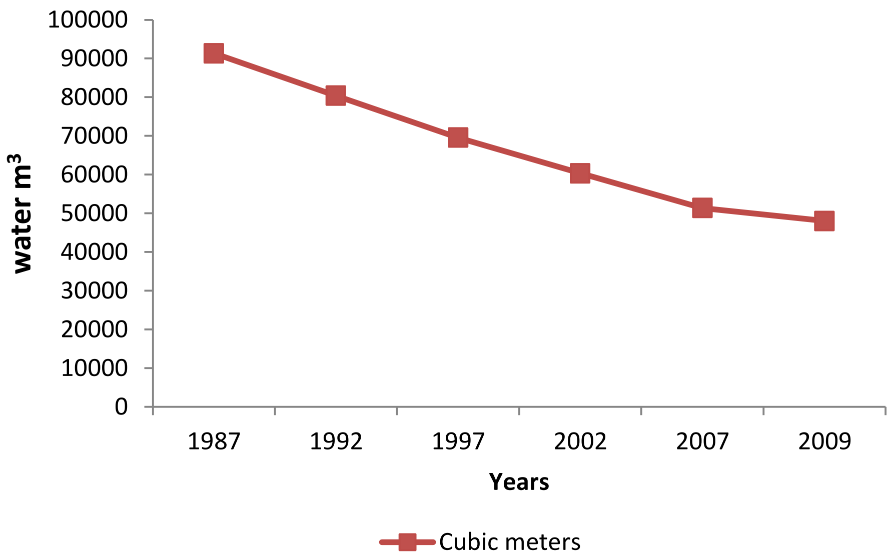


Figure 3. Renewable water resource in Belize 1987 - 2009
(Source: Aquastat FAO)

2.1.3. Soil Classification

The soils of the region are mainly consisting of fine and medium textured soils. According FAO in the soils classification, the predominant soil type within the basin is shown in Fig. 3; from these the Vertisols (Vp34-3a), Gleysol (Lg31-2a) and Cambisol (Bc4-3bc) occupy most of the area. Vertisols are characterized as *'mineral soils that have a mesic, isomesic or warmer soil temperature regime;…physical characteristics of Vertisols are particularly important, especially water-holding capacity, which in turn reflects their ability to store water by swelling.*', U.S. Soil taxonomy (1978). According to FAO, Cambisols '*are* *characterized by the absence of a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides. They differ from unweathered parent material in their aggregate structure, color, clay content, carbonate content, or other properties that give some evidence of soil-forming processes.*'. Same article refers to Gleysols as being '*formed under waterlogged conditions produced by rising groundwater. In the tropics and subtropics they are cultivated for rice or, after drainage, for field crops and trees*.' Figure 4 illustrates the main types of soil in the region, northern Belize, where the study area is located. The study area

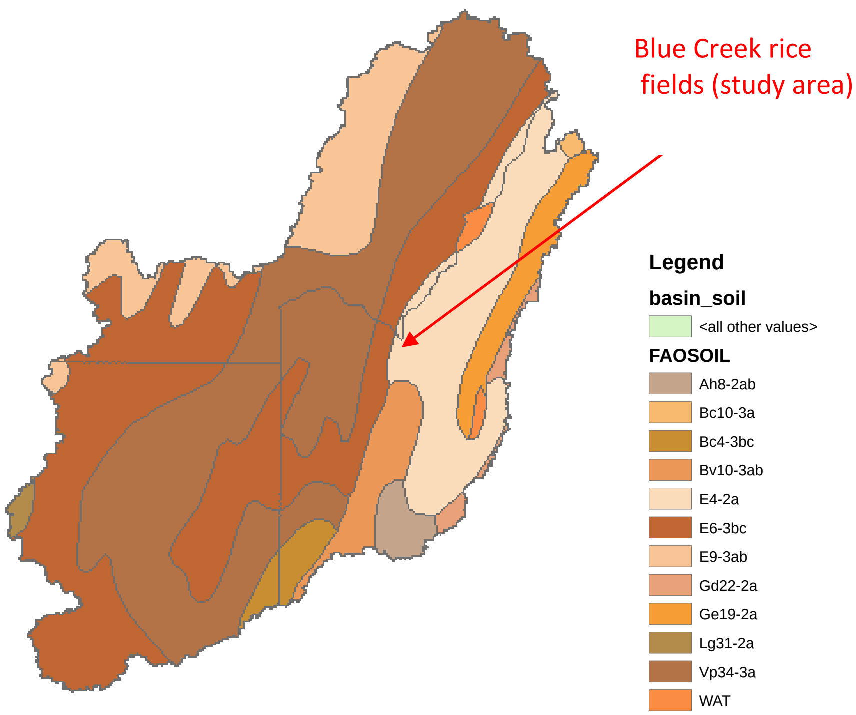


Figure 4. Types of soil in transboundary watershed Belize-Guatemala-Mexico Region
(Source: Own elaboration based on FAO's World Soil Classification)

2.2. Origin and Geographic distribution of Rice

Oryza sativa L. was domesticated from the wild grass *Oryza rufipogon* L. roughly 10,000–14,000 years ago. The two main subspecies of rice – indica (prevalent in tropical regions) and japonica (prevalent in the subtropical and temperate regions of East Asia) – are not believed to have been derived from independent domestication events. Another cultivated species, *O. glaberrima* L., was domesticated much later in West Africa **(**GRiSP, 2013**)**

Rice is non-native to Latin America but was introduced by European colonizers; Spaniards to Mexico, Portuguese and African slaves to Colonial Brazil. It is reported that Africans played an important role in establishing rice in the New World, making it an important crop from the early period, thereby spreading it through the Americas (GRiSP, 2013).

It is reported that the rice cultivation was introduced in Belize (formerly known as British Honduras) by the British in the 18th century, since the slaves working in the mahogany industry were cultivating the crop in 1809 (Bolland & Shoman 1975). Towards the end of the 19th century, the Mayas were already cultivating the crop. In 1919, efforts to grow rice in central Belize were done, thus expanding throughout the Belize River valley by Creole settlements, which grew it in half acre plots. A few years later, rice production had expanded to southern Belize, implementing the milpa system. By 1938, Belize received assistance from British Guiana for improving the rice production by determining suitable areas and varieties of production (Smith, 2013).

As per recommended, southern Belize became the most suitable area for production, thus being heavily subsidized by the government to shift from milpa system to mechanized farming, via assisting farmers with machinery. New rice varieties were also introduced from El Salvador and Colombia. Rice became successful that in 1972, Belize became self-sufficient and was even exporting to Jamaica. Unfortunately, some farms in southern Belize faced a financial crisis in 1982, forcing Belize to import 2.6 million lbs of rice (Smith, 2013).

Before the crisis, in 1978, Mennonites began rice production in Blue Creek, Orange Walk District. They began production at a large scale, heavily investing in machinery (tractors, combines, etc.), irrigation and pumps. Rice soon became a good investment for Mennonites, that up to date they have improved rice production to a better standard. Mennonite communities and small farmers (Creoles, Mayas, East Indian) have contributed significantly to Belize rice industry, making it self-sufficient once more in 2002 (Smith, 2013).

2.2.1. Growth and development

Germination (IRRI)

Seeds require adequate moisture and temperatures ranging 10 - 40°C, in order to break its dormancy seed stage and begin its metabolic processes. Germination occurs when the first shoot and root emerge from the seed, point when the plant starts to grow. Given the different methods of planting, when seeds are planting in dry ground, the roots emerge first then the shoot from the seed. Whenever seed are planted into flooded conditions, the shoot emerges first and once it has reached air, the roots begin to develop.

Vegetative phase (IRRI)

After emergence until the beginning of tillering, is considered the seedling stage. The vegetative phase is characterized by the development leaves, in the case of rice plants; it also involves its tillers. Tillering may begin from 20 days and reach maximum tillering around 40 days after planting. Depending on the variety, plants have high tillering capacity and longer period of vegetative growth. Once at maximum tillering, the stems begin to elongate, which may be characterized as panicle initiation, also a part of vegetation.

Reproductive phase (IRRI)

After panicle initiation, the stem elongates more, while developing the panicles with its respective spikelets or grains. Plants begin to flower around 65 – 95 days after planting, depending on the variety, this can be identified a few days prior, due to the swelling of the stem, known as booting stage. Flowering commence one day after heading is completed. Once the flowers are out, pollination occurs, which may continue for about 7 days.

Ripening phase (IRRI)

The ripening phase starts at flowering and ends when the grain is mature and ready to be harvested. This stage usually takes 30 days. Flowering and grain filling is sensitive to low temperatures and rainy days by prolonging the phase. Meanwhile sunny and warm days may shorten it.

Ripening follows fertilization and can be subdivided into milky, dough, yellow, ripe, and maturity stages. These terms are primarily based on the texture and color of the growing grains. The length of ripening varies among varieties from about 15 to 40 days. Ripening is also affected by temperature, with a range from about 30 days in the tropics to 65 days in cool temperate regions.

2.3. Water Requirement

Rice production is performed under two systems: rainfed or irrigation in upland or lowland areas. Water is essential for rice production, that it requires an average of 1,432 liters of water to produce 1 kg of rice. Irrigated rice receives an estimated 34−43% of the total world's irrigation water, or about 24−30% of the entire world's developed fresh water resources. Heavy clay soils may require an input of as little as 400 mm and more than 2000 mm in coarse-textured soils (IRRI).

Rice can be grown under flooded conditions, this helps in avoiding plant water stress, like weed control. Water requirement increases with crop stage, which varies in regions and forms of production (Maruyama et al, 1997). To calculate the requirement, it is necessary to know the precipitation, evaporation, seepage and percolation, rice water requirement, like the necessary established water layer in field for optimum production (Brouwer, 1986). In addition, the necessary agronomic practices must be considered when draining or flooding fields.

2.3.1. Irrigation

Upon determining the water requirement, the amount of water required for irrigation can be calculated by obtaining the following info.

<u>Step 1</u>: Determine the reference crop evapotranspiration: ETo

<u>Step 2</u>: Determine the crop factors: Kc

<u>Step 3</u>: Calculate the crop water need: ET crop = ETo × Kc

<u>Step 4</u>: Determine the effective rainfall: Pe

<u>Step 5</u>: Calculate the irrigation water need: IN = ET crop - Pe

Crop's water requirement should be supplied by irrigation or rainfall, but water is also needed for: saturation of the soil before planting, percolation and seepage losses and establishment of a water layer**.** Obtaining the above information, helps in determining the irrigation interval, this may avoid stressing rice plant due to shortage of water. At the same, it can help in improving water-use efficiency (Brouwer, 1986).

2.3.2. Water quality

Most water bodies contain soluble salts and trace elements which originate from the natural weathering of the earth's surface (Fipps, 2003). Irrigation's water quality primary concern is the salinity level, given that salinity can affect soil structure and crop yield, thus limiting the water use for irrigation (Tyagi, 2003), in addition to trace element levels.

In agriculture, the use of water is essential for optimum plant's development under irrigation systems. Irrigation water should comply with certain standards. Standards are primarily based on the electrical conductivity - EC (dS/m) or totally dissolved solids - TDS (ppm) plus the amount of cations and anions capable of forming salts, which may be precipitated when in contact with soil (Hussain et al, 2010; Fipps, 2003). Primary water quality guidelines are provided by Ayers & Westcott (1974), USDA (1954) Wilcox (1948), and Thorne & Thorne (1951). Ayers & Westcott provide a detailed guideline for the calculation and interpretation of water quality for irrigation, as illustrated in Table 2 & 3. These tables determine the optimum range of parameters, thereby classifying the water to its degree of restriction use (none, slight to moderate and severe).

Table 2. Guidelines for interpretation of water quality for irrigation (Source: Ayers & Westcott (1974))

Potential Irrigation Problem				Units	Degree of Restriction on Use		
					None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*							
	EC_w			dS/m	< 0.7	0.7 – 3.0	> 3.0
	(or)						
	TDS			mg/l	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*							
SAR	= 0 – 3	and EC_w	=		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6		=		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12		=		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20		=		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40		=		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*							
	Sodium (Na)						
	surface irrigation			SAR	< 3	3 – 9	> 9
	sprinkler irrigation			me/l	< 3	> 3	
	Chloride (Cl)						
	surface irrigation			me/l	< 4	4 – 10	> 10
	sprinkler irrigation			me/l	< 3	> 3	
	Boron (B)			mg/l	< 0.7	0.7 – 3.0	> 3.0
	Trace Elements (see Table 21)						
Miscellaneous Effects *(affects susceptible crops)*							
	Nitrogen (NO_3 - N)			mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)						
	(overhead sprinkling only)			me/l	< 1.5	1.5 – 8.5	> 8.5
	pH				Normal Range 6.5 – 8.4		

Table 3. Laboratory determinations for interpreting irrigation water quality problem.
(Source: Ayers & Westcott (1974))

Water parameter	Symbol	Unit[1]	Usual range in irrigation water	
SALINITY				
Salt Content				
Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
(or)				
Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO^{--}_3	me/l	0 – .1	me/l
Bicarbonate	HCO_3^-	me/l	0 – 10	me/l
Chloride	Cl^-	me/l	0 – 30	me/l
Sulphate	SO_4^{--}	me/l	0 – 20	me/l
NUTRIENTS				
Nitrate-Nitrogen	NO_3^-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4^-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Basicity	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio	SAR	(me/l)	0 – 15	

[1] dS/m = deciSiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/centi-metre)

In addition, the United States Department of Agriculture produced another guideline that is very useful in determining the different classes of irrigation water. The guideline is based on different levels of electrical conductivity and sodium content, the latter is evaluated as sodium absorption ratio (SAR). Figure 5 shows the different classification. Considering the electrical conductivity and sodium level, water can be classified as follows (USDA, 1954, p.79-81):

Low salinity water (C1): can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium salinity water (C2): can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High salinity water (C3): cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

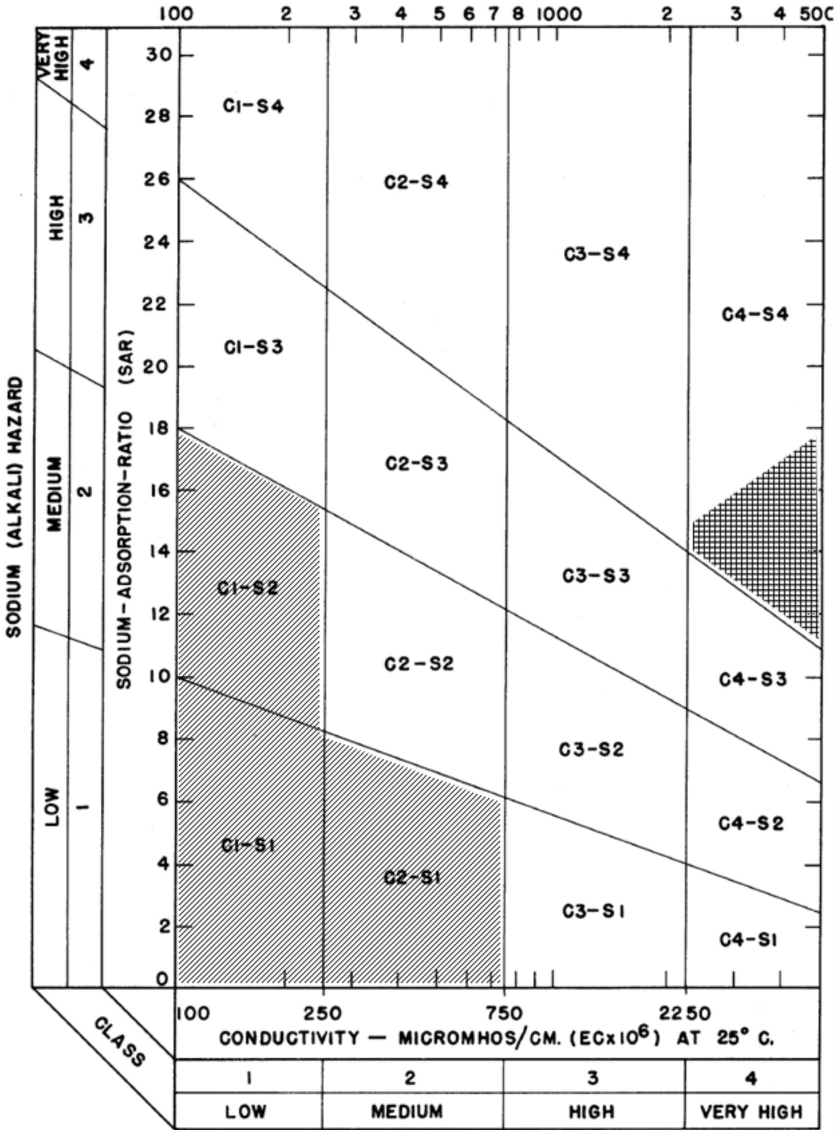
Very high salinity water (C4): is not suitable for agriculture under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, adequate drainage, irrigation water must be applied in excess to provide considerable leaching, and very salt tolerant crops should be selected.

Low-sodium water (S1); can be used for irrigation on almost all soils with little danger of development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentration of sodium.

Medium-sodium water (S2): will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low leaching condition, unless gypsum is present in the soil. This water may be used on coarse textured or organic soils with good permeability.

High-sodium water (S3): may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic matter additions. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with water of very high salinity.

Very high-sodium water (S4): is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of the water feasible.



Good quality water for irrigation Water to be used with precaution Not suitable for irrigation

Figure 5. Water classification scheme provided by USDA (1954)
(Source: USDA, 1954)

Water analysis permits to understand the concentration of cations and anions present. This may be performed through calculation of ion speciation and modeling programs. Ion speciation defines the chemical reactivity in a solution (Stumm & Morgan, 1981). In natural waters, the main precipitated salts are shown in table 4. These salts can accumulate in the soil when water evaporates from the surface, plants use it, leaching deficient, and precipitation is not enough for washing of salts (Bauder et al, 2008).

Table 4. Primary salts formed in Natural waters
(Source: Bauder et al, 2008)

Salt	Symbol	Common Name
Sodium chloride	$NaCl$	Table salt
Calcium chloride	$CaCl_2$	Common deicing agent
Magnesium chloride	$MgCl_2$	Common deicing agent
Sodium sulfate	Na_2SO_4	Thenardite; Galuber's salt when hydrated
Calcium sulfate	$CaSO_4$	Gypsum
Magnesium sulfate	$MgSO_4$	Epsom salt
Sodium bicarbonate	$NaHCO_3$	Baking soda
Calcium carbonate	$CaCO_3$	Limestone
Calcium-magnesium carbonate	$CaMg(CO_3)_2$	Dolomite

2.3.3. Salinity stress in plants

Plants absorb water through its entire surface – leaves, stems and roots. Primary absorption occurs via the roots by exerting and absorptive force greater than the soil's (Ayers &Westcott, 1984). Whenever salts are present in the water-soil medium, the plant must exert a greater force, thus called the osmotic effect or osmotic potential. Salinity affects plant growth through osmotic stress, thereby limiting water uptake and excessive uptake of ions (Levitt, 1980) Limiting water absorption can cause a reduction in plant's growth and development and yield reduction. In cases where salinity is very high, leaf edges may become necrotic, thus leading to plants death (Bauder et al, 2008)

Rice plants are considered sensitive to salt stress. At salinity levels of 3.0 dS/m, it can adversely affect rice plants (Maas & Hoffman 1977). Plant's physiological response to salinity levels differ according to development stage. It is known that high salinity levels can affect rice .plants during the germination phase through the absorption of high salt content. During the tillering, panicle initiation, flowering and grain filling stage are highly sensitive phases of rice development to salinity stress (Rad et al, 2012; Grattan, 2002).

2.4. Sustainable Agriculture

The term sustainable agriculture (SA) has been highly debated given its use in different agricultural systems. Authors like Pretty (1995), Gliessmann (2005) and others concur that the term managed includes biodynamic, community based, ecoagriculture, ecological, environmentally sensitive, extensive, farm fresh, free range, low input, organic, permaculture, sustainable and wise use resources. To define SA, the following key principles provided by Pretty (2008, p. 451) are utilized:

“(i) *integrate biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy, competition, predation and parasitism into food production processes,*
(ii) minimize the use of those non-renewable inputs that cause harm to the environment or to the health of farmers and consumers,
(iii) make productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs, and
(iv) make productive use of people’s collective capacities to work together to solve common agricultural and natural resource problems, such as for pest, watershed, irrigation, forest and credit management.”

2.5. Crop modeling

The rapid changing environments in agriculture production are uncertain. In order to keep up, modeling programs have been developed to assist in simulating crops behavior in different scenarios. Crop modeling programs are powerful tools for identifying potential yields (Droogers & Hunink, 2012). At the same time, models can assist in evaluating and reducing time intensive and expensive field experiments (Whisler et al. 1986). In addition, crop modeling results in terms of performance, management and yield estimates can help decision makers to decide optimum location and provide information to farmers of which management system is suitable (Sarangi, 2012).

Agricultural models frequently utilized are: CERES, DSSAT, CropWat, CropSyst, SWAP/WOFOST and AquaCrop (Hunink & Droogers, 2011). These models are capable of simulating crop growth for a range of crops. They may differ in their physical process representation and its main focus. Modeling may include analysis of fertilizer use, crop varieties, farmer's practices, climatic conditions, water availability and stresses. These models can also be user-friendly and some may require more parameters than others, where data availability may influence in the choice of model (Nikolaus, 2013).

In order to simulate the crop's response to water, an attempt to implement the AquaCrop program developed by the Land and Water Division of FAO was chosen. AquaCrop can perform various application, of the following will aid in the development of this research (Steduto, 2012):

- assessing water-limited, attainable crop yields at a given geographical location
- as a benchmarking tool, comparing the attainable yields against actual yields of a field, farm, or region, to identify the yield gap and the constraints limiting crop production
- developing irrigation schedules for maximum production (seasonal strategies and operational decision-making), and for different climate scenarios
- evaluating the impact of fixed delivery irrigation schedules on attainable yields
- simulating crop sequences
- carrying out future climate scenario analyses
- optimizing a limited amount of water available (economic, equitability, and sustainability criteria)

2.5.1. Aquacrop

AquaCrop was developed to replace the approach developed by Doorenbos and Kassam (1979), which relates yield response to water deficit of field, vegetable and tree crops. Among the significant departures of the model from its precursors is that it separates 1) the ET into soil evaporation (E) and crop transpiration (T) and 2) the final yield (Y) into biomass (B) and harvest index (HI). The separation of Y into B and HI allows the distinction of the functional relations between the environment and B from those between environment and HI. One of the important key features of AquaCrop is the simulation of green canopy cover (CC) instead of leaf area index (LAI). The impact of water deficit is expected to be accounted for by the variation of the green LAI. This variable is critical in plant modeling (Duchemin *et al*., 2008). The CC must be monitored at the field given that the model uses canopy ground cover instead of LAI, In AquaCrop, the inputs are saved in climate, crop, soil type, management (irrigation) and initial soil water condition files. Certain parameters do not change; remain constant, such as water productivity, harvest index, canopy development coefficient and transpiration. The locations and cultivar-dependent parameters, as well as weather data, irrigation schedule, and planting density are referred to as user defined parameters (Raes *et al*., 2009a).

Aquacrop has water a driving force of growth, considering water productivity plus crop evaporation, as the main component for biomass production. FAO, 2011 states that the program "to be functional, Eq. 1 was inserted in a complete set of additional model components, including: the soil, with its water balance; the crop, with its development, growth and yield processes; and the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration. Additionally, some management aspects are explicitly considered (e.g., irrigation, fertilization, etc.), as they will affect the soil water balance, crop development and therefore final yield. AquaCrop can also simulate crop growth under climate change scenarios (global warming and elevated carbon dioxide concentration) while pests, diseases, and weeds are not yet considered. The functional relationships between the different model components are depicted in Fig. 4."

$$(1 - \frac{Ya}{Yx}) = Ky(1 - \frac{ETa}{ETx)}) \qquad (1)$$

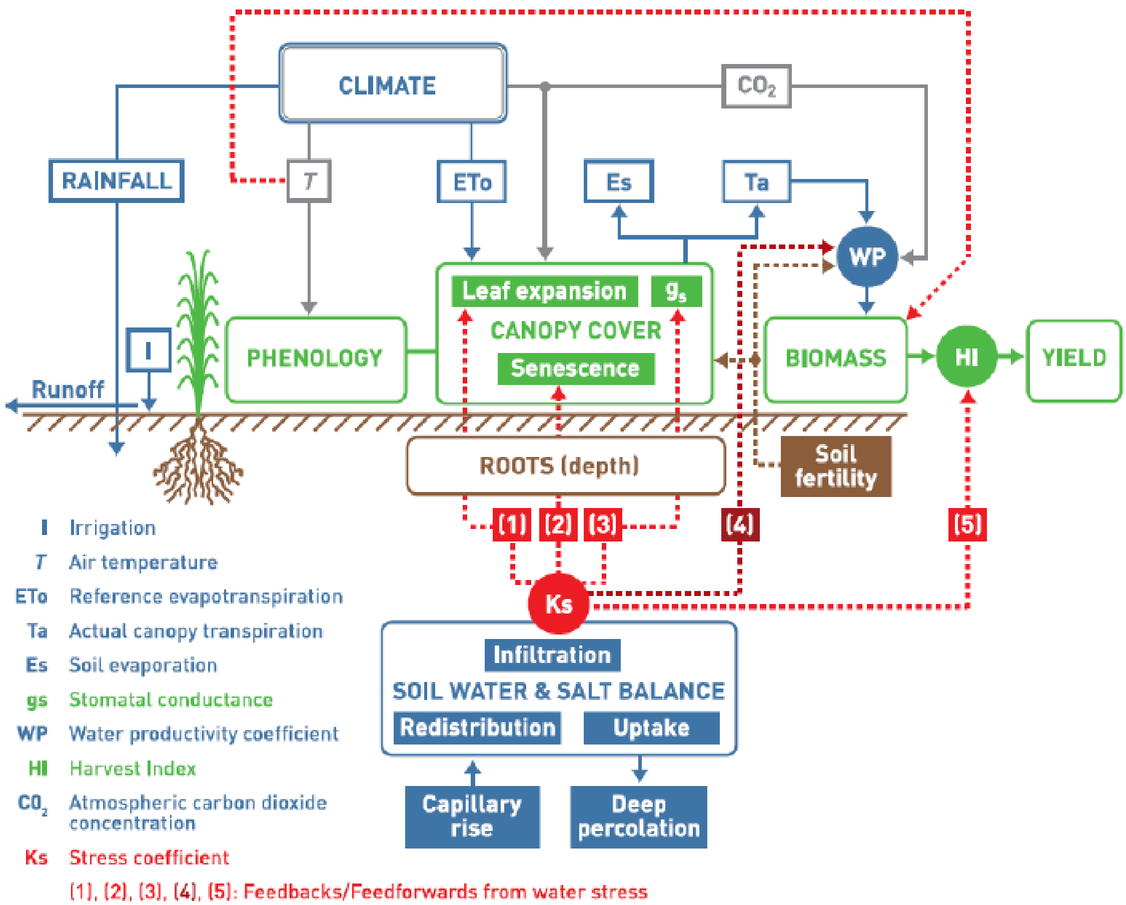


Figure 6. AquaCrop's modeling component and its relationship
(Source: Steduto et al, 2010)

The parameters incorporated in AquaCrop include infiltration of water, drainage out of the root zone, evaporation and transpiration rate, biomass production and yield formation. Simulation can be paused by users at intervals to observe the response of crop growth to the change in water. AquaCrop simulates output hydrological parameters including soil water content in the profile and in compartments and net irrigation requirement (Raes et al, 2009). Additionally, users can use AquaCrop for simulating crop sequences and analyzing future climate scenarios (FAO, 2011).

The functional relationships between the different AquaCrop components are represented in Figure 6. The atmosphere and the soil components are largely in common with many other models. The plant component and its relations to soil water status and evaporative demand of the atmosphere are more distinctive, with effects of water stress separated into four elements, that on leaf and hence canopy growth, on stomata opening and hence transpiration, on canopy senescence and on harvest index (Steduto, 2009).

Aquacrop model has been recognized for use in rice and defined its overall calibration grade for rice (Raes et al, 2010). Amiri et al, (2014), Nikolaus (2013), Cortes (2013) have succesfully calibrated AquaCrop for use in rice in different regions, Iran, Benin and Colombia, respectively. The versatility of Aquacrop has been implemented in cotton, maize, wheat, eggplant, amongst other crops.

3. Material and methods

This research was performed at Paul's Dyck field in Blue Creek, Orange Walk District, Belize through the assistance of Circle R Products Ltd, who assisted in some of the data collection during the period January – June, 2013. The following flowchart was implemented for the development of this study.

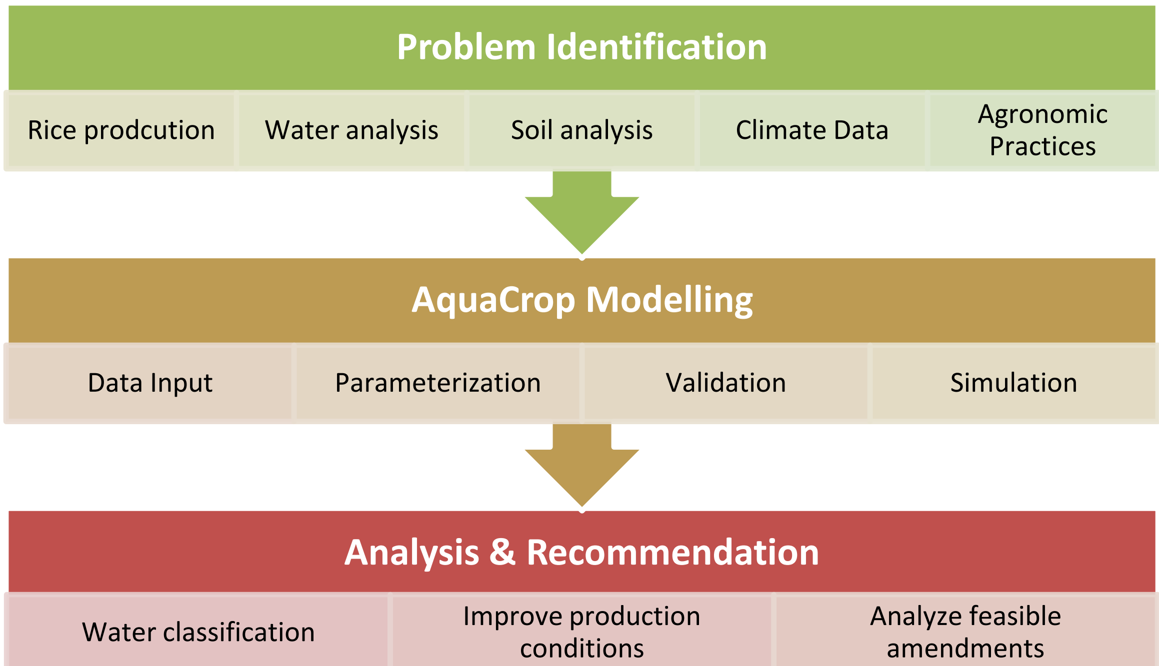


Figure 7. Research flowchart

3.1. Experimetnal Location

The study was conducted at a rice farm located in the community of Blue Creek in the northern part of Belize. The experimental site was situated at 17^{o}52'13.84"N and 88^{o}51'14.80"W at an altitude of 6 meters above sea level. The experiment was set up on a rice field located in the community of Blue Creek, Orange Walk District. The rice field comprises of 700 acres, of which, 120 acres was divided into 3 replicas; as shown in the diagram below demarcated in yellow lines.

Figure 8. Paul's Dyck field map
(Source: Google earth)

Blue Creek Village belongs to the Northern Coastal Plain which is underlain by Cenozoic limestone, decreasing in age and hardness. The natural forest over limestone is semi-deciduous broadleaf forest, but there are also large areas of pine forest and orchard savannah over leached soils from Pleistocene alluvium. The altitude ranges from sea level to 20 m, with local maxima of 40 m. Classification obtained from King et al. (1992). The rice field belongs to a lowland area, comprising of different vegetation and soil classifications.

3.1.2. Climatic Features

Belize is under a tropical climate region. Belize's yearly average temperature is approximately 27 C, bearing maximum of 34 and a minimum of 15 between the months of

May-August and December-February, respectively. During the cropping season, 22 January (Day 1) – May 6 (Day 106), temperatures peaked 33.6 in April and its lowest 17.9 in March (Figure 9). Planting period coincides with the months of lowest rainfall, hence it need for irrigation. A total of 170 mm was accumulated in the first trimester of the year, April being the lowest with 5.9 mm. The relative humidity followed a similar pattern in comparison to the accumulated precipitation, ranging from 86.4% to 73.8%, the former for January and the latter for April. The total monthly sunshine hours peaked in April, 279.8 hours; meanwhile the lowest was recorded in the last trimester of the year. Consequently, the highest evaporation rates were recorded in the months of April and May.

3.1.3. Soil Classification

The area of study belongs to the northern plains of Belize. King et al, 1992, classified the area under the Tintal Suite and Sibal Subsuite. Area that contains herbaceous swamps, savannah plain and marsh forest plain. Sibal soils are characterized by having a clayey texture, dark colors, poor drainage, plasticity when wet and shrinking when dry. These are similar characteristics of Vertisol soils, which are the FAO, 1988 classification for the study area. FAO's description include very slow saturated hydraulic conductivity, soil compaction resulting from swelling (when wet), available water capacity, and possible salt content, amongst others. These characteristics are limiting to agricultural production.

Table 5. Soil classification for area under study
(Source: King et al, 1992, FAO and USDA)

Belizean Classification (King et al, 1992)		International Classification	
Suite	Subsuite	FAO/UNESCO, 1988	USDA, 1978
Tintal	Sibal	Pellic Vertisols, including Vertic cambisols, Eutric and Mollic Gleysols	Vertisols

3.2. Agricultural Practices

Rice production includes numerous mechanical operations for large scale production. Activities such as disking, plowing, harrowing, and land leveling are performed before planting. The AquaCrop modeling program requires some practices done during the crop cycle, beginning from the method of planting and amount, amount of water required and interval of application, and fertilization.

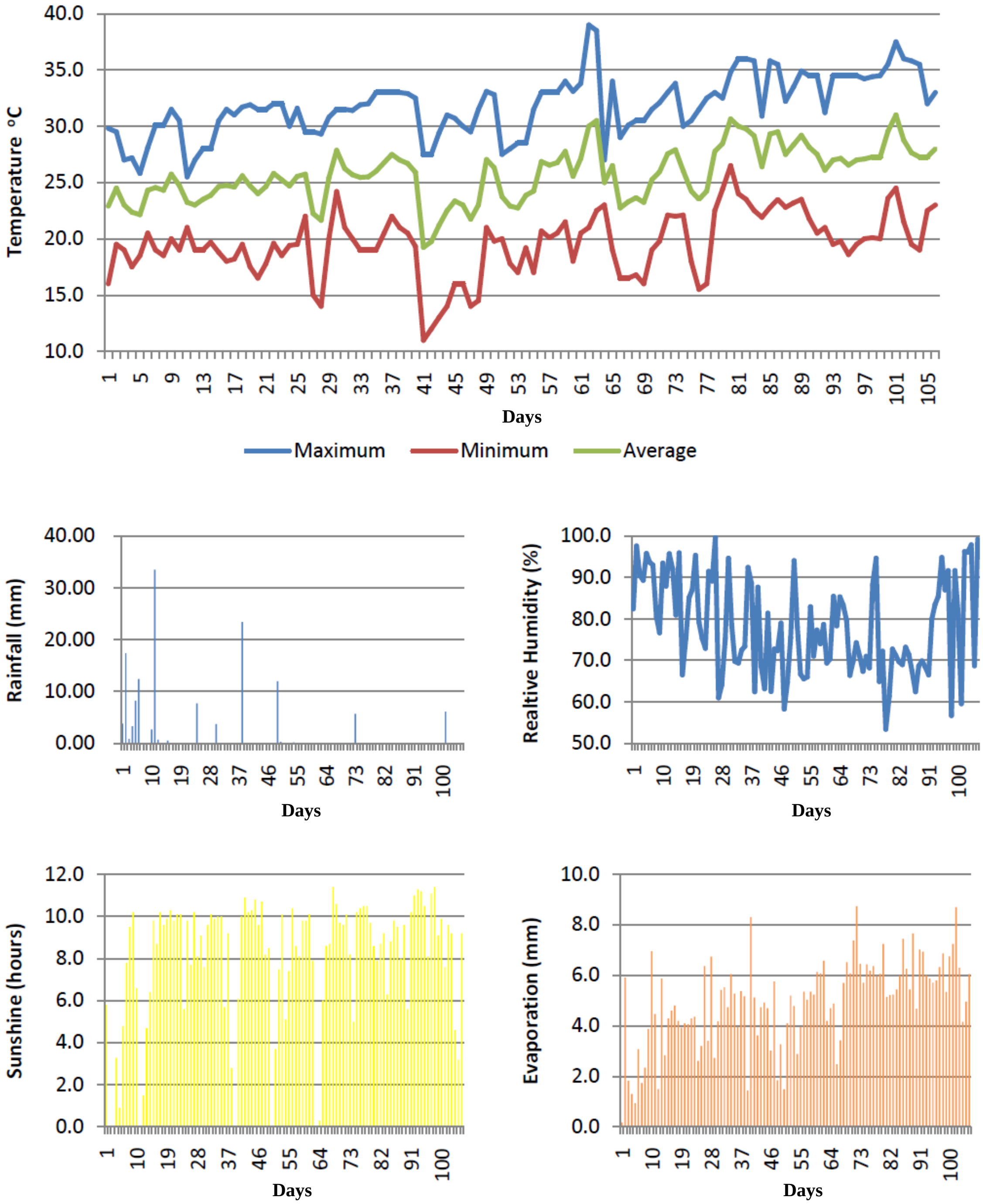


Figure 9. Daily climate parameters for Blue Creek, Belize
(Source: Own elaboration; data from Belize Sugar Industries)

3.3. Irrigation

The rice seeds are broadcasted on dry ground. Once completed, the fields are flushed to field capacity for seeds to germinate. One the crop is established, irrigation is carried out every 10-15 days, depending on agronomic practices to be performed and weather pattern. During the growing season, a water layer of 50 mm is maintained until 2 weeks before harvest.

3.4. Water Analysis

To further analyze the problematic, a series of water samples were collected at the entrance of the rice field, likewise at the exit, which is discharged into a canal (Fig. 9). The samples were collected five times, which are the instances that an irrigation practice is performed. These were analyzed by Bowen and Bowen laboratories in Belize. Table 6 shows the parameters measured and its method

In Belize, water quality standards have not been determined (BEST, 2012) for agriculture use. In order to classify the irrigation water for the study area, the parameters and standards provided by Ayers & Westcott, 1984 was implemented, as shown in Table 2 and 3; the USDA classification was also included, Figure 5; as per mentioned in chapter 3.

3.5. Ion speciation

The analyzed water parameters and its concentration were also utilized to calculate the ionic strength and the capacity of forming compounds. This was done to find out which would be the predominant salts formed. The following equations help in the calculation.

$$I = \frac{1}{2} \cdot \sum c_i \cdot Z_i^2 \quad (2)$$

where:

I = ionic strength

c_i = concentration of the ith species, mole/L

Z_i^2 = valence (or oxidation) number of the ith species

The activity coefficient is calculated with equation (3):

$$\log(\gamma) = -\frac{0.5 \cdot (Z_i)^2 \cdot \sqrt{I}}{1+\sqrt{I}} \text{ so } \gamma = 10^{-\log(\gamma)} \quad (3)$$

γ =activity coefficient

Source: Stumm & Morgan, 1981

These concentrations were also computed through the Visual MINTEQ chemical modeling program.

Table 6. Laboratory Water Analysis

(Source: Bowen & Bowen laboratories)

Physico-chemical Parameters	Unit	Method
Conductivity	µs/cm	Conductivity(probe)
Total Dissolved Solids (TDS)	mg/l	Conductivity (probe)
pH	unit	pH/ISE meter (probe)
Turbudity	ntu	Nephelometric -Tungsten
Metals	Unit	Method
Calcium (Ca)	mg/l	UV VIS Spectro/ Titration
Magnesium (Mg)	mg/l	UV VIS Spectro / Titration
Sodium (Na)	mg/l	Probe
Non-metals	Unit	Method
Phosphorus, total (P)	mg/l	PhosVer / Orthophosphate/ UV VIS Spectro
Chlorine ,total (Cl_2)	mg/l	UV VIS Spectro / DPD
Inorganic compounds	Unit	Method
Bicarbonate (HCO_3)	mg/l	Titration
Nitrate	mg/l	Cadmium Reduction/ UV VIS Spectro
Salinity	ppt	Mercuric Nitrate Titration
Sulphate (SO_4)	mg/l	Sulfa Ver 4/ UV VIS Spectro

Figure 10. Point of water sample collection
(Source: Google earth and own markings)

3.6. Soil Analysis

Furthermore, soil samples were collected at the beginning of the crop cycle and at the end of it. The samples were collected randomly in the field and analyzed by the laboratory Agro Service International (ASI) implementing the methods described by Portch & Hunter (2002). In table 7, a summary of parameters measured are shown.

Table 7. Parameters measured for soil analysis.
(Source: Agro Services International Laboratory (Porth et al, 2002))

Physical	C.E.C (neq/100cm3)	pH (unit)	Base saturation (%)
	Organic matter (%)	Soluble salts (ppm)	Porosity (%)
	Infiltration rate (ins/hr)	Water retention (% by dry weight)	
	Bulk density (g/cc)	Texture (% of sand, silt, clay)	
Chemical	Calcium (meq/100cm3)	Magnesium (meq/100cm3)	Potassium (meq/100cm3)
	Sodium (ppm)	Nitrogen (ug/100cm3)	Phosphorus (ug/100cm3)
	Sulfur (ug/100cm3)	Boron (ppm)	Copper (ppm)
	Iron (ppm)	Manganese (ppm)	Zinc (ppm)

3.7. Aquacrop Model

The Aquacrop model was developed and updated by FAO for the assessment of water productivity and crop productions for different scenarios. Andarzain et al, 2011 implemented the program for crop growth simulation against a long series of past climatic data. The program also assists in simulating crop yields under various responses of rainfed or irrigated systems, like under conditions water scarcity or affluence (Steduto et al., 2009).

In order for the full functioning the modeling crop the following data was collected.

Table 8. AquaCrop input parameters

Crop	Climate	Soil	Management Practices	
			Irrigation	Field
Planting method Planting date Germination Flowering initiation and duration Grain physiological maturity Senescence Harvest Index Canopy cover Root depth Water productivity	Precipitation Temperature (maximum and minimum) Evapotranspiration CO2 concentration	Texture Horizons Hydraulic conductivity Field capacity Wilting point Saturation point	Irrigation method Irrigation schedule Water layer Water efficiency Water quality	Soil fertility Organic matter Water standing

The data collected was then inserted in the modeling program, following the flowchart below.

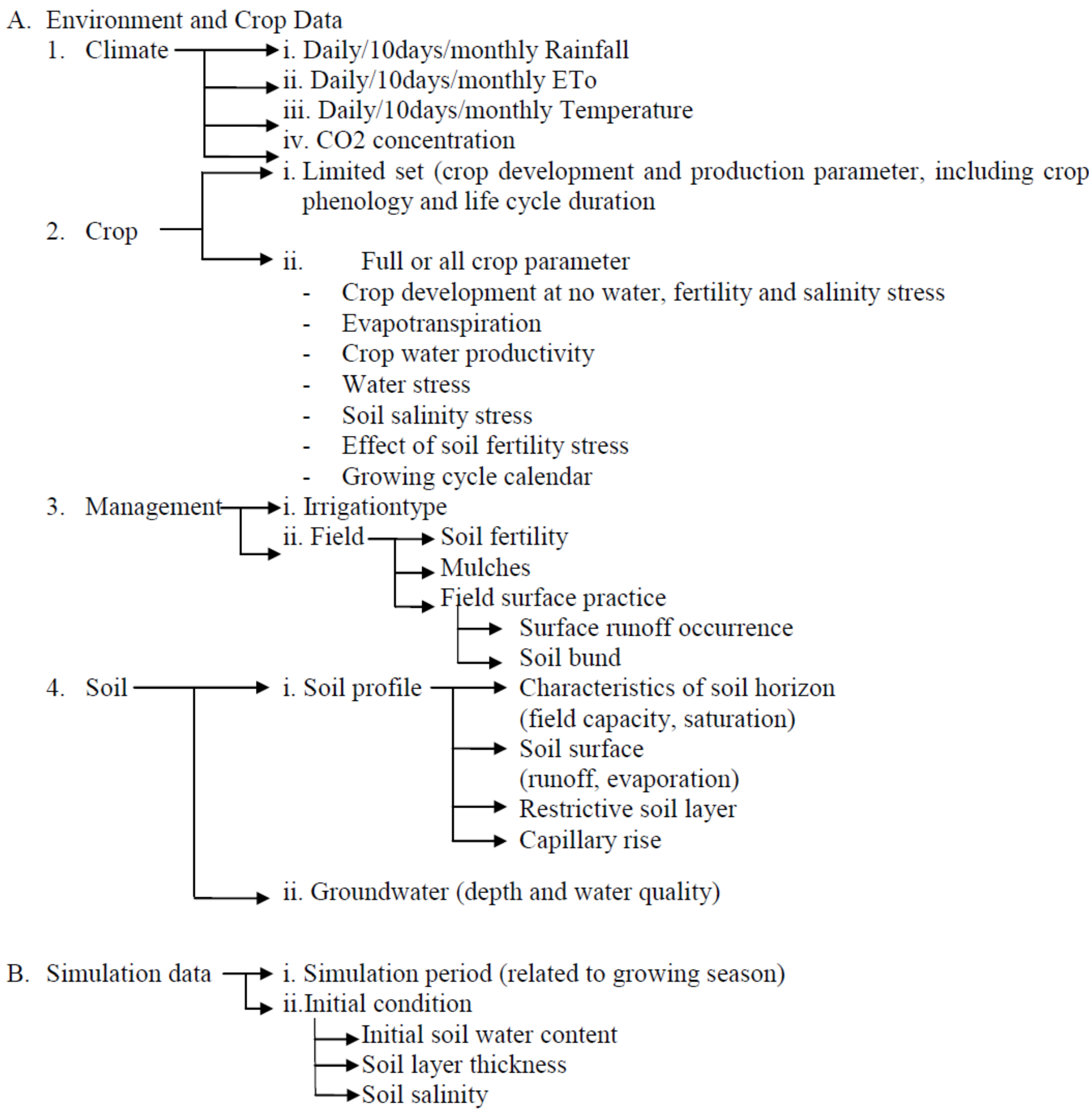


Figure 11. Procedures for running AquaCrop.
(Source: own elaboration based on Steduto, 2009)

All these input data were utilized in the model to predict rice yield, water productivity, biomass and harvest index, of which, the yield is compared to simulated and observed.

The collected data was analyzed via descriptive analysis and ANOVA.

4. Results and Discussion

Rice history in Belize began from late 19th century, since then, the cultivation practices have improved, from milpa system to fully mechanized and low-input to high-input crops. These changes are primarily observed with rice farmers from Blue Creek, O.W.D, Belize, whom since 1978 have managed to develop rice fields in lowland and upland areas, land leveling and levees uplift for water capturing. In lowland areas, close to rivers, it is prone to flooding, thereby farmers choose to plant during the dry season in Belize and aiding production with irrigation.

In the study area, an interview with the farmer was conducted to familiarize with the agronomic practices enforced over the years. During the experiment, the following practices were performed, as shown in table 9.

Table 9. Agronomic practices performed at study area.
(Source: Own elaboration)

Day	Activities	Rate
	Land Preparation: disking, plowing, harrowing, leveling, etc.	
0	Burndown herbicide	0.4 – 0.8 L/ha
	Base fertilizer application	170 – 225 kg/ha
	Planting of rice seed	110 kg/ha
1	Flooding and flushing of fields	Field capacity
3	Soil application of microorganisms, root stimulants and micronutrients	
14	Herbicide Application	
17	Nitrogen fertilizer application	70 – 110 kg/ha
19	Flooding of fields	25 mm
26	Soil application of microorganisms, root stimulants and micronutrients	
28	Granular fertilizer application (N, P, K)	110 kg/ha
29	Flooding of fields	50 mm
35	Fungicide and foliar fertilizer application	
42	Granular fertilizer application (N, P, K)	110 kg/ha
43	Flooding of fields	50 mm
45	Foliar fertilizer application	
58	Foliar fertilizer application	
60	Granular fertilizer application(N, P, K)	110 kg/ha
61	Flooding of fields	50 mm
70-75	Fungicide, insecticide and foliar fertilizer	

	application	
76	Flooding of fields	75 mm
95 - 105	Harvest	

As observed above, different agronomic practices are performed periodically. In terms of fertilizer use, they are applied according to the crops requirements. Given that phosphorus becomes slowly available once applied, most of it applied at base fertilization, 55 kg/ha. As the crop develops, mostly nitrogen based fertilizer is applied, up to 145 kg/ha. Potassium is applied during the base fertilization and throughout the growing cycle, 60 kg/ha. On the other hand, various micronutrients are applied throughout the season as foliar applications. This done to meet the crop needs, for example, Zinc is applied few days after planting and again after tillering (3 and 26 DAP).

In terms of agrochemicals, herbicides are applied at the initial phase, in order to burndown any weeds before planting. Another herbicide is performed before tillering, in this season, a herbicide based on propanil and clomazone was used. An adequate control was achieved.

Fungicides are applied in two occasions: after tillering and at 5% heading stage. These are carried out as a preventative measure and crop boost. Insecticides are applied whenever foliar feeding is required or in the case that an insect outbreak occurs.

Other practices involved are flooding and draining of fields when necessary. Normally, fields are flooded and the n let dry through evaporation. Once saturation or field capacity level is obtained, flooding performed again.

4.1. Water Quality

Rice production can be performed under rainfed or irrigation condition. Irrigated agriculture is dependent on the water quality and availability (FAO, 1984). FAO (1984) produced a series of guidelines for analyzing chemical and physical properties to determine its suitability in agriculture. Given the nature of rice plants, capable to grow under anaerobic conditions, it requires vast amount of water, executing between 1500 – 5000 liters/kg of paddy rice, depending on soil type, local climate and rice variety (IRRI).

Considering the provided guidelines, the following water quality parameters were determined and analyzed, Table 10.

Table 10. Irrigation water analysis

PHYSICAL	Unit	Value	Range (FAO)	Status
Electrical Conductivity	dS/m	2.79	0-3	Slight to moderate
Total Dissolved Solids (TDS)	mg/l	1394.3	0-2000	Slight to moderate
pH	unit	7.5	6-8.5	Adequate
Turbidity	ntu	0.4		Very low
Sodium Absoption Ratio	meq/l	0.037	0-15	Very low
METALS	**Unit**			
Calcium (Ca)	mg/l	76.87	0-20	High
Magnesium (Mg)	mg/l	34.62	0-5	High
Sodium (Na)	mg/l	0.28	0-40	Adequate
NON-METALS	**Unit**			
Phosphorus, Total (P)	mg/l	0.5	0-2	Adequate
Chlorine Total (Cl_2)	mg/l	0.0005	0-30	Adequate
INORGANIC COMPOUNDS	**Unit**			
Bicarbonate (HCO_3)	mg/l	3.24	0-10	Adequate
Nitrate	mg/l	5.3	0-10	Slight to moderate
Salinity	mg/l	100		Low
Sulfate(SO_4)	mg/l	26.79	0-20	High

Water quality may be determined by physical, chemical and biological properties. The water implemented for rice production in Blue Creek, Belize, may be considered as suitable for use under a precaution advice. One of the primary parameters measured is the electrical conductivity and sodium absorption ratio, which were 2.79 dS/m and 0.037 meq/l, respectively. The former one can be classified as slight to moderate for use in agriculture; meanwhile the latter's value is very low, according to the Water Guidelines produced for FAO by Ayers and Wescott (1984). At the same time, the United States Department of Agriculture (USDA, 1954) mentions that the most important factors in determining quality are the total concentration of soluble salts, relative proportion of sodium to other cations, nutrient elements for toxicity and under some conditions, bicarbonate concentration and its relation to calcium plus magnesium.

In relation to the nutrients present in water, they can contribute to unsuitable water for irrigation. High levels of sodium, calcium, magnesium can lead to sodification and/or salinization of water and water properties, thereby influencing in plants growth and development (Hussain et al, 2010; Rhoades, 1984). However, the water implemented was for irrigation was only saline due the high levels of calcium, magnesium and sulfates.

According the scheme presented by USDA (1974) in previous chapter for determining water quality, the irrigation water used at the study area it can be classified as **C4-S1**. **C4** belongs to 'very high salinity water' which is not suitable for irrigation under ordinary conditions. It is recommended to be used under special circumstances where there is permeable soil, adequate drainage and abundant water to provide considerable leaching, also select salt-tolerant crops. **S1** represents 'low-sodium water' which is suitable for irrigated agriculture on most soils with low risk of accumulating harmful levels of exchangeable sodium (Perez, 2011; Hussain et al, 2010; USDA, 1954). Such is the case with Vertisol soils in the area.

Appropriate water quality is not only determined by the salt content, but also by the type of salt contained (FAO, 1984). Irrigation water contains many dissolved mineral salts depending on the source, thus it's the concentration and composition of salts varies (Grattan, 2002). As per described by Grattan (2002), the most common salts present include: sodium chloride, calcium sulfate (gypsum), magnesium sulfate and sodium bicarbonate which are composed of cations (Ca^{2+}, Mg^{2+}, Na^{+}) and anions (Cl^{-}, SO_4^{2-}, HCO^{3-}). In the above table 10, all these cations and anions were measured, obtaining their concentration. The presence of cations and anions (soluble salts) create a difference in the osmotic pressure of plants, increasing it and thereby affecting plants. To further understand the chemical behavior of nutrients, an ionic speciation was performed, as follows, table 11.

The ionic strength of water properties is the most important parameter in determining ion components as their activities and mobilities. The process of cations being attracted to a more negative potential, meanwhile the anions will favor a more positive region (Stumm & Morgan, 1981). The ionic strength was of 0.1093 and the sum of cations and anions were

6.0840E-02 and 4.8824E-02, respectively. These calculations lead to the activity coefficient of ions in the solution. The activity coefficient is used to determine the minimum concentration of dissolved elements required to be in equilibrium with its solid (salt) element (Stumm & Morgan, 1981). The total concentration of possible salt formation is shown in table 11.

The predominant elements in the water analyzed were calcium, magnesium and sulfates. Due to this, the main compounds that could be formed are primarily calcium sulfate ($CaSO_4$), followed by magnesium sulfate ($MgSO_4$) and magnesium and calcium phosphate. These results were found with the chemical modeling program (VMINTEQ) through the saturation indexes (SI). In a solution of sulfates and calcium being predominant, their SI can be 34.02% and 41.52%, respectively (Table 11). Calcium is an essential plant nutrient, it may occur as calcium carbonate or calcium sulfate, the latter being moderately soluble. Complimenting the $CaSO_4$ is the sulfate ion which causes no particular detrimental effect on soils or plants; nevertheless, it contributes high salinity levels in the soil solution (Glover, 1996).

In general, these salts not only affect plants but may also influence in the agronomic practices. If one of the predominant salts forms is magnesium and calcium phosphates, the former I slight soluble whilst the other is insoluble. Knowing this, whenever phosphate fertilizers are applied, there is a high possibility that it becomes bound to the calcium in soil, thus reducing the phosphorus efficiency in the soil for plant availability.

In order to reduce this, methods of reducing soil pH may help, thereby avoiding the formation of insoluble salts. The use of sulfate based fertilizers can aid in the problem.

Table 11. Ionic speciation of analyzed irrigation water
(Source: Own elaboration)

pH		**Temperature**		**Ionic strength**	
7.5		25^{o}C		0.1093	
Sum of cation (eq/kg)		**Sum of anions (eq/kg)**		**Charge by difference%**	
6.0840E-02		4.8824E-02		10.956934	
Component	**% of total concentration**	**Species name**	**Component**	**% of total concentration**	**Species name**

SO_4^{-2}	54.5	SO_4^{-2}	**PO_4^{-3}**	29.516	HPO_4^{-2}
	11.453	$MgSO_4$ (aq)		6.879	$H2PO_4^-$
	34.019	**$CaSO_4$ (aq)**		0.027	$MgPO_4^-$
	0.028	$NaSO_4^-$		**21.507**	**$MgHPO_4$ (aq)**
Ca^{+2}	58.433	Ca^{+2}		**36.76**	**$CaHPO_4$ (aq)**
	41.524	**$CaSO_4$ (aq)**		4.088	$CaPO_4^-$
	0.025	$CaNO^{3+}$		1.187	$CaH_2PO_4^+$
	0.016	$CaHPO_4$ (aq)		0.033	$NaHPO_4^-$
Mg^{+2}	63.901	Mg^{+2}	**Cl^{-1}**	96.857	Cl^{-1}
	36.07	**$MgSO_4$ (aq)**		1.876	$CaCl^+$
	0.025	$MgHPO_4$ (aq)		1.26	$MgCl^+$
Na^{+1}	95.391	Na^{+1}	**NO_3^{-1}**	97.616	NO_3^{-1}
	4.601	$NaSO_4^-$		2.38	$CaNO_3^+$

Given the water quality classification as C4-S1, very high saline water with low sodium content, it can lead to soil salinization. Salinization may occur when salts accumulate and concentrate in top soil layer, root zone or other soil horizons, as a result from water evaporation from soil surface , plant water use, inadequate leaching of salts beyond root zone and/or insufficient washing of salt from land surface by precipitation (Flynn & Ulery, 2011; Bauder, 2008).

In addition, yield decreased has been observed in most areas where saline conditions are present (IRRI; Thiago, 2010, Grattan, 2002; Maas & Hoffman, 1977). Maas & Hoffman (1977) reports that rice yield decreases by 12% for every dS/m above 3.0; Grattan (2002) found that rice can be affected at thresholds below 3.0 dS/m. An electrical conductivity of 1.9 dS/m showed a decrease in tillers/plant, fertility, kernel weight, # of spikelet/panicle and grain weight/plant. In this manner, contributing to estimate rice yield potential against salinity condition through the following formula:

$$\%\ yield = 100 - 9.1\ (EC_{fW} - 1.9) \qquad (2)$$

where EC_{fW}, is the seasonal, time- weighted average salinity in the field water.

Under such conditions, the water implemented in Blue Creek for rice production can present a decrease of 8% due to water salinity. Decrease that may augment as the duration of salinity increases during the seedling stage, even at low values of 1.9 dS/M (Zeng et al, 2000).

4.2. Soil Analysis

The soil samples collected showed a homogenous distribution in terms of its physical and chemical properties; there was no significant difference amongst the samples. The samples collected at the beginning of the experiment, showed slight difference compared to the soil sample collected after harvesting. After harvest, there was an increase in the CEC, EC, calcium, sulfur and iron, as shown in table 12.

The increase in soluble salts may be attributed to the accumulation of the predominant salt formed, calcium sulfate. Bauder et al, (2008) explains the possible accumulated salts in the soil (Table 4). Amongst these, calcium sulfate is present, commonly known as gypsum. Gypsum is commonly used for treating sodic soils, which captures the Na^+ and thereby make it leachable. However, given that the study does not present sodium issues, the presence of calcium sulfate does compete with other salts, thus affecting water and nutrient absorption within rice plants (Flynn & Ulery, 2011; Levitt, 1980).

Table 12. Soil analysis: initial and final phase of experiment

(Source: Own elaboration)

		INITIAL			FINAL		
PARAMETER	**UNIT**	**Lot 1**	**Lot 2**	**Lot 3**	**Lot 1**	**Lot 2**	**Lot 3**
C.E.C	meq/100 cm^3	43.7	45.0	44.7	79.5	83.5	84.7
pH		7.1	7.1	7.2	7.4	7.5	7.5
O.M.	%	0.1	0.1	0.1	0.1	0.1	0.1
EC	dS/M	3.01	2.56	2.26	3.16	3.24	3.19
Macro							
Nitrogen	meq/100cm^3	2.5	2.2	2.3	2.5	2.5	2.3
Phosporus	meq/100cm^3	2.0	2.8	1.8	1.0	1.0	1.0
Potassium	meq/100cm^3	0.2	0.2	0.2	0.1	0.1	0.1
Calcium	meq/100cm^3	27.6	30.6	30.8	67.5	71.9	73.5
Magnesium	meq/100cm^3	14.2	13.4	13.0	10.7	10.4	10.3
Sulfur	meq/100cm^3	732.8	755.2	754.5	803.2	812.0	815.3
Sodium	meq/100cm^3	1.5	0.8	0.7	1.1	1.0	0.8
Micro							
Boron	mg/l	1.5	1.8	1.9	1.3	2.0	2.3
Copper	mg/l	1.5	1.6	1.8	2.3	2.6	3.0
Iron	mg/l	3.2	2.3	2.3	6.0	4.8	4.2
Manganese	mg/l	4.0	3.7	4.3	7.4	7.8	9.3
Zinc	mg/l	3.2	2.8	3.7	2.5	2.9	3.0

Soil salinity may originate from soil weathering, irrigation water quality, stream banks during and following precipitation (Rhoades, 1984). Bauder (2008) assessed the suitability of water for irrigation and reports that the "*amount of salt dissolved in water - directly affects plant growth, generally has adverse effect on agricultural crop performance, and can also affect soil properties*." Furthermore, unknown levels of water and soil salinity along with inappropriate management can decrease crop productivity.

Salt accumulates and concentrates in soil when water evaporates from the soil surface, when plants use water, when leaching is not adequate to leach salts beyond the root zone, coastal water infiltration, and/or when precipitation does not wash salts off the land surface (Gergerly, 2012; Bauder, 2008). Moreover, crop development is adversely affected under excessive amount of soluble salts. Although rice is moderately tolerant to salt content, it is more susceptible at seedling stage and at flowering phase (IRRI, Maas & Hoffman, 1977).

The soil under study presented an increase in electrical conductivity (EC) which may be attributed to salts levels in the soil, be it accumulated through the water application. The initial soil analyzed presented an average of 2.62 dS/m, while the final phase measured a 3.20 dS/m; an increase of 22% in salinity levels. Soils can be classified as saline or not through the following guideline provide by the USDA: Natural Resource Conservation Service (NRCS), table 13.

Table 13. Classes of salinity and EC (1 dS/m = 1 mmhos/cm)
(Source: NRCS Soil Survey Handbook)

EC (dS/m)	Salinity Class
0 < 2	Non-saline
2 < 4	Very slightly saline
4 < 8	Slightly saline
8< 16	Moderately saline
≥ 16	Strongly saline

As observed, the soil can be classified as very slightly saline, given that both measurements fall under this category. It must be observed, that salts in the salts can be accumulated if not treated. In the case of these Vertisol soils, they tend to swell and crack when wet and dry respectively. When excessive cracking occurs, followed my rain or irrigation, washing away of salts to lower soil profile may be an option, thus lowering salinity levels. On the other hand, rice field studied are mostly flooded throughout the crop cycle and after harvest, the latter is due to the rainy season in Belize. However, when possible, soils are allowed to dry completely for mechanical labor be carried out.

4.3. Aquacrop Modelling

As per described in chapter 4, table 8, the following parameters were collected and summarized below in table 14. The parameters were used for calibration and simulation of rice crop in AquaCrop.

Table 14. Aquacrop parameters: Data collected and standard values from Aquacrop program

Description	Value	Units
Crop parameters		
Plant Density	1,800,000	Plants/ha
Days to emergence	3	Days
Days to flowering	65	Days
Days to maturity	100	Days
Canopy growth coefficient	8.5	%
Canopy decline coefficient	10.6	%
Maximum Canopy	100	%
Water productivity	17	g/m^2
Water electrical conductivity	2.7	dS/m
Soil/Water stress	Moderately sensitive	-
Reference harvest index	60	%
Soil fertility effect	Mild stress	-
Soil salinity effect	Mild stress	-
Fertility/Salinity effect	Mild stress	--
Climate		
Temperature (max - season)	39	^oC
Temperature (min - season)	25.5	^oC
Evaporation (season)	524.26	mm
Precipitation (season)	142.50	mm
Soil		
Permanent wilting point	6-10	Vol %
Hydraulic conductivity at sat point	61	mm/day
Field capacity	42	%
Soil texture	Clay	-
CN number	40	-
Irrigation		
Number of events	5	-
Amount irrigation	275	mm

Amount percolation	130	mm
Amount drainage	8.6	mm

The AquaCrop model simulates the variation in attainable crop biomass and harvestable yield in response to variation in soil moisture in the root zone (Geerts et al., 2010). This is accomplished on daily basis by considering the incoming and outgoing water fluxes and by taking into account the daily transpiration rate (Araya et al., 2010). The daily increment in yield depends on the normalized transpiration for the local climate and the separation of yield into biomass and grain. Biomass growth is associated with crop parameters such as stomatal conductance, canopy senescence and harvest index (Mati et al., 2011, Steduto et al, 2009).

4.3.1. Biomass and yield

The collected data was input in the AquaCrop model for the calculation of green canopy expansion. Green canopy is directly related to the yield (Steduto, 2009). Table 15 shows the observed and simulated biomass and yield.

Table 15. Observed and Simulated rice yields
(Source: Own elaboration)

	Observed			**Simulated**		
	Days to maturity	Biomass (t/ha)	Yield (t/ha)	Days to maturity	Biomass (t/ha)	Yield (t/ha)
I	108	19.22	6.4	102	12.135	6.058
II	110	18.91	6.9	102	12.45	6.33
III	110	18.65	6.7	102	12.34	6.04

Under the described conditions of rice production, the crop was ready for harvest at 110 days after planting, upon achieving 95% grain maturity and plant senescence. The rice crop yielded an average of 6.67 t/ha, a decrease yield in comparison to previous years (unpublished data). After many years of rice farming under irrigated systems, the yield has gradually decreased under similar conditions and agronomic practices, an estimated 10% (Personal interview).

The simulated yield was inferior to the observed data in all treatments. Statistically, there was no significant difference, based on ANOVA. Similar results were found by Cortes (2013) in a study performed in Colombia and found a difference of 15% between observed and simulated. Amiri et al, (2014) found that there is high correlation between observed and simulated rice biomass production in AquaCrop modeling. The capacity of the modeling program to simulate yields similar to real experiments has been proven efficient (Amiri et al, 2014; Cortes, 2013; Flores, et al 2012; Bwalya, 2013).

AquaCrop simulated the average biomass production of a crop's cycle, obtaining 8.891 ton/ha, while the observed was of 13.957/ha. There is a normalized root mean square of 39.9% (Figure 12).

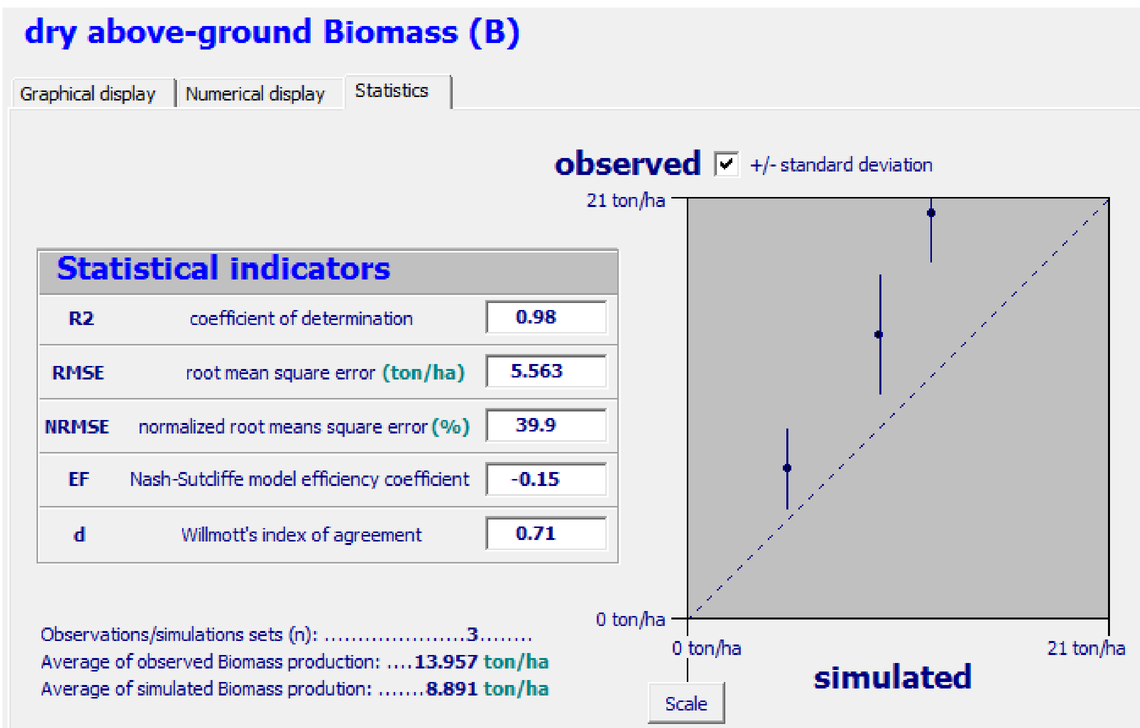


Figure 12. Biomass statistics for simulated and observed production
(Source: Own elaboration in AquaCrop modeling program)

4.3.2. Canopy Cover

Aquacrop calculates the canopy cover by employing four parameters: canopy cover at 90% emergence (CCo), canopy growth coefficient (CGC), maximum canopy cover (CCx), canopy decline coefficient (CDC) and the moment when green canopy senescence is triggered. Field observation recorded maximum canopy cover after plant flowering, approx. 80 days after planting with 98% cover; meanwhile the simulated version showed 84% maximum canopy cover at the beginning of plant flowering, 65 days after planting; as illustrated in figure 13.

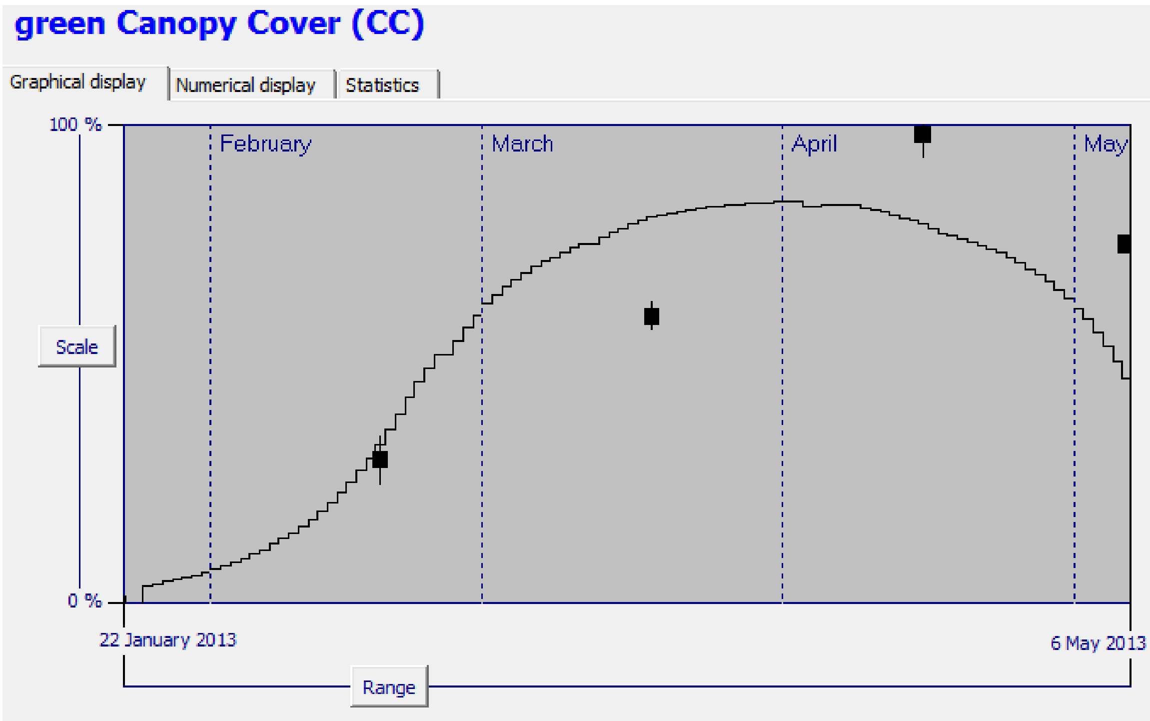


Figure 13. Rice's green canopy simulation
(Source: Own elaboration in AquaCrop modeling program)

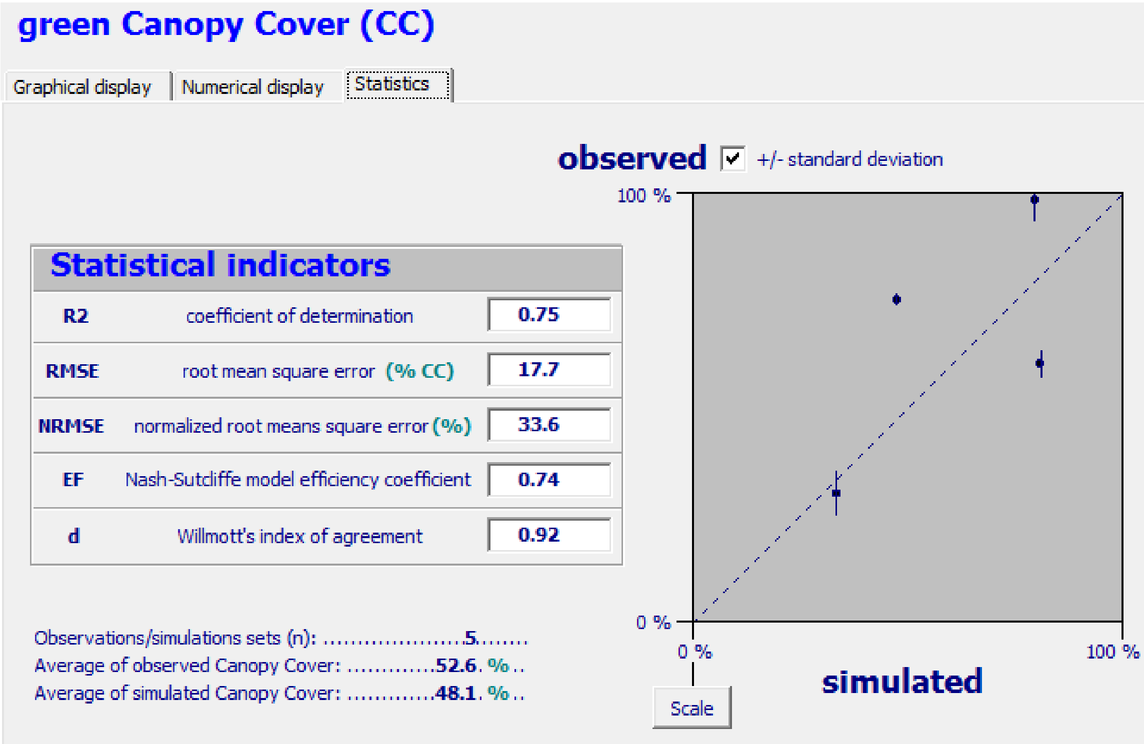


Figure 14. Green canopy statistics for simulated and observed production
(Soucre: Own elaboration in AquaCrop modeling program)

The AquaCrop program calculates an average canopy cover, which includes the coverage percentage from the beginning to end of crop cycle. The observed canopy cover was of 52.6% and the simulated of 48.1%. Both values measured a normalized root mean square error of 33.6 % (Figure 14).

Under the given conditions, the simulation of rice production also included the transpiration rate (Tr – mm/day) and soil water content (Dr) during the growing season, as per shown in figure 12. Implementing the recommended coefficients in the model along with observed data, the transpiration increases as the biomass increases. At the same time, factors like temperature, water availability can influence in said factor, due to direct effect on stomatal closure.

In respect to soil water content, water levels tend to be under field capacity, according to the simulation in several instances. This behavior may be inaccurate due to growing conditions – anaerobic. Rice fields were drained only when necessary for a herbicide or fertilizer application. During the growing season, the most common practice is to establish a layer of water then leave it to evaporate until reaching field capacity. Plants are not allowed to undergo water stress. Amiri et al (2014) and Saadati (2011) have successfully managed to simulate rice yields under different irrigation systems, thus proving the reliability of Aquacrop for rice crop simulation.

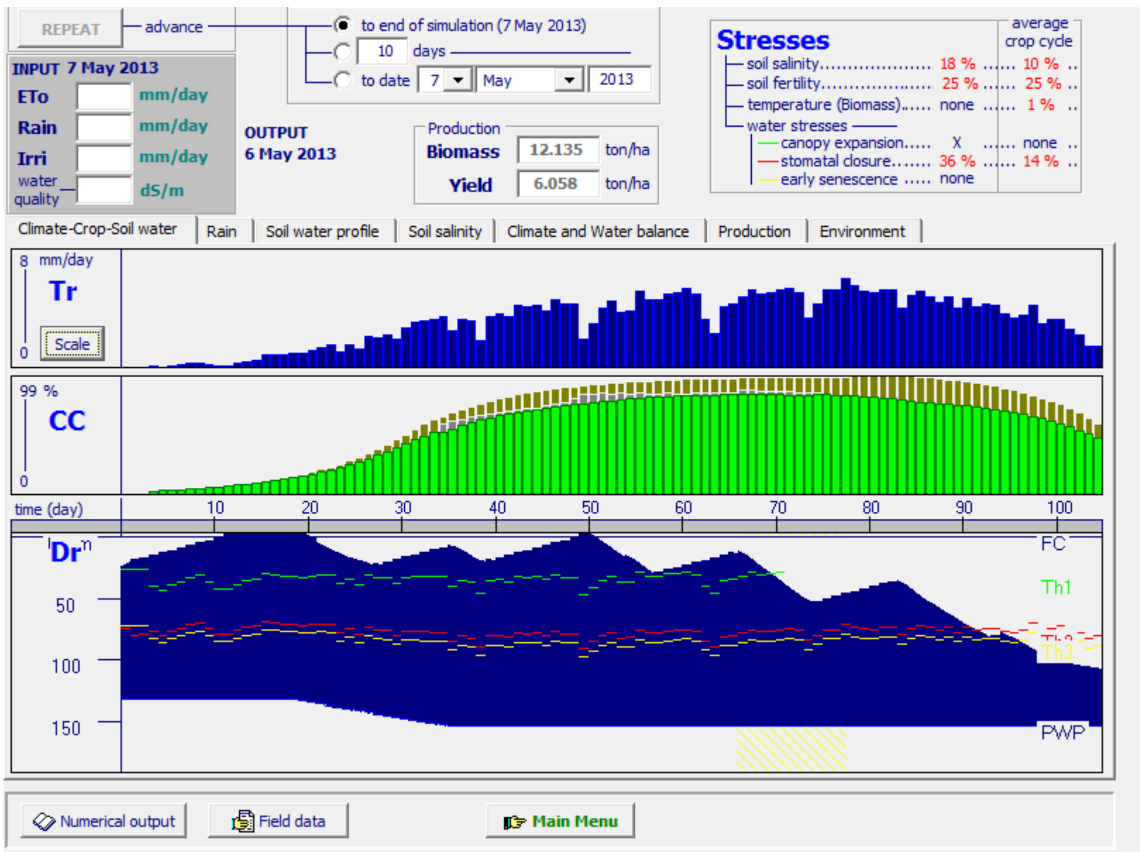


Figure 15. Climate-crop-water relation simulation
(Source: Own elaboration in AquaCrop program)

4.3.3. Soil Water Dynamics

Most crops under irrigation system are provided with sufficient water for plants to not be under water stress. In the case of rice plants, it has the capacity to live under anaerobic condition, to extremes that a crop can be completely submerged for a few days (IRRI). Nonetheless, several soil reactions are triggered under anaerobic condition: Fe^{3+} and Mn^{4+} reduction, denitrification, fermentation, nitrate respiration, dissimilatory nitrate reduction to ammonium, sulfate reduction, carbon dioxide reduction, acetate splitting, and proton reduction (Tiedje et al, 1984). In addition, the quality of water applied influences significantly on the physical and chemical soil component. Water is the primary carrier of salt content (FAO, 1988), containing considerable quantities of soluble salts; which may accumulate in the soil, if not properly leached. In general, salts may precipitate on the soil's surface, leaving a white crust on the soil horizons; which is the case observed at the current study area (Figure 16).

Figure 16. Precipitated salt on soil surface layer of study area.
(Source: Own elaboration)

The electrical conductivity of the water implemented for irrigation was 2.7 dS/m, and it also contained high levels of calcium and magnesium, which can form salts and thus accumulate in the soil horizons (FAO, 1984). The AquaCrop simulated the effect of water salinity accumulation in the soil horizons, illustrated in figure 15. Understanding the soil structure, being of clay, it possesses poor drainage and infiltration, facilitating the accumulation of salts. Throughout the growing season a total of 6.66 dS/m was simulated on the first 0.10 meter of soil horizon in the root zone. The observed soil salinity was 3.2 dS/m in the first 0.10 meters, varying almost 50% from the simulated.

To simulate the effect of soil salinity on biomass production and yield, the following parameters are considered: stress coefficient for maximum canopy cover, stress coefficient for canopy expansion and decline coefficient for canopy cover. These parameters have an effect on canopy development and induced stomatal closure (Steduto, 2012). The parameters were calibrated according to the recommended values for rice production. An 18% soil salinity stress and 25% fertility stress (Figure 18) was calculated by the program, which when combined, produces a yield of 6.058 ton/ha, value inferior to the observed, 6.40 ton/ha; also a biomass of 12.135 ton/ha. In this same manner, the program is adjusted to simulate crop development under no stress (water, salinity, fertility), thereby providing an estimated biomass of 16.366 ton/ha (Figure 19).

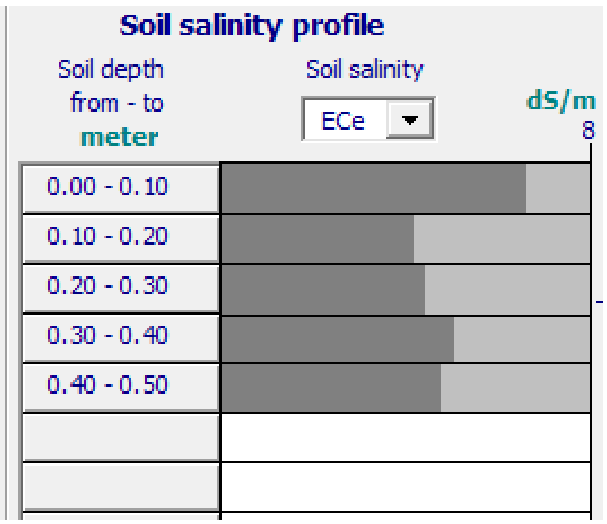


Figure 17. Simulated soil salinity profile
(Source: own elaboration in AquaCrop program)

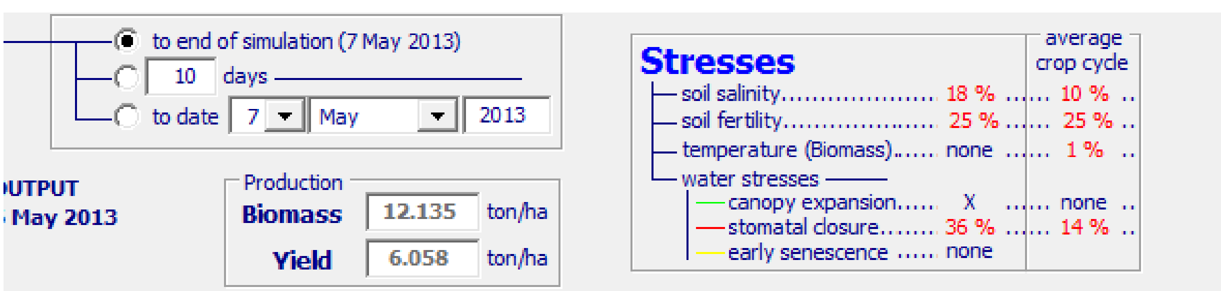


Figure 18. Simulated rice plant stresses
(Source: own elaboration in AquaCrop program)

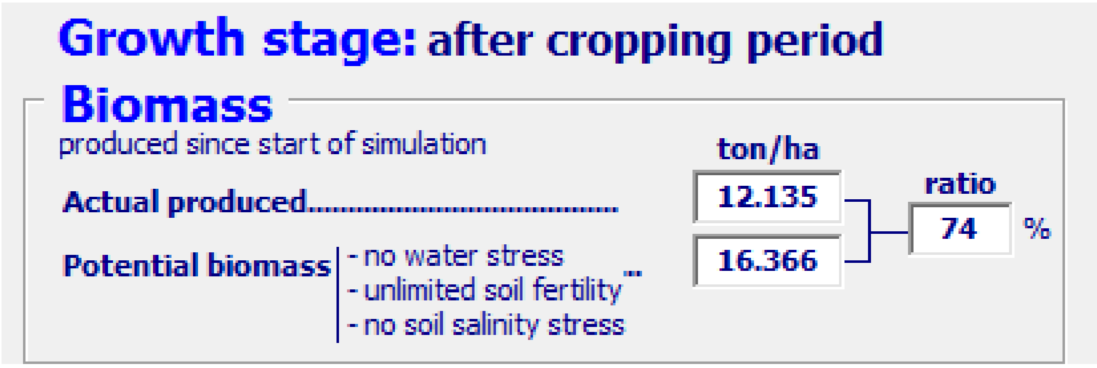


Figure 19. Biomass yield simulation
(Source: own elaboration in AquaCrop program)

Implementing the Aquacrop modeling program to simulate rice yield may seem effective given its accuracy in respect to grain yield (Cortes, 2013, Amiri et al, 2014). Other experiments conducted in wheat, corn, rice, eggplants under various climatic conditions, like agronomic practices have obtained similar results. However, others have found different results, for instance, AquaCrop over estimates the green canopy cover in eggplant (Bwalya, 2013); Sam-Amoah et al (2013) obtained high variations between measured and simulated yields of hot pepper. The flexibility of AquaCrop to simulate numerous crops may be vulnerable to the specific coefficients required for calibration, since these may be the same for same plant species but may vary from location to location in ongoing experiments. However, the use of such program may be improved by obtaining accurate data corresponding to specific areas of study.

4.4.Water and Soil amendments

One of the objectives of this research was to establish or recommend a suitable treatment for the water quality if deemed inappropriate for rice production. Constructing an industrialized water treatment plant may not be the most adequate, yet feasible solution. In the literature there exist many solutions, but the suitability to the conditions of Belize, may not be the most viable.

The water implemented in rice production in Blue Creek can be considered inappropriate under the guidelines of Ayers & Westcott (1984) and USDA (1954). Considering the water's high salinity, it can affect plant development (Hopkins et al, 2007), similar condition found in the research. Nonetheless, the low sodium content of the water may not be an influence on the soil texture. In order to improve crop productivity, a water treatment prior to irrigation would seem appropriate.

Yiasoumi et al (2005) recommend reverse osmosis, deionisation and electrodialysis, which are commercially available treamtments. Given the large volumes of water required, these treatments seem costly and ineffective. The most common and cost effective water treatment is gypsum application. Gypsum is mainly utilized to recover sodic soils (Hopkins, 2007; FAO, 1984), which is not the case for the area under study.

Many studies reveal the effectiveness of using magnetic fields for water treatment, thus altering the chemical reactions of soil-water and capturing/forming salts, preventing them to adhere to soil particles and facilitating its leaching process (Mostafazadeh et al, 2011;. Diaz et al, 2004). The effectiveness of this type of treatment would depend on the many factors: magnetic field strength, direction and duration exposure, flow rate of solution, additives present and the pH (Chibowski et al. 2005). Other than treating the water for improving the quality, it is being attributed to increase the vegetative growth and yield of crops, as found by Ahmed (2014), Nasher (2008) in broad bean, chick-pea and rice through seed treatment and irrigated magnetized water. This positive effect can be attributed to the increase in photosynthetic pigments, endogenous promoters (IAA); increase protein biosynthesis (Ahmed, 2014). The combined effect of water treatment and positive rice plant development may be an important factor in determining the feasibility of implementing such water treatment. Given that the main salt to be formed is based on sulfates, Mostafazadeh et al (2011) found that magnetized irrigation water decreases significantly the sulfate ions in soil, thus preventing the precipitation of calcium sulfate in soil.

In reference to improving sustainable agriculture, the use of organic matter (OM) seems like a viable option in decreasing salt content in soil, improve soil structure, leaching, thereby creating optimum condition for crop development. Mahmoud (2012) evaluated the use of vermicompost in saline sodic soils and obtained a significant reduction of soil EC, SAR, Cl^- and Na+ with the application of vermicompost. Additionally, Organic matter, CEC and nutrients available (N, P and K) were increased as the rate of the organic materials increased. These reactions can be explained through the application of OM promoting the flocculation of clay minerals, an essential condition for the aggregation of soil particles (Lakhda et al, 2008). Furthermore, it increases the biological porosity, which enhances soluble salts leaching. Similar results were also found by Saranraj (2012) whom combined the combined vermicompost with synthetic fertilizers.

Other forms of organic matter may also be implemented. In the literature exists of some products being developed from organic matter – whereby the extraction of humic and fulvic acids is made and then converted to stable molecules for its soil application, may aid in the treatment of saline soils (Olsen, 2012).

The continuous use of inappropriate water for irrigation may only be useful for several years. Tyagi (2003) reports that several studies have shown that such water may be used for 6-7 years without significant yield loss; however the possibility of long term effects may occur including soil dispersion, crusting, reduced water-infiltration capacity and accumulation of toxic elements. Tyagi furthermore discusses that the "evaporative demand, salt content, soil type, rainfall, water table conditions and type of crop and water-management practices, determines salinity build-up in the soil and crop performance resulting from long-term application of saline water." As result, Tyagi (2003) recommends the following for root-zone salinity management for improving crop productivity: multi-quality water use in different modes, thereby avoiding application of saline water during sensitive stages, use of chemical amendments, precision leveling and high frequency irrigation. The study area is precisely leveled but areas too large to practice high frequency irrigation. The most viable treatment is the multi-quality water use. As mentioned above, the water implemented in irrigation originates from a karstic spring, nonetheless, nearby exists a river – Rio Bravo which contains less salt content. Alternating water use or blending it may reduce the soil impact (Sharma et al, 2005; Tyagi, 2002; Sharma et al, 1993). By reducing the salinity levels or alternating the quality water use, it can improve productivity. Zeng et al (2001) and Rad et al (2012) found that rice was more sensitive to water salinity level during tillering (21-35 DAP) and at panicle initiation (35-40 DAP); meanwhile Bauder (2008) also attributes a negative impact to rice seed germination.

5. Conclusion

The water samples collected were analyzed for electrical conductivity, pH, and other elements necessary to determine its quality. According to the guidelines provided by the USDA and FAO, the irrigation water analyzed belongs to the class C4-S1 due to its electrical conductivity of 2.7 dS/m. The water is high in calcium, magnesium and sulfate levels which contribute to soil salinity. Salt accumulation can cause deterioration of the soil texture and structure, like a reduction in crop yields. The combination of salt presence in water and salt accumulation in soil, cause a higher effect of osmotic pressure and soil matrix, respectively. It is known that for very dS/m increase above plants threshold, there is a decrease in yield, of 12% is rice production. It was determined that there is a decrease of 8% in rice yield when cultivated under the water quality used for irrigation. Thereby confirming that under the conditions provided, there is negative impact.

A further analysis was performed with AquaCrop 4.0 modeling program, released by FAO, to simulate rice growth under the observed environmental conditions for the period January – May, 2013. The program was capable of simulating the green canopy cover and evapotranspiration rates which were converted to biomass production and grain yield. It was observed that the biomass production was different between observed and simulated, yet the total grain yields were similar. The observed yield was of 6.67 ton/ha, meanwhile the simulated was 6.14 ton/ha.

A reduction of 8% in rice yield can be converted to a loss of 0.533 t/ha. Implementing the market value and price paid to farmer after milling and marketing rice, a farmer receives US$0.82/kg. This is transformed to a loss of almost $440/ha, whereby, if the current farmer who has 285 ha, he is being challenged by a loss of US$12,456.00. Bearing this in mind, the amount lost is significant. In addition, the continuous use of the water, on the longer run, may influence in higher levels of salts accumulation which may lead to land desertification. Thereby, an application of soil or water amendment is necessary to guarantee a sustainable production of the area.

Furthermore, the study area has access to a different water source which contains a better quality. The blending and replacement of current water source, would aid in the reduction of salts applied to the soil. It may require constructing an infrastructure that would allow it, but it would be beneficial for the soil and plants, likewise for the improvement of rice production, thus contributing to the nation's food security.

Long term use of inadequate resources and materials, may lead to detrimental conditions of its own, like have a major impact on agriculture production. The use of water treatment and soil amendments, along with modeling programs, it can aid to better understand the production environment and expected outcomes; thereby forecasting real-time experiments that may be lengthy. The use of crop modeling programs can also aid in the decision making of following crops.

6. Recommendation

Rice production in Belize should be improved in order to continue being self-sufficient in the industry. The results obtained from this study, leads to the following recommendations:

1) Continue monitoring the water quality used for irrigation in various areas where irrigated rice system is implemented, and monitor the soil nutrient content for the increase in salinity levels.
2) Perform further data collection and analysis of parameters used for the parameterization, calibration and validation of the AquaCrop modeling program.
3) Gradually implement water and soil amendments to the study area, like modify agronomic practices, while monitoring the effects on rice production.
4) Apply this research to other crops and production areas in Belize.

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