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The Potential Environmental Benefits of Hybrid Rice Varieties

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THE POTENTIAL ENVIRONMENTAL BENEFITS OF HYBRID RICE VARIETIES

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ABSTRACT

With water insufficiency being already a major issue and potential carbon policies on greenhouse gas (GHG) emissions, Arkansas rice producers may need to undergo some changes in regards to rice cultivar selection. The purpose of this study is to estimate the environmental benefits of cultivating hybrid rice varieties as opposed to conventional and Clearfield rice varieties. To accomplish this goal, water use and GHG emissions were estimated on per acre (ac) and per bushel (bu) basis for most commonly cultivated rice varieties in Arkansas. The study focuses particularly on six main rice stations in the State of Arkansas. The hypothesis of this study is that hybrid rice varieties use less water and emit less GHG on both per ac and per bu, which would make them the ideal choice to meet the increasing demand for rice while reducing water use and GHG emission from its production. This study found that hybrid rice varieties have statistically lower water-use/bu and GHG emissions/bu than conventional and Clearfield.

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DEDICATION

This thesis is dedicated to my family: my parents Jetnor and Hemedie Myrteza, and my two sisters Ediola and Gentiana, whose support and motivation were encouraging throughout the Master's program and specifically during the thesis preparation process.

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I. INTRODUCTION

Rice (*Oriza Sativa L.*) is an important food crop around the world, providing the main source of calories for more than half of the world's population (International Rice Research Institute [IRRI], n.da). Given the large projected increase in the world's population, rice will continue to play an important nutritional role, especailly because rice is the staple crop in many of the countries that are growing the quickest in population. Despite its nutritional importance, paddy rice production can be environmentally straining in that it is the greatest water consuming crop in the world and a large greenhouse gas (GHG) emitter.

According to Dobermann (2012), irrigated rice fields use about 25% of world's total freshwater annually. Greenhouse gas emissions from paddy rice, mainly through methane production, have been shown to have serious environmental impacts as well. Rosegrant et al. (2008) stated, "Flooded rice fields are the third largest source of agricultural emissions, contributing to 11 percent in the form of methane arising from anaerobic decomposition of organic matter" (p. 8). Given the increasing water scarcity in many rice-growing areas worldwide and an increasing pressure to lower global GHG emissions, rice-producers around the world could soon face both environmental pressures to increase water use-efficiency and public/governmental pressure to lower their net GHG emissions.

Relatively speaking, the United States (U.S.) is a small rice consumer and producer, but a large rice exporter. The U.S. only produces two percent of the world's rice, but it is the third largest rice exporter (Bennett, 2010). Among six major rice-producing states in the U.S., Arkansas ranks first which accounts for approximately 48% of U.S. rice production (Arkansas Rice Federation, 2012). The average American consumes roughly 22 pounds of rice annually compared to many Asian countries whose average consumption exceeds 220 pounds/year (Chapagain & Hoekstra, 2010).

Rice cultivation was first introduced to the state of Arkansas in 1897 (The Encyclopedia of Arkansas History & Culture, 2011); however, rice did not immediately take over other crops such as cotton which at the time was the most profitable commodity in the state. There was a transition time where farmers had to learn the agronomic techniques for more efficient rice production. Today, rice ranks second of agricultural commodities in Arkansas in terms of revenue, contributing 16% of state total farm receipts (United State Department of Agriculture [USDA], 2012). According to USDA (2012), in 2010, rice exports accounted for an economic contribution of nearly $1 billion. Arkansas rice is mainly cultivated in the eastern part of the state along the Mississippi River Delta. In 2010, rice was sown on about 1.8 million ac (Environmental Defense Fund [EDF], 2011), which is equivalent to about 13% of Arkansas farmland. Like many major rice-producing countries around the world, Arkansas, specifically the Delta, has begun to experience large decreases in groundwater, which allows rice cultivation to exist.

A rise in rice production during the last few decades is thought to be the main cause for a decline in Arkansas groundwater supplies. In 2004, the Arkansas Natural Resources Commission (ANRC) estimated groundwater withdrawals in Arkansas at 6.5 billion gallon (gal) per day, a 70% increase from the amount used in 1985 and over 12 times that of 1945 (ANRC, 2007). Today's irrigation level is unsustainable in the sense that water use exceeds recharge in the Alluvial aquifer, which is the aquifer that supplies the groundwater to most of the rice acreage in Arkansas. To reach sustainable pumping levels, the U.S. Geological Survey's (USGS) 2006 estimates indicated that certain counties in the Arkansas Delta will need to reduce irrigation pumping rates by as much as 67% from their 2004 usage. This is significant since approximately 63% of the state's total water supply is sourced from groundwater, and 95% of that comes from the Alluvial aquifer in the Delta region of Arkansas (USGS, 2008). To put this in context, Popp, Nalley, and Vickery (2010) reported that Arkansas, Lonoke, Lee, Poinsett and St. Francis counties would all need to reduce their irrigation pumping rates by over 40% to maintain groundwater levels. These counties alone consisted of 28% of Arkansas's total rice acreage, or 14% of the nation's rice supply.

Water for irrigation has until today been free to all Arkansas farmers with the exception of pumping costs. Farmers may thus be indifferent towards water resources, leading to unsustainable irrigation levels. The ratio between groundwater withdrawal to natural groundwater recharge in the past few decades has been disproportional in many parts of the Alluvial aquifer, which suggests a continuous decline in future groundwater supplies. The ANRC estimated that in 2004 groundwater withdrawal increased by 70% from that of 1983 and was 12 times more compared to that in 1945 (ANRC, 2007). At this rate of water usage, groundwater availability for irrigation will soon be a major constraint for sustaining the current rice acreage.

While a decrease in rice acreage in the U.S. will have revenue implications for American producers, other global negative externalities could occur. Since rice provides 21% of global human per capita energy and 15% of per capita protein, price/supply shocks can have large impacts on the low-income world. For example, in 2008, when rice prices tripled, the World Bank estimated that an additional 100 million people were pushed into poverty (IRRI, n.da). Further, 10.2% of global rice exports were provided by the U.S.in 2009 (Childs and Baldwin, 2010) and nearly half of that was supplied by Arkansas. Therefore, an acreage reduction due to irrigation constraints could have ripple effects across the world given that small supply shocks can have large effects across the world. Furthermore, since rice is the largest GHG crop emitter in the United States, rice acreage could decrease if a GHG policy on reducing emission is implemented (McFadden et al. 2011).

Implementation of GHG policies, therefore, represents another potential threat for rice producers and rice acreage in the United States. Nalley, Popp, and Fortin (2011) estimated that GHG emissions associated with rice production in Arkansas are four times higher than corn, which is the next largest emitter on a per ac basis. Generally, GHG from rice production is emitted in three forms. First are the direct emissions that come from on-farm operations. Examples are carbon dioxide (CO_2) emissions from diesel used by tractors and irrigation equipment. Second are indirect emissions that are generated off farm as a result of manufacturing inputs used on the farm. Examples of indirect emissions are the GHG emissions from natural gas to produce commercial fertilizer. Third are nitrous oxide (N_2O) emissions from application of nitrogen fertilizer and methane (CH_4) emissions which are a result of anaerobic decomposition of organic matter during flooding. When comparing among these three sources of GHG emission (CO_2, N_2O, & CH_4) in rice production, methane accounts for nearly half of total GHG emission, followed by nitrous oxide and carbon dioxide as the second and third largest, respectively (McFadden et al., 2011).

The emission of methane to the atmosphere from flooded paddy rice in Arkansas starts typically two weeks after flooding, reaches its peak at around 50 days after flooding followed by a constant decrease until the flood is released prior to harvest. During flooding, methane is released mainly through the plants themselves as the flood prevents direct methane emission from the soil to the atmosphere. The emitted quantity of methane in flooded rice fields directly depends on two factors: aboveground dry matter and the number of days on flood, the later varying by rice variety type. Methane emissions increase as the rice plant grows larger, reaches a peak, then later decreases as the plant nears harvesting stage. Varieties that require longer flooding periods presumably emit a higher quantity of methane (K.R. Brye, personal communication, January 31, 2012).

Taking into account both increasing water constraints and the potential for either a government policy regulating GHG emissions or increasing consumer demand for agricultural goods with lower GHG emissions, hybrid rice varieties could be a solution to help alleviate some of the water stress and GHG emissions. The hybrid rice varieties are thought to have on average shorter life cycle and higher rice yield per acre. Shorter life cycle implies shorter period of time under flood which in return means less water usage and less GHG emissions per ac and possibly per bu of rice produced. Such characteristics fit the need for sustainable agriculture in Arkansas and the U.S.in general.

The aim of this study, therefore, is to estimate the environmental benefits of Hybrid rice varieties in comparison to the conventional and Clearfield rice varieties commonly sown in Arkansas. To achieve this goal water usage and GHG emission on per ac and per bu basis will be estimated and compared between hybrids, conventional and Clearfield rice varieties. Thus, the hypothesis of this study is that hybrid rice varieties use less water, and emit less GHG both per ac and bu of rice produced. The hypothesized reason why such outcomes are associated with Hybrid rice varieties is because Hybrids have on average a shorter life cycle; therefore, they stay under flood for a shorter period of time. This would imply less water use, and less GHG emissions (methane from flooding, carbon dioxide from diesel used for irrigation and other operating equipment). In addition hybrid rice varieties on average have higher rice yield, which will directly affect the per bu estimations. Values on water use and GHG emission (carbon equivalents) will first be estimated on a per ac basis. The next step is to calculate yield/water use and yield/GHG emissions ratios which can be used on a comparative basis across time, variety and space.

This study focused on six major Rice Research and Extension Centers in Arkansas; however, the study could have worldwide implications given the fact that switching to a different rice cultivar does not require new agronomic techniques. Unlike changing production practices or adopting new technology which is often costly and can bring on additional risk, changing rice cultivars based on length of their life cycle and yield (bu/ac) is something most producers could do seamlessly with little to no additional cost.

II. LITERATURE REVIEW

A. Rice Introduction

Rice is an ancient crop which is believed to originate as far back as 130 million years ago in Gondwanaland (Khush, 1997). Before its break up, Gondwanaland was a super continent which included what is nowadays Asia, Africa, the Americas, Australia, and Antarctica (Khush, 1997). The genus *Oryza* consists of 21 wild rice species and only two cultivated species: *Oryza sativa*, *Oryza glabberima*. Of the two cultivated species, *Oryza sativa* (Asian Rice) is commonly cultivated around the world, while *Oryza glabberima* (African Rice) is grown in parts of Southern Africa.

Rice can be grown in a multitude of environments. Today, the three most common rice ecosystems are: irrigated lowland, rain-fed lowland, and rain-fed upland. Irrigated lowland rice is grown in bunded fields with 2-4 inches of continuous water flooding from crop establishment to near harvesting time. Rice produced under irrigated lowland conditions accounts for 75% of world's total rice supply (Oliver, Talukder, & Ahmed, 2008; Bouman, Humphreys, Tuong, & Barker, 2007b). All rice in the U.S. is grown under irrigated lowland ecosystem (United States Environmental Protection Agency [EPA], 2010). Rainfed lowland rice is grown in bunded fields that are flooded with rainwater for a portion of the cropping season. Water supply in this ecosystem is unpredictable (too much or too little water in the same season) and droughts are both problematic and common given the fact water is typically a constraint if this is the production practice selected. Rice that is grown under such environment supplies about 20% of the world's rice production (IRRI, n.db). Finally, upland rice is grown under dry-land conditions in mixed farming systems without irrigation and without puddling (an agronomic practice done typically during land preparation which hardens the bottom part of the soil in order to reduce unproductive water outflows). Only four percent of the world's total rice production is grown in rain-fed upland ecosystem (IRRI, n.db).

Given its ability to adopt different growing environments, rice is cultivated in more than a hundred countries worldwide in every continent with the exception of Antarctica. However, despite its relative worldwide range of cultivation, 90% of the world's rice is produced and consumed in Asia alone (Bouman, Barker, Humphrey, & Tuong, 2007a). The top five rice producing and consuming countries are: China, India, Indonesia, Bangladesh, and Vietnam, respectively. In the United States, Arkansas is the largest rice-producing state accounting for 48% of the total U.S. rice production (Arkansas Rice Federation, 2012).

Rice is a staple food for nearly one-half of the world's population, the majority of whom live in low-income countries. Rice and specifically brown rice is rich in nutrients and contains a number of vitamins and minerals. Rice is a good source of complex carbohydrates which are an energy source. Approximately 50% of world's population (3.5 billion people) depends on rice for more than 20% of their daily calories (IRRI, n.da). Despite its nutritional importance, paddy rice production can be environmentally straining in that paddy rice is the greatest water consuming crop in the world and a large greenhouse gas (GHG) emitter.

B. Water-Use

As the world's population continuous to increase, so does the demand of water for domestic, industrial and agricultural use. This situation greatly concerns rice growers since a large quantity of water is required for rice production. Given the scarce nature of water sources and the high rate of water exploitation, many rice producing regions in the world will soon face water shortages or even crises. Water sources, therefore, need immediate attention in water-related investments and policies to increase water use efficiency across all water user sectors.

In the event of reduced water supplies or stricter water policies, rice producers will need to find ways to increase water use efficiencies through either increasing output with the same amount of water or holding yield constant using less total water. Higher demand for water as a result of population growth is accompanied with an increase in food demand as well, which strongly calls for an increase on yields with less water input.

1. Water-Use in Rice Production

Rice is a very water intensive crop, accounting for approximately 25% of world's fresh water usage (Dobermann, 2012). According to Mekonnen and Hoekstra (2010, 2011), on average, a bu of paddy rice requires 8,997 gal of water, while a bu of milled rice requires 13,405 gal of water. Paddy rice is rice as harvested from the field (Mekonnen & Hoekstra, 2010, 2011), while milled rice is the whole or broken rice kernels from which the hulls and at least the outer bran layers have been removed (USDA, 2007). Growing a pound of rice takes normally two to three times more water compared to other cereals (Tuong, Bouman, & Mortimer, 2005; Grassi, Bouman, Castaneda, Manzelli, & Vecchio, 2009).

Although rice can be grown under different ecosystems, more than 75% of the world's rice supply is produced under irrigated lowland, while only about half (~51%) of its global acreage is cultivated under this environment (Tabbal, Bouman, Bhuiyan, Sibayan, & Sattar, 2002; Tuong & Bouman, 2003; Tuong et al., 2005). These figures clearly indicate the importance of irrigated lowland systems in rice production and food security worldwide, but also pose a problem given that irrigated lowland system is the most water-intensive production method.

Given the fact that rice is a water-intense crop, countries that produce more rice are prone to greater water resource exploitation. Parts of China, India, Pakistan, and other Asian countries are presently facing water supply shortages (Tuong & Bouman, 2003), which given the large population growth and increased demand for food, is expected to become a larger issue in the near future. The water resource per capita in Asian countries decreased by 40-60% between 1955 and 1990 (Gleick, 1993), and by 2025 is expected to decline by 15-54% compared to that of 1990 (Guerra, Bhuiyan, Tuong, & Barker, 1998). Asia's agriculture sector consumes 90% of the total freshwater used, 50% of which is used for rice irrigation only (Barker, Dawe, Tuong, Bhuiyan, Guerra, 1999). Thus, increases in water-use efficiencies in rice could have large impacts on the water supply in one of the most populated and fastest growing parts of the world.

While rice production is a large strain on water supplies in many parts of the world, water shortages (as a result of droughts, increasing water demand for agriculture and non-agriculture sector, water pollution etc.) can also become a cause for a decrease in rice production. Australia, for instance, is a good example of how water shortages have become a major constraint for rice production. Historically, Australia produced enough rice to feed about 20 million people annually (Bradsher, 2008; Ricegrowers' Assocaition of Australia Inc [RGA], 2012). However, six incessant years of drought caused a dramatic decline of 98% on Australia's rice production (Bradsher, 2008). The New York Times reported that the effect of Australian droughts on its rice production caused ripple effects on the global market, and somewhat contributed to the price increase in 2008 (Bradsher, 2008).

Similarly, in the state of Arkansas, which is the largest rice producer in the U.S., accounting for 48% of American rice production [Arkansas Rice Facts (ARF), 2012], water constraint is becoming more apparent and in some cases a binding production issue. The U.S.is a small rice consumer and producer; however, it is third largest rice exporter ranking after Thailand and Vietnam (Bennett, 2010). Therefore, although U.S.is a small global player from a production standpoint, given the tight supply for rice, its production has global implications from a humanitarian viewpoint since rice is the most important food crop of the low-income world and the staple food of more than half of the world's population (IRRI, n.da). Rice provides 21% of global human per capita energy and 15% of per capita protein and price/supply shocks can have large impacts on the developing world. For example, in 2008, when rice prices tripled, the World Bank estimated that an additional 100 million people were pushed into poverty (IRRI, n.da). Further, 10.2% of global rice exports were provided by the U.S.in 2009 (Childs & Baldwin, 2010) and nearly half of that was supplied by Arkansas. Hence, a decrease in rice production due to water or other constraints in the U.S. could have ripple effects across the world given that small supply shocks can have large effects across the world.

Moreover, it is critical that world's rice production increases to meet the growing demand for rice due to a strong demographic boom in the world's population. In Asia, for instance, rice production will need to increase by 70% of 1999's amount by the year 2025 to meet market demand for rice (Tuong & Bhuiyan, 1999). Further, in 2020, global rice is projected to increase by 35% compared to that of 1995 (Cabangon, Tuong, & Abdullah, 2002). As the demand for rice increases, so does the competition on water supplies from both agricultural and non-agricultural sectors. Agriculture is losing water shares as a result of increasing water demand for domestic, municipal, industrial and environmental purposes (Guerra et al. 1998). Such mounting needs for water towards scarce water resources will soon lead to serious water supply exploitation if actions are not taken to improve the situation.

Like many other rice-producing areas around the world, Arkansas is experiencing groundwater supply exploitation. In 2004, the Arkansas Natural Resources Commission (ANRC) estimated groundwater withdrawals in Arkansas at 6.5 billion gal per day, a 70% increase from the amount used in 1985 and over 12 times from that of 1945 (ANRC, 2007). Today's irrigation level is unsustainable in the sense that water use exceeds recharge in the Alluvial aquifer, which is the aquifer that supplies the groundwater to the majority of the rice acreage in Arkansas. To reach sustainable pumping levels, the U.S. Geological Survey's 2006 estimates indicated that certain counties in the Arkansas Delta will need to reduce irrigation pumping rates by as much as 67% from their 2004 usage (USGS, 2008). This is significant since approximately 63% of the state's total water supply is sourced from groundwater, 95% of which comes from the Alluvial aquifer in the Delta region of Arkansas (USGS, 2008). To put this in context, Popp et al. (2010) reported that Arkansas, Lonoke, Lee, Poinsett and St. Francis counties would all need to reduce their irrigation pumping rates by over 40% to maintain ground-water levels. These counties alone consisted of 28% of Arkansas's total rice acreage, or 14% of the nation's rice supply.

In order to avoid the decrease of rice production acreage due to ground-water depletion, Arkansas rice producers, as well as other rice producers around the world, need to proactively look for new technologies/genetics which will allow them to improve their water-use efficiency. As one of the most water-intensive crops and the most commonly grown of all crops under irrigation (Guerra et al., 1998), rice makes one of best targets for water conservation projects.

2. Increasing Water-Use Efficiency in Rice Production

Several studies (Guerra et al, 1998; Tuong & Bhuiyan, 1999; Tabbal et al., 2002; Tuong & Bouman, 2003; Tuong et al., 2005) have divided improvements of water-use efficiency in rice production into two major groups: (1) increase in rice yield per unit of water input, and (2) reduction of unproductive water outflows.

2.1 Increasing Rice Yield per Unit of Water Input

Increasing rice yield while keeping water input constant is usually attained through improved germplasm development and more intensive agronomic practice (Tuong & Bouman, 2003), both associated with direct and indirect impact on rice yield.

Improvement in germplasm development can result in efficient water usage by increasing grain yield and/or reducing rice's growth duration (Tuong & Bouman, 2003). A higher yield with constant water input logically leads to an increase in water-use efficiency. Additionally, assuming constant or higher yields, a shorter duration on rice growth can also result in higher water efficiency since less water is needed for irrigation purposes. Reduction of water input in rice varieties with a shorter life cycle are facilitated through less water outflows on evaporation (E) from the soil or water surface, transpiration (T) from the plant, seepage (S) and percolation (P).

The hybrid rice, an example of improved germplasm development, is rice created by crossing two different parental strains which generally result in first filial (F1) generation that is more robust than either of the parental strains. Filial 1 typically possess greater agronomic qualities such as higher yield, resistance to diseases, and higher efficiency in soil nutrient usage. Hybrid rice typically yields 15-20% more than conventional cultivars under the same growing conditions with roughly the same input requirements (Tuong & Bhuiyan, 1999; McFaddan et al., 2011). However, because of the difficulty of producing hybrid rice seeds, they can only be produced by seed companies. Additionally, given that F1 offspring (F2) do not perform as well as the F1 generation, producers must purchase fresh seeds each growing season making hybrid rice production more costly than other conventional counterparts (McFaddan et al., 2011).

Higher rice yields with constant water input can also be achieved through agronomic practices such as: better nutrition and better control for diseases, pest and weed etc. However, such intensive agronomic practices typically come at a higher labor and other input costs.

Hybrid rice and intensive agronomic practices have the potential to increase water-use efficiency; however, rice farmers will not apply them unless such practices lead to higher profits.

2.2 Reducing Unproductive Water Outflows

Most of the world's rice, and all rice in the United States, is grown in irrigated lowland ecosystems (EPA, 2010). Therefore, given the fact that the irrigated lowland rice production system is the most water intensive of all rice production systems, technologies and production techniques which may reduce water inputs while maintaining a constant yield are commonly strived for in this system.

Rice grown under flooded conditions is subject to larger unproductive (water that flows from the field without being consumed by rice crop) water outflows. The main forms of water outflows at the farm level include: evaporation (E) from the saturated soil or water surface, transpiration (T) from the plant, seepage (S) and percolation (P). Seepage (S) and percolation (P) are water outflows that occur at the soil level. Percolation represents the vertical movement of water beyond the root zone to the water table, while lateral seepage represents the movement of subsurface water between fields (Huang, Liu, Chen, & Chen, 2003). Percolation and seepage are usually measured and reported as a single value (S&P), as distinct measures of these two are difficult. For the same reason evaporation (E) and transpiration (T) are commonly measured as one value (evapotranspiration ET) as well.

The percentage of water outflows through S&P and ET may vary with soil texture and temperatures. A study conducted in irrigated rice fields of Bangladesh reported that, irrespective of season and year around, 50% of the irrigation water is needed for ET and the remaining 50% is lost through S&P annually from the double cropped rice fields (Rashid, Kabir, Khan, Saleh, & Khair, 2009).

If a variety with reduced growth duration were to be released which stays on flood for a shorter time, water use efficiency would increase, assuming constant or higher yields. Water efficiency in such a scenario is affected by a shorter flooding period, which results in less water outflows – specifically evapotranspiration (ET). Seepage and percolation are not expected to be affected at the same as ET, since the majority of S&P water outflows occur during the first stages of growth. Later on, soil becomes less permeable.

Of the four forms of water outflows, transpiration (T) is the only explicit factor which impacts yield. Therefore, reducing water input by keeping yield constant can only be achieved by targeting the unproductive water outflows such as S&P, and E. Among the most common practices that reduce unproductive water outflows (S,P, & E) are: (i) minimizing land preparation time, (ii) adopting water-efficient crop establishment methods, and (iii) improving soil and water management (Guerra et al, 1998; Tuong & Bhuiyan, 1999; Tabbal et al., 2002; Tuong & Bouman, 2003).

2.2.1 Land Preparation Period

Land preparation is the first step in irrigated lowland rice production. This step starts with land soaking, which is the process of saturating the top soil with standing water at a depth of 0.4 – 2.0 inches for two or more days (Cabangon & Tuong, 2000). Normally, if measures are not taken to prevent or close the cracks before soil soaking, water will bypass the soil top through the cracks. Toung, Cabangon and Wopereis (1996) estimated the water waste caused by cracks to be between 41-57% of total water used for land soaking. This leads to an increase in the time needed for land preparation as well as water requirements during this stage.

One way to minimize land preparation period, and ultimately reduce water requirements at this stage, is by changing the soil physical properties in order to make soil more resistant towards water pressure (Toung & Bouman, 2003). This is usually done through tillage right after the harvest of the previous crop (preventing crack formation) or right before land preparation (closing the formed cracks) (Guerra et al., 1998). Cabangon and Toung (2000) found that shallow tillage before land preparation reduced water inputs required for land preparation by 31-34%. Despite its effectiveness, tillage is out of budget reach for most rice farmers (Guerra et al., 1998).

Soil management, however, is not the only practice to reduce land preparation time. According to Pandey and Velasco, (2002), the transplanted rice establishment method is the most common method of rice establishment is Asia. This method requires germination of seedlings in a seedbed for a period of 2-4 weeks (Toung & Bouman, 2003) before transplanting them in the main field. In rice fields where sophisticated irrigation systems are absent, the entire rice field is flooded during seedling germination. This practice prolongs land preparation time by an additional 2-4 weeks as well as increases unproductive water outflows through E and S&P. This phenomenon is not an issue in the state of Arkansas, given that 97% of Arkansas's rice is established using the dry-seeded method (Slaton & Cartwright, 2001).

For the rice growing areas where transplanted rice is commonly sown, the land preparation period can be reduced by separating the water supply for the seedbed from that of the main field, soaking the rest of the field only shortly before the seedlings are ready to be transplanted. Water supply separation, however, requires the presence of field-level infrastructure as well as a main infrastructure tuned to the delivery of small amounts of irrigation water during the seedbed period (Tuong, 1999).

2.2.2 Rice Establishment Methods

There are three common methods of rice establishment: (1) transplanted rice (TPR), (2) wet-seeded rice (WSR), and (3) dry-seeded rice (DRS). Wet-seeded rice and DSR are usually categorized under the direct-seeding rice system. Transplanted rice is a crop establishment method where rice is germinated for a period of 2-4 weeks in seedbeds and later transplanted to main field (Toung & Bouman, 2003; Cabangon et al., 2002) and is the typical rice establishment method in Asia. In wet-seeded rice (WSR), pregerminated rice seeds are planted directly to a saturated and usually puddled field (Guerra et al., 1998), which is typical in Asia and is common in California in the U.S. but unlike the Asian countries, California sows using airplanes to save on labor costs. Dry-seeded rice (DSR), on the other hand, is planted in ungerminated conditions in dry or moist soil (Cabangon et al., 2002), which is common in the American south including Arkansas, where 97% of rice is established through this method (Slaton & Cartwright, 2001).

Numerous studies (Bhuiyan, Sattar, & Khan, 1995; Tabbal et al., 2002; Cabangon et al., 2002; Yadav, Gill, Humphreys, Kukal, & Walia, 2011) have been conducted to estimate and compare water-efficiency differences between wet- and dry-seeded rice systems with that of the traditional Asian TPR system. The performance of these three methods of rice establishment is known to be site-specific depending on physical soil properties, weather condition, water management; therefore, contradictions on the results regarding water efficiency and yield between different studies exists.

In a study conducted in the Philippines, Bhuiyan et al. (1995) reported a drop of approximately 18 inches of total water use in the WSR system compared to the traditional Asian methods of transplanted rice. In addition to a drop in water input, WSR proved to be more drought resistant, had higher grain yield, and was associated with lower production (labor) cost. According to Bhuiyan et al. (1995), less water was used in WSR for both land preparation and the crop growth period; however, the majority of the drop in water requirements was attributed to shorter land preparation time. Tabbal et al. (2002) also observed that wet-seeded rice yields were 3-17% higher than these of transplanted rice under continuously flooded conditions while requiring 11-18% less water input during the crop growth period.

Cabangon et al. (2002), on the other hand, contradicts Bhuiyan et al. (1995) and Tabbal et al. (2002) foundings, concluding that, despite the fact that WSR establishment method shortens the land preparation period, this method is usually associated with a longer crop growth period in the main field, requiring a greater amount of water, compared to that of TPR. As a result of this characteristic of WSR, TPR and WSR end up using about the same water input through their entire life cycle. In regards to yield, Cabangon et al. (2002) reported WSR to yield less than TPR. Further, from a study conducted in the Republic of Korea, Lee Seung Chan reported a 15% increase in irrigation water requirement in WSR compared to that of TPR (Lee Seung Chan, as cited in Guerra et al., 1998). Lee Seung Chan associated this increase of water requirements to a prolonged life cycle of wet-seeded rice as a result of cold temperatures that wet-seeded are exposed to in the main field.

In the commonly used dry-seeded rice (DSR) system in Arkansas, rice is typically planted in late March or early April. The early seed establishment allows rice to make use of rainfall on its first life stages and uses irrigation water only for the later stages of its life cycle. Dry-seeded rice method, therefore, offers an alternative for significant potential water conservation, generally associated with a yield penalty. Yadav et al. (2011), however, reported no yield difference between DSR and TPR when soil water tension had increased to 20 kPa at soil depth of 7-8 inches, and significant water requirement reduction of 33-53% in dry-seeded rice irrigation system. Tabbal et al. (2002) also reported no yield difference between DSR and that of TPR in the wet season with comparable water input during the crop growth period. Cabangon et al. (2002), on the other hand, reported a yield drop in DSR compared to the TPR with no difference in water efficiency between the two. Despite its potential to save water, Upasena, Moody, & Itoh et al. state that direct-seeded rice establishment methods are often associated with poor germination and profuse weed growth (as cited in Guerra et al., 1998, p. 10).

2.2.3 Soil and Water Management

Soil management can increase water efficiency through reducing seepage and percolation (S&P). Activities such as tillage and puddling make soil more resistant to water pressure through changing soil physical properties (increasing soil compaction/reducing soil permeability) (Guerra et al., 1998; Cabangon & Tuong, 2000). Cabangon and Toung (2000) observed that shallow tillage before land preparation reduced water inputs required for land preparation by 31-34%. Dayanand and Singh as cited in Guerra et al. (1998) reported that puddling during land preparation can reduce water input requirement by 40-60% during crop growth.

Water management techniques that reduce unproductive water outflows have been studied thoroughly, especially in Asian countries such as: Philippines, China, India, and Pakistan, where rice is an important food crop and water shortage has become a serious concern for their future food security. According to these studies, most common practices that are qualified under a water-saving irrigation (WSI) system are the saturated soil condition and intermittent irrigation. Soil saturation is an irrigation method where a small water quantity (about

0.4 inches water depth) is applied frequently, almost on a daily basis or as soon as the standing water disappears, to maintain the soil in a saturated condition. Intermittent irrigation, which is also known in the literature as alternate wetting and drying irrigation (AWDI) or alternately submerged-nonsubmerged (ASNS) system, is an irrigation system where paddy rice is irrigated intermittently during the production period.

Typically, traditional flooded rice is covered by 2-4 inches of water; however such a heavy flood causes hydraulic pressure, which in turn increases the amount of water loss through S&P. In addition, flooded fields are also associated with higher amount of water outflows through (E) as it has been proven that evaporation occurs faster from free-water surface than wet soil surfaces (saturated fields).

According to Guerra et al. (1998) “Numerous studies conducted on the manipulation of depth and interval of irrigation to save water use without any yield loss have demonstrated that continuous submergence is not essential for obtaining high yield.” Therefore, unproductive water outflows such as S, P, and E at the field level can be reduced by applying different depths and intervals of irrigation.

Soil saturation and alternate wetting and drying irrigation (AWDI) are the most common practices of water-saving irrigation (WSI) techniques. Such WSI practices can reduce water use by about 40-70% compared with the traditional practice of continuous shallow submergence, without significant yield loss (Hatta, 1967; Tabbal et al., 1992; & Singh et al., 1996). Furthermore, Keisuke et al. as cited in Chapagain, Riseman and Yamaji (2011) reported a 20-50% reduction in water requirements of a non-flooded rice field compared to a flooded one, emphasizing that a difference in results can strongly depend on soil texture, rainfall and water management. With regards to soil texture, Guerra et al. (1998) claims that WSI techniques are more water efficient in lighter soils.

Soil saturation WSI is normally associated with a significant water input reduction and only a moderate decline in yield. Bouman and Tuong (2000) actually suggested that soil saturation is the best method of WSI, which when compared to traditional flood irrigation saves on average 23% (± 14%) water with a yield decrease of only 6% (±6%). Tabbal et al. (2002) confirms this finding by reporting an average yield decreased of 5%, and reduced water input requirements by 35%. Tabbal et al. (2002) also reported that intermittent irrigation further reduces water inputs and thus costs, but at the expense of rice yield and thus revenue.

Chapagain et al. (2011), who applied AWDI with irrigation schedule of 10 wet days alternated with 10 dry days for example, observed water requirements reduced by 29% with a yield decline of approximately 8% compared with conventional irrigation. Furthermore, Oliver at al. (2008) reported that at an AWDI where 2 inches of irrigation was applied to the field every time the water level fell 4 inches below the ground level, water efficiency increased by about 16% and yield declined by approximately 4% compared to that of continuous submergence.

Other studies have concluded that the AWDI technique reduces water input requirements significantly with slight to no penalty on rice yield. Hatta (1967), Tabbal, Lampayan, and Bhuiyan (1992), and Singh, Aujla, Sandhu, and Khera (1996) reported that WSI systems such as AWDI can reduce water use by 40-70 % without significant decline in yield. Belder et al. (2004) also reported a 15-18% water input reduction on alternately submerged-nonsubmerged (ASNS) system compared with continuous submergence (CS), with no statistical differences in yield.

Yet other studies have reported that AWDI maintains or even increases yield in addition to water input reduction. Uphoff as cited in Chapagain et al. (2011), for example, suggested that

AWDI allows for good aeration of the soil and better root growth and thereby increases rice yield and water-use efficiency. Yang, Liu, Wang, Du and Zhang (2007) also reported that WSI enhances physiological activities of roots, in addition to increasing grain yield by 7.4-11.3%, and reducing irrigation water by 24.5-29.2% compare to that of conventional irrigation. Belder at al. (2004), however, states that evidence on this category of studies which have suggested an increase in yield from WSI is still scarcely reported in international published reports.

Most of the rice in the U.S. is irrigated under continuous flooding (EPA, 2010). However, with the increase of water scarcity and increased demand for rice in the world markets, rice farmers have started to look at alternative production systems to continuous flooding such as center pivot sprinkler systems. This irrigation system has great potential in increasing water-use efficiency and has introduced the possibility of rice production on land that is not suitable for conventional flooded rice. Yet, despite its potential to reduce water inputs and production (water extraction) cost; this irrigation method is associated with a yield penalty which makes this alternative unattractive to rice producers. In a study conducted in Texas for instance, McCauley (1990) observed that sprinkler irrigation reduces rice yield by 20%. One large barrier to adoption of the center pivot system is that a producer must sow a variety that is blast (a common rice fungus) resistant. While blast can be mitigated by proper flood control, it cannot be mitigated under a sprinkler system without the application of a fungicide. Therefore, such an irrigation system currently is not appealing to rice producers who want to consider cultivating rice varieties that are not blast resistant which is a majority of currently used varieties in Arkansas.

Although the changes in rice yields are moderate (decrease/increase) to zero, rice under WSI is more prone to weed and disease pressure. Reduction in rice yield caused by weeds can be severe. However, Tabbal et al. (1992) suggested that for areas where weeds are a major issue, a continuous flood to the panicle initiation stage followed by continuous saturation reduced water input by 35% without yield penalty or increase in weed infestation. Chapagain et al. (2011), also suggested that the possibility of controlling for weeds in AWDI system can be achieved by using a single dose of appropriate herbicides and maintaining a shallow water depth until crop establishment.

Another reason for the lag in adoption of WSI techniques is the high labor and infrastructure costs. Water-saving irrigation techniques require a high degree of management control and infrastructure at both the field and system levels. More supervision and labor is required also, as a result of small amount of water but more frequent application (Guerra et al., 1998). Such techniques have been applied quite widely in areas that possess appropriate infrastructure including farms in southern China and could be great techniques in water saving elsewhere if affordable. That being said, labor is relatively cheap and abundant in China and relatively expensive and scarce in the United States.

However, despite the fact that the majority of WSI methods have proven to be significantly efficient in increasing water-use efficiency, the decision to adopt WSI techniques is more of a resource constraint and not a profit maximization issue. Therefore, unless the government intervenes by imposing an economic value on water usage, rice producers will continue their traditional continuous flooding practices until water shortage becomes a constraint for continuously flooded rice. Rice producers in the U.S. and more specifically those in Arkansas pay no fees on water usage (except the extracting cost) and they prefer to take the extra cost on water extracting for continuous flooding just to avoid the risks associated WSI techniques.

C. Greenhouse Gas (GHG) Emissions

The popular thought is that the buildup of GHG emissions, like carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), have resulted in climate change. The agricultural sector contributes a significant percentage of the total global atmospheric GHG emission. In 2000, agriculture's share on total GHG emissions was 13% (Rosegrant et al., 2008). This percentage has steadily increased and is expected to continue to climb in the future as a result of the growing world population's need for food. Emissions from the agricultural sector are primarily in the form of CH_4 (from the rice and livestock industries) and N_2O (from the application of nitrogen fertilizers), which according to Intergovernmental Panel on Climate Change (IPCC) are recognized as potent greenhouse gases with 25 and 298 times higher global warming potential than CO_2, respectively, over a time horizon of 100 years (as cited in Yao et al., 2012, p. 1). Agricultural activities alone are responsible for approximately 50% of the global atmospheric inputs of CH_4, 10 % of which is attributed to paddy rice production (Scheehle & Kruger, & USEPA as cited in Zhang, Wang, Su, & Li, 2011). Rosegrant et al. (2008) also ranked rice as the third largest source of agricultural GHG emissions, contributing about 11% mainly in the form of methane arising from anaerobic decomposition of organic matter.

1. GHG Emissions in Rice Production

Rice, specifically rice produced under continuous flooding, accounts for a significant percentage of total GHG emissions, mainly through methane emissions. In the U.S., where all rice is produced under flooded condition (EPA, 2010), rice is ranked as the greatest crop emitter of GHG. Nalley et al. (2011) estimated that GHG emissions associated with rice production in Arkansas was four times greater than corn, which is the next greatest crop emitter on a per ac basis.

Generally, GHG from flooded rice production is emitted in three forms. First are the direct emissions that come from on-farm operations. Examples are CO_2 emissions from diesel used by tractors and irrigation equipment. Second are indirect emissions that are generated off-farm as a result of manufacturing inputs used on the farm. Examples of indirect emissions are the GHG emissions from natural gas to produce commercail fertilizer. Third are N_2O emissions from the application of nitrogen fertilizer and CH_4 emissions which are a result of anaerobic decomposition of organic matter during flooding. Among the three sources of GHG emission (CO_2, N_2O, and CH_4) from flooded rice production, CH_4 accounts for nearly half of total GHG emission, followed by nitrous oxide N_2O as the second largest, and CO_2 being the smallest (McFadden et al., 2011).

1.1 Life Cycle Analysis

Life cycle analysis (LCA) provides quantitative models to evaluate production processes, analyze options for innovation, and improve understanding of the complexity of factors influencing sustainability in agricultural production systems. Broadly, a LCA consists of four stages: 1) Defining the goal and scope; 2) Conducting life cycle inventory (collection of data needed to perform the necessary calculations); 3) Performing an impact assessment; 4) Analyzing and interpreting the results. The structure of an LCA is determined by its purpose (or function unit or metric). The scope of LCAs can be as broad as "all material and energy inputs and outputs of a process or product" to "GHG use in production of a crop." The scale of the purpose defines the scale of the analysis.

A Life cycle inventory (LCI) incorporates both direct and indirect GHG emissions associated with the production of a unit (in this case paddy rice). Direct emissions are those that come from on-farm operations. Examples are carbon dioxide emissions from diesel used by tractors and irrigation equipment. Indirect emissions are generated off farm as a result of manufacturing inputs used on the farm. Examples of indirect emissions are the GHG emissions from natural gas to produce commercail fertilizer.

Methane emissions – a result of anaerobic decomposition of organic matter during flooding - are the largest contributor to the total GHG emissions in paddy rice production. Nitrous oxide emission from application of nitrogen fertilizer is a large contributor to GHG emissions (Bouwman, 1996; Smith, McTaggart, & Tsuruta, 1997; Yanai et al., 2003; Del Grosso, Mosier, Parton, & Ojima, 2005; Snyder, Bruulsema, Jensen, & Fixen, 2009) as well. Therefore, both methane (CH_4) and nitrous oxide (N_2O) emissions from paddy rice production were included in estimations of GHG emissions.

1.2 Methane (CH_4)

Methane is produced as a result of anaerobic degradation of organic matter in the rice fields under flooded conditions (EPA, 2010). Given the fact that methane is produced in anaerobic conditions, its production does not begin immediately after the flood is applied. First, aerobic decomposition of organic matter takes place until the oxygen present in the soil is gradually depleted, causing anaerobic soil conditions, which eventually facilitates the beginning of the CH_4 production process by methanogenic bacteria (EPA, 2010).

According to EPA (2010) Continuous shallow flooding (2-4 inches, commonly used in the United States) causes the largest CH_4 production as it keeps the soil continuously under anaerobic conditions. Upland (non-flooded) rice fields do not produce $CH_{4,}$ while deepwater rice fields (i.e., fields with flooding depths greater than one meter) are not believed to be significant CH_4 emitters, since the lower stems and roots of the rice plants are dead, which blocks the primary CH_4 transport pathway to the atmosphere. The continuous shallow flooding is practiced in most of the rice cultivation around the world, and on all acres in the U. S. (EPA, 2010), making flooded rice a great target for potential opportunities for mitigating GHG emissions. Soil aeration of shallow flooded fields oxidizes CH_4 and prevents further CH_4 production in soils (EPA, 2010). Interrupting continuous flooding by releasing the flood one or more times during rice growing stage allows for soil aeration, and thus CH_4 reduction.

Other factors that influence CH_4 emissions from flooded rice fields include fertilization practices, soil temperature, soil texture, rice variety (aerenchyma system development, body mass, days on flood), and cultivation practices (e.g., tillage, seeding, and weeding practices) (Wassmann, Papen, & Rennenberg, 1993; EPA, 2010). Most of the produced CH_4 is oxidized by aerobic methanotrophic bacteria in the soil, and only about 30% of the produced methane is emitted to the atmosphere mainly through the rice plant, air bubbles, and molecular diffusion (Wang, Shangguan, Shen, Wassmann, & Seiler, 1993; EPA, 2010).

Methane emissions from flooded paddy rice in Arkansas starts typically two weeks after flooding, reaches its peak around 50 days after flooding followed by a constant decrease until the flood is released prior to harvesting. During flooding, methane is released mainly through plants as the flood prevents methane release from the soil to the atmosphere. The emitted quantity of methane in paddy rice directly depends on two factors: aboveground dry matter and the number of days on flood, the later varying by rice variety. Methane emissions increase as the rice plant grows larger, reaches a peak, and then later decreases as the plant nears harvest. Varieties that require longer flooding periods release a greater quantity of methane (K.R. Brye, personal communication, January 31, 2012).

1.3 Nitrous Oxide (N_2O)

Nitrous oxide (N_2O), the second largest GHG from flooded rice, is produced in the soil mainly through the microbial process of nitrification and denitrification (Zou et al., 2005). Studies have shown that microbial organisms that produce N_2O are more productive in aerated soil conditions. Zou et al. (2005), for example, reported that N_2O emission increased significantly during the midseason drainage, however, dropped to almost zero once the field was flooded again. That is, unlike methane which is released while the rice plant is flooded, N_2O is released after the flood is removed. In addition, Zou et al. (2005) also noticed N_2O emission to be lower in intermittent irrigation systemS with waterlogged soil condition compared to that with moist soil conditionS.

Nitrogen (N) fertilizer application has a significant effect on N_2O as well. However, given the fact that the N_2O production process is affected by soil condition (aerobic/anaerobic), Zou et al. (2005) suggested that N fertilizer impact on N_2O emission depended strongly on irrigation method. Further Zou et al. (2005) claimed that the availability of organic C is often considered to be a major factor influencing denitrification under anaerobic conditions.

Given that rice is a large GHG emitter, rice producers face great public/governmental pressure to lower their net GHG emissions. On the other hand, with the increasing food demand as the world's population continues to grow, rice producers are expected to increase rice production. Rice producers, therefore, are under pressure to find technologies that will help them increase rice production and simultaneously reduce GHG emissions.

2. Mitigating GHG Emission in Rice Production

Several factors that can help mitigate GHG emissions from flooded rice fields include irrigation methods, amendment of fertilizers (organic – crop residue incorporation, and inorganic), soil characteristics (soil texture, temperature, pH, Eh) cultivar selection (aerenchyma system development, body mass, days on flood), cultivation practices (e.g., tillage, seeding, crop rotation, and weeding practices), (Wang et al., 1993; USEPA, 2012). Factors that have shown great impact are discussed below.

2.1. Irrigation Methods

Water management in rice fields is an important factor that significantly influences CH_4 and N_2O emission; therefore, alternative irrigation systems, with continuous flooding as a baseline irrigation practice, have been analyzed to observe its impacts on the two most important greenhouse gases (CH_4 & N_2O) in rice production. Numerous studies (Sass, Fisher, Wang, Turner, & Jund, 1992; Wassmann, et al., 1993; Yagi, Tsuruta, Kanda, & Minami, 1996; Corton et al., 2000; Wassmann et al., 2000; Yang and Chang, 2001; Ma et al., 2007) reported that alternative irrigation (e.g., mid-season drainage, intermittent irrigation, saturation soil condition etc.) which allows for aeration during the rice growing season, reduces CH_4 emission compared to continuous flooding. Corton et al. (2000) and Wassmann et al. (2000) reported a decline in CH_4 emissions from midseason drainage by 43% and 7-80%, respectively, from the baseline irrigation practice. Intermittent irrigation also reduces CH_4 emissions by 20-80% compared to that of continuous flooding (Yang & Chang, 2001).

Several other studies (Cai et al., 1999; Wassamann et al., 2000; Nishimura, Sawamoto, Akiyama, Sudo, & Yagi, 2004; Li et al., 2004; Li et al., 2005; Zou, Huang, Jiang, Zheng, & Sass, 2005) have observed a trade-off between CH_4 and N_2O based on water management. Midseason drainage in Zou et al. (2005), for instance, decreased CH_4 emission by 65%; however, it triggered N_2O emission spikes. Zou et al. (2005) also observed N_2O emissions and found them strongly depended on the soil conditions. In intermittent irrigation with moist soil conditions

N_2O was much higher than in that with waterlogged conditions. In addition to CH_4 and N_2O trade-offs from changing water management, Li et al. (2005) also detected a CO_2 reduction as a result of switching from continuous flooding to midseason drainage. Therefore, different irrigation methods will be associated with a different trade-off in regards to CH_4 and N_2O emissions, but an optimal trade-off lowest Global Warming Potential (GWP) can be reached. This optimal point, according to Zou et al., (2005), may vary with the rice growing areas.

Li, Yuan, Xu, Cai, and Yagi, (2011) conducted an experiment to measure the effects on CH_4 and N_2O emission from alternating timing and duration of midseason drainage (aeration). Li et al. (2011) reported that a prolonged aeration period had the lowest (GWP) of CH_4 and N_2O emissions, as opposed to early aeration, normal aeration (the same as the local – China – practice in timing and duration of aeration) and delayed aeration. However, prolonged aeration was associated with a 15.3% yield decline compared to that of normal aeration.

Alternative irrigation methods, which have significant potential to reduce GWP, are not common irrigation practices in U.S. rice production. According to EPA (2010), all rice in the U.S. is grown under continuously flooded conditions, where mid-season drainage does not occur except by accident (e.g., due to levee breach). Continuous flooding enables weed control, lower labor cost (from: weed control, irrigation management etc.), and it is typically associated with greater rice yield. Unless “water supplies” and “GHG emissions” are not considered as economic “good” and “bad”, respectively, U.S. rice producers will not have incentives to apply irrigation methods with lower GWP.

Rice varieties with shorter life cycle (less days under flood), however, represent a potentially efficient strategy to mitigate CH_4 emissions, assuming yields are constant or even higher. The benefit of this strategy is that all of the agronomic practices in rice production are the same, except choosing a rice variety with reduced growth duration. Unlike changing production practices or adopting new technology, which is often costly and can bring on additional risk, changing rice cultivars based on growth duration is something most producers could do seamlessly with little additional cost.

2.2. Fertilizer Amendment

Nitrogen fertilizers, such as urea and ammonium sulfate, are commonly used in rice production to increase yield (Zou et al., 2005; Yao et al., 2012). The application of these synthetic fertilizers has been shown to inhibit CH_4 emissions (USEPA, 2010). Various studies (Wang et al., 1993; Cai et al.,1997; Zou et al., 2005; Yao et al., 2012) have shown that alteration of nitrogen fertilizers amount generally reveals a trade-off between CH_4 and N_2O emissions. Cai et al. (1997) reported that CH_4 emission, on average, decreased by 42 and 60% in the ammonium sulphate treatments and 7 and 14% in the urea treatments at rates of 89 and 268 lbs. per ac, respectively, compared to the control (0 lbs/ac). Nitrous oxide emissions, on the other hand, increased significantly with the increase in the nitrogen application rate, with greater N_2O emissions from ammonium sulphate treatments than from the urea treatments at the same application rate (Cai et al., 1997). Zou et al. (2005) also noticed that increasing the application of urea reduced CH_4 and triggered N_2O emissions. Similarly, in an experiment in a sandy loam paddy field in China, Yao et al. (2012) observed that the application of urea tends to reduce CH_4, but significantly increases N_2O emissions. The trade-off between the two in this experiment depended on the amount of applied urea, where a greater urea application resulted in an overall lower emission of CH_4 and N_2O expressed in CO_2 equivalents. Ma et al. (2007), however, reported that stimulation or inhibition by nitrogen fertilization on CH_4 was affected by application rate. For instance, an increase in nitrogen fertilizer from 0 to 179 lbs/ac reduced CH_4

emissions significantly, but the effect of nitrogen fertilizers on CH_4 emissions decreased as the nitrogen fertilizer rate increased beyond 240 lbs/ac.

Kruger and Frenzel (2003) and Li et al. (2004) observed no significant effect on CH_4 emissions with nitrogen fertilizers; however, they noticed an increase in N_2O emissions. Lindau, Bollich, Delaune, Patrick, and Law, (1991), on the other hand, observed increased CH_4 emissions with an increase in urea application.

Crop residue incorporation also has an effect on the amount of CH_4 and N_2O emitted. Crop residue incorporation is typically associated with a major increase in CH_4 emission (Cai et al., 1999; Corton et al., 2000). Corton et al. (2000) observed an increase in CH_4 by 23-30% and 162-250% resulting from compost and fresh rice straw incorporation, respectively. The CH_4 increase from crop residue incorporation occurs due to an increase in organic matter added in the soil, as it is the organic matter decomposition in anaerobic conditions which causes CH_4 production. Type and condition (fresh/composted) of crop residue incorporation, therefore, result in different CH_4 emissions.

Different crop residues have shown different impacts on N_2O emissions as well. This is attributed to their type and quality (C, N, C/N ratio) which facilitates nitrification and denitrification processes from which N_2O is produced. Ma et al. (2007), for example, reported a slight decline in N_2O emissions due to wheat straw incorporation. Li et al. (2004) showed crop residue incorporation to also have an effect on CO_2 emission. This study indicated that the percent of above-ground crop residue incorporation had notable impacts on net CO_2 emissions.

2.3. Soil Characteristics

Among factors that influence GHG emissions in paddy rice are also soil characteristics such as: soil texture, temperature, pH, Eh etc. (Cai et al., 1999; Xiong, Xing, & Zhu, 2007; EPA, 2010). Cai et al. (1999), for instance, observed that among sandy, loamy, and clayey soils, clayey soils emitted a greater amount of CH_4 in both years (1993 and 1994) of the experiment. Furthermore, Cai et al. (1999) reported that soil temperature and soil Eh at 2-inches depth significantly affected the fluctuations of the CH_4 flux measured in the morning and afternoon, but they were not the main factors controlling the seasonal variation of CH_4 emissions. Xiong et al. (2007) showed N_2O and CH_4 emissions to be significantly greater from clayey soil than from loessial soil during the flooded period. EPA (2010) stated that soil temperature is known to be an important factor regulating the activity of methanogenic bacteria, and therefore the rate of CH_4 production, by controlling the amount of time it takes to convert a given amount of organic material to CH_4. However, EPA (2010) claimed that the time it takes to convert organic material to CH_4 is short relative to a growing season; therefore, the dependence of total emissions over an entire growing season on soil temperature is weak.

2.4. Cultivation Practices

Cultivation practices have been observed to effect GHG emissions as well. Cai et al. (1999) and USEPA (2010), for instance, reported that large rates of water percolation resulted in lower emissions of CH_4 as part of the CH_4 is leached away as dissolved CH_4 in floodwater that percolates from the field. Corton et al. (2000) and Wassmann et al. (2000) reported direct-seeding rice establishment practices to have an impact on CH_4 emissions. Corton et al. (2000) observed that direct-seeding reduced CH_4 emissions by 16-54% compared to that of the transplant method of rice establishment. Similarly, Wassmann et al. (2000) observed a 16-22% decrease of CH_4 as a result of switching from the transplant to direct-seeding establishment method. However, Corton et al. (2000) noted that the mechanisms for the reducing effect are not clear. Li et al. (2004) showed that crop rotation is a management practices found to have notable impacts on net CO_2 emissions.

2.5 Cultivar Selection

Cultivar selection has been documented to have an impact on GHG emission by reducing CH_4 emissions (Huang, Sass, & Fisher 1997; Mitra, Jain, Kumar, Bandyopadhyay, & Kalra, 1999). As mentioned above, the main pathway of CH_4 from soil to the atmosphere is through the rice plant itself. This path, according to Wassmann et al. (1993), is connected to the development of the aerenchymal system of the rice plant; therefore, selecting a cultivar with a less developed aerenchymal system could be a way to mitigate CH_4.

Selecting a rice cultivar with a shorter flooding period could also be an effective way to reduce methane emissions, which in return will result in lower total GHG emission from paddy rice.

The effect of management practices which are used to mitigate GHG emissions from flooded rice production vary significantly with climatic zones, soil texture, or cropping systems. In other words, practices that can be effective in mitigating GHG emission in one rice production area might not be as effective in other areas. Thus, it is important that site-specific management practices are developed based on the rice production area. In addition, these GHG emission mitigating management practices are often associated with greater labor costs, negative impacts on rice yield and soil fertility, and increased time requirement for practical application (Yagi, Tsuruta, & Minami, 1996). Mitigation of GHG emissions through cultivar selection (based on growth duration and yield) could be one of the most efficient strategies since it does not require new production practices or adopting new technology, which is often costly and can bring on additional risk.

D. Rice Types

Conventional (traditional) rice varieties, which are the most commonly sown in the United States, are simply created using conventional breeding techniques. A conventional rice variety is a rice line that is a group of rice plants distinguished by common characteristics of significance to agriculture and often has been assigned a commercail name. When rice is produced from a variety, a single line is planted and it is fertilized by self-pollination. When a rice variety is reproduced, it retains its distinguishing characteristics, and farmers can keep seeds for replanting next season.

Clearfield® rice varieties were developed by mutating the DNA of conventional rice with radiation and then making selections following crosses with other conventional varieties. Because Clearfield® rice maintains pure DNA from only rice; it is not considered a genetically modified organism (GMO). The main benefit of Clearfield® rice is that it is resistant to Newpath® herbicide. A persistent problem for rice producers in the Southeast is the presence of red rice (a weed) throughout their fields. Red rice was estimated to be present in approximately 20% of all rice acreage in Arkansas in 2002 (Annou, Thomsen, Hansen, Wailes, & Cramer, 2005). Because of its nearly identical genetic structure to commercail rice, there is no existing herbicide that can adequately control red rice without also injuring or killing conventional rice. That being said, Clearfield® rice which is resistant to imidazolinone herbicides (Newpath, which kills red rice but not conventional rice) was developed.

Hybrid rice is rice that has been created by crossing two different parental strains. Such crosses generally result in an F1 generation that is more robust than either of the parental strains. The hybrid vigour may result in superior agronomic qualities such as higher yield, stronger resistance to diseases, more efficient use of soil nutrients, and better weed control. Hybrid Rice has been documented to yield approximately 15-20% more than the best inbred cultivar grown under similar conditions through hybrid vigor (Tuong & Bhuiyan, 1999; Virmani, Sun, Mou, Jahuar Ali, & Mao, 2003). Due to the difficulty of making hybrids, they are generally only produced by seed companies. Farmers do not save hybrid seeds for replanting because self-fertilization will result in genetic segregation of traits. Since hybrid offspring (F2) generally do not perform as well as their parents (F1), producers must purchase fresh seeds each growing season (McFadden et al., Forthcoming).

The following chapter will focus on estimating water use and GHG emissions (per ac & per bu) on a variety basis. After variety specific values have been estimated, they will be grouped in three different categories (conventional, Clearfield, & hybrid) in order to be able to compare as to which rice type is more water and GHG emission efficient.

III. METHODOLOGY AND DATA

A. Data

This study empirically examines the environmental benefits of hybrid rice varieties. It focuses particularly on the differences in seasonal water use and GHG emissions between hybrid, conventional and Clearfield rice varieties.

Estimation of water use (both per ac and per bu) was performed for seven consequent years (2004-2010) on most commonly sown rice varieties in Arkansas. Water use varies between rice varieties (aboveground dry matter & number of days under flood), location (elevation) and the growing year (weather differences).

To easily estimate total GHG emissions, GHG emissions were grouped into three different sources. First source includes emissions from diesel (tractor operation), fungicide, herbicide, pesticide, fertilizer (Sum of N-P-K application) and N_2O (correlated with nitrogen fertilizer application. The GHG emission values from this source were obtained from McFadden et al. (2011). Given than McFadden et al. (2011) had estimations on only 14 most commonly cultivated rice varieties in Arkansas, while this study includes about 60 rice varieties, the average GHG emissions (Table 6) on a cultivar type basis (conventional, Clearfield and hybrid) were used instead of variety specific GHG emissions. Second source comprises off carbon dioxide emissions which are caused by burning diesel fuel to raise water for irrigation. Third source includes Methane emissions caused by flooding. Original data on methane emission were obtained from Rogers et al. (2012) and were used to estimate seasonal methane emission for each rice variety (based on number of days under flood and cultivar type [conventional & hybrid]).

1. Arkansas Rice Performance Trials (ARPT) Data

Data on yield, variety, location, season, variety type, emergence date[1], and 50%-HEADING[2] were attained from ARPT. These data are available in yearly basis for seven consecutive years from 2004 to 2010 for six different rice stations which include: 1) Northeast Research and Extension Center, Keiser, Arkansas (Mississippi County), 2) Rice Research and Extension Center, Stuttgart, Arkansas (Arkansas County), 3) Southeast Research and Extension Center, Rohwer, Arkansas (Desha County), 4) Coring (Clay County), 5) Newport (Jackson County), and 6) Pine Tree Branch Experiment Station, Colt, Arkansas (St. Francis County).

[1] Emergence data is defined as the date when the rice plant emerges from the soil.
[2] 50% HEADING is defined as the time when 50% of the panicles in the field have emerged from the boot.

Table 1. Data from ARPT at the Stuttgart Rice Research & Extension Center (RB) for the Growing Year 2010

Year	Yield	Variety	Location	V-Type	Emergence Date	50% Heading
2010	130	RU0701124	RB	LG	4/22/2010	75
2010	223	CLXL745	RB	CLHYB	4/22/2010	82
2010	198	CL151	RB	CL	4/22/2010	85
2010	180	CL111	RB	CL	4/22/2010	86
2010	231	CLXL729	RB	CLHYB	4/22/2010	87
2010	252	XL723	RB	HYB	4/22/2010	87
2010	152	CL131	RB	CL	4/22/2010	86
2010	191	CL261	RB	CL	4/22/2010	86
2010	205	Bengal	RB	MG	4/22/2010	86
2010	178	Francis	RB	LG	4/22/2010	87
2010	167	Rex	RB	LG	4/22/2010	87
2010	149	CL142AR	RB	CL	4/22/2010	88
2010	223	Jupiter	RB	MG	4/22/2010	89
2010	161	Catahoula	RB	LG	4/22/2010	90
2010	156	Cybonnet	RB	LG	4/22/2010	90
2010	206	Neptune	RB	MG	4/22/2010	90
2010	175	Cheniere	RB	LG	4/22/2010	90
2010	143	CL181AR	RB	CL	4/22/2010	90
2010	151	Wells	RB	LG	4/22/2010	91
2010	148	Cocodrie	RB	LG	4/22/2010	92
2010	150	Taggart	RB	LG	4/22/2010	94
2010	161	Templeton	RB	LG	4/22/2010	94
2010	147	Bowman	RB	LG	4/22/2010	96
2010	161	RoyJ	RB	LG	4/22/2010	97

Source: Arkansas Rice Performance Trials (ARPT) 2010.

2. Data Used to Estimate Evapotranspiration

2.1 Data Used to Estimation Evaporation

Water evaporation (from plain flooded area) was calculated by using "Energy Balance Method for Evaporation." Calculating evaporation is necessary to account for water use. To calculate evaporation, soil radiation, air temperature, relative humidity and average precipitation (rain) were necessary, all of which were obtained from NASA Climatology Resource for Agroclimatology Daily Averaged Data. Elevation (per each location) was attained from the same source as well, given that it was a required variable for evaporation calculation. To obtain the above information longitude and latitude were essential, both of which were found on goole-earth based on the address of each of the six Rice Research and Extension Centers. An example of the data is provided in table 2.

Table 2. Daily Averaged Data from NASA Climatology Resource for Agroclimatology Utilized to Estimate Evaporation at the Stuttgart ARPT Station in 2010

Year	Day of Year	Soil Radiation (MJ/m^2/day)	Min Temp. (ºC)	Max Temp. (ºC)	Relative Humidity (%)	Rain (mm/day)	Elevation (m)
2010	140	10	21	26	82	0.0	87
2010	141	24	20	29	76	0.1	87
2010	142	25	20	30	77	0.0	87
2010	143	24	23	29	82	0.0	87
2010	144	24	23	29	74	0.0	87
2010	145	26	21	30	67	0.0	87
2010	146	25	20	29	69	0.3	87
2010	147	27	20	30	72	0.0	87
2010	148	26	21	30	69	0.0	87
2010	149	25	19	30	57	0.0	87
2010	150	26	20	29	70	0.2	87
2010	151	25	20	31	63	0.0	87
2010	152	26	22	32	58	0.0	87
2010	153	26	22	30	74	0.0	87
2010	154	24	22	28	83	0.0	87

Source: NASA Climatology Resource for Agroclimatology Daily Averaged Data (2012).

NASA Climatology Resource for Agroclimatology Daily Averaged Data did not have data on rain for 2010 for any of the locations; therefore, data on rain for 2010 in this study were obtained from Arkansas State Plant Board, Weather Web (2012).

2.2 Data Used to Estimation Transpiration

Transpiration was derived by multiplying evaporation values with two (0.45 and 1.15) constant numbers reported by Allen et al. (1998), where the constant 0.45 is multiplied with evaporation values for the first 27 day of flooding while 1.15 is multiplied with the daily evaporation values from the 28^{th} day on flood to the drainage day.

3. Data Used to Estimate CO_2 from Irrigation

The GHG emission contributed by CO_2 from irrigation was estimated by multiplying the amount of evapotranspiration for each variety, at each rice station, in each year with two constants (1.022 and 7.01). The first constant 1.022 is the amount of diesel fuel (gal) used to raise one ac-in of water for irrigation pumped from 100 feet (Slaton, 2001), while 7.01 is a constant of carbon equivalent (CE) emitted per every one gallon of diesel fuel used to raise water for irrigation (EPA 2007 & 2009, and Sima Pro).

4. Methane Data

Data on methane emissions were obtained from Rogers et al. (2012) who collected it through a research conducted during 2011 growing season at the Rice Research and Extension Center near Stuttgart in Arkansas County, Arkansas. Rogers at al. (Forthcoming) selected long-grain, conventional rice cultivar “Wells” for use in their study. The average daily/ac methane emission for conventional varieties was derived from their research and was used in this study to estimate seasonal methane emission for every rice variety (based on the number of days each variety stays under flood).

B. Methodology

1. Water-Use

This section will outline how estimation of water outflows from the rice field through evaporation and transpiration (evapotranspiration) are calculated. Evaporation is the process by which liquid water passes directly to the vapor phase. Transpiration, on the other hand, is the process by which liquid water passes from liquid to vapor through plant metabolism. Other forms of water outflows such as seepage (S) and percolation (P) are assumed to be constant across all varieties with the same agronomic practices, regardless of the length of rice variety’s life cycle. Such an assumption has been drawn based on the fact that S&P occur in the beginning of flooding period; therefore, S&P will be the same regardless of the number of days under flooding. Evapotranspiration, however, directly depends on the length of flooding period, as this phenomenon continues to occur as long as the paddy rice is flooded.

1.1 Evaporation

Allen, Pereira, Raes, & Smith, (1998) have defined evaporation as the process whereby liquid water is converted into water vapor (vaporization) and removed from the evaporating surface. The phenomenon of water evaporation takes place in a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation (Allen et al., 1998). Evaporation in rice production occurs from flooded paddy rice or saturated/moisten soil and rice plant. In the absence of a more sophisticated model which would account for the impacts of rice vegetation in evaporation during the rice growing season, this study used a model that estimates evaporation from plain (no vegetation) flooded fields. The model is called “Energy Balance Method for Evaporation.”

1.1.1 Energy Balance Method of Evaporation

To estimate the amount of water outflows through evaporation for each variety, daily evaporation rates by location year were necessary. Using the data on soil radiation, air temperature, relative humidity, average precipitation and elevation from NASA Climatology Resource for Agroclimatology Daily Averaged Data, daily evaporation per location was calculated through “Energy Balance Method for Evaporation.” The “Energy Balance Method for Evaporation” is estimated using equation 1 (Chow, Maidment, & Mays, 1988):

$$E_r = \frac{R_n}{l_v \rho_w} \qquad (1)$$

where:

E_r is daily evaporation measured in meter/second which is later converted to inches/day for the purpose of this study.

R_n is the net radiation (MJ m^{-2} day^{-1}),

l_v is the latent heat of vaporization (J/kg),

ρ_w is the density of water (kg/m^3).

Latent heat of vaporization (l_v) and density of water (ρ_w) are given by equations 2 & 3:

l_v= 2.501x10^6 - 2370* T (2)

ρ_w = 0.00001*T^3-0.005*T^2-0.0007*T+1000.2 (3)

where:

T is the average daily temperature between T-min and T-max ($^{\circ}$C).

1.1.2 Net radiation (R_n)

Net radiation (R_n) is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}) (Allen et al., 1998):

$R_n = R_{ns} - R_{nl}$ (4)

where:

R_n is the net radiation expressed in MJ m^{-2} day^{-1}

R_{ns} is calculated from (Equation 5) net solar or net shortwave radiation (MJ m^{-2} day^{-1}),

R_{nl} is calculated from (Equation 6) net longwave radiation (MJ m^{-2} day^{-1}).

1.1.3 Net solar (R_{ns})

Net solar or net shortwave radiation (R_{ns}) is expressed in MJ m^{-2} day^{-1}. The R_{ns} results from the balance between incoming and reflected solar radiation. The R_{ns} is calculated by equation 5:

$R_{ns} = (1-\alpha) R_s$ (5)

where:

α (Albedo or canopy reflection coefficient) is 0.23 for the hypothetical grass reference crop (dimensionless),

R_s is the incoming solar radiation (MJ m^{-2} day^{-1}), which was obtained from NASA Climatology Resource for Agroclimatology Daily Averaged Data.

1.1.4 Net Longwave Radiation (R_{nl})

The rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law. Net outgoing longwave radiation (R_{nl}) is expressed in MJ m^{-2} day^{-1} and is estimated by equation 6:

$$R_{nl} = \sigma[\frac{T_{maxK^4} + T_{minK^4}}{2}](0.34 - 0.14\sqrt{e_a})(1.35\frac{R_s}{R_{so}} - 0.35) \quad (6)$$

where:

σ is Stefan-Boltzmann constant (4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}),

$T_{max,\,K}$ is maximum absolute temperature during the 24-hour period (K = °C + 273.16),

$T_{min,\,K}$ is minimum absolute temperature during the 24-hour period (K = °C + 273.16),

e_a is calculated from (Eqation 7) actual vapor pressure (kPa),

R_s/R_{so} is relative shortwave radiation (limited to ≤ 1.0),

R_s solar radiation (MJ m^{-2} day^{-1}), which was obtained from NASA Climatology Resource for Agroclimatology Daily Averaged Data,

R_{so} is calculated from (Equation 10) clear-sky radiation (MJ m^{-2} day^{-1}).

1.1.5 Actual Vapor Pressure (e_a)

The actual vapor pressure (e_a) can be calculated from the relative humidity and is measured in (kPa). In the absence of RH_{max} and RH_{min}, RH_{mean} can be used to estimate e_a by equation 7:

$$e_a = \frac{RH_{mean}}{100}\left[\frac{e^0(Tmax)+e^0(Tmin)}{2}\right] \quad (7)$$

Where:

RH_{mean} is the mean relative humidity, defined as the average between RH_{max} and RH_{min},

$e^0(Tmin)$ is calculated in (Equation 8) saturation vapour pressure at the air temperature T (kPa),

$e^0(Tmax)$ is calculated in (Equation 9) saturation vapour pressure at the air temperature T (kPa).

1.1.6 Saturation Vapour Pressure At The Air Temperature T [e°(T)]

As saturation vapour pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed by equations 8 & 9:

$$e^0(Tmin) = 0.6108 \exp\left[\frac{17.27Tmin}{Tmin+237.3}\right] \quad (8)$$

$$e^0(Tmax) = 0.6108 \exp\left[\frac{17.27Tmax}{Tmax+237.3}\right] \quad (9)$$

where:

e°(Tmin) & e°(Tmax) are the saturation vapour pressure at the air temperature T (kPa), Tmin and Tmax are the air temperature (°C),

Exp (..) 2.7183 (base of natural logarithm) raised to the power (..).

1.1.7 Clear-Sky Solar Radiation (R_{so})

The calculation of the clear-sky radiation (R_{so}) when n = N, is required for computing net longwave radiation. R_{so} is expressed in MJ m^{-2} day^{-1} and is estimated by equation 10:

$$R_{so} = (0.75 + 2\ 10^{-5} z)\ R_a \qquad (10)$$

where:

z is the station elevation above sea level (meters),

R_a is calculated from (Equation 9) extraterrestrial radiation (MJ m^{-2} day^{-1}).

1.1.8 Extraterrestrial Radiation For Daily Periods (R_a)

The extraterrestrial radiation (R_a) for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by equation 11:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] \qquad (11)$$

where:

R_a is the extraterrestrial radiation (MJ m^{-2} day^{-1})

G_{sc} is the solar constant = 0.0820 MJ m^{-2} min^{-1},

d_r is the inverse relative distance Earth-Sun (Equation 12),

ω_s is the sunset hour angle (rad) (Equation 14),

φ is the latitude [rad] (Equation 15),

δ is the solar decimation (rad) (Equation 13).

The inverse relative distance Earth-Sun (d_r) and the solar declination (δ) are given by equations 12 & 13:

$$d_r = 1 + 0.033\cos(\frac{2\pi}{365}J) \quad (12)$$

$$\delta = 0.409 sin(\frac{2\pi}{365}J - 1.39) \quad (13)$$

Where:

J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The sunset hour angle (ω_s) is given by (Equation 14): ω_s = arccos [-tan (φ) tan (δ)]

The latitude (φ) expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by equation 15:

[Radians] = $\frac{\pi}{180}$[decimaldegrees]

(15)

1.1.9 Days on Flood and Drainage Date

Given that each variety stays on flood for a different length of time (given the length of the vegetative stage), each variety loses different amounts of water to evaporation and transpiration. Once the evaporation on a daily basis for each rice variety at each of the six rice statins for each of the seven years is estimated, the total evaporation for each rice variety *i* at each location *l* in year *n* (TE_{iln}) can be calculated given the total number of days a specific rice variety stays under flood.

$$TE_{iln} = \text{Cumulative of daily Evaporation}_{iln} \text{ (Flood starting date-ending date)} \qquad (16)$$

where:

TE_{iln} is the total evaporation for a specific variety, location and year measured in ac-in/ac,

Daily evaporation is calculated from Equation 1.

To estimate total days on flood for each variety, flooding date and drainage dates are required. Research conducted by University of Arkansas physiologists suggest that flooding of rice fields in Arkansas typically begins 28 days after emergence (P. A. Counce, personal communication, October 4, 2011). Emergence date (ED) for each rice variety at each station for years 2004-2010 were reported by ARPT. Additionally, number of days from emergence to 50%-HEADING for each variety at each rice station for all seven years, were also reported by ARPT. Given genetic differences in maturity rates, each rice variety heads at slightly different times. From previous research, P.A. Counce has observed the optimal drainage time to be at approximately 23.7 days after 50%-HEADING (personal communication, November 10, 2011).

While each variety has a vegetative stage that is variable, most varieties fill grain at the same rate. Thus, a short season rice variety would be a variety that has a quick vegetative state and a long season variety would be a variety that has a longer vegetative state. Therefore, the total number of days under flood (TNDF) for variety *i* at location *l* in year *n* was calculated as follows:

$$TNDF_{iln} = 50\%\text{-}HEADING - 28 + 23.7 \qquad (17)$$

The $TNDF_{iln}$ was also necessary to estimate the drainage date for every rice variety, as the total amount of evaporation directly depends not only on the number of days a rice variety stays under flood but also the time frame during which flooding take place. Varieties that stay longer under flood are associated with greater total evaporation. Furthermore, two rice varieties with the same number of days under flood at the same location might result in different amount of total evaporation if they were to be flooded at different times. This occurs as a result of differences on evaporation factors such as: soil radiation, min and max temperature, relative humidity and rain. Drainage date (DD) for variety *i* at location *l* in year *n* was calculated as follows:

$$DD_{iln} = \text{Flooding Date} + TNDF \qquad (18)$$

Where flooding date (FD) for variety *i* at location *l* in year *n* is:

$$FD_{iln} = ED_{iln} + 28 \qquad (19)$$

Daily evaporation values from the first day of flooding to the drainage date were added to estimate the seasonal evaporation for each rice variety at each rice station in each year. Table 3 is an example of how days on flood and draining date for each rice variety were calculated.

Table 3. Days on Flood and Draining Date for nine Rice Varieties at the Stuttgart Rice Research and Extension Center for the Growing Year 2010

Variety	Emergence Date[a]	Flood After Emergence[b]	Flooding Date[c]	50% Heading[d,*]	Flood After 50%-Heading[e,*]	Days on Flood[f,*]	Draining Date[g]
CLXL745	4/22/2010	28	5/20/2010	82	24	78	7/31/2010
CLXL729	4/22/2010	28	5/20/2010	87	24	83	8/4/2010
XL723	4/22/2010	28	5/20/2010	87	24	83	8/4/2010
CL131	4/22/2010	28	5/20/2010	86	24	81	8/3/2010
CL261	4/22/2010	28	5/20/2010	86	24	81	8/3/2010
Bengal	4/22/2010	28	5/20/2010	86	24	82	8/4/2010
Francis	4/22/2010	28	5/20/2010	87	24	83	8/5/2010
Wells	4/22/2010	28	5/20/2010	91	24	86	8/8/2010
Cocodrie	4/22/2010	28	5/20/2010	92	24	87	8/9/2010

[a] Reported by ARPT.
[b] Field record by P. A. Counce (personal communication, October 4, 2011).
[c] Emergence Date + 28 Days.
[d] Number of Days from Emergence till 50% of the panicles have emerged from the boot (as reported by ARPT).
[e] Recommended Flooding after 50%-hd (P.A. Counce, personal communication, November 10, 2011).
[f] 50%-hd -28 Days + 23.7 Days.
[g] Flooding Date + Days on Flood.
* Denotes number rounding to the nearest day.

1.2 Transpiration (T)

Transpiration (T) is the process by which liquid water passes from liquid to vapor through plant metabolism (Allen et al., 1998). To account for transpiration from the rice plant in this study, two constants (0.45 and 1.15) were obtained from Allen et al. (1998). The constant 0.45 from Allen et al. (1998) is multiplied with the daily evaporation value of each variety to give the transpiration for each of the 27 first days of flooding. This would indicate that during the initial part of the vegetative stage of growth for the rice plant – given the low amount of biomass above the water line – more water is lost to evaporation than transpiration. Transpiration for the first 27 days is estimated by equation 20:

$$T_{1\_iln} = E_{iln(1^{st} - 27^{th} \text{ flooding day})} * 0.45 \quad (20)$$

Where:

T_{1_iln} is the total transpiration from 1st to 27th day of flooding for a specific variety, location and year measured in ac-in/ac,

E_{iln} is daily evaporation estimated by equation 1.

Transpiration for the first 27 days of flooding for variety *i* at location *l* in year *n* ($T_{1\text{-}iln}$) is estimated by multiplying daily evaporation (from day one to 27th) with the constant 0.45. Given that every rice station during a given year plants all rice varieties at the same date; therefore, floods at the same date, cumulative transpiration for the first 27 days is the same for all rice varieties in a given rice station and year.

The constant 1.15 from Allen et al. (1998) is multiplied with the daily evaporation values of each variety to give transpiration from the 28th flooding day to drainage day which varies by variety. Given the fact that past a certain point, in this case the 28th day after flooding, the rice canopy covers a large portion of the exposed water surface area, transpiration becomes larger than evaporation and thus the coefficient after the 28th day is larger than one. Because of the embedded genetic differences affecting maturity rates, rice varieties have different drainage dates. Therefore, the total amount of evaporation from the 28^{th} day to drainage point is different based on the total amount of days a rice variety stays under flood during this period (from 28^{th} days under flood to drainage point). Transpiration for variety *i* at location *l* in year *n* from the 28^{th} day under flood to drainage was calculated as follows:

$$T_{2\_iln} = E_{iln(28^{th} – drainage\ day)} * 1.15 \tag{21}$$

Where:

T_{2_iln} is the total transpiration from 28^{th} day of flooding to drainage date for a specific variety, location and year measured in ac-in/ac,

E_{iln} is daily evaporation estimated by equation 1.

After calculating T_{1_iln} and T_{2_iln}, total transpiration (T_{T_iln}) for each rice variety *i* (based on number of days under flood) at location *l* in year *n* is calculated by adding T_{1_iln} and T_{2_iln}:

$$T_{T\_iln} = T_{1\_iln} + T_{2\_iln} \tag{22}$$

Where T_{T_iln} is the total transpiration from T_{1_iln} (Equation 20) and T_{2_iln} (Equation 22) for a specific variety, location and year measured in ac-in/ac.

After the separate computations of evaporation and transpiration, the two were added up to give an estimated evapotranspiration for each rice variety at each ARPT station in each year.

1.3 Evapotranspiration (ET)

Allen et al. (1998) defined Evapotranspiration (ET) as a combination of two separate processes whereby water is lost on the one hand from the soil surface (or other surfaces) by evaporation and on the other hand from the crop by transpiration. In this study, evaporation was first calculated based on the “Energy Balance Method of Evaporation”. Evaporation values were later used to derive transpiration, where finally total evaporation (TE_{iln}) and total transpiration (T_{T_iln}) where added to estimate evapotranspiration as the total amount of water outflows from each rice variety (*i*) at each of the six ARPT stations (*l*) for seven sequential years (*n*) by equation 23:

$$ET_{iln} = TE_{iln} + T_{T\_iln} \tag{23}$$

where:

ET_{iln} is the total evapotranspiration for a specific variety, location and year measured in ac-in/ac,

TE_{iln} is calculated by equation 16,

T_{T_iln} is calculated by equation 22.

Table 4 demonstrates examples of cumulative evaporation, transpiration and evapotranspiration for rice varieties with different number of days under flood.

Table 4. Evapotranspiration Derived from Estimated Evaporation and Transpiration at Stuttgart Rice Station for the Growing Year 2010

Days on Flood (DF)	Cumulative Evaporation (in/ac)	Cumulative Transpiration (in/ac)	Cumulative Evapotranspiration (in/ac)	Larger % than 71 DF
71	22.03	19.52	41.55	0.00
72	22.36	19.90	42.26	1.68
73	22.69	20.28	42.97	3.30
74	23.03	20.67	43.70	4.92
75	23.37	21.06	44.43	6.48
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
88	27.44	25.74	53.17	21.85
89	27.75	26.09	53.84	22.83
90	28.05	26.44	54.49	23.75
91	28.35	26.79	55.14	24.65
92	28.59	27.07	55.66	25.35

The information in the table 4 can be interpreted as follows: A rice variety with 71 total numbers of days under flood for the rice station at Stuttgart in the growing year 2010 uses 41.55 ac-in/ac of water, 22.03 ac-in/ac of which through evaporation and 19.52 ac-in/ac through transpiration. A rice variety with 92 total numbers of days under flood at the same rice station and growing year, on the other hand, uses 55.66 ac-in/ac water , 28.59 ac-in/ac of which through evaporation and 27.07 ac-in/ac through transpiration. The variety with 92 days on flood uses 25.35% more water than the variety with 71 days under flood through evapotranspiration.

2. Greenhouse Gas Emissions

2.1 Life Cycle Analyses

The Life Cycle Inventory (LCI) used in this study incorporated both direct and indirect GHG emissions associated with paddy rice production. Direct emissions are those that come from on-farm operations. Examples are carbon dioxide emissions from diesel used by tractors and irrigation equipment. Indirect emissions are generated off-farm as a result of manufacturing inputs used on the farm. Examples of indirect emissions are the GHG emissions from natural gas to produce commercail fertilizer. Excluded from this study are embedded carbon emissions as a result of upstream production of equipment and tools used on farm for agricultural production and any GHG emissions that may occur beyond the farm gate. Methane emissions – a result of anaerobic decomposition of organic matter during flooding - are the largest contributor to the total GHG emissions in paddy rice production and are therefore included in the estimations of GHG emissions. Included in estimations of GHG emission was also nitrous oxide emissions from the application of nitrogen fertilizers, given the fact that it represents a large contributor to GHG emissions (Bouwman, 1996; Smith, McTaggart, & Tsuruta, 1997; Yanai et al., 2003; Del Grosso, Mosier, Parton, & Ojima, 2005; Snyder Bruulsema, Jensen, & Fixen, 2009). McFadden et al. (2011) reported N_2O emissions to be the second largest contributor to GHG emissions in rice production, after CH_4.

2.2 Carbon Emission Calculations

2.2.1 Carbon Equivalent (CE) Values

Given the multiple GHG's associated with global warming, each was converted to their carbon equivalent to obtain a "carbon footprint" -- a process stemming from a rich engineering literature on CE. The CE provided by the US Environmental Protection Agency (EPA, 2007; EPA, 2009) was used for diesel combustion emissions (Table 5). EcoInvent's life cycle inventory database through SimaPro (2009) was used to calculate the upstream emissions from the production of diesel. Values provided by Lal (2004), a synthesis of numerous studies measuring carbon emissions from farm operations, were used for all other inputs (Table 5). While the carbon equivalent of one pound of urea produced in a specific location is nearly constant the emissions from the application of that N fertilizer is not. The N_2O emissions are a function of location, temperature, soil conditions, and weather. Given this, location specific (state of Arkansas) N_2O emissions were obtained from the DayCent Century model.

Annual estimates of cost of production for four major production methods of rice by the University of Arkansas Cooperative Extension Service (UACES, 2008a) are used for different soils, production regions and production practices commonly used by producers. These costs of production methods are then disaggregated (between cultivar-specific input requirements) so that they can represent the cost of production for the most commonly produced rice cultivars throughout Arkansas. Using the carbon equivalents from table 5 and the recommended input usage for each of the cultivars in this study, a GHG emission estimate per ac could be calculated for each cultivar by location similar to Nalley et al. (2010).

Total carbon emissions per ac simply indicate the amount of GHG emitted and not the efficiency of or benefit derived from each unit of GHG. By dividing the total GHG by the yield of rice harvested on each ac, an efficiency measure per unit of rice can be established. That is, while CE per ac is an important measure, in particular as a baseline to compare changes over time for potential carbon policies, CE emitted per bu of rice is a more comprehensive measure for comparing impacts from production across space and time with respect to GHG emissions efficiency. While carbon offsets will focus more on GHG emissions per ac, buyers of rice – such as Kellogg's or Wal-Mart – will be more interested in the GHG emissions per bu of rice so they can market the differences accordingly.

Table 5. Carbon Equivalent Emission Factors by Input[A]

Input	Carbon-Equivalent (CE)	Source
Diesel	7.01 lbs C/Gal	EPA 2007 & 2009, Sima Pro
Fertilizer		
Nitrogen	1.30 lbs C/lb	Lal, R. 2004
Nitrogen N_2O	2.18 lbs C/lb	DayCent
Phosphate	0.20 lbs C/lb	Lal, R. 2004
Potash	0.16 lbs C/lb	Lal, R. 2004
Herbicide	6.44 lbs C/pt	Lal, R. 2004
Insecticide	5.44 lbs C/pt	Lal, R. 2004
Fungicide	5.44 lbs C/pt	Lal, R. 2004

[A] As derived from McFadden et al. (2011).

2.2.2 Total GHG Emissions Excluding CH_4 and CO_2 from Irrigation

The 2008 estimates of cost of production for four of the most common rice production methods (Clearfield®, Clearfield ® hybrid, conventional, and hybrid) put forth by (UACES) were used as a baseline to create cultivar-specific costs of production. The input data were collected from enterprise budgets put forth by UACES for each cultivar type. The average nitrogen fertilizer recommended application rates from Norman and Moldenhauer (2009) for Arkansas for conventional cultivars was 148 lbs/ac, while for Clearfield® and hybrid were 130 lbs/ac (Table 6). Diesel usage was calculated by summing the amount of fuel required for cultivar-specific fungicide applications and fertilizer applications (via crop duster), pesticide applications, herbicide applications, as well as standard fuel usage for planting and harvesting as noted from the enterprise budgets.

According to McFadden et al. (2011), the Clearfield® cultivars require the largest average fuel usage (Table 6) due to the requirement of more fungicide applications because of their susceptibility to both blast and sheath blight (two common rice fungi). However, the Clearfield® lines also require the least herbicide per ac since producers can use the herbicide Newpath® for efficient control of red rice (Table 6). Red rice is a persistent problem for rice producers in the Southeast and was estimated to be present in approximately 20% of all rice acreage in Arkansas in 2002 (Annu et al. 2005). Its dark kernel color requires costly separation during the milling process. Also, its nearly identical genetic structure to commercail rice means that no existing herbicide could adequately control red rice without also injuring or killing conventional rice.

The hybrid cultivars, all released by Rice-Tec (a private seed company), use the least fungicide, and thus less fuel, given their resistance to blast and only moderate susceptibility to sheath blight. Some of the hybrids contain the Clearfield® trait. Hybrids are the F1 seeds of a cross between two genetically dissimilar parents, which results in a yield increase of 15-20% more than the best inbred cultivar grown under similar conditions through hybrid vigor (Virmani et al. 2003). Since hybrid offspring (F2) generally do not perform as well as their parents (F1), producers must purchase fresh seeds each growing season. Given the difficulty and costs of producing hybrid seeds, the cost of seed to producers is the greatest of the three types of rice production at approximately $88 per ac compared to $42 and $18 per ac for Clearfield® and conventional cultivars, respectively in 2009.

Table 6. Average per ac Input Requirements by Cultivar on Slit-Loam Soils[A]

Average/Cultivar	N (lb/ac)[a]	Fungicide (pt/ac)[b]	Herbicide (pt/ac)	Diesel (gal/ac)[c]
Conventional	148	0.29	6.76	14.94
Clearfield	130	1.07	2.56	16.04
Hybrid	130	0.10	6.76	14.73

[A] As derived from McFadden et al. (2011).
[a] Summation of pre-flood and midseason nitrogen application. Nitrogen rate recommendation for rice following soybeans (Norman & Moldenhauer, 2009).
[b] Summation of fungicide used to mitigate blast, sheath blight and smut.
[c] Summation of diesel used in tractors and crop dusters but not including diesel used for irrigation.

2.2.3 Carbon Dioxide Emissions from Irrigation

Given the fact that this study specifically estimates the evapotranspiration by variety, variety-specific GHG emissions in CE from diesel use for irrigation can be derived. Therefore, while the GHG emissions from fuel for cultivar- (Conventional, Clearfield, & Hybrid) specific fungicide applications and fertilizer applications (via crop duster), pesticide applications, herbicide applications, as well as standard fuel usage for planting and harvesting were obtained from McFadden et al. (2011), GHG emissions from diesel for irrigation were calculated separately based on the quantity of water required per ac per day and the total number of days that each variety was under flood.

Water from the rainfall has been taken into account when deriving the amount of irrigation water (IW) applied to each variety at each rice location in each seven years.

$$IW_{iln} = ET_{iln} - \text{Cumulative Rainfall} \quad (24)$$

where:

IW_{iln} is the total amount of irrigation water applied to a specific rice variety at a specific location and specific year measured in ac-in/ac,

ET_{iln} is estimated by equation 16,

Cumulative rainfall is the total amount rain (in) from 1st day of flooding to drainage date for a specific variety at a specific rice station and year.

This study assumed that water for irrigation was pumped from 100 feet using a diesel pump which required 1.022 gallons of diesel to raise one ac-inch of water (Slaton, 2001). Equation 25 estimates the amount of GHG emissions (lb of CE/ac) from diesel required for irrigation for variety *i* at location *l* in year *n*:

$$CE_{iln} = IW_{iln} * 1.022 * 7.01 \quad (25)$$

Where:

CE_{iln} is the total GHG emissions from a specific rice variety at a specific location and specific year measured in lb of CE/ac,

IW_{iln} is estimated by equation 24

1.022 is a constant amount of total diesel fuel (measured in gallons) necessary to raise one ac-in/ac of water for irrigation [assuming that water for irrigation is pumped from 100 feet (Slaton, 2001)],

7.01is a constant of CE emitted per every one gallon of diesel fuel used to raise water for irrigation (EPA 2007 & 2009, and Sima Pro).

2.2.4 Methane Emissions from Flooding

To estimate total methane emissions per season for each variety, this study obtained daily methane emission data from Rogers et al. (2012). Rogers et al. (2012) conducted a research on methane emissions during the 2011 growing season at the Rice Research and Extension Center near Stuttgart in Arkansas County, Arkansas. The authors selected the long-grain, conventional rice cultivar “Wells” for use in their study due to its high-yield potential (Norman et al., 2000) and widespread use in Arkansas (Wilson, Runsick, & Mazzanti, 2009).

Based on the data from Rogers et al. (2012), on average conventional rice varieties reach a peak of 35.04 lb/ac of CE at approximately 50^{th} day under flood. Given that hybrid rice varieties have on average larger aboveground dry matter and shorter vegetative period than conventional varieties, this study assumed hybrid varieties to peak at a greater magnitude of CE (38.93 lb/ac) within shorter period of time under flood (approximately 47 days).

For conventional rice varieties, methane emissions (from the flooded paddy rice to the atmosphere) starts typically two weeks after flooding, reaches its peak at around 50 days after flooding followed by a constant decrease until flood release prior to harvesting. From start of flooding until the 16^{th} day, CH_4 emission is assumed to be zero. Starting at 1.03 lb/ac/day of CE on the 17^{th} day of flooding, CH_4 reaches 35.04 lbs/ac/day of CE on the 50^{th} day (emitting every day approximately 1.03 more lbs/ac of CE). After the 50^{th} day under flood the CH_4 emission starts to decrease from 35.04 lbs/ac/day to 9.73 lbs/ac/day of CE at the drainage point.

The values mentioned in the paragraph above come from:

1) 16 days after flood (CH_4 emission starting point), 50 days after flood (peak time), 35.04 lb/ac/day of CE (peak magnitude), and 9.73 lb/ac/day of CE (drainage stage) were obtained from Rogers et al. (2012).

2) 1.03 = 35.04/34, where 34 = 50-16

Figure 1 shows two hypothetical conventional rice varieties with different number of days under flood (80 and 90) with methane emissions as derived by Rogers et al. (2012).

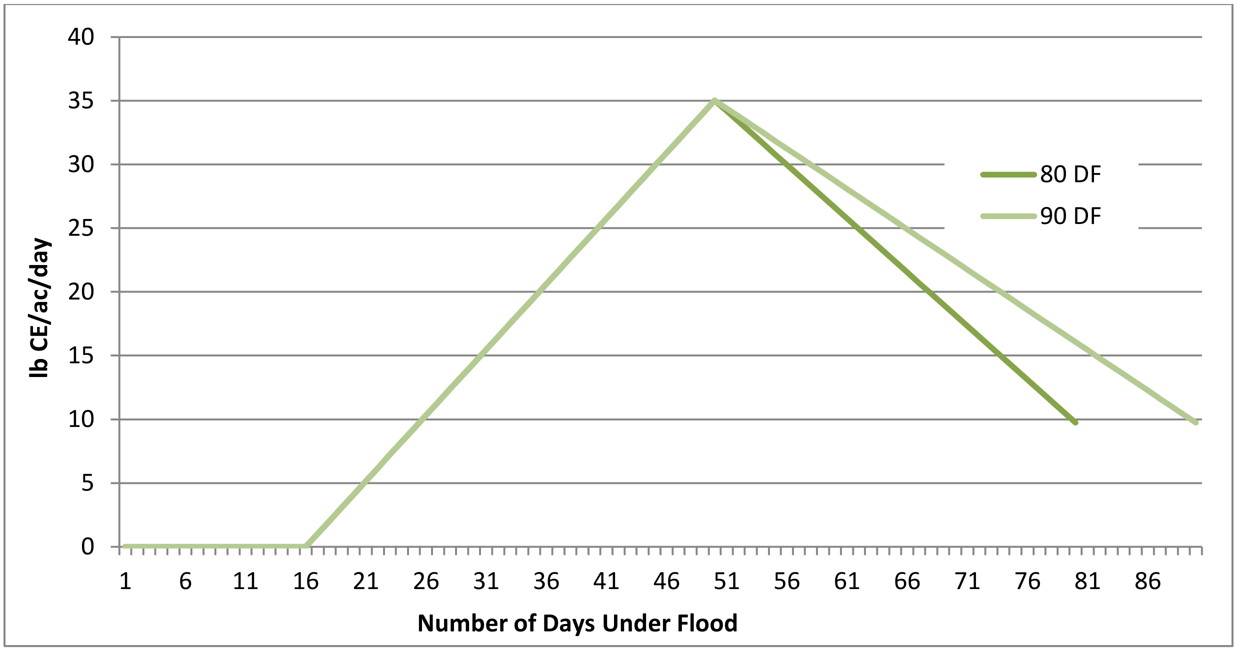


Figure 1. Methane Emissions for Conventional Rice Varieties with 80 and 90 Days on Flood

Methane emission from hybrid rice, however, is thought to start and peak about three days earlier compared to the conventional rice, peaking at a greater CH_4 emission (see graph 2) given its faster and more dense vegetative state and total biomass. Methane emission from hybrid rice is considered to be zero until the 13th day. Starting at 1.15 lb/ac/day of CE on the 14th day of flooding, CH_4 reaches 38.93 lbs/ac/day of CE on the 47th day (emitting every day approximately 1.15 more lbs/ac of CE). After the 47th day under flood the CH_4 emission starts to drop from 38.93 lbs/ac/day to 9.73 lbs/ac/day of CE at the drainage stage.

The values mentioned in the paragraph above come from:

1) 13 days after flood (CH_4 emission starting point), 47 days after flood (peak time), 38.93 lb/ac/day of CE (peak magnitude), and 9.73 lb/ac/day of CE (drainage stage) adjusted values for hybrid varieties based on conventional data from Rogers et al. (2012).

2) 1.15 = 38.93/34, where 34 = 47-13

Figure 2 shows two hypothetical hybrid rice varieties with different number of days under flood (80 and 90) with methane emissions as derived by Rogers et al. (2012).

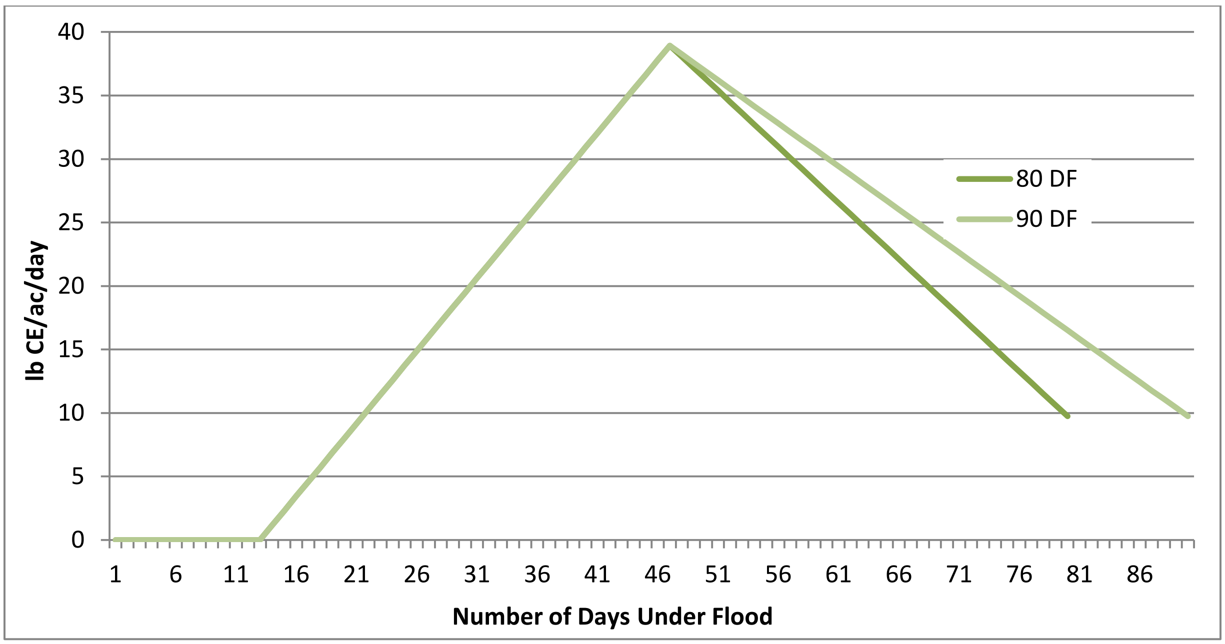


Figure 2. Methane Emission for Hybrid Rice Varieties with 80 and 90 Days on Flood

Despite the fact that both varieties for conventional and hybrid have the same number of days under flood, there are three differences between figures 1 and 2: 1) the day which CH_4 emissions start, 2) the day which CH_4 emissions peak, and 3) the magnitude of the CH_4 emissions rate at the peak.

Figure 3 illustrates two hypothetical rice varieties (one conventional and the other hybrid) with the same number of days under flood (85).

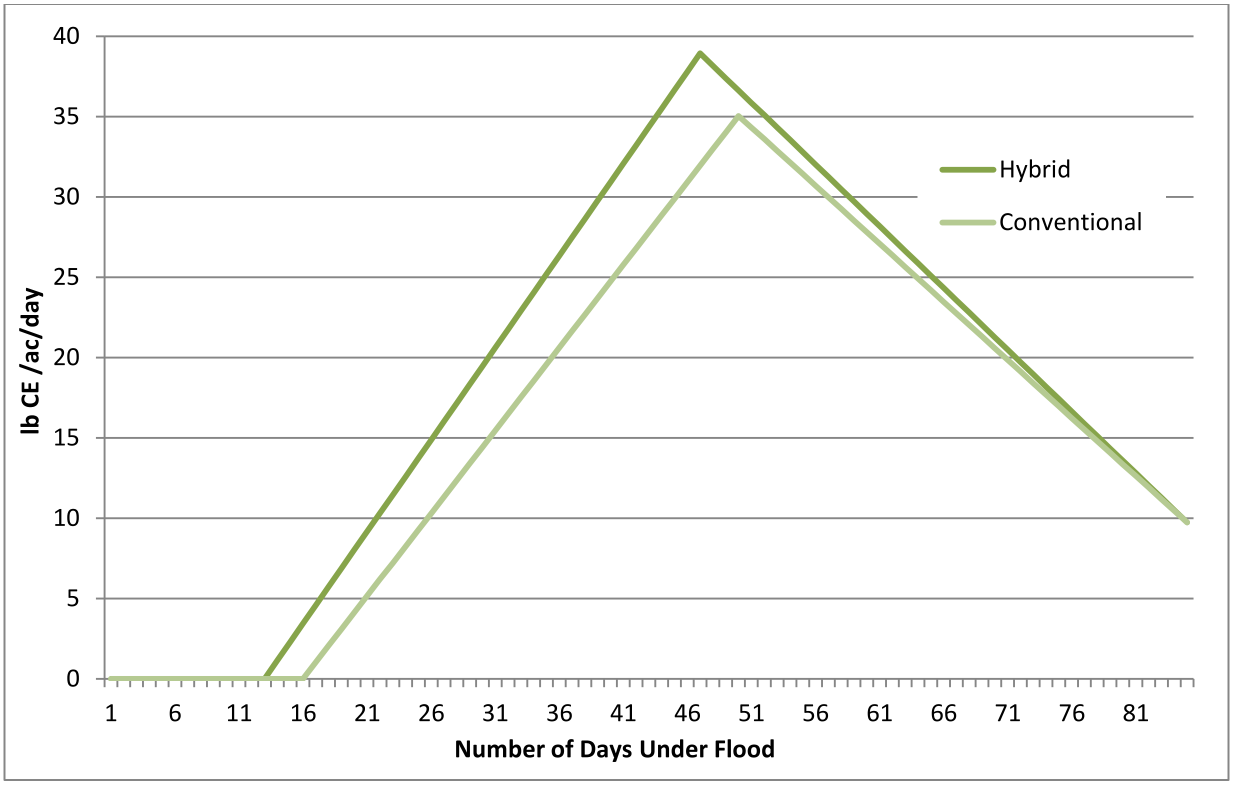


Figure 3. Methane Emissions for Conventional and Hybrid Rice Varieties with 85 Days on Flood

Further, an estimation of the total amount of CH_4 per growing season in its carbon equivalent was estimated by summing up CH_4 emissions from day one of CH_4 emissions (day 17 for conventional rice and 14 for hybrid rice) until four days after the drainage point which differs for different rice varieties within both conventional and hybrid rice. A period of four days past flooding has been included in the total number of days under flood for every rice variety as a result of a CH_4 emissions spike observed within these four days past flooding.

Given that the production of CH_4 is only possible in anaerobic environments, flood release allows for the oxygen to get into the soil. The presence of oxygen, therefore, converts the anaerobic environment to an aerobic one, which in return discontinues the process of CH_4 production and oxidizes the already produced CH_4. However, the oxidation process requires a certain number of days which depend on how much produced CH_4 is present in an area of rice field. It has been estimated that rice fields in the state of Arkansas take on average four days post flooding to complete the oxidization of CH_4. During these four days, as the oxidization process continues, some of the CH_4 diffuses from the soil to the atmosphere as flooding is no longer a barrier to this methane emission path (K.R. Brye, personal communication, January 31, 2012).

IV. RESULTS

A. Water-Use

This chapter presents the estimated results on evapotranspiration (ac-in/ac and ac-in/ bu) and greenhouse gas emissions (lb of CE/ac and lb of CE/bu) only for the 2010 season. That being said, the methodology described in the last chapter can be used for any other year (2004-2009) but given the large amounts of estimations required for each year only 2010 is highlighted.

1. Evaporation (E)

Tables 7-12 present the estimated results for evaporation (ac-in/ac) for each variety at each of the six ARPT stations for the growing year 2010. The variables included in these tables are: variety, type, emergence date, flooding date, days to 50% heading, days on flood and drainage date all of which were used to calculate evaporation in ac-in/ac through Equation 16.

Table 7. Evaporation in ac-in/ac for Rice Varieties at the Stuttgart ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Evap. (ac-in/ac)
RU0701124	Conv.	4/22/2010	5/20/2010	75	71	7/29/2010	22.03
CLXL745	CLHYB	4/22/2010	5/20/2010	82	78	8/6/2010	24.36
CL151	CL	4/22/2010	5/20/2010	85	81	8/8/2010	25.20
CL111	CL	4/22/2010	5/20/2010	86	82	8/10/2010	25.52
CLXL729	CLHYB	4/22/2010	5/20/2010	87	83	8/10/2010	25.84
XL723	HYB	4/22/2010	5/20/2010	87	83	8/10/2010	25.84
CL131	CL	4/22/2010	5/20/2010	86	81	8/9/2010	25.20
CL261	CL	4/22/2010	5/20/2010	86	81	8/9/2010	25.20
Bengal	Conv.	4/22/2010	5/20/2010	86	82	8/10/2010	25.52
Francis	Conv.	4/22/2010	5/20/2010	87	83	8/11/2010	25.84
Rex	Conv.	4/22/2010	5/20/2010	87	83	8/11/2010	25.84
CL142AR	CL	4/22/2010	5/20/2010	88	84	8/11/2010	26.16
Jupiter	Conv.	4/22/2010	5/20/2010	89	85	8/13/2010	26.48
Catahoula	Conv.	4/22/2010	5/20/2010	90	85	8/13/2010	26.48
Cybonnet	Conv.	4/22/2010	5/20/2010	90	85	8/13/2010	26.48
Neptune	Conv.	4/22/2010	5/20/2010	90	85	8/13/2010	26.48
Cheniere	Conv.	4/22/2010	5/20/2010	90	86	8/13/2010	26.80
CL181AR	CL	4/22/2010	5/20/2010	90	86	8/13/2010	26.80
Wells	Conv.	4/22/2010	5/20/2010	91	86	8/14/2010	26.80
Cocodrie	Conv.	4/22/2010	5/20/2010	92	87	8/15/2010	27.11
Taggart	Conv.	4/22/2010	5/20/2010	94	90	8/17/2010	28.05
Templeton	Conv.	4/22/2010	5/20/2010	94	90	8/18/2010	28.05
Bowman	Conv.	4/22/2010	5/20/2010	96	92	8/20/2010	28.59
RoyJ	Conv.	4/22/2010	5/20/2010	97	92	8/20/2010	28.59
Avg. Conventional				90	86		26.61
Avg. Clearfield				87	82		25.68
Avg. Hybrid				85	81		25.34

Table 8. Evaporation in ac-in/ac for Rice Varieties at the Rohwer ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Evap. (ac-in/ac)
RU0701124	Conv.	4/20/2010	5/18/2010	81	76	8/2/2010	23.12
CLXL745	CLHYB	4/20/2010	5/18/2010	85	80	8/6/2010	24.34
CLXL729	CLHYB	4/20/2010	5/18/2010	88	84	8/10/2010	25.47
XL723	HYB	4/20/2010	5/18/2010	88	84	8/10/2010	25.47
CL111	CL	4/20/2010	5/18/2010	90	86	8/11/2010	26.11
CL151	CL	4/20/2010	5/18/2010	90	86	8/12/2010	26.11
CL261	CL	4/20/2010	5/18/2010	89	85	8/10/2010	25.80
Francis	Conv.	4/20/2010	5/18/2010	90	86	8/11/2010	26.11
Bengal	Conv.	4/20/2010	5/18/2010	90	86	8/12/2010	26.11
Jupiter	Conv.	4/20/2010	5/18/2010	90	86	8/12/2010	26.11
CL131	CL	4/20/2010	5/18/2010	91	86	8/12/2010	26.11
Cheniere	Conv.	4/20/2010	5/18/2010	91	87	8/13/2010	26.41
Neptune	Conv.	4/20/2010	5/18/2010	91	87	8/13/2010	26.41
Rex	Conv.	4/20/2010	5/18/2010	91	87	8/13/2010	26.41
CL142AR	CL	4/20/2010	5/18/2010	92	88	8/14/2010	26.70
Cybonnet	Conv.	4/20/2010	5/18/2010	95	90	8/16/2010	27.33
Catahoula	Conv.	4/20/2010	5/18/2010	96	92	8/17/2010	27.90
Wells	Conv.	4/20/2010	5/18/2010	97	93	8/19/2010	28.18
Cocodrie	Conv.	4/20/2010	5/18/2010	99	95	8/20/2010	28.77
CL181AR	CL	4/20/2010	5/18/2010	99	95	8/21/2010	28.77
Templeton	Conv.	4/20/2010	5/18/2010	98	94	8/19/2010	28.46
Taggart	Conv.	4/20/2010	5/18/2010	98	94	8/20/2010	28.46
Bowman	Conv.	4/20/2010	5/18/2010	99	95	8/21/2010	28.77
RoyJ	Conv.	4/20/2010	5/18/2010	102	98	8/24/2010	29.68
Avg. Conventional				94	90		27.37
Avg. Clearfield				92	88		26.60
Avg. Hybrid				87	83		24.31

Table 9. Evaporation in ac-in/ac for Rice Varieties at the Keiser ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Evap. (ac-in/ac)
RU0701124	Conv.	5/10/2010	6/7/2010	70	66	8/12/2010	20.84
CLXL745	CLHYB	5/10/2010	6/7/2010	80	76	8/21/2010	23.91
CL151	CL	5/10/2010	6/7/2010	82	78	8/23/2010	24.49
CL111	CL	5/10/2010	6/7/2010	83	79	8/25/2010	24.77
CLXL729	CLHYB	5/10/2010	6/7/2010	85	80	8/26/2010	25.03
CL261	CL	5/10/2010	6/7/2010	81	77	8/22/2010	24.18
Bengal	Conv.	5/10/2010	6/7/2010	82	78	8/23/2010	24.49
CL131	CL	5/10/2010	6/7/2010	83	79	8/25/2010	24.77
CL142AR	CL	5/10/2010	6/7/2010	83	79	8/25/2010	24.77
Cheniere	Conv.	5/10/2010	6/7/2010	84	80	8/26/2010	25.03
Jupiter	Conv.	5/10/2010	6/7/2010	85	80	8/26/2010	25.03
Catahoula	Conv.	5/10/2010	6/7/2010	85	81	8/27/2010	25.32
Cybonnet	Conv.	5/10/2010	6/7/2010	85	81	8/27/2010	25.32
Rex	Conv.	5/10/2010	6/7/2010	85	81	8/27/2010	25.32
Francis	Conv.	5/10/2010	6/7/2010	86	81	8/27/2010	25.32
Neptune	Conv.	5/10/2010	6/7/2010	86	81	8/27/2010	25.32
Wells	Conv.	5/10/2010	6/7/2010	86	81	8/27/2010	25.32
CL181AR	CL	5/10/2010	6/7/2010	87	82	8/28/2010	25.61
Cocodrie	Conv.	5/10/2010	6/7/2010	87	83	8/29/2010	25.89
Bowman	Conv.	5/10/2010	6/7/2010	86	82	8/28/2010	25.61
Templeton	Conv.	5/10/2010	6/7/2010	87	82	8/28/2010	25.61
Taggart	Conv.	5/10/2010	6/7/2010	87	83	8/29/2010	25.89
RoyJ	Conv.	5/10/2010	6/7/2010	90	86	9/1/2010	26.56
Avg. Conventional				85	81		25.12
Avg. Clearfield				83	79		24.76
Avg. Hybrid				82	78		24.47

Table 10. Evaporation in ac-in/ac for Rice Varieties at the Newport ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Evap. (ac-in/ac)
RU0701124	Conv.	6/2/2010	6/30/2010	61	57	8/25/2010	17.01
CLXL745	CLHYB	6/2/2010	6/30/2010	71	66	9/4/2010	19.11
XL723	HYB	6/2/2010	6/30/2010	73	69	9/7/2010	19.91
CL151	CL	6/2/2010	6/30/2010	74	70	9/8/2010	19.99
CL111	CL	6/2/2010	6/30/2010	75	71	9/8/2010	20.12
CLXL729	CLHYB	6/2/2010	6/30/2010	78	74	9/11/2010	20.73
Wells	Conv.	6/2/2010	6/30/2010	75	70	9/8/2010	19.99
CL131	CL	6/2/2010	6/30/2010	75	70	9/8/2010	19.99
Rex	Conv.	6/2/2010	6/30/2010	76	72	9/9/2010	20.22
CL261	CL	6/2/2010	6/30/2010	77	72	9/10/2010	20.22
Bengal	Conv.	6/2/2010	6/30/2010	77	73	9/11/2010	20.48
Cybonnet	Conv.	6/2/2010	6/30/2010	77	73	9/11/2010	20.48
Cheniere	Conv.	6/2/2010	6/30/2010	78	74	9/11/2010	20.73
CL142AR	CL	6/2/2010	6/30/2010	78	74	9/11/2010	20.73
Catahoula	Conv.	6/2/2010	6/30/2010	78	74	9/12/2010	20.73
Francis	Conv.	6/2/2010	6/30/2010	79	75	9/12/2010	20.99
Jupiter	Conv.	6/2/2010	6/30/2010	79	75	9/12/2010	20.99
CL181AR	CL	6/2/2010	6/30/2010	80	75	9/13/2010	20.99
Cocodrie	Conv.	6/2/2010	6/30/2010	80	76	9/13/2010	21.24
Neptune	Conv.	6/2/2010	6/30/2010	83	79	9/17/2010	21.85
Taggart	Conv.	6/2/2010	6/30/2010	79	75	9/12/2010	20.99
Templeton	Conv.	6/2/2010	6/30/2010	81	76	9/14/2010	21.24
Bowman	Conv.	6/2/2010	6/30/2010	81	77	9/15/2010	21.39
RoyJ	Conv.	6/2/2010	6/30/2010	84	79	9/17/2010	21.85
Avg. Conventional				78	74		20.68
Avg. Clearfield				76	72		20.34
Avg. Hybrid				74	70		19.92

Table 11. Evaporation in ac-in/ac for Rice Varieties at the Colt ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Evap. (ac-in/ac)
RU0701124	Conv.	5/4/2010	6/1/2010	71	67	8/7/2010	21.20
CLXL745	CLHYB	5/4/2010	6/1/2010	80	75	8/15/2010	23.62
CL151	CL	5/4/2010	6/1/2010	83	79	8/18/2010	24.85
CL111	CL	5/4/2010	6/1/2010	84	79	8/19/2010	24.85
XL723	HYB	5/4/2010	6/1/2010	86	81	8/21/2010	25.45
CLXL729	CLHYB	5/4/2010	6/1/2010	87	82	8/22/2010	25.73
CL261	CL	5/4/2010	6/1/2010	83	79	8/18/2010	24.85
CL131	CL	5/4/2010	6/1/2010	84	80	8/19/2010	25.16
Bengal	Conv.	5/4/2010	6/1/2010	85	81	8/20/2010	25.45
Rex	Conv.	5/4/2010	6/1/2010	85	81	8/20/2010	25.45
CL142AR	CL	5/4/2010	6/1/2010	86	82	8/22/2010	25.73
CL181AR	CL	5/4/2010	6/1/2010	87	82	8/22/2010	25.73
Catahoula	Conv.	5/4/2010	6/1/2010	88	84	8/23/2010	26.31
Cheniere	Conv.	5/4/2010	6/1/2010	88	84	8/23/2010	26.31
Cybonnet	Conv.	5/4/2010	6/1/2010	88	84	8/23/2010	26.31
Jupiter	Conv.	5/4/2010	6/1/2010	88	84	8/23/2010	26.31
Francis	Conv.	5/4/2010	6/1/2010	89	85	8/24/2010	26.59
Neptune	Conv.	5/4/2010	6/1/2010	89	85	8/24/2010	26.59
Wells	Conv.	5/4/2010	6/1/2010	89	85	8/24/2010	26.59
Cocodrie	Conv.	5/4/2010	6/1/2010	91	87	8/27/2010	27.14
Taggart	Conv.	5/4/2010	6/1/2010	90	86	8/26/2010	26.85
Bowman	Conv.	5/4/2010	6/1/2010	91	86	8/26/2010	26.85
Templeton	Conv.	5/4/2010	6/1/2010	92	88	8/27/2010	27.43
RoyJ	Conv.	5/4/2010	6/1/2010	93	89	8/28/2010	27.71
Avg. Conventional				88	84		26.20
Avg. Clearfield				84	80		25.19
Avg. Hybrid				84	80		24.93

Table 12. Evaporation in ac-in/ac for Rice Varieties at the Coring ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Evap. (ac-in/ac)
RU0701124	Conv.	4/13/2010	5/11/2010	80	76	7/26/2010	22.79
CLXL729	CLHYB	4/13/2010	5/11/2010	85	81	7/31/2010	24.26
CLXL745	CLHYB	4/13/2010	5/11/2010	85	81	7/31/2010	24.26
XL723	HYB	4/13/2010	5/11/2010	87	83	8/2/2010	24.92
CL151	CL	4/13/2010	5/11/2010	88	83	8/2/2010	24.92
CL111	CL	4/13/2010	5/11/2010	89	85	8/3/2010	25.59
CL261	CL	4/13/2010	5/11/2010	88	83	8/2/2010	24.92
CL131	CL	4/13/2010	5/11/2010	89	84	8/3/2010	25.24
CL142AR	CL	4/13/2010	5/11/2010	90	86	8/4/2010	25.91
Bengal	Conv.	4/13/2010	5/11/2010	91	86	8/5/2010	25.91
Cheniere	Conv.	4/13/2010	5/11/2010	91	86	8/5/2010	25.91
Cybonnet	Conv.	4/13/2010	5/11/2010	91	86	8/5/2010	25.91
Francis	Conv.	4/13/2010	5/11/2010	91	86	8/5/2010	25.91
Wells	Conv.	4/13/2010	5/11/2010	91	87	8/5/2010	26.17
Catahoula	Conv.	4/13/2010	5/11/2010	91	87	8/6/2010	26.17
Rex	Conv.	4/13/2010	5/11/2010	91	87	8/6/2010	26.17
CL181AR	CL	4/13/2010	5/11/2010	92	87	8/6/2010	26.17
Cocodrie	Conv.	4/13/2010	5/11/2010	94	89	8/8/2010	26.80
Jupiter	Conv.	4/13/2010	5/11/2010	96	92	8/10/2010	27.69
Neptune	Conv.	4/13/2010	5/11/2010	96	92	8/10/2010	27.69
RoyJ	Conv.	4/13/2010	5/11/2010	91	87	8/6/2010	26.17
Templeton	Conv.	4/13/2010	5/11/2010	91	87	8/6/2010	26.17
Taggart	Conv.	4/13/2010	5/11/2010	92	87	8/6/2010	26.17
Bowman	Conv.	4/13/2010	5/11/2010	92	88	8/6/2010	26.48
Avg. Conventional				91	87		26.14
Avg. Clearfield				89	85		25.46
Avg. Hybrid				86	82		24.48

The estimated results from tables 7 through 12 indicate that Newport has the lowest average evaporation value (20.50 ac-in/ac) during 2010 growing season, while Rohwer is the rice station with highest average evaporation value (26.80 ac-in/ac) in the same growing season. This makes some intuitive sense since Rohwer is located in the far southeast Arkansas and Newport is located in Northeast Arkansas where temperatures are relatively cooler.

Comparing averages across conventional, Clearfield and hybrids in these same tables (7-12), a systematic pattern is observed across all ARPT stations during 2010 growing season. The pattern indicates that conventional rice varieties use on average the most water through evaporation, followed by Clearfield and the hybrids. The same pattern is also noticed with number of days on flood where conventional rice varieties have the largest number of days under flood, followed by the Clearfield and the hybrids, respectively. Hence, this study assumes that the number of days a variety stays under flood plays the greatest role on the amount of evaporation. Again, making intuitive sense, the longer the field stays under flood the more time for evaporation to take place.

When comparing across individual rice varieties, the experimental University of Arkansas rice variety RU0701124 is estimated to have the lowest evaporation values in each of the six ARPT stations (given it has the fewest days on flood). Varieties with the highest evaporation values are not consistent across rice stations switching mainly from RoyJ (Stuttgart, Rohwer, Keiser, Newport, & Colt) to Neptune (Newport & Coring), Bowman (Stuttgart) and Jupiter (Coring).

These estimated results on evaporation (ac-in/ac), however, do not necessarily define water use efficiency, which is the main purpose of this study. That is, just because variety X uses less water/ac than variety Y does not indicate that variety X is more efficient at the water it does use. Estimations on water use efficiency will be discussed later in this section when yield/ac is presented.

2. Transpiration (T)

Tables 13 through 18 present estimated results on transpiration (ac-in/ac) for each rice variety at six ARPT stations for 2010. These tables include: variety, type, emergence date, flooding date, days to 50% heading, days on flood and drainage date all of which were used to calculate transpiration in ac-in/ac through Equation 22.

Table 13. Transpiration in ac-in/ac for Rice Varieties at the Stuttgart ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Transp. (ac-in/ac)
RU0701124	Conv.	4/22/2010	5/20/2010	75	71	7/29/2010	19.52
CLXL745	CLHYB	4/22/2010	5/20/2010	82	78	8/6/2010	22.19
CL151	CL	4/22/2010	5/20/2010	85	81	8/8/2010	23.17
CL111	CL	4/22/2010	5/20/2010	86	82	8/10/2010	23.53
CLXL729	CLHYB	4/22/2010	5/20/2010	87	83	8/10/2010	23.90
XL723	HYB	4/22/2010	5/20/2010	87	83	8/10/2010	23.90
CL131	CL	4/22/2010	5/20/2010	86	81	8/9/2010	23.17
CL261	CL	4/22/2010	5/20/2010	86	81	8/9/2010	23.17
Bengal	Conv.	4/22/2010	5/20/2010	86	82	8/10/2010	23.53
Francis	Conv.	4/22/2010	5/20/2010	87	83	8/11/2010	23.90
Rex	Conv.	4/22/2010	5/20/2010	87	83	8/11/2010	23.90
CL142AR	CL	4/22/2010	5/20/2010	88	84	8/11/2010	24.27
Jupiter	Conv.	4/22/2010	5/20/2010	89	85	8/13/2010	24.64
Catahoula	Conv.	4/22/2010	5/20/2010	90	85	8/13/2010	24.64
Cybonnet	Conv.	4/22/2010	5/20/2010	90	85	8/13/2010	24.64
Neptune	Conv.	4/22/2010	5/20/2010	90	85	8/13/2010	24.64
Cheniere	Conv.	4/22/2010	5/20/2010	90	86	8/13/2010	25.00
CL181AR	CL	4/22/2010	5/20/2010	90	86	8/13/2010	25.00
Wells	Conv.	4/22/2010	5/20/2010	91	86	8/14/2010	25.00
Cocodrie	Conv.	4/22/2010	5/20/2010	92	87	8/15/2010	25.36
Taggart	Conv.	4/22/2010	5/20/2010	94	90	8/17/2010	26.44
Templeton	Conv.	4/22/2010	5/20/2010	94	90	8/18/2010	26.44
Bowman	Conv.	4/22/2010	5/20/2010	96	92	8/20/2010	27.07
RoyJ	Conv.	4/22/2010	5/20/2010	97	92	8/20/2010	27.07
Avg. Conventional				90	86		24.79
Avg. Clearfield				87	82		23.72
Avg. Hybrid				85	81		23.33

Table 14. Transpiration in ac-in/ac for Rice Varieties at the Rohwer ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Transp. (ac-in/ac)
RU0701124	Conv.	4/20/2010	5/18/2010	81	76	8/2/2010	20.96
CLXL745	CLHYB	4/20/2010	5/18/2010	85	80	8/6/2010	22.35
CLXL729	CLHYB	4/20/2010	5/18/2010	88	84	8/10/2010	23.65
XL723	HYB	4/20/2010	5/18/2010	88	84	8/10/2010	23.65
CL111	CL	4/20/2010	5/18/2010	90	86	8/11/2010	24.39
CL151	CL	4/20/2010	5/18/2010	90	86	8/12/2010	24.39
CL261	CL	4/20/2010	5/18/2010	89	85	8/10/2010	24.03
Francis	Conv.	4/20/2010	5/18/2010	90	86	8/11/2010	24.39
Bengal	Conv.	4/20/2010	5/18/2010	90	86	8/12/2010	24.39
Jupiter	Conv.	4/20/2010	5/18/2010	90	86	8/12/2010	24.39
CL131	CL	4/20/2010	5/18/2010	91	86	8/12/2010	24.39
Cheniere	Conv.	4/20/2010	5/18/2010	91	87	8/13/2010	24.73
Neptune	Conv.	4/20/2010	5/18/2010	91	87	8/13/2010	24.73
Rex	Conv.	4/20/2010	5/18/2010	91	87	8/13/2010	24.73
CL142AR	CL	4/20/2010	5/18/2010	92	88	8/14/2010	25.07
Cybonnet	Conv.	4/20/2010	5/18/2010	95	90	8/16/2010	25.79
Catahoula	Conv.	4/20/2010	5/18/2010	96	92	8/17/2010	26.45
Wells	Conv.	4/20/2010	5/18/2010	97	93	8/19/2010	26.77
Cocodrie	Conv.	4/20/2010	5/18/2010	99	95	8/20/2010	27.44
CL181AR	CL	4/20/2010	5/18/2010	99	95	8/21/2010	27.44
Templeton	Conv.	4/20/2010	5/18/2010	98	94	8/19/2010	27.09
Taggart	Conv.	4/20/2010	5/18/2010	98	94	8/20/2010	27.09
Bowman	Conv.	4/20/2010	5/18/2010	99	95	8/21/2010	27.44
RoyJ	Conv.	4/20/2010	5/18/2010	102	98	8/24/2010	28.49
Avg. Conventional				94	90		25.84
Avg. Clearfield				92	88		24.95
Avg. Hybrid				87	83		22.32

Table 15. Transpiration in ac-in/ac for Rice Varieties at the Keiser ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Transp. (ac-in/ac)
RU0701124	Conv.	5/10/2010	6/7/2010	70	66	8/12/2010	17.89
CLXL745	CLHYB	5/10/2010	6/7/2010	80	76	8/21/2010	21.42
CL151	CL	5/10/2010	6/7/2010	82	78	8/23/2010	22.09
CL111	CL	5/10/2010	6/7/2010	83	79	8/25/2010	22.41
CLXL729	CLHYB	5/10/2010	6/7/2010	85	80	8/26/2010	22.71
CL261	CL	5/10/2010	6/7/2010	81	77	8/22/2010	21.74
Bengal	Conv.	5/10/2010	6/7/2010	82	78	8/23/2010	22.09
CL131	CL	5/10/2010	6/7/2010	83	79	8/25/2010	22.41
CL142AR	CL	5/10/2010	6/7/2010	83	79	8/25/2010	22.41
Cheniere	Conv.	5/10/2010	6/7/2010	84	80	8/26/2010	22.71
Jupiter	Conv.	5/10/2010	6/7/2010	85	80	8/26/2010	22.71
Catahoula	Conv.	5/10/2010	6/7/2010	85	81	8/27/2010	23.04
Cybonnet	Conv.	5/10/2010	6/7/2010	85	81	8/27/2010	23.04
Rex	Conv.	5/10/2010	6/7/2010	85	81	8/27/2010	23.04
Francis	Conv.	5/10/2010	6/7/2010	86	81	8/27/2010	23.04
Neptune	Conv.	5/10/2010	6/7/2010	86	81	8/27/2010	23.04
Wells	Conv.	5/10/2010	6/7/2010	86	81	8/27/2010	23.04
CL181AR	CL	5/10/2010	6/7/2010	87	82	8/28/2010	23.38
Cocodrie	Conv.	5/10/2010	6/7/2010	87	83	8/29/2010	23.70
Bowman	Conv.	5/10/2010	6/7/2010	86	82	8/28/2010	23.38
Templeton	Conv.	5/10/2010	6/7/2010	87	82	8/28/2010	23.38
Taggart	Conv.	5/10/2010	6/7/2010	87	83	8/29/2010	23.70
RoyJ	Conv.	5/10/2010	6/7/2010	90	86	9/1/2010	24.47
Avg. Conventional				85	81		22.82
Avg. Clearfield				83	79		22.41
Avg. Hybrid				82	78		22.06

Table 16. Transpiration in ac-in/ac for Rice Varieties at the Newport ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Transp. (ac-in/ac)
RU0701124	Conv.	6/2/2010	6/30/2010	61	57	8/25/2010	13.82
CLXL745	CLHYB	6/2/2010	6/30/2010	71	66	9/4/2010	16.24
XL723	HYB	6/2/2010	6/30/2010	73	69	9/7/2010	17.16
CL151	CL	6/2/2010	6/30/2010	74	70	9/8/2010	17.25
CL111	CL	6/2/2010	6/30/2010	75	71	9/8/2010	17.40
CLXL729	CLHYB	6/2/2010	6/30/2010	78	74	9/11/2010	18.11
Wells	Conv.	6/2/2010	6/30/2010	75	70	9/8/2010	17.25
CL131	CL	6/2/2010	6/30/2010	75	70	9/8/2010	17.25
Rex	Conv.	6/2/2010	6/30/2010	76	72	9/9/2010	17.52
CL261	CL	6/2/2010	6/30/2010	77	72	9/10/2010	17.52
Bengal	Conv.	6/2/2010	6/30/2010	77	73	9/11/2010	17.82
Cybonnet	Conv.	6/2/2010	6/30/2010	77	73	9/11/2010	17.82
Cheniere	Conv.	6/2/2010	6/30/2010	78	74	9/11/2010	18.11
CL142AR	CL	6/2/2010	6/30/2010	78	74	9/11/2010	18.11
Catahoula	Conv.	6/2/2010	6/30/2010	78	74	9/12/2010	18.11
Francis	Conv.	6/2/2010	6/30/2010	79	75	9/12/2010	18.40
Jupiter	Conv.	6/2/2010	6/30/2010	79	75	9/12/2010	18.40
CL181AR	CL	6/2/2010	6/30/2010	80	75	9/13/2010	18.40
Cocodrie	Conv.	6/2/2010	6/30/2010	80	76	9/13/2010	18.69
Neptune	Conv.	6/2/2010	6/30/2010	83	79	9/17/2010	19.39
Taggart	Conv.	6/2/2010	6/30/2010	79	75	9/12/2010	18.40
Templeton	Conv.	6/2/2010	6/30/2010	81	76	9/14/2010	18.69
Bowman	Conv.	6/2/2010	6/30/2010	81	77	9/15/2010	18.86
RoyJ	Conv.	6/2/2010	6/30/2010	84	79	9/17/2010	19.39
Avg. Conventional				78	74		18.04
Avg. Clearfield				76	72		17.65
Avg. Hybrid				74	70		17.17

Table 17. Transpiration in ac-in/ac for Rice Varieties at the Colt ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Transp. (ac-in/ac)
RU0701124	Conv.	5/4/2010	6/1/2010	71	67	8/7/2010	18.38
CLXL745	CLHYB	5/4/2010	6/1/2010	80	75	8/15/2010	21.16
CL151	CL	5/4/2010	6/1/2010	83	79	8/18/2010	22.57
CL111	CL	5/4/2010	6/1/2010	84	79	8/19/2010	22.57
XL723	HYB	5/4/2010	6/1/2010	86	81	8/21/2010	23.27
CLXL729	CLHYB	5/4/2010	6/1/2010	87	82	8/22/2010	23.59
CL261	CL	5/4/2010	6/1/2010	83	79	8/18/2010	22.57
CL131	CL	5/4/2010	6/1/2010	84	80	8/19/2010	22.94
Bengal	Conv.	5/4/2010	6/1/2010	85	81	8/20/2010	23.27
Rex	Conv.	5/4/2010	6/1/2010	85	81	8/20/2010	23.27
CL142AR	CL	5/4/2010	6/1/2010	86	82	8/22/2010	23.59
CL181AR	CL	5/4/2010	6/1/2010	87	82	8/22/2010	23.59
Catahoula	Conv.	5/4/2010	6/1/2010	88	84	8/23/2010	24.25
Cheniere	Conv.	5/4/2010	6/1/2010	88	84	8/23/2010	24.25
Cybonnet	Conv.	5/4/2010	6/1/2010	88	84	8/23/2010	24.25
Jupiter	Conv.	5/4/2010	6/1/2010	88	84	8/23/2010	24.25
Francis	Conv.	5/4/2010	6/1/2010	89	85	8/24/2010	24.58
Neptune	Conv.	5/4/2010	6/1/2010	89	85	8/24/2010	24.58
Wells	Conv.	5/4/2010	6/1/2010	89	85	8/24/2010	24.58
Cocodrie	Conv.	5/4/2010	6/1/2010	91	87	8/27/2010	25.21
Taggart	Conv.	5/4/2010	6/1/2010	90	86	8/26/2010	24.87
Bowman	Conv.	5/4/2010	6/1/2010	91	86	8/26/2010	24.87
Templeton	Conv.	5/4/2010	6/1/2010	92	88	8/27/2010	25.54
RoyJ	Conv.	5/4/2010	6/1/2010	93	89	8/28/2010	25.87
Avg. Conventional				88	84		24.14
Avg. Clearfield				84	80		22.97
Avg. Hybrid				84	80		22.67

Table 18. Transpiration in ac-in/ac for Rice Varieties at the Coring ARPT Station in 2010

Variety	Type	Emergence Date	Flooding Date	Days to 50% HD	Days on Flood	Drainage Date	Transp. (ac-in/ac)
RU0701124	Conv.	4/13/2010	5/11/2010	80	76	7/26/2010	20.96
CLXL729	CLHYB	4/13/2010	5/11/2010	85	81	7/31/2010	22.65
CLXL745	CLHYB	4/13/2010	5/11/2010	85	81	7/31/2010	22.65
XL723	HYB	4/13/2010	5/11/2010	87	83	8/2/2010	23.41
CL151	CL	4/13/2010	5/11/2010	88	83	8/2/2010	23.41
CL111	CL	4/13/2010	5/11/2010	89	85	8/3/2010	24.17
CL261	CL	4/13/2010	5/11/2010	88	83	8/2/2010	23.41
CL131	CL	4/13/2010	5/11/2010	89	84	8/3/2010	23.78
CL142AR	CL	4/13/2010	5/11/2010	90	86	8/4/2010	24.55
Bengal	Conv.	4/13/2010	5/11/2010	91	86	8/5/2010	24.55
Cheniere	Conv.	4/13/2010	5/11/2010	91	86	8/5/2010	24.55
Cybonnet	Conv.	4/13/2010	5/11/2010	91	86	8/5/2010	24.55
Francis	Conv.	4/13/2010	5/11/2010	91	86	8/5/2010	24.55
Wells	Conv.	4/13/2010	5/11/2010	91	87	8/5/2010	24.84
Catahoula	Conv.	4/13/2010	5/11/2010	91	87	8/6/2010	24.84
Rex	Conv.	4/13/2010	5/11/2010	91	87	8/6/2010	24.84
CL181AR	CL	4/13/2010	5/11/2010	92	87	8/6/2010	24.84
Cocodrie	Conv.	4/13/2010	5/11/2010	94	89	8/8/2010	25.57
Jupiter	Conv.	4/13/2010	5/11/2010	96	92	8/10/2010	26.60
Neptune	Conv.	4/13/2010	5/11/2010	96	92	8/10/2010	26.60
RoyJ	Conv.	4/13/2010	5/11/2010	91	87	8/6/2010	24.84
Templeton	Conv.	4/13/2010	5/11/2010	91	87	8/6/2010	24.84
Taggart	Conv.	4/13/2010	5/11/2010	92	87	8/6/2010	24.84
Bowman	Conv.	4/13/2010	5/11/2010	92	88	8/6/2010	25.21
Avg. Conventional				91	87		24.81
Avg. Clearfield				89	85		24.03
Avg. Hybrid				86	82		22.91

The estimated results on transpiration, from tables 13 through 18, indicate the same patter with that of evaporation. The Newport ARPT station has the lowest average transpiration value (17.84 ac-in/ac) during 2010 growing season, while Rohwer is the one with the highest average evaporation value (25.18 ac-in/ac) in the same growing season.

When comparing averages across conventional, Clearfield and hybrids in these same tables (13-18), a systematic pattern is observed across all ARPT stations during 2010 growing season. The pattern illustrates that Conventional rice varieties use, on average, the largest amount of water through transpiration, followed by Clearfield and the hybrids. This is most likely attributed to the fact that the conventional rice varieties have the largest number of days under flood, followed by Clearfield and the hybrids, respectively. Hence, this study assumes that the number of days a variety stays under flood plays the greatest role on the amount of both evaporation and transpiration.

When comparing individual rice varieties, again the University of Arkansas experimental rice variety RU0701124 is observed to have the lowest evaporation values in each of the six ARPT stations. Varieties with the highest evaporation values are not consistent across rice stations switching mainly from RoyJ (Stuttgart, Rohwer, Keiser, Newport, & Colt) to Neptune (Newport & Coring), Bowman (Stuttgart) and Jupiter (Coring), all of which have large values for the number of days on flood.

Once again, the estimated results on transpiration (ac-in/ac) alone do not necessarily define water use efficiency, which is the purpose of this study. To estimate water use efficiency evaporation, transpiration and yield need to be accounted for.

For all six ARPT locations in 2010 there were 24 commonly cultivated rice varieties with the exception of Keiser station where XL723 is not sown. However, the fact that each of the six ARPT stations cultivates the same varieties does not indicate that each variety has the same growth duration across locations. For instance, Wells reaches its 50% heading within 91 days at Stuttgart and Coring, 97 days at Rohwer, 86 days at Keiser, 75 days at Newport, and 89 days at Colt. In addition to genetics, some other factors that influence the number of days to 50% heading (number of days under flood) are: 1) planting date, and 2) climatic variables (temperature, relative humidity, rain and solar radiation).

Not surprisingly the number of days under flood is the major contributor to the total amount of water used for irrigation. For example, CLXL745 and Wells at the Stuttgart ARPT location have the same planting date and climatic variables but differ in evaporation by 2.44 ac-in/ac, where CLXL745 loses 24.34 ac-in/ac of water to evaporation while Wells loses 26.80 ac-in/ac. Similar variations, in varieties which have the same planting date and climatic variables but different number of days under flood, have been observed in transpiration as well. For instance, CLXL745 transpires 22.19 ac-in/ac of water while Wells transpires 25.00 ac-in/ac.

Planting Date and Climatic variables, however, have an impact on rice growth duration, which in return affects evaporation and transpiration. In addition to the indirect impact, planting date and climatic variables affect evaporation and transpiration directly as well. For instance, as mentioned above Wells (a popular variety) at the Stuttgart and Coring stations reaches 50% heading on the 91st day after emergence. The methodology implemented here would imply that Wells stays under flood for the same number of days both at Stuttgart and Coring; however, Wells at Stuttgart evaporates 26.80 ac-in/ac of water while Wells at Coring evaporates 26.17 ac-in/ac. The same phenomenon is observed in transpiration, where Wells at Stuttgart transpires 25.00 ac-in/ac of water, while Wells at Coring transpires 24.85 ac-in/ac.

3. Evapotranspiration (ET)

The estimated values of water use from both evaporation (E) and transpiration (T) are summed by variety by location to estimate evapotranspiration. Measures on evapotranspiration/ac indicate show that the experimental variety RU0701124 is the variety with the least total water usage per ac. The varieties with the highest evapotranspiration values are not consistent across rice stations switching mainly from RoyJ (Stuttgart, Rohwer, Keiser, Newport, & Colt) to Neptune (Newport & Coring), Bowman (Stuttgart) and Jupiter (Coring).

The variations in the amount of water use between varieties in general are attributed mainly to differences in the length of the flooding period. However, while total water use per ac is important it is not a measure of efficiency. The per ac average total water use per bu of rice produced, a direct measure of water use efficiency, is used on a comparative basis across time, variety and space. These ratios have been estimated in Tables 19 through 24 and illustrated in Figures 4 through 9.

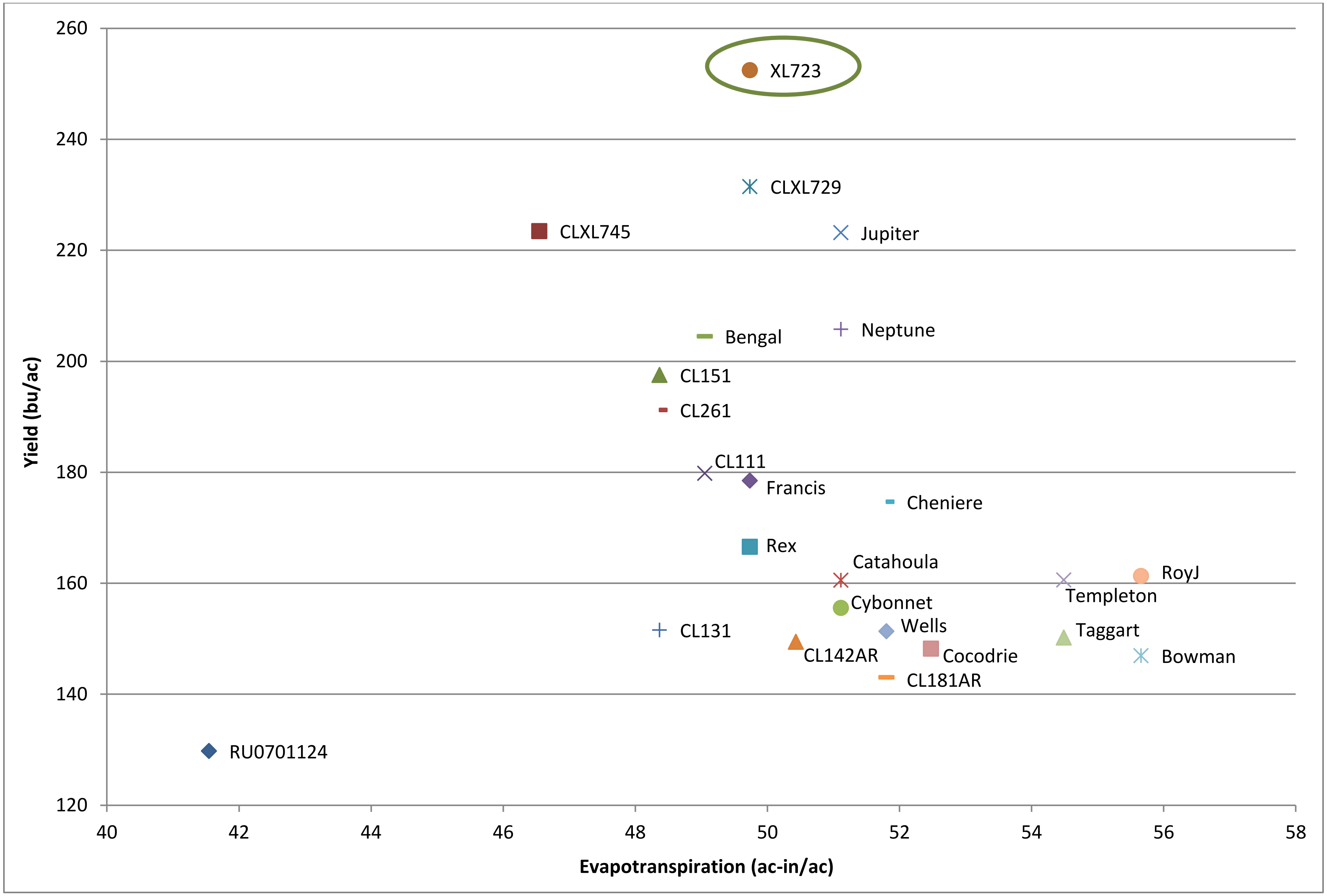
As inputs (in this case water) remain constant and yield increases, water per bu of rice produced decreases leading to an increase in water use efficiency. Conversely, as yield remains constant and water requirements per ac decrease, water per bu of rice produced also decreases, increasing water use efficiency. Thus, it is important to note that just because a variety or a location uses the least amount of water it does not mean that it is the most efficient in using that water. For instance, the experimental variety RU0701124 uses 8.26 ac-in/ac less water than the average of all other rice varieties at all six ARPT stations; however it yields 25 bu/ac less rice. Similarly, on average Newport uses 9.68 ac-in/ac less water than all six ARPT other stations, but it yields 48.50 bu/ac less rice. Therefore, improvements to water use efficiency can either be sought through increased yield per unit of input or reduced input per bu of rice produced.

Through the estimated evapotranspiration (ac-in/ac) and the given rice yield (bu/ac), water efficiency (yield/evapotranspiration) was calculated and presented in Tables (19-24) and Figures (4-9) for each rice variety at all six rice stations in year 2010.

Table 19. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Stuttgart ARPT Station in 2010

Variety	Type	Days on Flood	E[a] (ac-in/ac)	T[b] (ac-in/ac)	ET[c] (ac-in/ac)	Yield[d] (bu/ac)	Yield(bu)/ ET(ac-in)
RU0701124	Conv.	71	22.03	19.52	41.55	130	3.123
CLXL745	CLHYB	78	24.36	22.19	46.55	223	4.800
CL151	CL	81	25.20	23.17	48.37	198	4.083
CL111	CL	82	25.52	23.53	49.05	180	3.665
CLXL729	CLHYB	83	25.84	23.90	49.74	231	4.654
XL723	HYB	83	25.84	23.90	49.74	252	5.076*
CL131	CL	81	25.20	23.17	48.37	152	3.134
CL261	CL	81	25.20	23.17	48.37	191	3.953
Bengal	Conv.	82	25.52	23.53	49.05	205	4.169
Francis	Conv.	83	25.84	23.90	49.74	178	3.589
Rex	Conv.	83	25.84	23.90	49.74	167	3.349
CL142AR	CL	84	26.16	24.27	50.43	149	2.963
Jupiter	Conv.	85	26.48	24.64	51.12	223	4.365
Catahoula	Conv.	85	26.48	24.64	51.12	161	3.141
Cybonnet	Conv.	85	26.48	24.64	51.12	156	3.042
Neptune	Conv.	85	26.48	24.64	51.12	206	4.025
Cheniere	Conv.	86	26.80	25.00	51.80	175	3.371
CL181AR	CL	86	26.80	25.00	51.80	143	2.761
Wells	Conv.	86	26.80	25.00	51.80	151	2.922
Cocodrie	Conv.	87	27.11	25.36	52.48	148	2.824
Taggart	Conv.	90	28.05	26.44	54.49	150	2.757
Templeton	Conv.	90	28.05	26.44	54.49	161	2.947
Bowman	Conv.	92	28.59	27.07	55.66	147	2.640
RoyJ	Conv.	92	28.59	27.07	55.66	161	2.898

[a] Obtained from results on **Table 7**.
[b] Obtained from results on **Table 13**.
[c] Evaporation (a) + Transpiration (b).
[d] Reported by 2010 ARPT
*Denotes the most water use efficient variety.



° Green circles in figures 4-9 denote the most water use efficient variety.

Figure 4. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Stuttgart ARPT Station in 2010

Table 20. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Rohwer ARPT Station in 2010

Variety	Type	Days on Flood	E[a] (ac-in/ac)	T[b] (ac-in/ac)	ET[c] (ac-in/ac)	Yield[d] (bu/ac)	Yield(bu)/ ET(ac-in)
RU0701124	Conv.	76	23.12	20.96	44.08	139	3.143
CLXL745	CLHYB	80	24.34	22.35	46.69	149	3.198
CLXL729	CLHYB	84	25.47	23.65	49.12	141	2.861
XL723	HYB	84	25.47	23.65	49.12	182	3.709*
CL111	CL	86	26.11	24.39	50.51	139	2.755
CL151	CL	86	26.11	24.39	50.51	152	3.011
CL261	CL	85	25.80	24.03	49.83	129	2.598
Francis	Conv.	86	26.11	24.39	50.51	154	3.055
Bengal	Conv.	86	26.11	24.39	50.51	143	2.822
Jupiter	Conv.	86	26.11	24.39	50.51	145	2.870
CL131	CL	86	26.11	24.39	50.51	138	2.742
Cheniere	Conv.	87	26.41	24.73	51.14	148	2.894
Neptune	Conv.	87	26.41	24.73	51.14	146	2.852
Rex	Conv.	87	26.41	24.73	51.14	147	2.866
CL142AR	CL	88	26.70	25.07	51.77	165	3.178
Cybonnet	Conv.	90	27.33	25.79	53.12	135	2.541
Catahoula	Conv.	92	27.90	26.45	54.35	111	2.048
Wells	Conv.	93	28.18	26.77	54.96	118	2.156
Cocodrie	Conv.	95	28.77	27.44	56.21	124	2.211
CL181AR	CL	95	28.77	27.44	56.21	112	2.001
Templeton	Conv.	94	28.46	27.09	55.55	131	2.360
Taggart	Conv.	94	28.46	27.09	55.55	145	2.609
Bowman	Conv.	95	28.77	27.44	56.21	181	3.223
RoyJ	Conv.	98	29.68	28.49	58.17	157	2.697

[a] Obtained from results on **Table 8**.
[b] Obtained from results on **Table 14**.
[c] Evaporation (a) + Transpiration (b).
[d] Reported by 2010 ARPT.
* Denotes the most water use efficient variety.

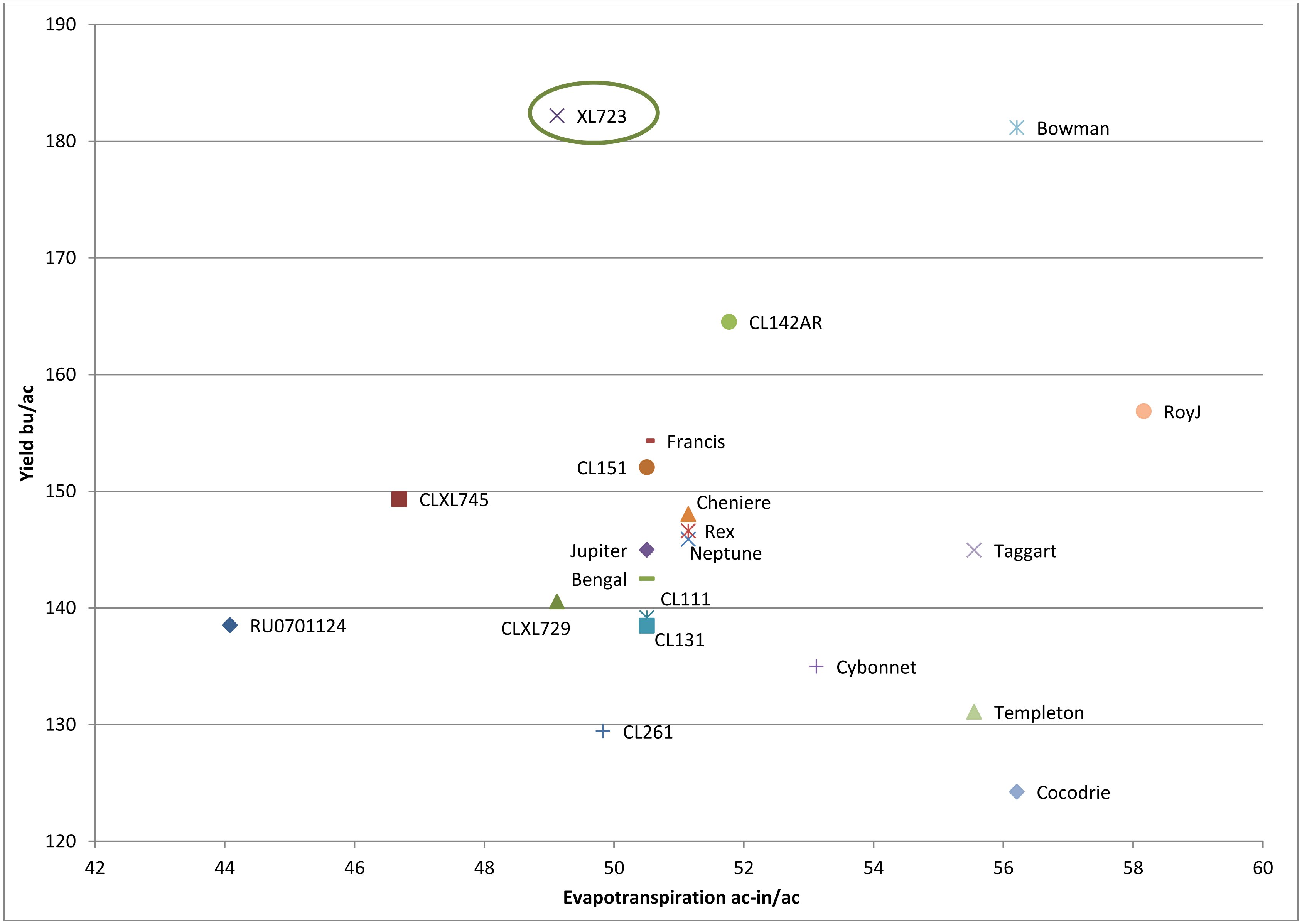


Figure 5. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Rohwer ARPT Station in 2010

Table 21. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Keiser ARPT Station in 2010

Variety	Type	Days on Flood	E[a] (ac-in/ac)	T[b] (ac-in/ac)	ET[c] (ac-in/ac)	Yield[d] (bu/ac)	Yield(bu)/ ET(ac-in)
RU0701124	Conv.	66	20.84	17.89	38.74	169	4.362*
CLXL745	CLHYB	76	23.91	21.42	45.33	174	3.839
CL151	CL	78	24.49	22.09	46.58	162	3.472
CL111	CL	79	24.77	22.41	47.18	154	3.268
CLXL729	CLHYB	80	25.03	22.71	47.74	205	4.301
CL261	CL	77	24.18	21.74	45.92	153	3.338
Bengal	Conv.	78	24.49	22.09	46.58	172	3.700
CL131	CL	79	24.77	22.41	47.18	152	3.227
CL142AR	CL	79	24.77	22.41	47.18	165	3.495
Cheniere	Conv.	80	25.03	22.71	47.74	165	3.450
Jupiter	Conv.	80	25.03	22.71	47.74	167	3.496
Catahoula	Conv.	81	25.32	23.04	48.36	163	3.380
Cybonnet	Conv.	81	25.32	23.04	48.36	156	3.218
Rex	Conv.	81	25.32	23.04	48.36	175	3.616
Francis	Conv.	81	25.32	23.04	48.36	192	3.965
Neptune	Conv.	81	25.32	23.04	48.36	176	3.634
Wells	Conv.	81	25.32	23.04	48.36	157	3.243
CL181AR	CL	82	25.61	23.38	48.99	142	2.898
Cocodrie	Conv.	83	25.89	23.70	49.59	142	2.871
Bowman	Conv.	82	25.61	23.38	48.99	158	3.226
Templeton	Conv.	82	25.61	23.38	48.99	176	3.596
Taggart	Conv.	83	25.89	23.70	49.59	156	3.153
RoyJ	Conv.	86	26.56	24.47	51.03	156	3.064

[a] Obtained from results on **Table 9**.
[b] Obtained from results on **Table 15**.
[c] Evaporation (a) + Transpiration (b).
[d] Reported by 2010 ARPT.
* Denotes the most water use efficient variety.

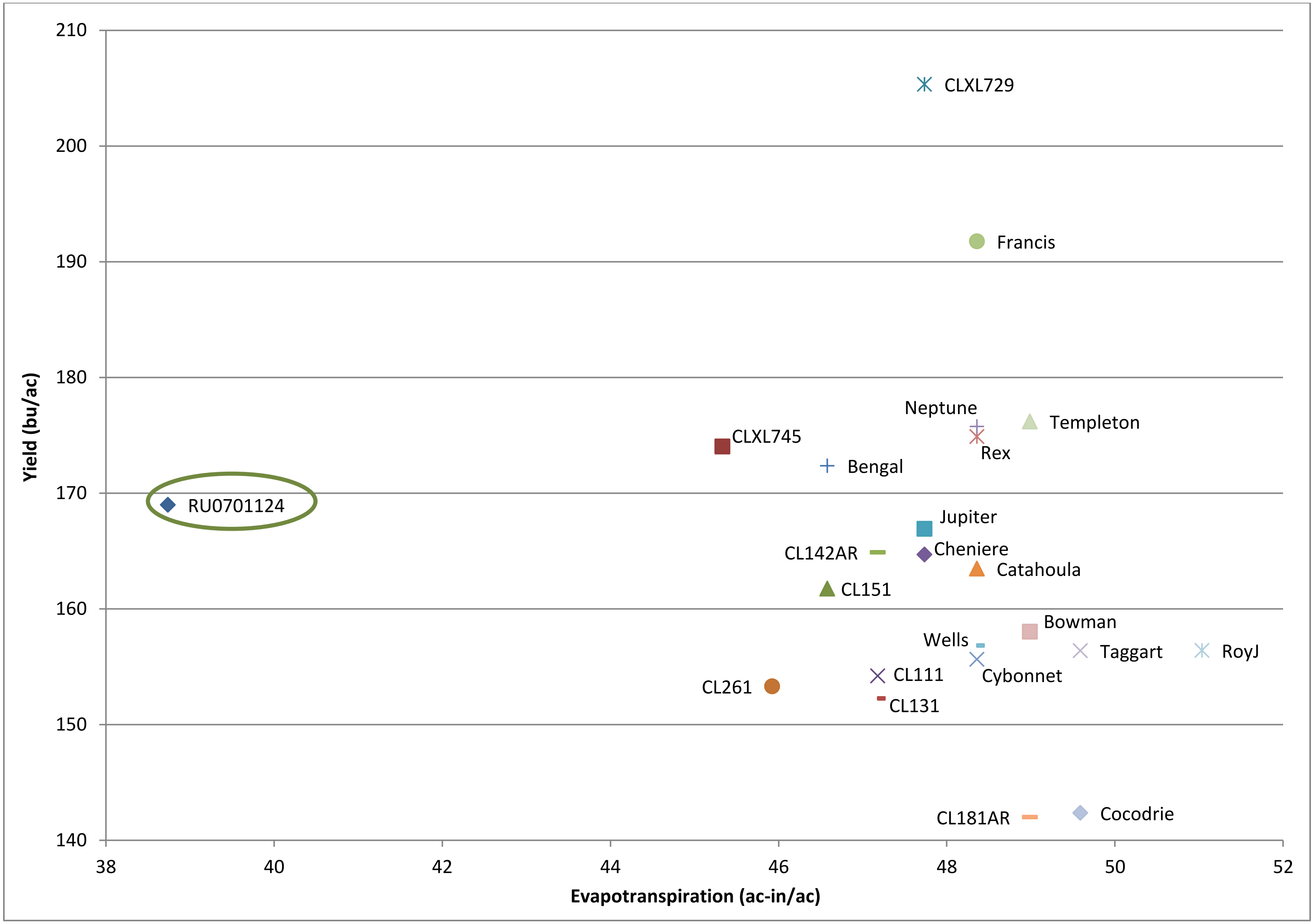


Figure 6. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Keiser ARPT Station in 2010

Table 22. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Newport ARPT Station in 2010

Variety	Type	Days on Flood	E^a (ac-in/ac)	T^b (ac-in/ac)	ET^c (ac-in/ac)	Yield[d] (bu/ac)	Yield(bu)/ ET(ac-in)
RU0701124	Conv.	57	17.01	13.82	30.83	96	3.115
CLXL745	CLHYB	66	19.11	16.24	35.35	174	4.919
XL723	HYB	69	19.91	17.16	37.07	192	5.168*
CL151	CL	70	19.99	17.25	37.23	99	2.663
CL111	CL	71	20.12	17.40	37.52	93	2.471
CLXL729	CLHYB	74	20.73	18.11	38.84	157	4.044
Wells	Conv.	70	19.99	17.25	37.23	142	3.819
CL131	CL	70	19.99	17.25	37.23	93	2.508
Rex	Conv.	72	20.22	17.52	37.74	112	2.972
CL261	CL	72	20.22	17.52	37.74	135	3.586
Bengal	Conv.	73	20.48	17.82	38.30	99	2.596
Cybonnet	Conv.	73	20.48	17.82	38.30	111	2.901
Cheniere	Conv.	74	20.73	18.11	38.84	103	2.664
CL142AR	CL	74	20.73	18.11	38.84	116	2.986
Catahoula	Conv.	74	20.73	18.11	38.84	104	2.685
Francis	Conv.	75	20.99	18.40	39.39	94	2.374
Jupiter	Conv.	75	20.99	18.40	39.39	116	2.954
CL181AR	CL	75	20.99	18.40	39.39	126	3.211
Cocodrie	Conv.	76	21.24	18.69	39.93	115	0.377
Neptune	Conv.	79	21.85	19.39	41.24	82	1.989
Taggart	Conv.	75	20.99	18.40	39.39	166	4.219
Templeton	Conv.	76	21.24	18.69	39.93	105	2.617
Bowman	Conv.	77	21.39	18.86	40.25	78	1.945
RoyJ	Conv.	79	21.85	19.39	41.24	143	3.456

[a] Obtained from results on **Table 10**.
[b] Obtained from results on **Table 16**.
[c] Evaporation (a) + Transpiration (b).
[d] Reported by 2010 ARPT.
* Denotes the most water use efficient variety.

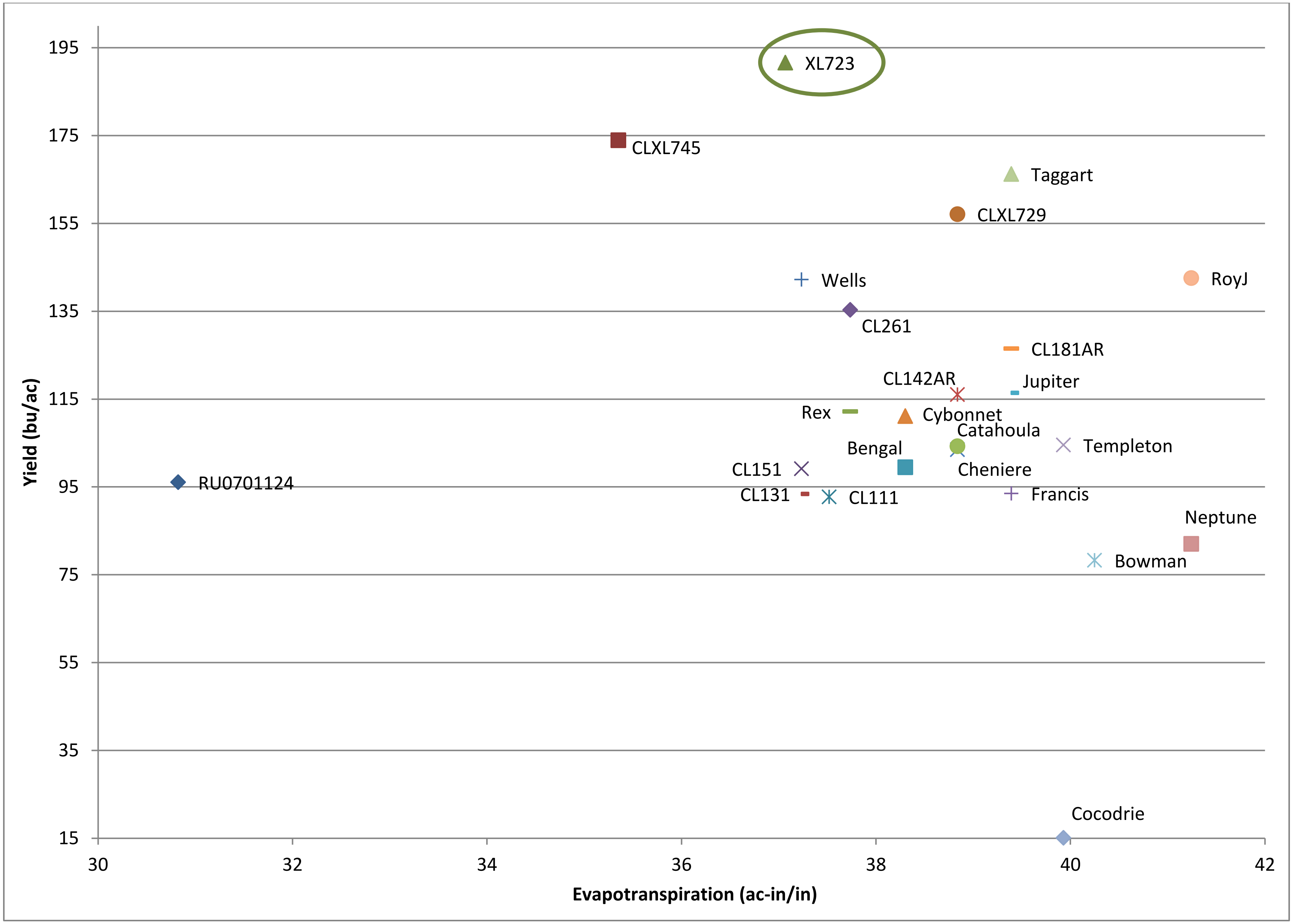


Figure 7. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Newport ARPT Station in 2010

Table 23. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Colt ARPT Station in 2010

Variety	Type	Days on Flood	E[a] (ac-in/ac)	T[b] (ac-in/ac)	ET[c] (ac-in/ac)	Yield[d] (bu/ac)	Yield(bu)/ ET(ac-in)
RU0701124	Conv.	67	21.20	18.38	39.59	129	3.262
CLXL745	CLHYB	75	23.62	21.16	44.78	198	4.433
CL151	CL	79	24.85	22.57	47.42	169	3.570
CL111	CL	79	24.85	22.57	47.42	168	3.553
XL723	HYB	81	25.45	23.27	48.72	201	4.136
CLXL729	CLHYB	82	25.73	23.59	49.31	227	4.604*
CL261	CL	79	24.85	22.57	47.42	156	3.284
CL131	CL	80	25.16	22.94	48.10	172	3.577
Bengal	Conv.	81	25.45	23.27	48.72	133	2.737
Rex	Conv.	81	25.45	23.27	48.72	174	3.579
CL142AR	CL	82	25.73	23.59	49.31	175	3.548
CL181AR	CL	82	25.73	23.59	49.31	160	3.251
Catahoula	Conv.	84	26.31	24.25	50.56	179	3.534
Cheniere	Conv.	84	26.31	24.25	50.56	162	3.202
Cybonnet	Conv.	84	26.31	24.25	50.56	159	3.144
Jupiter	Conv.	84	26.31	24.25	50.56	185	3.653
Francis	Conv.	85	26.59	24.58	51.16	184	3.591
Neptune	Conv.	85	26.59	24.58	51.16	167	3.269
Wells	Conv.	85	26.59	24.58	51.16	166	3.244
Cocodrie	Conv.	87	27.14	25.21	52.35	146	2.787
Taggart	Conv.	86	26.85	24.87	51.72	181	3.490
Bowman	Conv.	86	26.85	24.87	51.72	187	3.608
Templeton	Conv.	88	27.43	25.54	52.97	181	3.414
RoyJ	Conv.	89	27.71	25.87	53.57	186	3.475

[a] Obtained from results on **Table 11**.
[b] Obtained from results on **Table 17**.
[c] Evaporation (a) + Transpiration (b).
[d] Reported by 2010 ARPT.
* Denotes the most water use efficient variety.

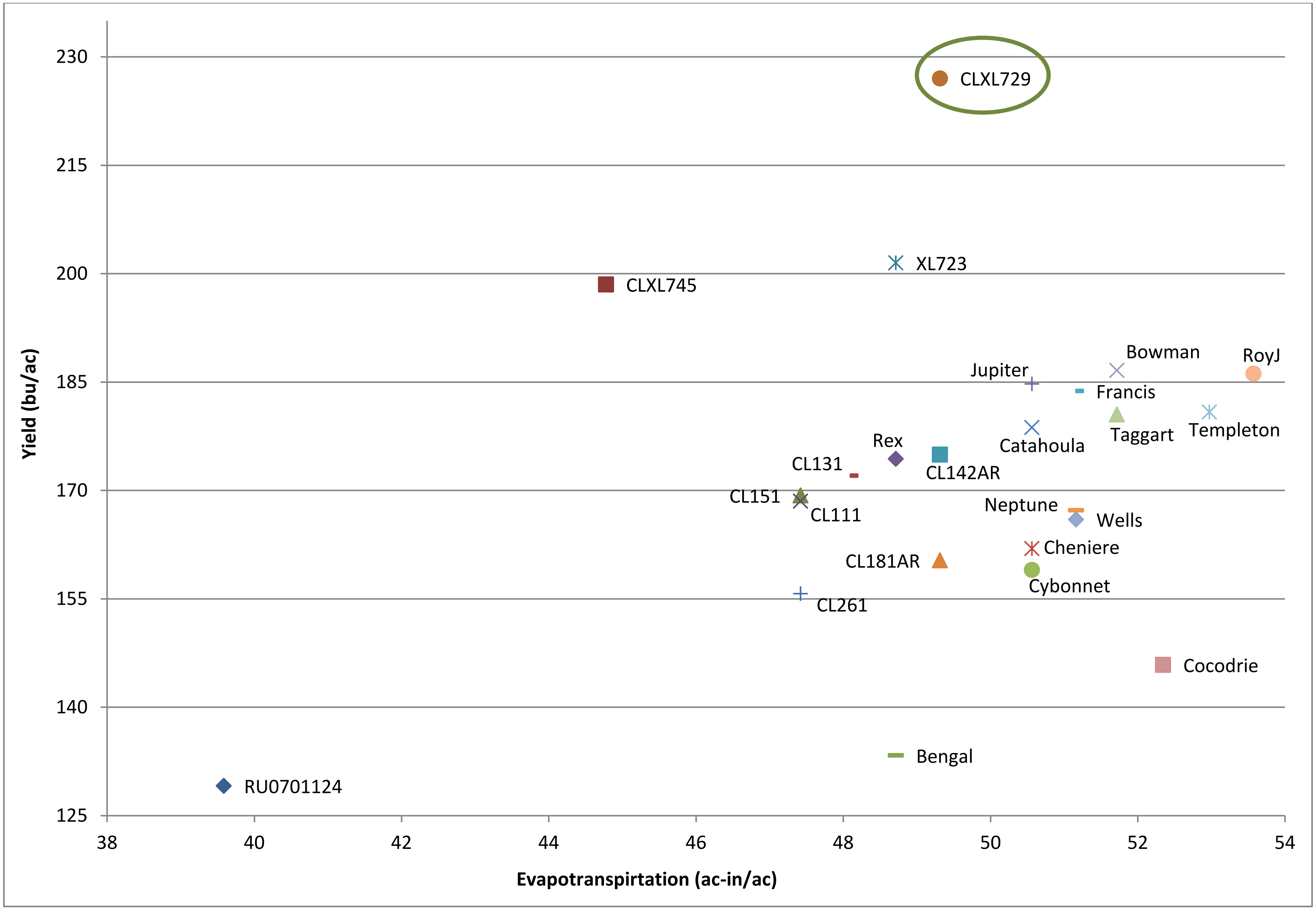


Figure 8. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Colt ARPT Station in 2010

Table 24. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Coring ARPT Station in 2010

Variety	Type	Days on Flood	E[a] (ac-in/ac)	T[b] (ac-in/ac)	ET[c] (ac-in/ac)	Yield[d] (bu/ac)	Yield(bu)/ ET(ac-in)
RU0701124	Conv.	76	22.79	20.96	43.75	169	3.868
CLXL729	CLHYB	81	24.26	22.65	46.92	232	4.944
CLXL745	CLHYB	81	24.26	22.65	46.92	217	4.626
XL723	HYB	83	24.92	23.41	48.33	240	4.969*
CL151	CL	83	24.92	23.41	48.33	238	4.914
CL111	CL	85	25.59	24.17	49.76	213	4.286
CL261	CL	83	24.92	23.41	48.33	196	4.059
CL131	CL	84	25.24	23.78	49.02	197	4.013
CL142AR	CL	86	25.91	24.55	50.46	202	4.009
Bengal	Conv.	86	25.91	24.55	50.46	219	4.331
Cheniere	Conv.	86	25.91	24.55	50.46	198	3.927
Cybonnet	Conv.	86	25.91	24.55	50.46	214	4.238
Francis	Conv.	86	25.91	24.55	50.46	230	4.552
Wells	Conv.	87	26.17	24.84	51.01	216	4.236
Catahoula	Conv.	87	26.17	24.84	51.01	207	4.063
Rex	Conv.	87	26.17	24.84	51.01	196	3.834
CL181AR	CL	87	26.17	24.84	51.01	186	3.642
Cocodrie	Conv.	89	26.80	25.57	52.38	180	3.430
Jupiter	Conv.	92	27.69	26.60	54.29	220	4.058
Neptune	Conv.	92	27.69	26.60	54.29	213	3.921
RoyJ	Conv.	87	26.17	24.84	51.01	206	4.040
Templeton	Conv.	87	26.17	24.84	51.01	195	3.826
Taggart	Conv.	87	26.17	24.84	51.01	215	4.209
Bowman	Conv.	88	26.48	25.21	51.69	183	3.536

[a] Obtained from results on **Table 12**.
[b] Obtained from results on **Table 18**.
[c] Evaporation (a) + Transpiration (b).
[d] Reported by 2010 ARPT.
* Denotes the most water use efficient variety.

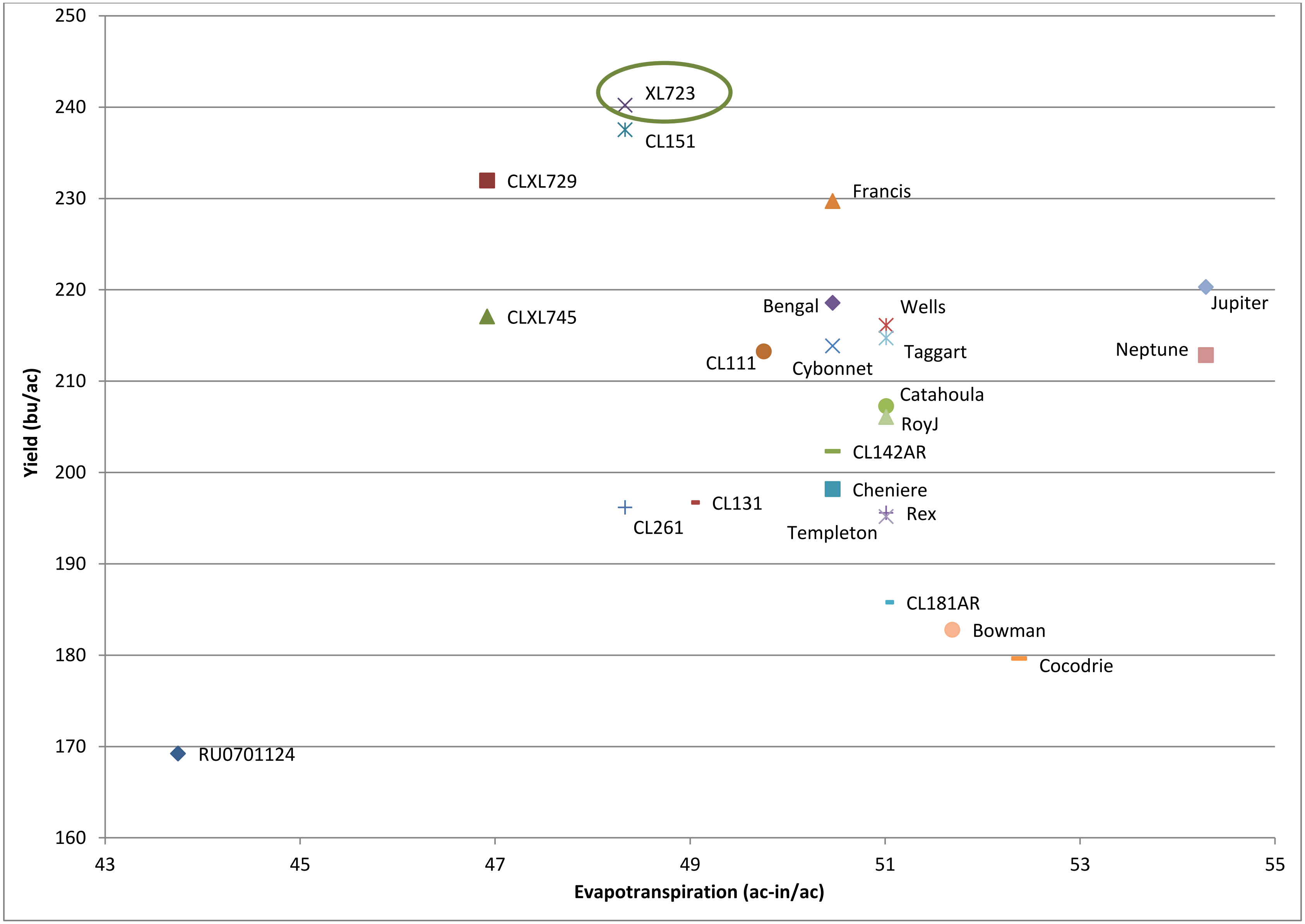


Figure 9. The Ratio of Yield (bu/ac) to Evapotranspiration (ac-in/ac) for Rice Varieties at the Coring ARPT Station in 2010

As stated in the evaporation and transpiration section, the experimental variety RU0701124 uses the least amount of water across all six ARPT stations. However, because of its relatively low yield, RU0701124 is not necessarily the most water efficient. In fact RU0701124 is only the most efficient variety at one location (Keiser) falling to the bottom quartile of efficiencies in many locations. Therefore, just because a certain variety is a short season variety (which would typically indicate it has relatively lower water requirements) does not imply it is as efficient at using that water to produce grain as a variety which requires more water.

Figures 4 through 9 illustrate a pattern where Hybrid rice varieties are more efficient at water usage (located in the upper left portion of the figure) while conventional varieties tend to be relatively less efficient (in the lower right part of the figures). This would indicate that on average Hybrid varieties are more water efficient than conventional varieties although in few cases they may use slightly more total water.

4. Statistical Results

An analysis of variance (ANOVA) was run to estimate whether or not hybrid rice varieties use less water/ac and are more water-use efficient varieties compared to the other two cultivar types (conventional & Clearfield). This is important; while the above findings suggest that the averages between hybrids, conventionals and Clearfield are different this does not necessarily imply they are statistically different. The statistical results indicate that on average hybrid rice varieties are not statistically different from conventional and Clearfield varieties in the total amount of water required per acre but are statistically superior in water use efficiency (ac-in/bu).

Table 25 provides the answers to whether or not each two cultivar types were significantly different from each other regarding water use/ac at all six rice stations. The table shows that on average, hybrid rice varieties use less water than the conventional ones only at Rohwer and Coring ARPT station and less water than Clearfield only at Coring Rice station. For other stations hybrid rice varieties are not statistically different from conventional and Clearfield rice varieties, meaning on average they all use the same amount of water/ac. The last bolded row of this table, "All Stations", shows the results from the ANOVA test run for all rice varieties from all six rice stations. None of the three cultivar type combinations (Conventional & Clearfield, Conventional & Hybrid, and Clearfield & Hybrid) indicate statistical difference between each-other.

Table 25. Statistical Differences on Total Water-Use/ac Between Cultivar Types (Conventional, Clearfield, & Hybrid) at 95% Level for Six ARPT Station in 2010

ARPT Stations/ Cultivar Type Combination	Conventional & Clearfield	Conventional & Hybrid	Clearfield & Hybrid
Stuttgart	NO	NO	NO
Rohwer	NO	YES^{+}	NO
Keiser	NO	NO	NO
Newport	NO	NO	NO
Colt	NO	NO	NO
Coring	NO	YES^{+}	YES^{+}
All Stations	**NO**	**NO**	**NO**

[a] YES^{+} indicates statistical difference; where on average hybrid rice varies use less total water/ac.
[b] NO indicates no statistical difference between the two rice types.

Statistical results on water-use efficiency, on the other hand, tell quite a different story. Table 26 shows that on average, hybrid rice varieties are more water-use efficient than conventional and Clearfield at all ARPT stations except Rohwer, where there is no statistical difference between Clearfield & Hybrid. The ANOVA test ran for all rice varieties from all six stations together also indicates that hybrid rice varieties are more water-use efficient than conventional and Clearfield rice varieties.

Table 26. Statistical Differences on Water-Use Efficiencies (bu/ac-in) Between Cultivar Types (Conventional, Clearfield, & Hybrid) at 95% Level for Six ARPT Station in 2010

ARPT Stations/ Cultivar Type Combination	Conventional & Clearfield	Conventional & Hybrid	Clearfield & Hybrid
Stuttgart	NO	YES+	YES+
Rohwer	NO	YES+	NO
Keiser	NO	YES+	YES+
Newport	NO	YES+	YES+
Colt	NO	YES+	YES+
Coring	NO	YES+	YES+
All Stations	**NO**	**YES+**	**YES+**

[a] YES[+] indicates statistical difference; where on average hybrid rice varies use less total water/bu.
[b] NO indicates no statistical difference between the two rice types.

Figure 10 shows the yield/water use ratio between a fairly short season rice variety - CLXL745 (hybrid with an average of 76 Days under flood for all six rice stations), and a fairly long season one – Wells (conventional with an average of 84 Days under flood for all six rice stations) across all ARPT stations in 2010.

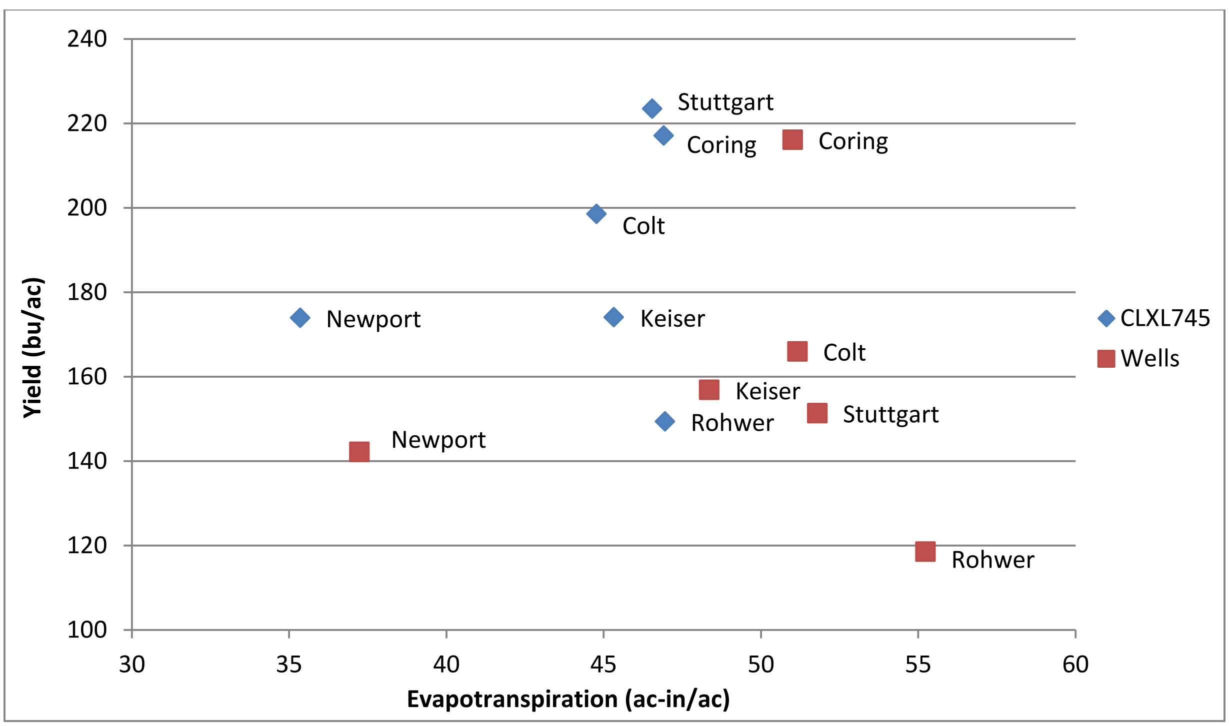


Figure 10. Yield (bu)/Evapotranspiration (ac-in) Ratio for CLXL745 and Wells Rice Varieties Across Six ARPT Stations in 2010

As illustrated in figure 10, variety CLXL745 is more efficient at producing grain with each unit of water compared to Wells across all six ARPT stations for the growing year 2010. For instance, at Stuttgart CLXL745 yields 223 bu/ac and uses 47 ac-in/ac of water, while Wells yields 151 bu/ac and uses 52 ac-in/ac of water. On average for all six rice station CLXL745 yields 31 bu/ac more than Wells and it uses on average 5 ac-in/ac less water (staying on flood for an average of 8 days less than Wells). This pattern is generally observed between Hybrids and Conventional. Thus, the main driver of water use efficiency seems to be that the Hybrid rice varieties possess genetic potential for higher yield and for shorter life cycles.

The results, therefore, indicate that CLXL745 and Hybrids in general could be ideal varieties not only to meet the increasing global market demand for rice but also conserving irrigation water reserves. That is not to say that varieties with very low water requirements (RU0701124) should be discarded due to their lower yield potential, in fact in locations with limited water availability varieties such as RU0701124 may have to be adopted for rice production to continue. That being said, in Arkansas where water is becoming more scarce but not a constraint yet, varieties like Hybrids seem to the most efficient water use varieties and are a viable option.

A. GHG Emissions

Given the fact that there are several sources of GHG emissions in rice production, total GHG emission was calculated in three separate groups, which were later summed up to give the total GHG emissions per ac by variety. The first source of GHG emissions included the average values on a cultivar basis (conventional, Clearfield and hybrid) for emissions from diesel (tractor operation), fungicide, herbicide, pesticide, fertilizer (Sum of N-P-K application) and N_2O

(correlated with nitrogen fertilizer application). The GHG emissions from this source were obtained from McFadden et al. (2011) and are illustrated in table 25.

Unlike the McFadden et al. 2011 study, GHG emissions from irrigation (assuming all pumps were diesel) were computed separately in order to account for the fact that each variety stays under flood different lengths and thus would use different amounts of diesel to pump the required water amounts. Emissions from irrigation were generated as follows: 1) the total amount of water for irrigation (evapotranspiration-rain) for every rice variety were multiplied by the amount of diesel fuel required to raise an ac-in/ac of water (1.022 gal), and 2) the total amount of diesel fuel required for every rice variety was multiplied by a constant CE per gal of diesel (7.01). Through these calculations the study attempts to point out that a rice variety with a shorter life cycle (shorter flooding period) emits less GHG emissions through using less water for irrigation. Calculations on GHG emissions from irrigation are presented in tables 26-31.

A third GHG section deals with the calculations of methane, which is generated as a result of an anaerobic decomposition of organic matter caused by flooding. The data on methane emission in a daily bases were obtained from Rogers et al. (2012) and was used to calculate the seasonal amount of methane emitted for every rice variety based on their number of days under flood.

1. GHG Emissions Estimates Taken from McFadden et al. (2011)

Table 27. Average Carbon Emission (CE) per Ac by Cultivar and Inputs on Silt Loam Soils across the Six APRT Stations[A]

	Greenhouse Gas Emissions (lb/ac)				
Cultivar	Diesel [a]	Fungicide, Herbicide & Pesticide	Fertilizer [b]	N_2O [c]	Total Emissions[d] (lb CE/ac)
Conventional Average	108	45	226	334	712
Clearfield Average	119	22	201	293	635
Hybrid Average	108	44	201	293	645

[A] As derived from McFadden et al. (2011).
[a] CE emitted from diesel use in tractors and crop dusters excluding CE emitted from diesel used for irrigation.
[b] CE emitted from N-P-K application.
[c] CE correlated with nitrogen fertilizer application.
[d] Total CE emission excluding CE from methane and CE diesel used for irrigation.

2. GHG Emissions from Irrigation

Tables 26 through 31 present estimated results on GHG emissions from irrigation in lb/ac carbon equivalent (CE) for each rice variety at each ARPT station in 2010. Variables included in these tables are: variety, type, evapotranspiration (total water usage) diesel and CE from burning one gal of diesel all of which were used to compute GHG emissions from rice irrigation in a lb CE/ac. Values on evapotranspiration were obtained from tables 19-24, whereas values on diesel were computed as value of irrigation water (evapotranspiration-rain) multiplied with a constant of 1.022 gal. This constant comes from the assumption that water for irrigation was pumped from 100 feet using a diesel pump which required 1.022 gallons of diesel to raise one ac-in of water (Slaton, 2001). Further to estimate the total amount of GHG emissions from irrigation, the total diesel (gal/ac-in) values per each rice variety are multiplied by 7.01 which is a constant of CE emitted per every gallon of diesel fuel used to raise water for irrigation (EPA 2007 & 2009, and Sima Pro).

Table 28. GHG Emissions (Carbon Equivalence) in lb/ac from Diesel used for Irrigation for Rice Varieties at the Stuttgart ARPT Station in 2010

Variety	Type	Days on Flood	Irrigation Water (ac-in/ac)	Diesel (gall/ac)[b]	GHG from Irrigation (lb CE/ac)[c]
RU0701124	Conv.	71	38.75	39.60	278
CLXL745	CLHYB	78	43.75	44.71	313
CL151	CL	81	42.87	43.81	307
CL111	CL	82	43.45	44.41	311
CLXL729	CLHYB	83	44.14	45.11	316
XL723	HYB	83	44.14	45.11	316
CL131	CL	81	42.87	43.81	307
CL261	CL	81	42.87	43.81	307
Bengal	Conv.	82	43.45	44.41	311
Francis	Conv.	83	44.14	45.11	316
Rex	Conv.	83	44.14	45.11	316
CL142AR	CL	84	44.83	45.82	321
Jupiter	Conv.	85	45.52	46.52	326
Catahoula	Conv.	85	45.52	46.52	326
Cybonnet	Conv.	85	45.52	46.52	326
Neptune	Conv.	85	45.52	46.52	326
Cheniere	Conv.	86	46.20	47.22	331
CL181AR	CL	86	46.20	47.22	331
Wells	Conv.	86	46.20	47.22	331
Cocodrie	Conv.	87	46.88	47.91	336
Taggart	Conv.	90	48.09	49.15	345
Templeton	Conv.	90	48.09	49.15	345
Bowman	Conv.	92	49.26	50.34	353
RoyJ	Conv.	92	49.26	50.34	353
Avg. Conventional		86	45.77	46.77	328
Avg. Clearfield		82	43.85	44.81	314
Avg. Hybrid		81	44.01	44.98	315

[a] Evapotranspiration (**Table 19) –** Rain (in inches from 1st day of flooding to drainage date by variety type).
[b] This study assumed that water for irrigation was pumped from 100 feet using a diesel pump which required 1.022 gallons of diesel to raise one ac-inch of water (Slaton, 2001). Total irrigation water (ac-in/ac) from each rice variety is therefore multiplied with the constant 1.022 to find total diesel burned for each cultivar.
[c] Total diesel per cultivar is then multiplied by 7.01, which is a constant of CE emitted per every gallon of diesel fuel used to raise water for irrigation (EPA 2007 & 2009, and Sima Pro), to estimate CE emission from irrigation for every cultivar.
[d] The above notes denoted as “b” and “c” apply to all five next tables below (27-31).

Table 29. GHG Emissions (Carbon Equivalence) in lb/ac from Diesel used for Irrigation for Rice Varieties at the Rohwer ARPT Station in 2010

Variety	Type	Days on Flood	Irrigation Water (ac-in/ac)	Diesel (gall/ac)[b]	GHG from Irrigation (lb CE/ac)[c]
RU0701124	Conv.	76	36.12	36.91	259
CLXL745	CLHYB	80	35.89	36.68	257
CLXL729	CLHYB	84	37.04	37.86	265
XL723	HYB	84	37.04	37.86	265
CL111	CL	86	38.43	39.27	275
CL151	CL	86	38.43	39.27	275
CL261	CL	85	37.75	38.58	270
Francis	Conv.	86	38.43	39.27	275
Bengal	Conv.	86	38.43	39.27	275
Jupiter	Conv.	86	38.43	39.27	275
CL131	CL	86	38.43	39.27	275
Cheniere	Conv.	87	39.06	39.92	280
Neptune	Conv.	87	39.06	39.92	280
Rex	Conv.	87	39.06	39.92	280
CL142AR	CL	88	39.69	40.57	284
Cybonnet	Conv.	90	41.04	41.94	294
Catahoula	Conv.	92	42.27	43.20	303
Wells	Conv.	93	42.88	43.82	307
Cocodrie	Conv.	95	44.13	45.10	316
CL181AR	CL	95	44.13	45.10	316
Templeton	Conv.	94	43.47	44.43	311
Taggart	Conv.	94	43.47	44.43	311
Bowman	Conv.	95	44.13	45.10	316
RoyJ	Conv.	98	46.09	47.10	330
Avg. Conventional		90	41.07	41.97	294
Avg. Clearfield		88	39.47	40.34	283
Avg. Hybrid		83	36.66	37.46	263

[a] Evapotranspiration (**Table 20) –** Rain (in inches from 1st day of flooding to drainage date by variety type).

Table 30. GHG Emissions (Carbon Equivalence) in lb/ac from Diesel used for Irrigation for Rice Varieties at the Keiser ARPT Station in 2010

Variety	Type	Days on Flood	Irrigation Water (ac-in/ac)	Diesel (gall/ac)[b]	GHG from Irrigation (lb CE/ac)[c]
RU0701124	Conv.	66	35.51	36.29	254
CLXL745	CLHYB	76	42.07	43.00	301
CL151	CL	78	43.32	44.27	310
CL111	CL	79	43.92	44.88	315
CLXL729	CLHYB	80	44.48	45.45	319
CL261	CL	77	42.66	43.60	306
Bengal	Conv.	78	43.32	44.27	310
CL131	CL	79	43.92	44.88	315
CL142AR	CL	79	43.92	44.88	315
Cheniere	Conv.	80	44.48	45.45	319
Jupiter	Conv.	80	44.48	45.45	319
Catahoula	Conv.	81	45.10	46.09	323
Cybonnet	Conv.	81	45.10	46.09	323
Rex	Conv.	81	45.10	46.09	323
Francis	Conv.	81	45.10	46.09	323
Neptune	Conv.	81	45.10	46.09	323
Wells	Conv.	81	45.10	46.09	323
CL181AR	CL	82	45.73	46.73	328
Cocodrie	Conv.	83	46.33	47.35	332
Bowman	Conv.	82	45.73	46.73	328
Templeton	Conv.	82	45.73	46.73	328
Taggart	Conv.	83	46.33	47.35	332
RoyJ	Conv.	86	47.72	48.77	342
Avg. Conventional		81	44.68	45.66	320
Avg. Clearfield		79	43.91	44.88	315
Avg. Hybrid		78	43.27	44.23	310

[a] Evapotranspiration (**Table 21) –** Rain (in inches from 1st day of flooding to drainage date by variety type).

Table 31. GHG Emissions (Carbon Equivalence) in lb/ac from Diesel used for Irrigation for Rice Varieties at the Newport ARPT Station in 2010

Variety	Type	Days on Flood	Irrigation Water (ac-in/ac)	Diesel (gall/ac)[b]	GHG from Irrigation (lb CE/ac)[c]
RU0701124	Conv.	57	25.07	25.63	180
CLXL745	CLHYB	66	29.49	30.14	211
XL723	HYB	69	31.21	31.89	224
CL151	CL	70	31.12	31.81	223
CL111	CL	71	31.27	31.95	224
CLXL729	CLHYB	74	31.47	32.16	225
Wells	Conv.	70	31.12	31.81	223
CL131	CL	70	31.12	31.81	223
Rex	Conv.	72	31.38	32.08	225
CL261	CL	72	31.38	32.08	225
Bengal	Conv.	73	31.95	32.65	229
Cybonnet	Conv.	73	31.95	32.65	229
Cheniere	Conv.	74	31.47	32.16	225
CL142AR	CL	74	31.47	32.16	225
Catahoula	Conv.	74	31.47	32.16	225
Francis	Conv.	75	32.02	32.73	229
Jupiter	Conv.	75	32.02	32.73	229
CL181AR	CL	75	32.02	32.73	229
Cocodrie	Conv.	76	32.56	33.27	233
Neptune	Conv.	79	33.74	34.48	242
Taggart	Conv.	75	32.02	32.73	229
Templeton	Conv.	76	32.56	33.27	233
Bowman	Conv.	77	32.88	33.60	236
RoyJ	Conv.	79	33.74	34.48	242
Avg. Conventional		74	31.73	32.43	227
Avg. Clearfield		72	31.40	32.09	225
Avg. Hybrid		70	30.72	31.40	220

[a] Evapotranspiration (**Table 22) –**Rain (in inches from 1st day of flooding to drainage date by variety type).

Table 32. GHG Emissions (Carbon Equivalence) in lb/ac from Diesel used for Irrigation for Rice Varieties at the Colt ARPT Station in 2010

Variety	Type	Days on Flood	Irrigation Water (ac-in/ac)	Diesel (gall/ac)[b]	GHG from Irrigation (lb CE/ac)[c]
RU0701124	Conv.	67	35.53	36.32	255
CLXL745	CLHYB	75	40.69	41.58	291
CL151	CL	79	43.33	44.28	310
CL111	CL	79	43.33	44.28	310
XL723	HYB	81	44.63	45.61	320
CLXL729	CLHYB	82	45.22	46.22	324
CL261	CL	79	43.33	44.28	310
CL131	CL	80	44.01	44.98	315
Bengal	Conv.	81	44.63	45.61	320
Rex	Conv.	81	44.63	45.61	320
CL142AR	CL	82	45.22	46.22	324
CL181AR	CL	82	45.22	46.22	324
Catahoula	Conv.	84	46.46	47.48	333
Cheniere	Conv.	84	46.46	47.48	333
Cybonnet	Conv.	84	46.46	47.48	333
Jupiter	Conv.	84	46.46	47.48	333
Francis	Conv.	85	47.06	48.10	337
Neptune	Conv.	85	47.06	48.10	337
Wells	Conv.	85	47.06	48.10	337
Cocodrie	Conv.	87	48.24	49.31	346
Taggart	Conv.	86	47.62	48.67	341
Bowman	Conv.	86	47.62	48.67	341
Templeton	Conv.	88	48.87	49.95	350
RoyJ	Conv.	89	49.47	50.56	354
Avg. Conventional		84	46.24	47.26	331
Avg. Clearfield		80	44.07	45.04	316
Avg. Hybrid		80	43.51	44.47	312

[a] Evapotranspiration (**Table 23) –** Rain (in inches from 1st day of flooding to drainage date by variety type).

Table 33. GHG Emissions (Carbon Equivalence) in lb/ac from Diesel used for Irrigation for Rice Varieties at the Coring ARPT Station in 2010

Variety	Type	Days on Flood	Irrigation Water (ac-in/ac)	Diesel (gall/ac)[b]	GHG from Irrigation (lb CE/ac)[c]
RU0701124	Conv.	76	39.51	40.38	283
CLXL729	CLHYB	81	42.50	43.44	305
CLXL745	CLHYB	81	42.50	43.44	305
XL723	HYB	83	43.92	44.89	315
CL151	CL	83	43.92	44.89	315
CL111	CL	85	45.34	46.34	325
CL261	CL	83	43.92	44.89	315
CL131	CL	84	44.61	45.59	320
CL142AR	CL	86	46.05	47.06	330
Bengal	Conv.	86	46.05	47.06	330
Cheniere	Conv.	86	46.05	47.06	330
Cybonnet	Conv.	86	46.05	47.06	330
Francis	Conv.	86	46.05	47.06	330
Wells	Conv.	87	46.60	47.62	334
Catahoula	Conv.	87	46.60	47.62	334
Rex	Conv.	87	46.60	47.62	334
CL181AR	CL	87	46.60	47.62	334
Cocodrie	Conv.	89	47.96	49.02	344
Jupiter	Conv.	92	49.88	50.97	357
Neptune	Conv.	92	49.88	50.97	357
RoyJ	Conv.	87	46.60	47.62	334
Templeton	Conv.	87	46.60	47.62	334
Taggart	Conv.	87	46.60	47.62	334
Bowman	Conv.	88	47.28	48.32	339
Avg. Conventional		87	46.55	47.58	334
Avg. Clearfield		85	45.07	46.06	323
Avg. Hybrid		82	42.98	43.92	308

[a] Evapotranspiration (**Table 24) –** Rain (in inches from 1st day of flooding to drainage date by variety type).

Given that the GHG emissions from rice irrigation (diesel) are a factor of the amount of applied irrigation water (evapotranspiration–rain), GHG emissions directly depend on the seasonal evapotranspiration and rainfall. Therefore, the general rule in this case would be that rice varieties with shorter period under flood will emit less GHG/ac; however, if a variety with a longer period under flood is observed to have less GHG emission from irrigation it means that during the additional days under flood this variety received more rainfall. For instance, at the Stuttgart location rice varieties with 81 and 82 days under flood emitted 307 and 311 lb of CE/ac, while rice varieties with 78 days under flood emit 313 lb of CE/ac.

Comparing averages on GHG emissions from irrigation between conventional, Clearfield and hybrids in tables 26 through 31, a systematic pattern is observed across all ARPT stations during 2010 growing season. The pattern indicates that conventional rice varieties on average use more water for irrigation (more days under flood), which requires more diesel fuel to raise irrigation water and therefore emit more GHG/ac, followed next by Clearfield and the hybrids, respectively. Thus, this study assumes the number of days a variety stays under flood plays the greatest role on the amount of GHG emissions from irrigation.

These estimated results on GHG emissions from irrigation (lb CE/ac), however, do not necessarily define GHG emission efficiency, which is the main purpose of this study. Estimations on GHG emission efficiency will be discussed later in this section when yield/ac is included in the estimations.

3. GHG Emissions from Methane

Tables 32-37 present results on GHG emissions from methane in a lb/ac carbon equivalent for each rice variety at each ARPT station in 2010. Variables included in these tables are: variety, type, and days on flood all of which were used to compute GHG emissions from methane.

Table 34. GHG Emissions (Carbon Equivalence) in lb/ac from Methane for Rice Varieties at the Stuttgart ARPT Station in 2010

Variety	Type	Days on Flood	Total Methane (lb of CE/ac)[a]
RU0701124	Conv.	71	1110
CLXL745	CLHYB	78	1460
CL151	CL	81	1333
CL111	CL	82	1356
CLXL729	CLHYB	83	1582
XL723	HYB	83	1582
CL131	CL	81	1333
CL261	CL	81	1333
Bengal	Conv.	82	1356
Francis	Conv.	83	1378
Rex	Conv.	83	1378
CL142AR	CL	84	1401
Jupiter	Conv.	85	1423
Catahoula	Conv.	85	1423
Cybonnet	Conv.	85	1423
Neptune	Conv.	85	1423
Cheniere	Conv.	86	1445
CL181AR	CL	86	1445
Wells	Conv.	86	1445
Cocodrie	Conv.	87	1468
Taggart	Conv.	90	1535
Templeton	Conv.	90	1535
Bowman	Conv.	92	1580
RoyJ	Conv.	92	1580
Avg. Conventional		86	1433
Avg. Clearfield		82	1367
Avg. Hybrid		81	1541

[a] Average daily values on methane emissions for Conventional and Hybrid were obtained from Rogers et al. (2012) and were adjusted to the total number of days a variety stays under flood.

Table 35. GHG Emissions (Carbon Equivalence) in lb/ac from Methane for Rice Varieties at the Rohwer ARPT Station in 2010

Variety	Type	Days on Flood	Total Methane (lb of CE/ac)
RU0701124	Conv.	76	1221
CLXL745	CLHYB	80	1509
CLXL729	CLHYB	84	1606
XL723	HYB	84	1606
CL111	CL	86	1445
CL151	CL	86	1445
CL261	CL	85	1423
Francis	Conv.	86	1445
Bengal	Conv.	86	1445
Jupiter	Conv.	86	1445
CL131	CL	86	1445
Cheniere	Conv.	87	1468
Neptune	Conv.	87	1468
Rex	Conv.	87	1468
CL142AR	CL	88	1490
Cybonnet	Conv.	90	1535
Catahoula	Conv.	92	1580
Wells	Conv.	93	1602
Cocodrie	Conv.	95	1647
CL181AR	CL	95	1647
Templeton	Conv.	94	1624
Taggart	Conv.	94	1624
Bowman	Conv.	95	1647
RoyJ	Conv.	98	1714
Avg. Conventional		90	1529
Avg. Clearfield		88	1483
Avg. Hybrid		83	1573

[a] Average daily values on methane emissions for Conventional and Hybrid were obtained from Rogers et al. (2012) and were adjusted to the total number of days a variety stays under flood.

Table 36. GHG Emissions (Carbon Equivalence) in lb/ac from Methane for Rice Varieties at the Keiser ARPT Station in 2010

Variety	Type	Days on Flood	Total Methane (lb of CE/ac)
RU0701124	Conv.	66	998
CLXL745	CLHYB	76	1411
CL151	CL	78	1266
CL111	CL	79	1289
CLXL729	CLHYB	80	1509
CL261	CL	77	1244
Bengal	Conv.	78	1266
CL131	CL	79	1289
CL142AR	CL	79	1289
Cheniere	Conv.	80	1311
Jupiter	Conv.	80	1311
Catahoula	Conv.	81	1333
Cybonnet	Conv.	81	1333
Rex	Conv.	81	1333
Francis	Conv.	81	1333
Neptune	Conv.	81	1333
Wells	Conv.	81	1333
CL181AR	CL	82	1356
Cocodrie	Conv.	83	1378
Bowman	Conv.	82	1356
Templeton	Conv.	82	1356
Taggart	Conv.	83	1378
RoyJ	Conv.	86	1445
Avg. Conventional		81	1320
Avg. Clearfield		79	1289
Avg. Hybrid		78	1460

[a] Average daily values on methane emissions for Conventional and Hybrid were obtained from Rogers et al. (2012) and were adjusted to the total number of days a variety stays under flood.

Table 37. GHG Emissions (Carbon Equivalence) in lb/ac from Methane for Rice Varieties at the Newport ARPT Station in 2010

Variety	Type	Days on Flood	Total Methane (lb of CE/ac)
RU0701124	Conv.	57	796
CLXL745	CLHYB	66	1168
XL723	HYB	69	1241
CL151	CL	70	1087
CL111	CL	71	1110
CLXL729	CLHYB	74	1177
Wells	Conv.	70	1087
CL131	CL	70	1087
Rex	Conv.	72	1132
CL261	CL	72	1132
Bengal	Conv.	73	1154
Cybonnet	Conv.	73	1154
Cheniere	Conv.	74	1177
CL142AR	CL	74	1177
Catahoula	Conv.	74	1177
Francis	Conv.	75	1199
Jupiter	Conv.	75	1199
CL181AR	CL	75	1199
Cocodrie	Conv.	76	1221
Neptune	Conv.	79	1289
Taggart	Conv.	75	1199
Templeton	Conv.	76	1221
Bowman	Conv.	77	1244
RoyJ	Conv.	79	1289
Avg. Conventional		74	1169
Avg. Clearfield		72	1132
Avg. Hybrid		70	1195

[a] Average daily values on methane emissions for Conventional and Hybrid were obtained from Rogers et al. (2012) and were adjusted to the total number of days a variety stays under flood.

Table 38. GHG Emissions (Carbon Equivalence) in lb/ac from Methane for Rice Varieties at the Colt ARPT Station in 2010

Variety	Type	Days on Flood	Total Methane (lb of CE/ac)
RU0701124	Conv.	67	1020
CLXL745	CLHYB	75	1387
CL151	CL	79	1289
CL111	CL	79	1289
XL723	HYB	81	1533
CLXL729	CLHYB	82	1557
CL261	CL	79	1289
CL131	CL	80	1311
Bengal	Conv.	81	1333
Rex	Conv.	81	1333
CL142AR	CL	82	1356
CL181AR	CL	82	1356
Catahoula	Conv.	84	1401
Cheniere	Conv.	84	1401
Cybonnet	Conv.	84	1401
Jupiter	Conv.	84	1401
Francis	Conv.	85	1423
Neptune	Conv.	85	1423
Wells	Conv.	85	1423
Cocodrie	Conv.	87	1468
Taggart	Conv.	86	1445
Bowman	Conv.	86	1445
Templeton	Conv.	88	1490
RoyJ	Conv.	89	1512
Avg. Conventional		84	1395
Avg. Clearfield		80	1315
Avg. Hybrid		80	1492

[a] Average daily values on methane emissions for Conventional and Hybrid were obtained from Rogers et al. (2012) and were adjusted to the total number of days a variety stays under flood.

Table 39. GHG Emissions (Carbon Equivalence) in lb/ac from Methane for Rice Varieties at the Coring ARPT Station in 2010

Variety	Type	Days on Flood	Total Methane (lb of CE/ac)
RU0701124	Conv.	76	1221
CLXL729	CLHYB	81	1533
CLXL745	CLHYB	81	1533
XL723	HYB	83	1582
CL151	CL	83	1378
CL111	CL	85	1423
CL261	CL	83	1378
CL131	CL	84	1401
CL142AR	CL	86	1445
Bengal	Conv.	86	1445
Cheniere	Conv.	86	1445
Cybonnet	Conv.	86	1445
Francis	Conv.	86	1445
Wells	Conv.	87	1468
Catahoula	Conv.	87	1468
Rex	Conv.	87	1468
CL181AR	CL	87	1468
Cocodrie	Conv.	89	1512
Jupiter	Conv.	92	1580
Neptune	Conv.	92	1580
RoyJ	Conv.	87	1468
Templeton	Conv.	87	1468
Taggart	Conv.	87	1468
Bowman	Conv.	88	1490
Avg. Conventional		87	1465
Avg. Clearfield		85	1415
Avg. Hybrid		82	1549

[a] Average daily values on methane emissions for Conventional and Hybrid were obtained from Rogers et al. (2012) and were adjusted to the total number of days a variety stays under flood.

GHG emission from methane is directly dependent on two major factors: rice type (Conventional vs. Hybrid) and number of days under flood. In computing methane emission values, the rice types were divided in conventional and hybrids. Despite the fact that Hybrid rice varieties have normally a shorter life cycle – shorter period of time under flood – it is assumed that they peak at a higher value of methane (38.93 lbs/ac/day of CE) released per day compared to the conventional varieties (35.04 lbs/ac/day of CE). This difference is associated to a greater aboveground dry matter in hybrid rice and a quicker vegetative stage, which facilitates for a higher methane emission through the plant.

The estimated results from tables 32 through 37 indicate that Newport has the lowest average value on GHG emission from methane (1163 lb CE/ac) during 2010 growing season, while Rohwer is the rice station with highest average value on GHG emission from methane (1523 lb CE/ac) in the same growing season.

Comparing averages on GHG emissions from methane between conventional, Clearfield and hybrids from tables 32-37, a systematic pattern is observed across all ARPT stations during 2010. The pattern indicates that Hybrid rice varieties on average emit more methane as a result of greater aboveground dry matter (methane is mainly emitted to the atmosphere through the rice plant), followed next by conventional and Clearfield, respectively. The average difference between conventional and Clearfield in this case is a pure result of days under flood. Hence, this study assumes that aside variety type (conventional vs. hybrid), the number of days a variety stays under flood plays a great role on the amount of GHG emissions from methane as well.

When comparing individual rice varieties, the experimental rice RU0701124 generates the least GHG emissions from methane in each of the ARPT rice stations; however, the varieties with the highest values on GHG emissions from methane are not consistent across rice stations switching mainly from RoyJ (Stuttgart, Rohwer, Keiser, Newport, & Colt) to Neptune (Newport & Coring), Bowman (Stuttgart) and Jupiter (Coring).

These estimated results on GHG emissions from methane (lb CE/ac), however, do not necessarily define GHG emission efficiency, which is the purpose of this study. Estimations on GHG emission efficiency will be discussed later in this section.

4. Total GHG Emissions

The estimated values of GHG emission from: 1) McFadden et al. (2011), 2) diesel fuel from irrigation and 3) methane, are summed by variety by location to estimate total GHG emissions. Per ac estimations on GHG emission across the ARPT stations in 2010 indicate that experimental variety RU0701124 has the lowest total GHG emissions. Varieties with the highest total GHG emission values, on the other hand, are not consistent across rice stations switching mainly from RoyJ (Stuttgart, Rohwer, Keiser, Newport, & Colt) to Neptune (Newport & Coring), Bowman (Stuttgart) and Jupiter (Coring). The variations in the amount of total GHG emissions between varieties in general are attributed mainly to differences on the length of flooding period.

However, while total GHG emission per ac is important it is not a measure of efficiency. The per ac average total GHG emission per bu of rice produced - a direct measure of GHG emission efficiency, is used on a comparative basis across time, variety and space. These ratios have been estimated in tables 39 through 43 and illustrated in figures 11 through 16.

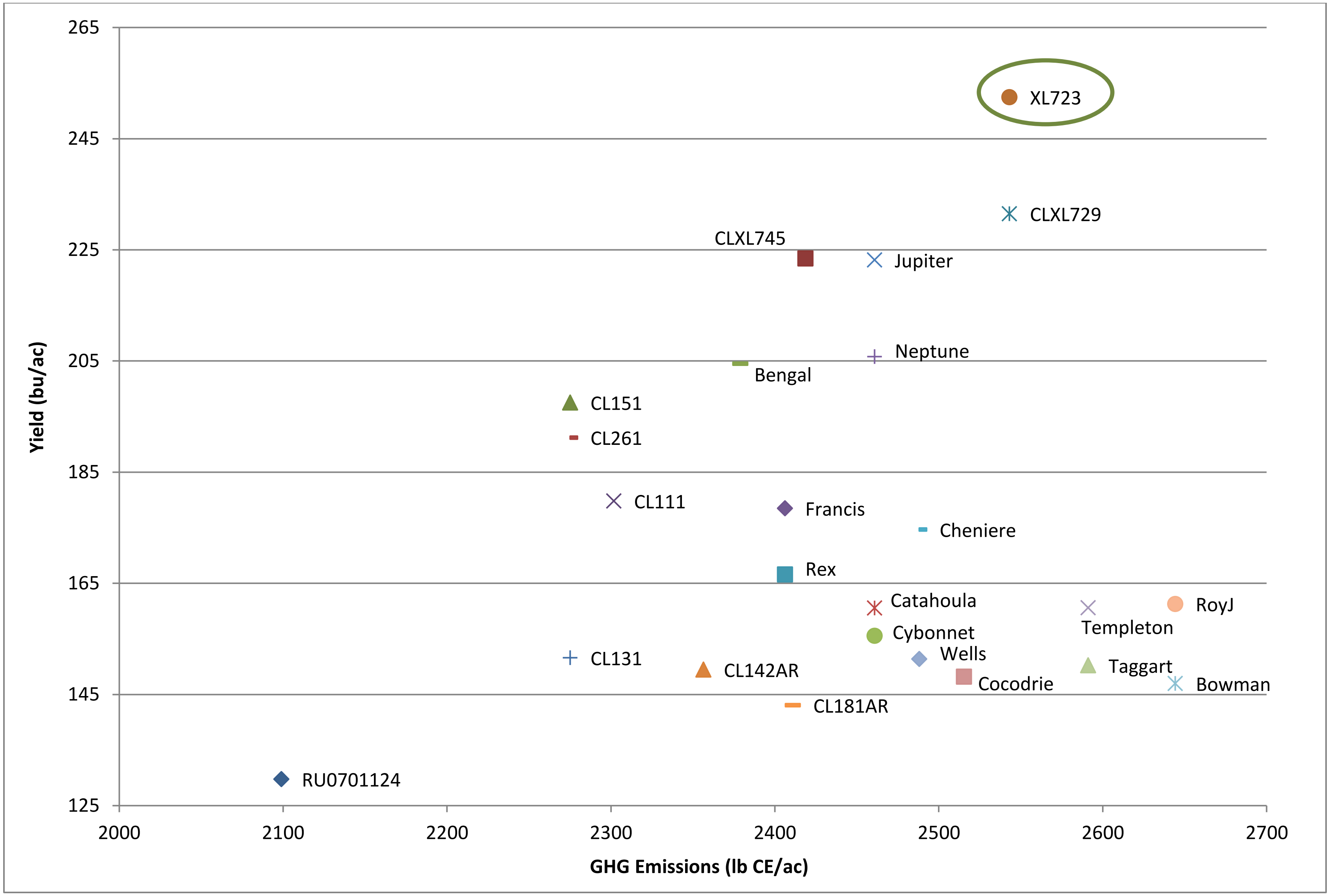
As GHG emissions remain constant and yield increases, GHG emission per bu of rice produced decrease, increasing GHG use efficiency. Conversely, as yield remains constant and GHG emission per ac decreases, GHG emission per bu of rice produced also decreases, again increasing GHG use efficiency. This is a direct measure of increased production efficiency. Thus, it is important to note that just because a variety or a location emits less GHG, it does not mean that it is efficient in reducing GHG emissions. Therefore, improvements to GHG emission efficiency can either be sought through increased yield per unit of GHG emission or reduced GHG emissions per bu of rice produced.

Through the estimated total GHG emissions (lb CE/ac) and the ARPT recorded rice yields (bu/ac), GHG emission efficiency (yield/ total GHG emissions) was calculated and presented in tables 38-43 and figures 11-16 for each rice variety at all six ARPT stations for 2010.

Table 40. Total GHG Emission (lb CE/ac) and Yield/T. GHG Emissions (bu/lb CE) for Varieties at the Stuttgart ARPT Station, 2010

Variety	Type	Days on Flood[a]	Yield (bu/ac)[b]	Greenhouse Gas Emissions (lb CE/ac)				Yield(bu)/Total GHG(lb CE)
				GHG from McFadden et al. (2011)[c]	GHG from Irrigation[d]	GHG from Methane[e]	Total GHG (c+d+e)	
RU0701124	Conv.	71	130	712	278	1110	2099	0.0618
CLXL745	CLHYB	78	223	645	313	1460	2419	0.0924
CL151	CL	81	198	635	307	1333	2275	0.0868
CL111	CL	82	180	635	311	1356	2302	0.0781
CLXL729	CLHYB	83	231	645	316	1582	2543	0.0910
XL723	HYB	83	252	645	316	1582	2543	0.0993*
CL131	CL	81	152	635	307	1333	2275	0.0666
CL261	CL	81	191	635	307	1333	2275	0.0840
Bengal	Conv.	82	205	712	311	1356	2379	0.0860
Francis	Conv.	83	178	712	316	1378	2406	0.0742
Rex	Conv.	83	167	712	316	1378	2406	0.0692
CL142AR	CL	84	149	635	321	1401	2356	0.0634
Jupiter	Conv.	85	223	712	326	1423	2461	0.0907
Catahoula	Conv.	85	161	712	326	1423	2461	0.0652
Cybonnet	Conv.	85	156	712	326	1423	2461	0.0632
Neptune	Conv.	85	206	712	326	1423	2461	0.0836
Cheniere	Conv.	86	175	712	331	1445	2488	0.0702
CL181AR	CL	86	143	635	331	1445	2411	0.0593
Wells	Conv.	86	151	712	331	1445	2488	0.0608
Cocodrie	Conv.	87	148	712	336	1468	2515	0.0589
Taggart	Conv.	90	150	712	345	1535	2591	0.0580
Templeton	Conv.	90	161	712	345	1535	2591	0.0620
Bowman	Conv.	92	147	712	353	1580	2644	0.0556
RoyJ	Conv.	92	161	712	353	1580	2644	0.0610

[a & b] Obtained from 2010 ARPT.
[c] Obtained from results on **Table 27**.
[d] Obtained from results on **Table 28**.
[e] Obtained from results on **Table 34**.
***** Denotes the most GHG emission efficient variety.



° Green circles in figures 11-16 denote the most efficient water use variety.

Figure 11. Yield (bu/ac) and GHG Emissions (lb CE/ac) for Rice Varieties at the Stuttgart ARPT Station in 2010

Table 41. Total GHG Emission (lb CE/ac) and Yield/T. GHG Emissions (bu/lb CE) for Varieties at the Rohwer ARPT Station, 2010

Variety	Type	Days on Flood[a]	Yield (bu/ac)[b]	Greenhouse Gas Emissions (lb CE/ac)				Yield(bu)/Total GHG(lb CE)
				GHG from McFadden et al. (2011)[c]	GHG from Irrigation[d]	GHG from Methane[e]	Total GHG (c+d+e)	
RU0701124	Conv.	76	139	712	259	1221	2192	0.0632
CLXL745	CLHYB	80	149	645	257	1509	2411	0.0619
CLXL729	CLHYB	84	141	645	265	1606	2517	0.0558
XL723	HYB	84	182	645	265	1606	2517	0.0724*
CL111	CL	86	139	635	275	1445	2355	0.0591
CL151	CL	86	152	635	275	1445	2355	0.0646
CL261	CL	85	129	635	270	1423	2328	0.0556
Francis	Conv.	86	154	712	275	1445	2432	0.0634
Bengal	Conv.	86	143	712	275	1445	2432	0.0586
Jupiter	Conv.	86	145	712	275	1445	2432	0.0596
CL131	CL	86	138	635	275	1445	2355	0.0588
Cheniere	Conv.	87	148	712	280	1468	2459	0.0602
Neptune	Conv.	87	146	712	280	1468	2459	0.0593
Rex	Conv.	87	147	712	280	1468	2459	0.0596
CL142AR	CL	88	165	635	284	1490	2409	0.0683
Cybonnet	Conv.	90	135	712	294	1535	2541	0.0531
Catahoula	Conv.	92	111	712	303	1580	2594	0.0429
Wells	Conv.	93	118	712	307	1602	2621	0.0452
Cocodrie	Conv.	95	124	712	316	1647	2675	0.0465
CL181AR	CL	95	112	635	316	1647	2598	0.0433
Templeton	Conv.	94	131	712	311	1624	2648	0.0495
Taggart	Conv.	94	145	712	311	1624	2648	0.0547
Bowman	Conv.	95	181	712	316	1647	2675	0.0677
RoyJ	Conv.	98	157	712	330	1714	2756	0.0569

[a & b] Obtained from 2010 ARPT.
[c] Obtained from results on **Table 27**.
[d] Obtained from results on **Table 29**.
[e] Obtained from results on **Table 35**.
***** Denotes the most GHG emission efficient variety.

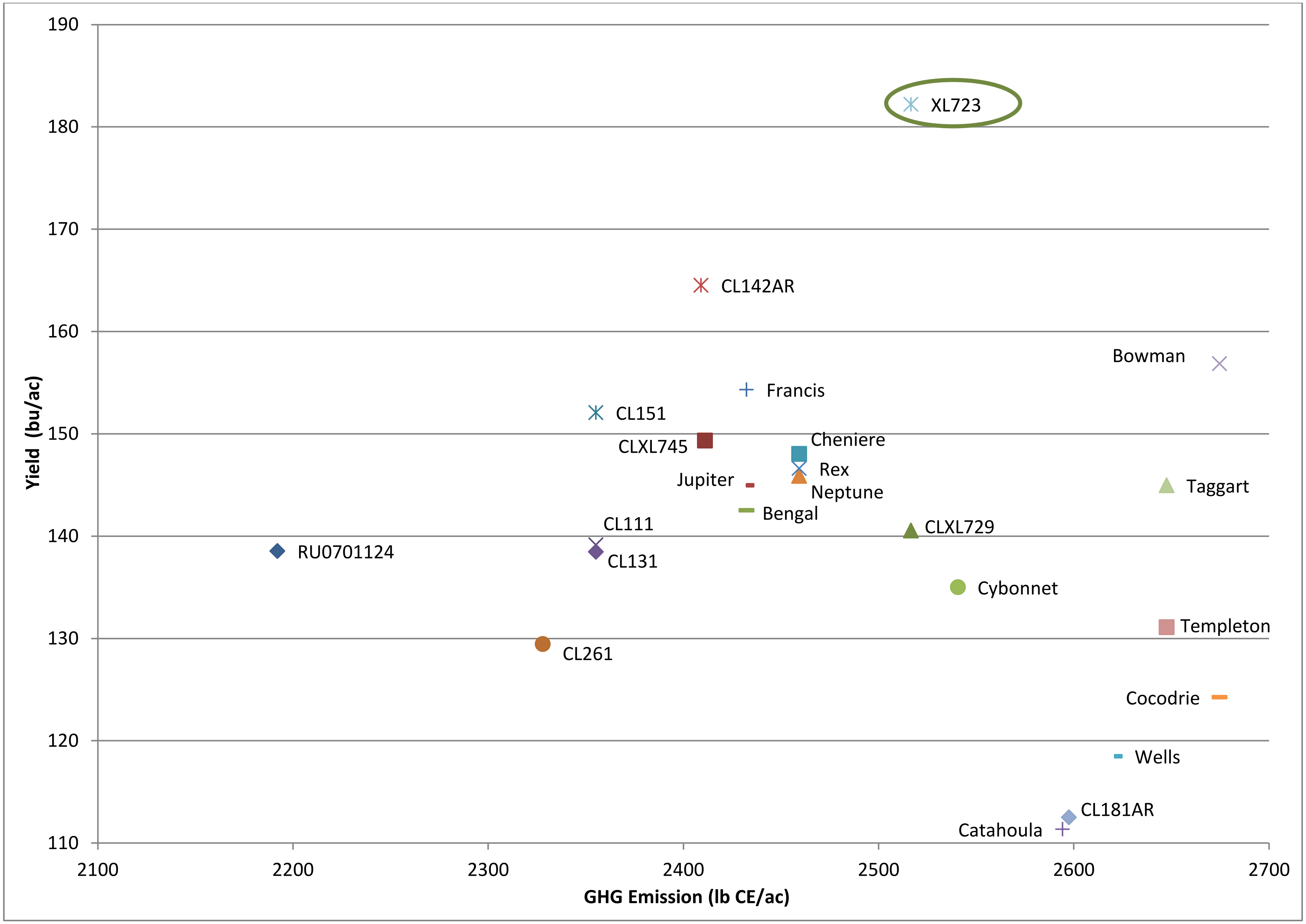


Figure 12. Yield (bu/ac) and GHG Emissions (lb CE/ac) for Rice Varieties at the Rohwer ARPT Station in 2010

Table 42. Total GHG Emission (lb CE/ac) and Yield/T. GHG Emissions (bu/lb CE) for Varieties at the Keiser ARPT Station, 2010

Variety	Type	Days on Flood[a]	Yield (bu/ac)[b]	Greenhouse Gas Emissions (lb CE/ac)				Yield(bu)/Total GHG(lb CE)
				GHG from McFadden et al. (2011)[c]	GHG from Irrigation[d]	GHG from Methane[e]	Total GHG (c+d+e)	
RU0701124	Conv.	66	169	712	254	998	1964	0.0860*
CLXL745	CLHYB	76	174	645	301	1411	2358	0.0738
CL151	CL	78	162	635	310	1266	2211	0.0731
CL111	CL	79	154	635	315	1289	2238	0.0689
CLXL729	CLHYB	80	205	645	319	1509	2473	0.0830
CL261	CL	77	153	635	306	1244	2184	0.0702
Bengal	Conv.	78	172	712	310	1266	2288	0.0753
CL131	CL	79	152	635	315	1289	2238	0.0680
CL142AR	CL	79	165	635	315	1289	2238	0.0737
Cheniere	Conv.	80	165	712	319	1311	2341	0.0703
Jupiter	Conv.	80	167	712	319	1311	2341	0.0713
Catahoula	Conv.	81	163	712	323	1333	2368	0.0690
Cybonnet	Conv.	81	156	712	323	1333	2368	0.0657
Rex	Conv.	81	175	712	323	1333	2368	0.0738
Francis	Conv.	81	192	712	323	1333	2368	0.0810
Neptune	Conv.	81	176	712	323	1333	2368	0.0742
Wells	Conv.	81	157	712	323	1333	2368	0.0662
CL181AR	CL	82	142	635	328	1356	2318	0.0613
Cocodrie	Conv.	83	142	712	332	1378	2422	0.0588
Bowman	Conv.	82	158	712	328	1356	2395	0.0660
Templeton	Conv.	82	176	712	328	1356	2395	0.0736
Taggart	Conv.	83	156	712	332	1378	2422	0.0646
RoyJ	Conv.	86	156	712	342	1445	2499	0.0626

[a & b] Obtained from 2010 ARPT.
[c] Obtained from results on **Table 27**.
[d] Obtained from results on **Table 30**.
[e] Obtained from results on **Table 36**.
***** Denotes the most GHG emission efficient variety.

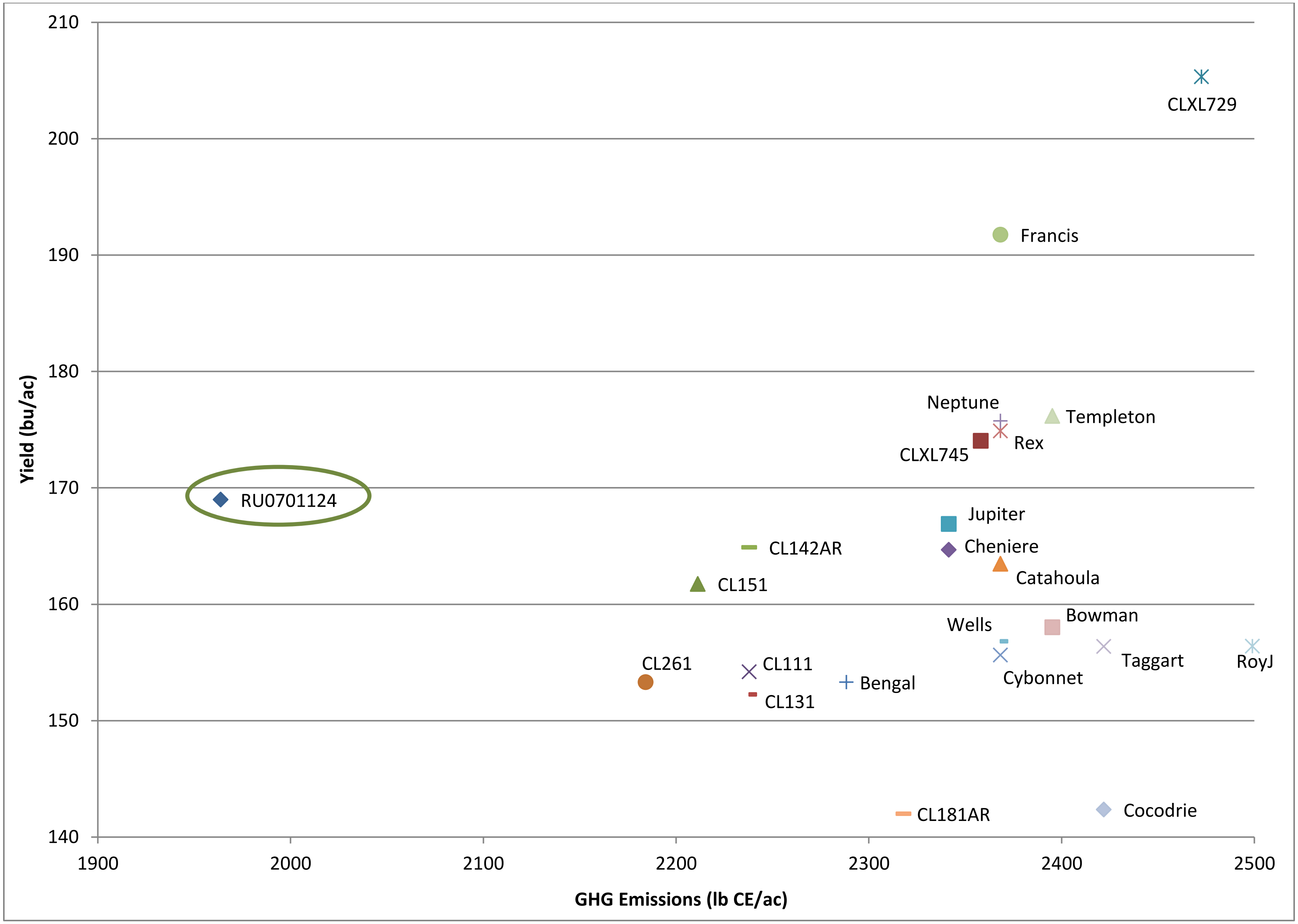


Figure 13. Yield (bu/ac) and GHG Emissions (lb CE/ac) for Rice Varieties at the Keiser ARPT Station in 2010

Table 43. Total GHG Emission (lb CE/ac) and Yield/T. GHG Emissions (bu/lb CE) for Varieties at the Newport ARPT Station, 2010

Variety	Type	Days on Flood[a]	Yield (bu/ac)[b]	Greenhouse Gas Emissions (lb CE/ac)				Yield(bu)/Total GHG(lb CE)
				GHG from McFadden et al. (2011)[c]	GHG from Irrigation[d]	GHG from Methane[e]	Total GHG (c+d+e)	
RU0701124	Conv.	57	96	712	180	796	1688	0.0569
CLXL745	CLHYB	66	174	645	211	1168	2025	0.0859
XL723	HYB	69	192	645	224	1241	2110	0.0908*
CL151	CL	70	99	635	223	1087	1945	0.0510
CL111	CL	71	93	635	224	1110	1968	0.0471
CLXL729	CLHYB	74	157	645	225	1177	2048	0.0767
Wells	Conv.	70	142	712	223	1087	2022	0.0703
CL131	CL	70	93	635	223	1087	1945	0.0480
Rex	Conv.	72	112	712	225	1132	2069	0.0542
CL261	CL	72	135	635	225	1132	1991	0.0680
Bengal	Conv.	73	99	712	229	1154	2095	0.0475
Cybonnet	Conv.	73	111	712	229	1154	2095	0.0530
Cheniere	Conv.	74	103	712	225	1177	2114	0.0489
CL142AR	CL	74	116	635	225	1177	2037	0.0569
Catahoula	Conv.	74	104	712	225	1177	2114	0.0493
Francis	Conv.	75	94	712	229	1199	2140	0.0437
Jupiter	Conv.	75	116	712	229	1199	2140	0.0544
CL181AR	CL	75	126	635	229	1199	2063	0.0613
Cocodrie	Conv.	76	15	712	233	1221	2167	0.0069
Neptune	Conv.	79	82	712	242	1289	2242	0.0366
Taggart	Conv.	75	166	712	229	1199	2140	0.0777
Templeton	Conv.	76	105	712	233	1221	2167	0.0482
Bowman	Conv.	77	78	712	236	1244	2191	0.0357
RoyJ	Conv.	79	143	712	242	1289	2242	0.0636

[a & b] Obtained from 2010 ARPT.
[c] Obtained from results on **Table 27**.
[d] Obtained from results on **Table 31**.
[e] Obtained from results on **Table 37**.
***** Denotes the most GHG emission efficient variety.

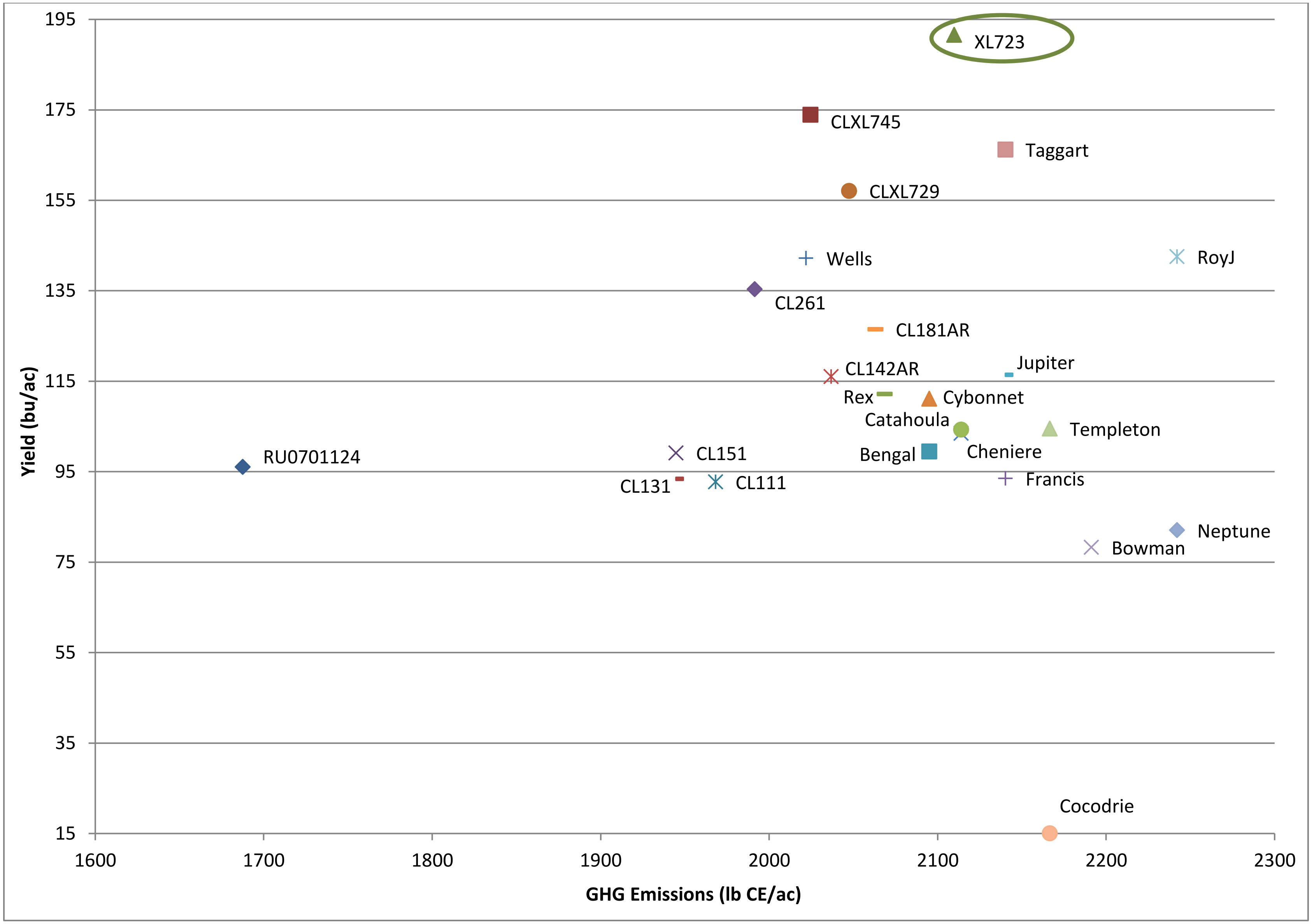


Figure 14. Yield (bu/ac) and GHG Emissions (lb CE/ac) for Rice Varieties at the Newport ARPT Station in 2010

Table 44. Total GHG Emission (lb CE/ac) and Yield/T. GHG Emissions (bu/lb CE) for Varieties at the Colt ARPT Station, 2010

Variety	Type	Days on Flood[a]	Yield (bu/ac)[b]	Greenhouse Gas Emissions (lb CE/ac)				Yield(bu)/Total GHG(lb CE)
				GHG from McFadden et al. (2011)[c]	GHG from Irrigation[d]	GHG from Methane[e]	Total GHG (c+d+e)	
RU0701124	Conv.	67	129	712	255	1020	1986	0.0650
CLXL745	CLHYB	75	198	645	291	1387	2324	0.0854
CL151	CL	79	169	635	310	1289	2234	0.0758
CL111	CL	79	168	635	310	1289	2234	0.0754
XL723	HYB	81	201	645	320	1533	2498	0.0807
CLXL729	CLHYB	82	227	645	324	1557	2527	0.0899*
CL261	CL	79	156	635	310	1289	2234	0.0697
CL131	CL	80	172	635	315	1311	2261	0.0761
Bengal	Conv.	81	133	712	320	1333	2365	0.0564
Rex	Conv.	81	174	712	320	1333	2365	0.0737
CL142AR	CL	82	175	635	324	1356	2314	0.0756
CL181AR	CL	82	160	635	324	1356	2314	0.0693
Catahoula	Conv.	84	179	712	333	1401	2445	0.0731
Cheniere	Conv.	84	162	712	333	1401	2445	0.0662
Cybonnet	Conv.	84	159	712	333	1401	2445	0.0650
Jupiter	Conv.	84	185	712	333	1401	2445	0.0755
Francis	Conv.	85	184	712	337	1423	2472	0.0743
Neptune	Conv.	85	167	712	337	1423	2472	0.0677
Wells	Conv.	85	166	712	337	1423	2472	0.0671
Cocodrie	Conv.	87	146	712	346	1468	2525	0.0578
Taggart	Conv.	86	181	712	341	1445	2498	0.0723
Bowman	Conv.	86	187	712	341	1445	2498	0.0747
Templeton	Conv.	88	181	712	350	1490	2552	0.0709
RoyJ	Conv.	89	186	712	354	1512	2579	0.0722

[a & b] Obtained from 2010 ARPT.

[c] Obtained from results on **Table 27**.

[d] Obtained from results on **Table 32**.

[e] Obtained from results on **Table 38**.

***** Denotes the most GHG emission efficient variety.

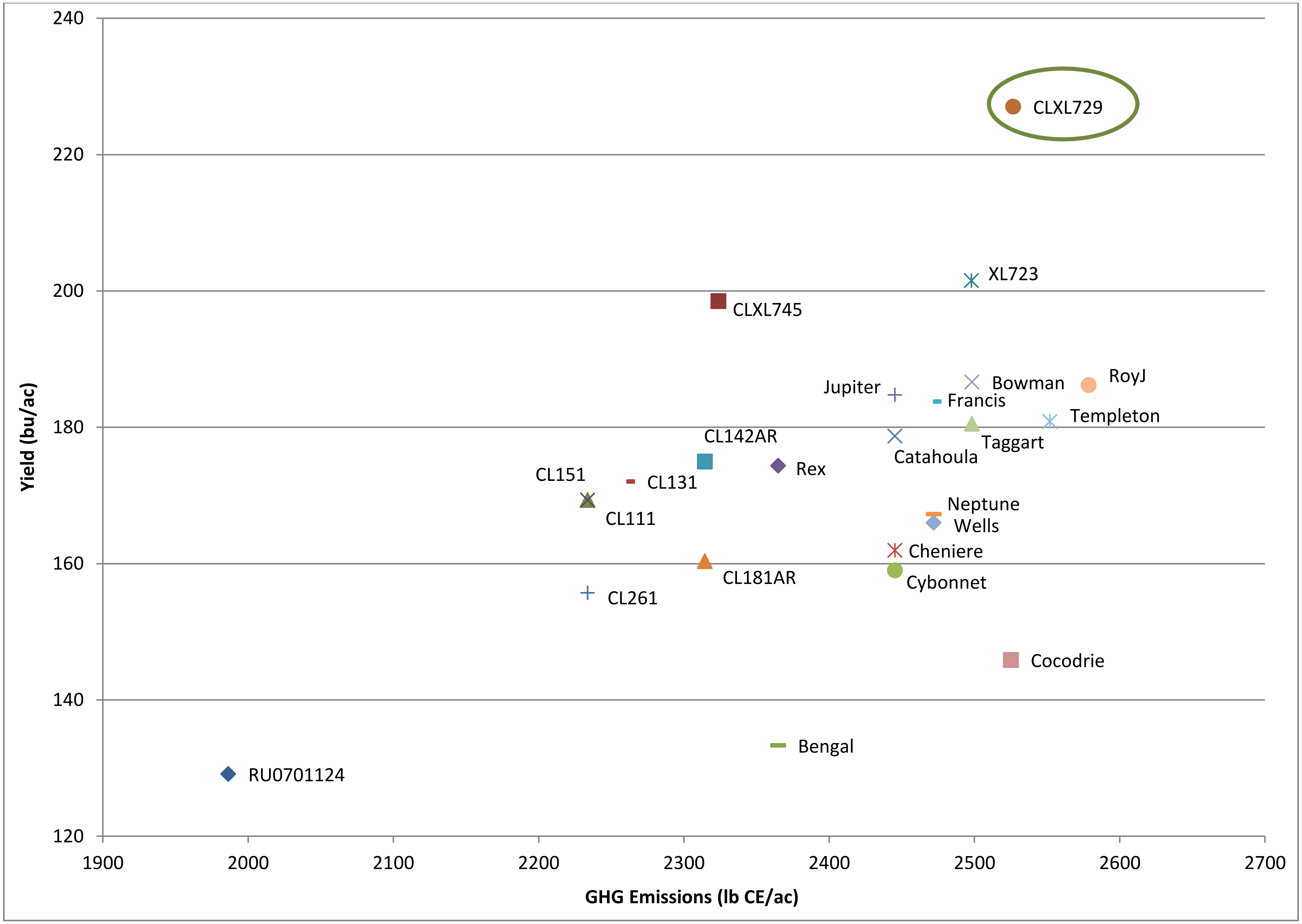


Figure 15. Yield (bu/ac) and GHG Emissions (lb CE/ac) for Rice Varieties at the Colt ARPT Station in 2010

Table 45. Total GHG Emission (lb CE/ac) and Yield/T. GHG Emissions (bu/lb CE) for Varieties at the Coring ARPT Station, 2010

Variety	Type	Days on Flood[a]	Yield (bu/ac)[b]	Greenhouse Gas Emissions (lb CE/ac)				Yield(bu)/Total GHG(lb CE)
				GHG from McFadden et al. (2011)[c]	GHG from Irrigation[d]	GHG from Methane[e]	Total GHG (c+d+e)	
RU0701124	Conv.	76	169	712	283	1221	2216	0.0763
CLXL729	CLHYB	81	232	645	305	1533	2483	0.0934
CLXL745	CLHYB	81	217	645	305	1533	2483	0.0874
XL723	HYB	83	240	645	315	1582	2542	0.0945
CL151	CL	83	238	635	315	1378	2327	0.1020*
CL111	CL	85	213	635	325	1423	2382	0.0895
CL261	CL	83	196	635	315	1378	2327	0.0843
CL131	CL	84	197	635	320	1401	2355	0.0835
CL142AR	CL	86	202	635	330	1445	2410	0.0839
Bengal	Conv.	86	219	712	330	1445	2487	0.0879
Cheniere	Conv.	86	198	712	330	1445	2487	0.0797
Cybonnet	Conv.	86	214	712	330	1445	2487	0.0860
Francis	Conv.	86	230	712	330	1445	2487	0.0924
Wells	Conv.	87	216	712	334	1468	2513	0.0860
Catahoula	Conv.	87	207	712	334	1468	2513	0.0825
Rex	Conv.	87	196	712	334	1468	2513	0.0778
CL181AR	CL	87	186	635	334	1468	2436	0.0763
Cocodrie	Conv.	89	180	712	344	1512	2568	0.0700
Jupiter	Conv.	92	220	712	357	1580	2649	0.0832
Neptune	Conv.	92	213	712	357	1580	2649	0.0804
RoyJ	Conv.	87	206	712	334	1468	2513	0.0820
Templeton	Conv.	87	195	712	334	1468	2513	0.0777
Taggart	Conv.	87	215	712	334	1468	2513	0.0854
Bowman	Conv.	88	183	712	339	1490	2541	0.0719

[a & b] Obtained from 2010 ARPT.
[c] Obtained from results on **Table 27**.
[d] Obtained from results on **Table 33**.
[e] Obtained from results on **Table 39**.
***** Denotes the most GHG emission efficient variety.

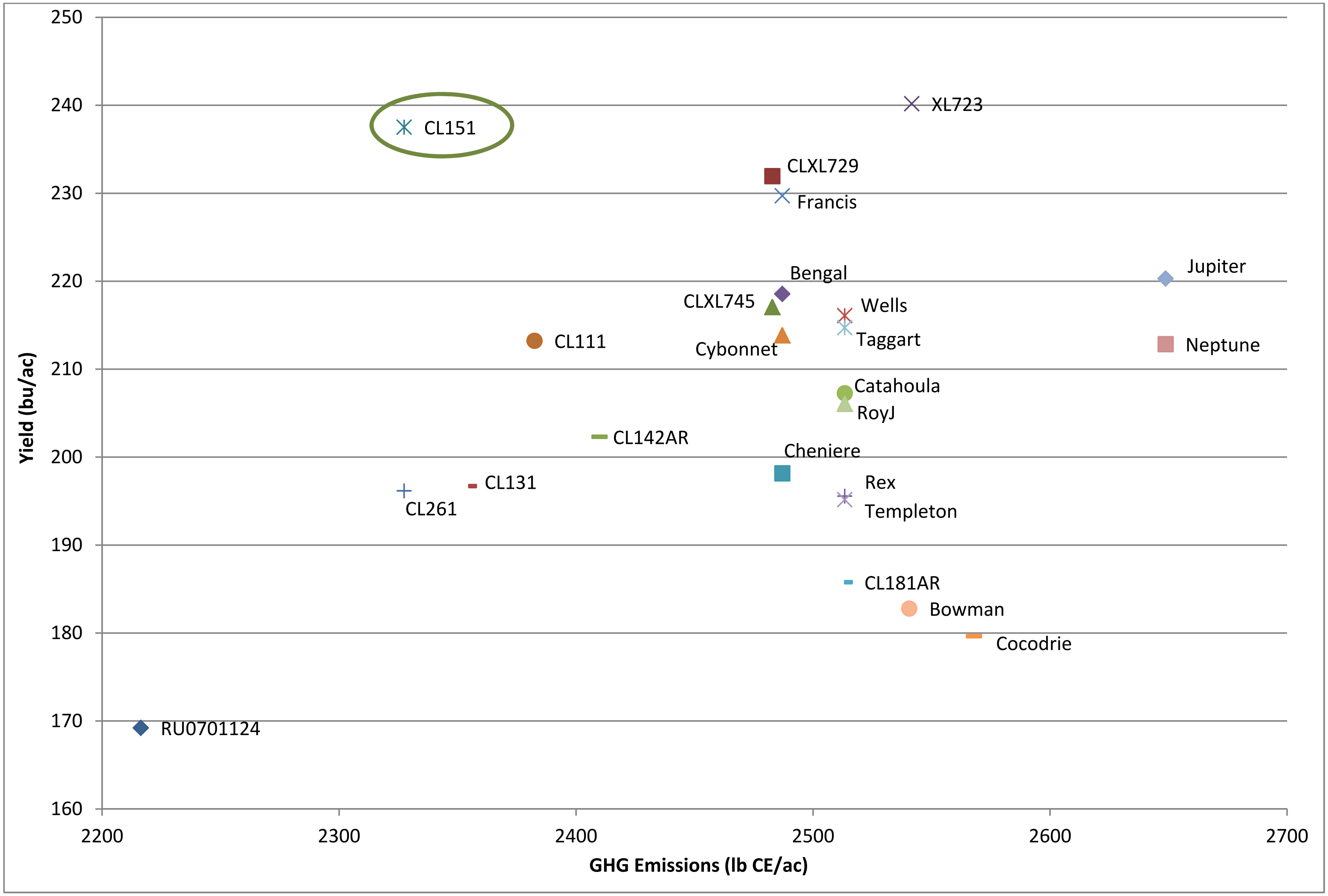


Figure 16. Yield (bu/ac) and GHG Emissions (lb CE/ac) for Rice Varieties at the Coring ARPT Station in 2010

As stated above the experimental variety RU0701124 emits the least amount of GHG across all six ARPT stations. However, because of its relatively low yield, RU0701124 is not necessarily the most efficient user of GHG emissions. In fact only one ARPT station (Keiser) indicates that RU0701124 is the most efficient variety.

Figures 11 through 16 generally illustrate a pattern where the Hybrid rice varieties are more efficient users of the GHG emissions associated to them.

5. Statistical Results

The ANOVA test was run to estimate whether or not hybrid rice varieties emit less GHG/ac and are more GHG emissions use efficient varieties compared to the two other cultivar types (conventional & Clearfield). This is important; while the above findings suggest that the averages between hybrids, conventionals and Clearfield are different this does not necessarily imply they are statistically different. The statistical results indicate that on average hybrid rice varieties are not statistically different from conventional varieties in the total GHG emissions/ac but are statistically superior in GHG emissions use efficiency (ac-in/bu).

Table 46 provides the answers to whether or not each two cultivar types were significantly different from each other regarding GHG emissions/ac at all six rice stations. The table shows that on average, hybrid rice varieties emit the same amount of GHG/ac with that of the Conventional rice varieties at all six rice stations. When comparing hybrids and Clearfield; however, Hybrids are observed to emit more GHG/ac for most of the rice stations (Stuttgart, Keiser, Colt, & Coring) and emit the same GHG/ac for the two remaining rice stations (Rowher & Newport). From the “All Station” statistical results in this table it is observed that on average hybrid and conventional rice varieties are not statistically different (emit same GHG/ac), while hybrid and Clearfield rice varieties are statistically different from each other (Hybrids emit more GHG/ac).

Table 46. Statistical Differences on GHG Emissions/ac Between Cultivar Types (Conventional, Clearfield, & Hybrid) at 95% Level for Six ARPT Station in 2010

ARPT Stations/ Cultivar Type Combination	Conventional & Clearfield	Conventional & Hybrid	Clearfield & Hybrid
Stuttgart	YES	NO	YES-
Rohwer	NO	NO	NO
Keiser	YES	NO	YES-
Newport	YES	NO	NO
Colt	YES	NO	YES-
Coring	YES	NO	YES-
All Stations	**YES**	**NO**	**YES-**

[1]YES$^-$ indicates statistical difference; where on average hybrid rice varies emit more GHG/ac.
[2] YES indicates statistical difference between the two rice types.
[3] NO indicates no statistical difference between the two rice types.

Statistical results on GHG emission efficiency, on the other hand, tell quite a different story. Table 47 shows that on average, hybrid rice varieties are more GHG emission use efficient than conventional and Clearfield at the majority of ARPT stations (Stuttgart, Newport, Colt, & Coring) and have no statistical difference on the remaining two other rice stations (Rohwer & Keiser). The ANOVA test ran for all rice varieties from all six stations together, on the other hand, indicates that hybrid rice varieties are more GHG emission use efficient than conventional and Clearfield rice varieties.

Table 47. Statistical Differences on GHG Emissions Use efficiencies (bu/lb of CE) Between Cultivar Types (Conventional, Clearfield, & Hybrid) at 95% Level for Six ARPT Station in 2010

ARPT Stations/ Cultivar Type Combination	Conventional & Clearfield	Conventional & Hybrid	Clearfield & Hybrid
Stuttgart	NO	YES+	YES+
Rohwer	NO	NO	NO
Keiser	NO	NO	NO
Newport	NO	YES+	YES+
Colt	NO	YES+	YES+
Coring	NO	YES+	NO
All Stations	**NO**	**YES+**	**YES+**

[1] YES+ indicates statistical difference; where on average hybrid rice varies emit less GHG/bu.
[2] NO indicates no statistical difference between the two rice types.

Figure 17 shows the yield/ GHG emission ratio between a fairly short season rice variety - CLXL745 (hybrid rice variety with an average of 76 Days under flood for all six rice stations), and a fairly long season one – Wells (conventional rice variety with an average of 84 Days under flood for all six rice stations) across all ARPT stations in 2010.

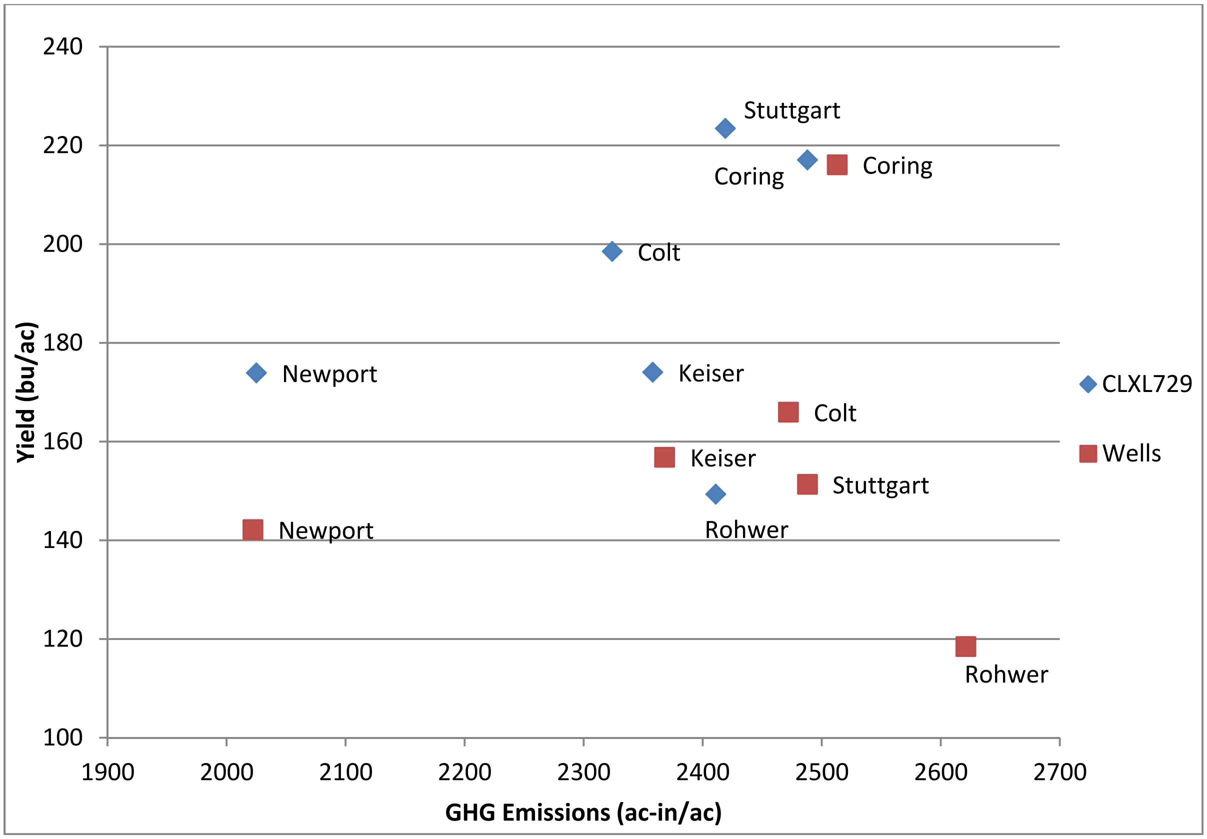


Figure 17. Yield (bu/ac)/GHG Emissions (lb CE/ac) Ratio for CLXL745 and Wells Rice Varieties Across Six ARPT Stations in 2010

As illustrated in figure 17, CLXL745 is located above and to the left of Wells at each ARPT station, indicating that CLXL745 is a more GHG emissions efficient than Wells across all stations. For instance, at Stuttgart CLXL745 yields 223 bu/ac and emits only 2419 lb CE/ac of GHG, while Wells yields only 151 bu/ac and emits 2488 lb CE/ac of GHG. On average for all six rice stations CLXL745 yields 31 bu/ac more than Wells and it emits on average 77 lb of CE/ac (staying on flood for an average of 8 days less than Wells). This pattern is generally observed between a Hybrid and a Conventional variety. The main drive for this phenomenon is the fact that Hybrid rice varieties possess genetic potential for higher yield and for shorter life cycle. Shorter life cycle implies shorter period under flood, which in return implies less total GHG emissions.

The results, therefore, indicate that CLXL745 specifically and Hybrids in general could be the ideal varieties not only to meet the increasing global market demand for rice but also reducing atmospheric pollution. This is not to say that varieties which have lower emissions and lower yields should simply be discarded. If some sort of carbon policy (offsets/permits) is to be implemented then those varieties with lower GHG emissions would become more attractive regardless of the yield.

B. Summary of the Results

1. Water-Use

Figures 18 through 23 present the efficiency measure of Yield/Evapotranspiration (bu/ac-in) ratio across all ARPT stations for 2010. The purpose of these summary figures is to clearly illustrate which varieties are more efficient at converting water to grain, at each of the six ARPT stations for the growing season of 2010.

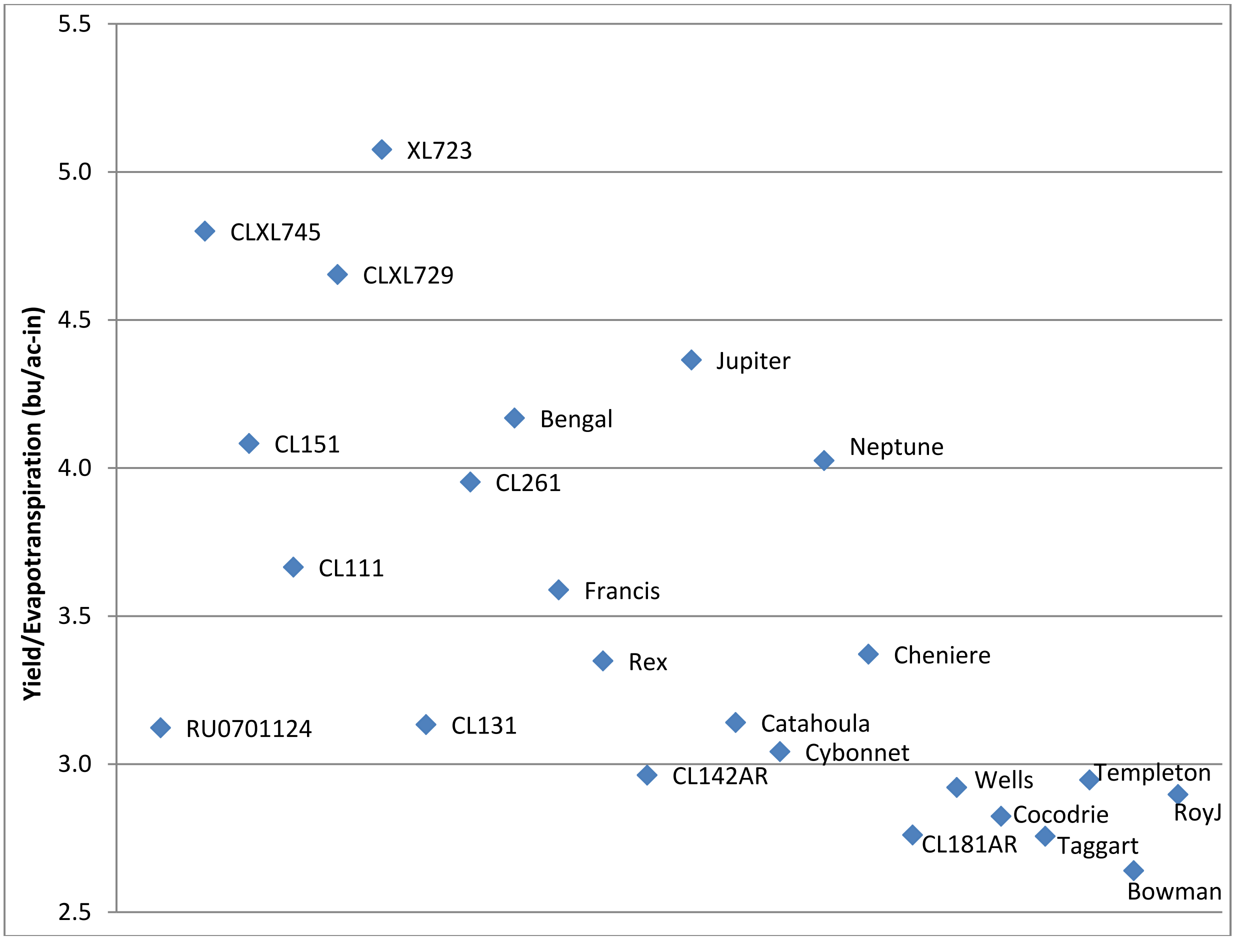


Figure 18. Yield/Evapotranspiration (bu/ac-in) Ratio for Rice Varieties at the Stuttgart ARPT Station in 2010

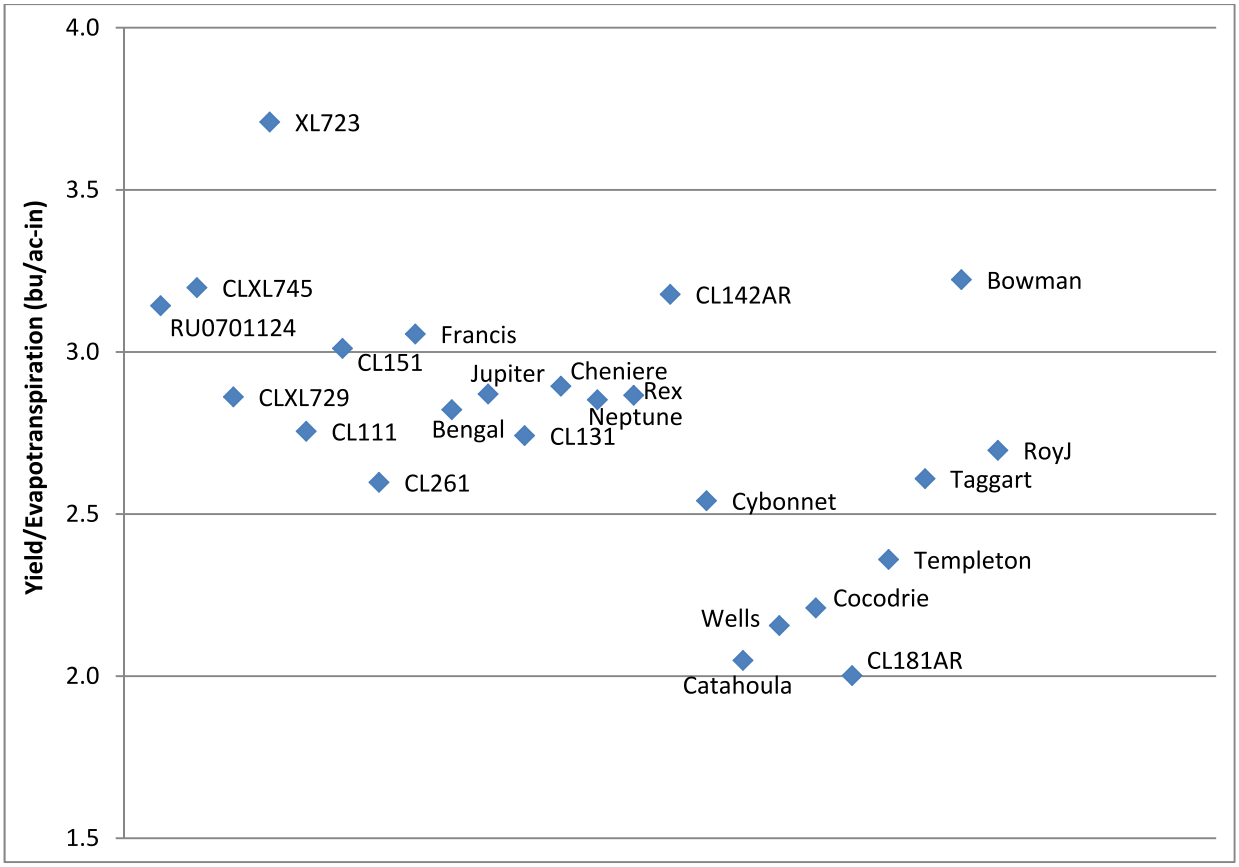


Figure 19. Yield/Evapotranspiration (bu/ac-in) Ratio for Rice Varieties at the Rohwer ARPT Station in 2010

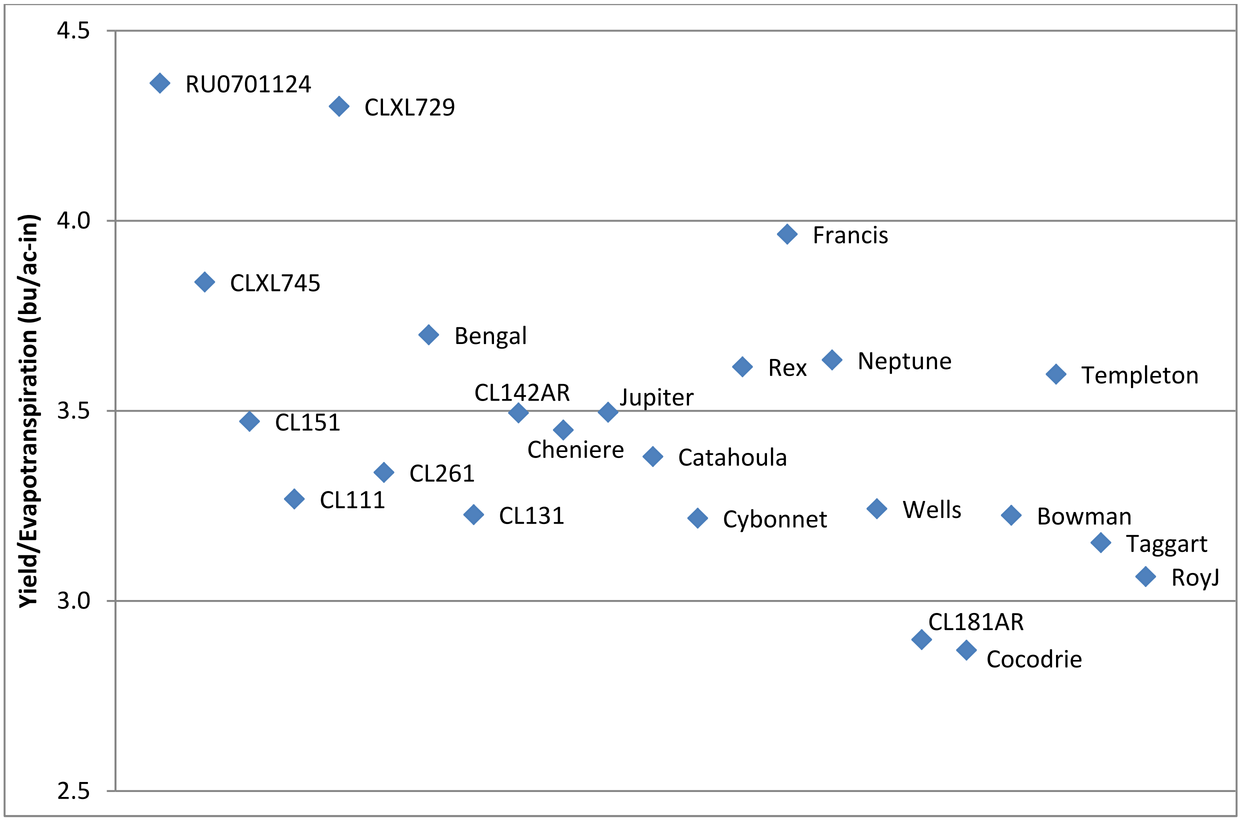


Figure 20. Yield/Evapotranspiration (bu/ac-in) Ratio for Rice Varieties at the Keiser ARPT Station in 2010

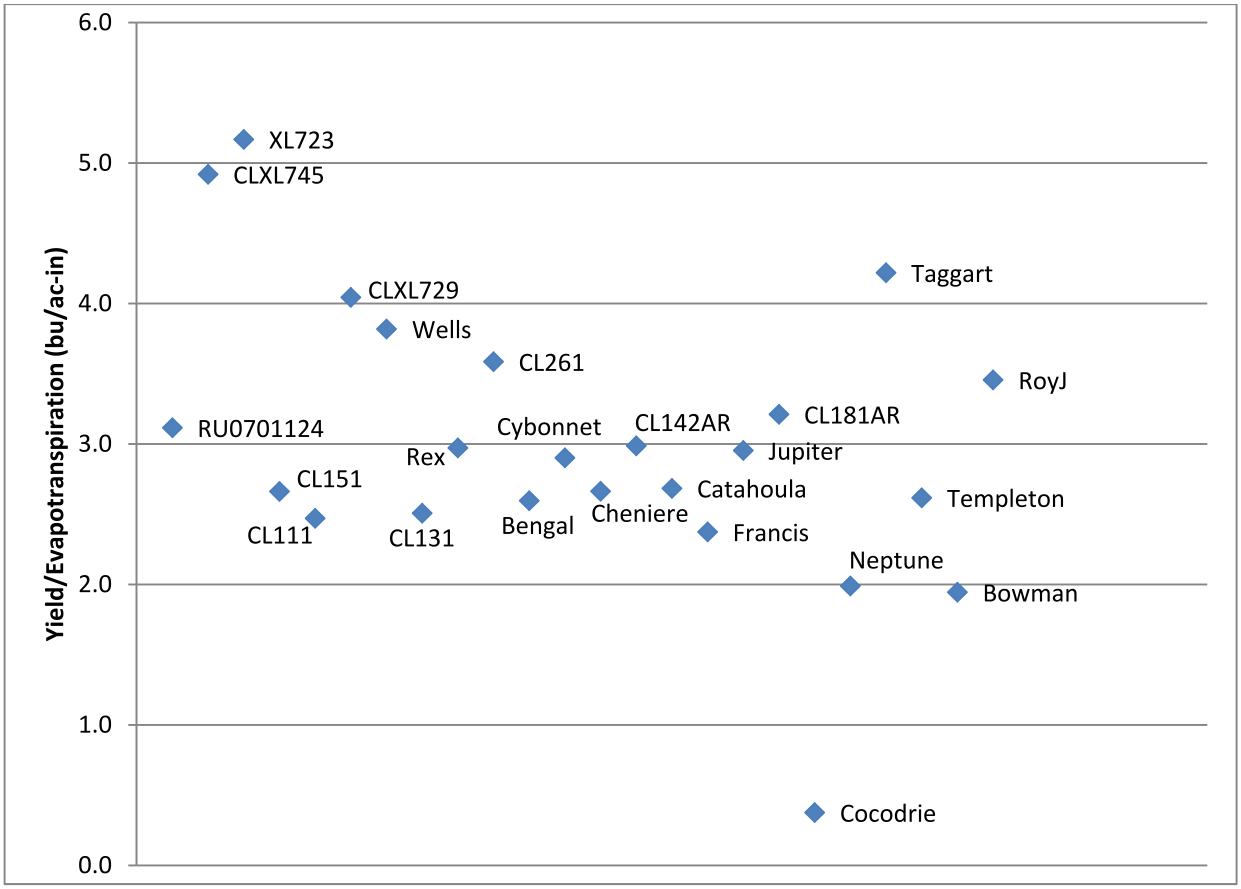


Figure 21. Yield/Evapotranspiration (bu/ac-in) Ratio for Rice Varieties at the Newport ARPT Station in 2010

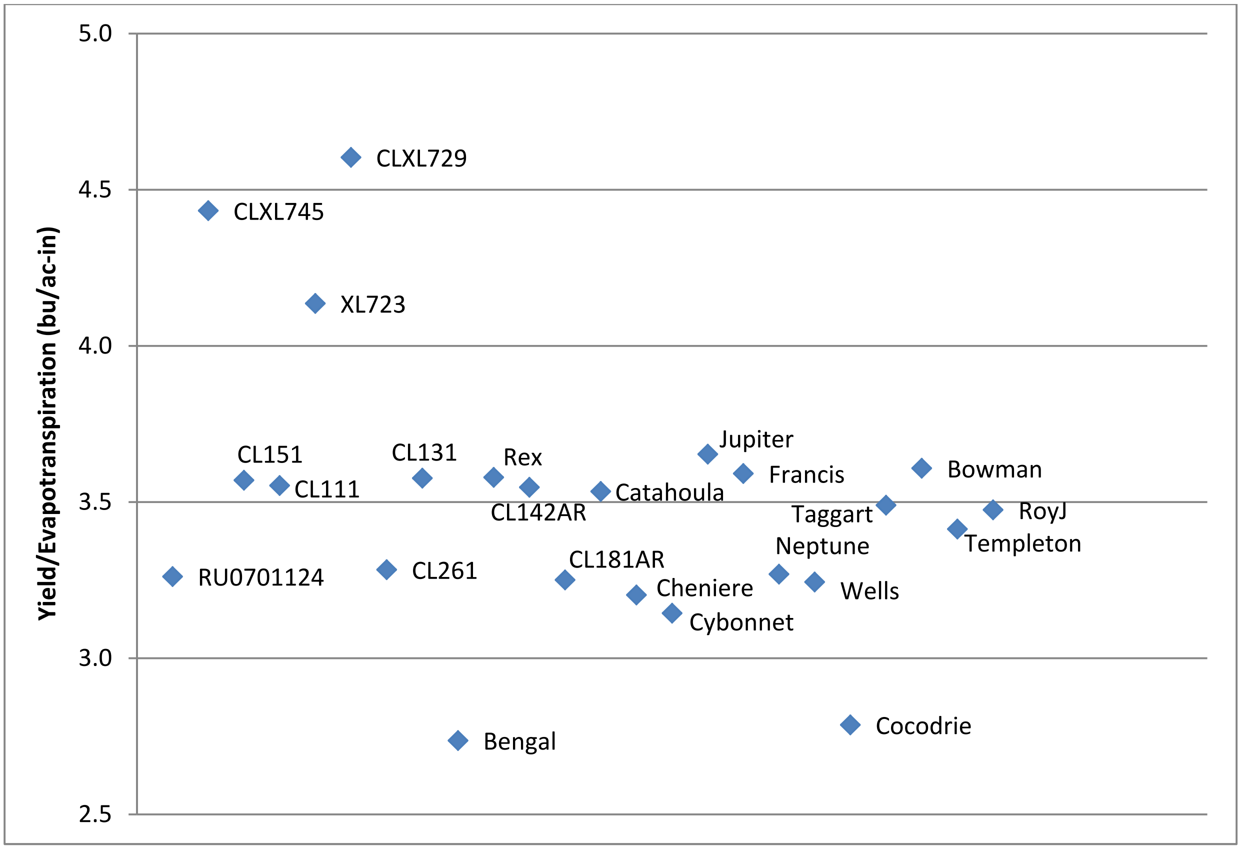


Figure 22. Yield/Evapotranspiration (bu/ac-in) Ratio for Rice Varieties at the Newport ARPT Station in 2010

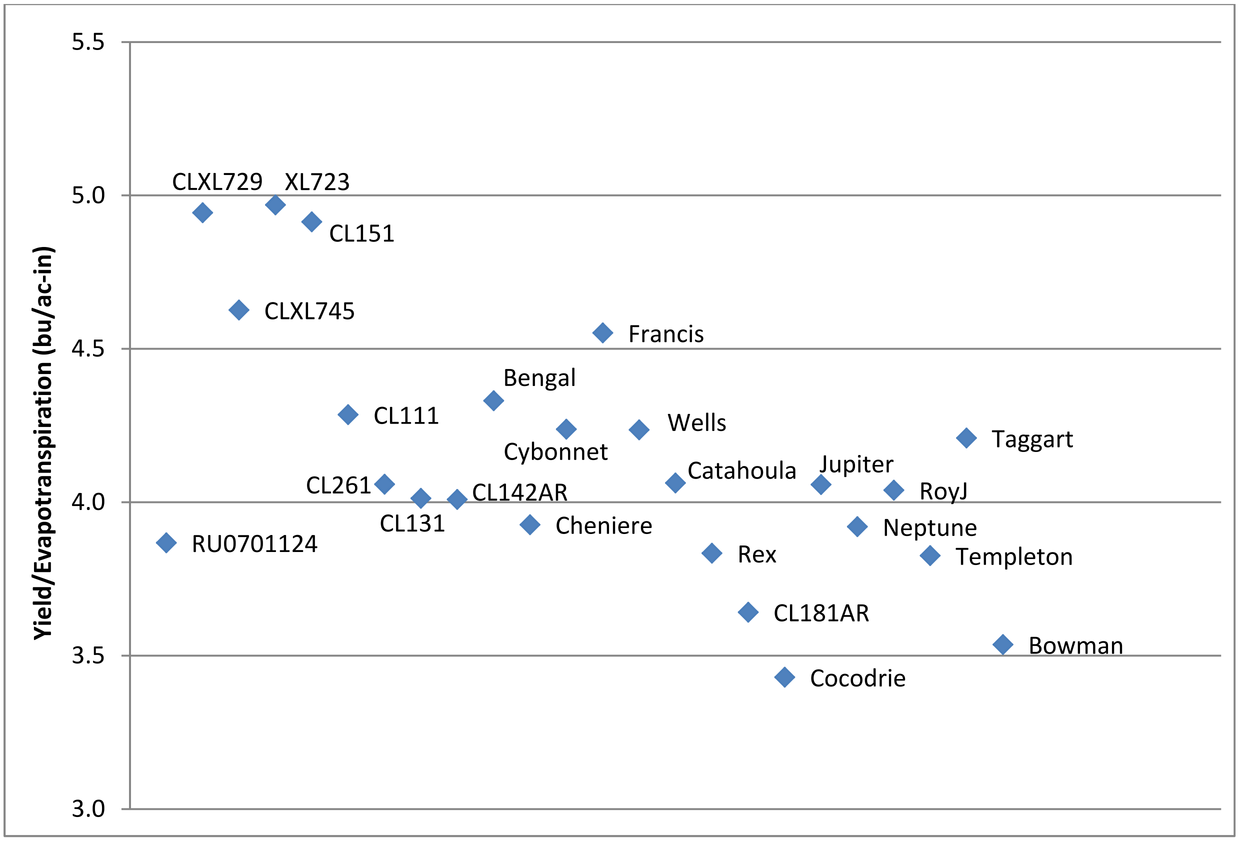


Figure 23. Yield/Evapotranspiration (bu/ac-in) Ratio for Rice Varieties at the Coring ARPT Station in 2010

Rice varieties located higher on the Y axis on six previous figures (18-23) are more water-use efficient than the ones on the bottom. Figures 18 through 23 illustrate that the three hybrid rice varieties typically have the highest water-use efficiency across all six ARPT stations. Water-use efficiency in hybrids is attributed to the genetic potential of these varieties for shorter life cycle and a higher yield. Hybrid rice varieties have on average shorter period under flood (shorter life cycle) and higher yields across all six locations. Therefore, both total water use (mainly depended on number of days under flood) and yield of produced rice per variety positively contribute to the water use efficiency ratios in hybrid varieties.

2. GHG Emissions

Figures 24 through 29 present the efficiency measure of Yield/GHG emissions (bu/lb CE) ratio. These figures clearly illustrate which varieties are the most efficient converters of GHG emissions into grain.

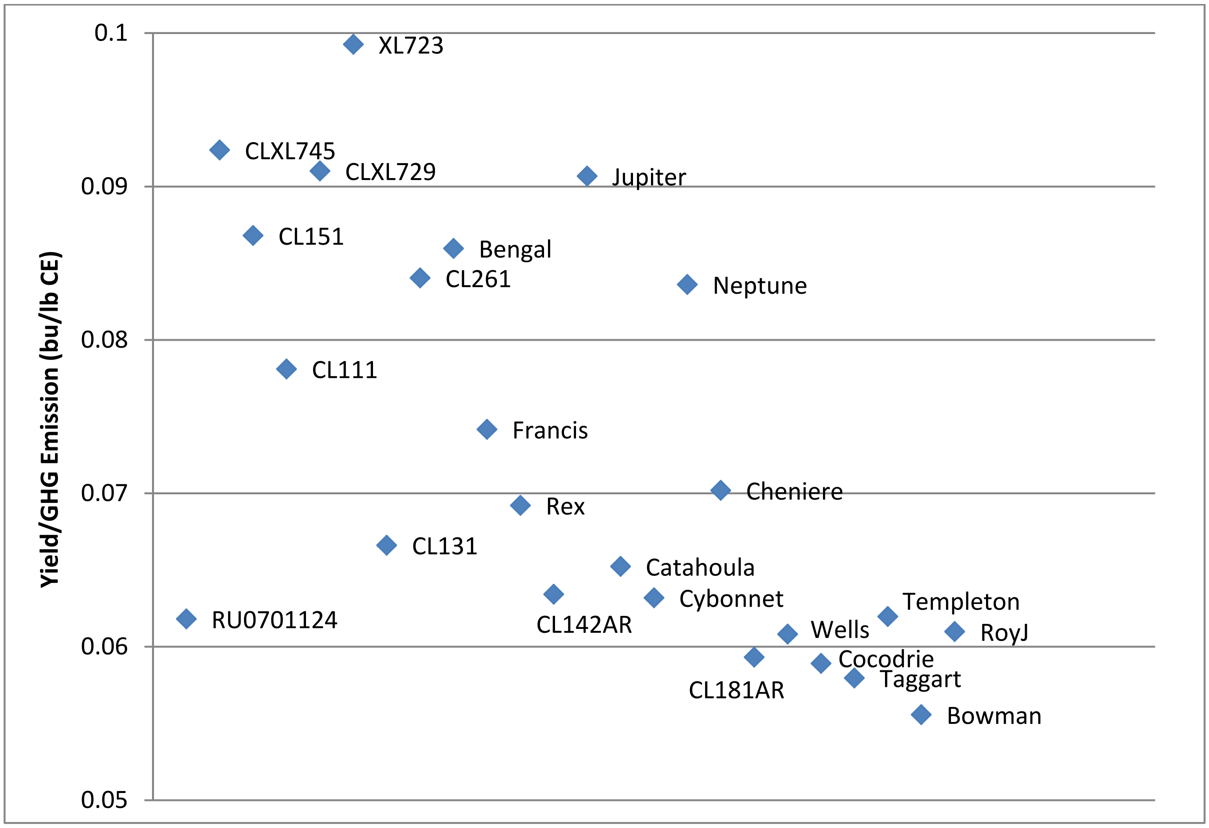


Figure 24. Yield/GHG Emissions (bu/lb CE) Ratio for Rice Varieties at the Stuttgart ARPT Station in 2010

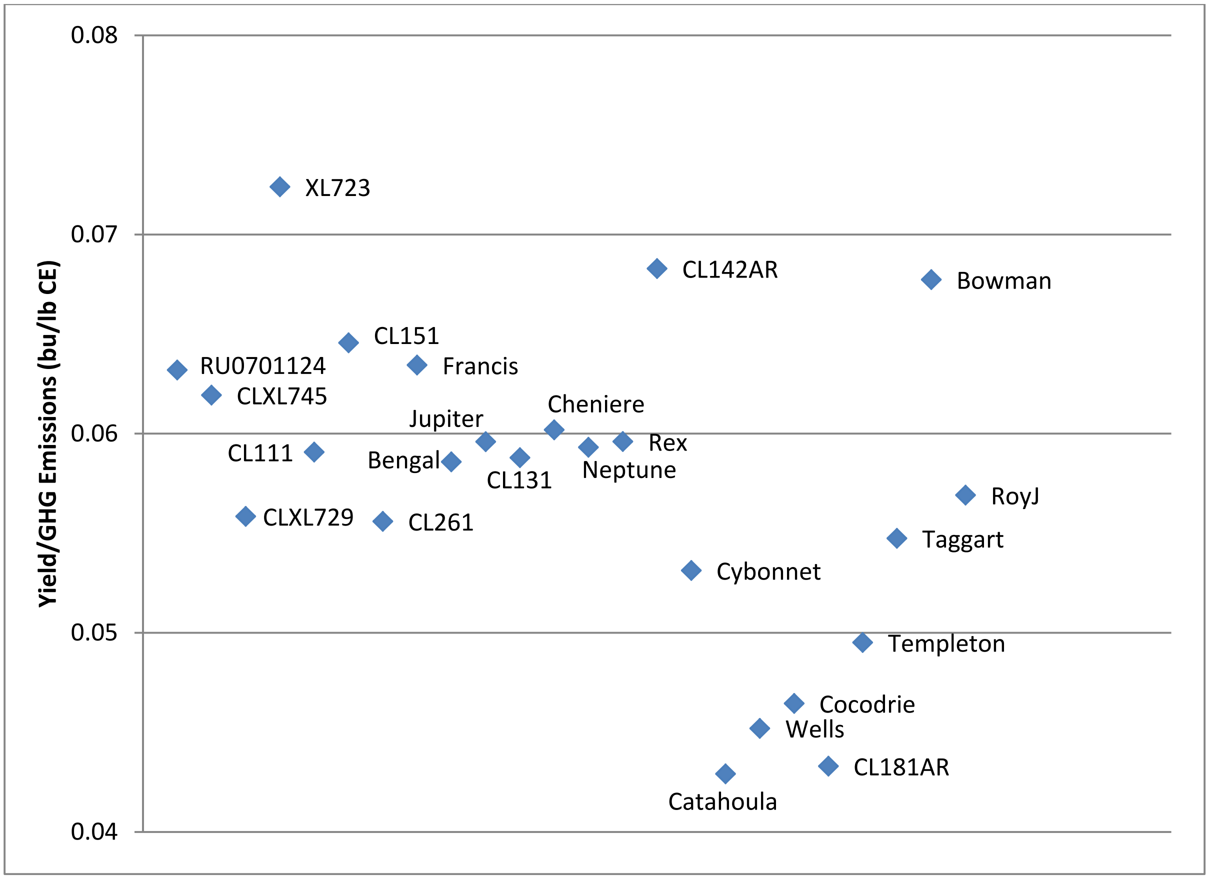


Figure 25. Yield/GHG Emissions (bu/lb CE) Ratio for Rice Varieties at the Rohwer ARPT Station in 2010

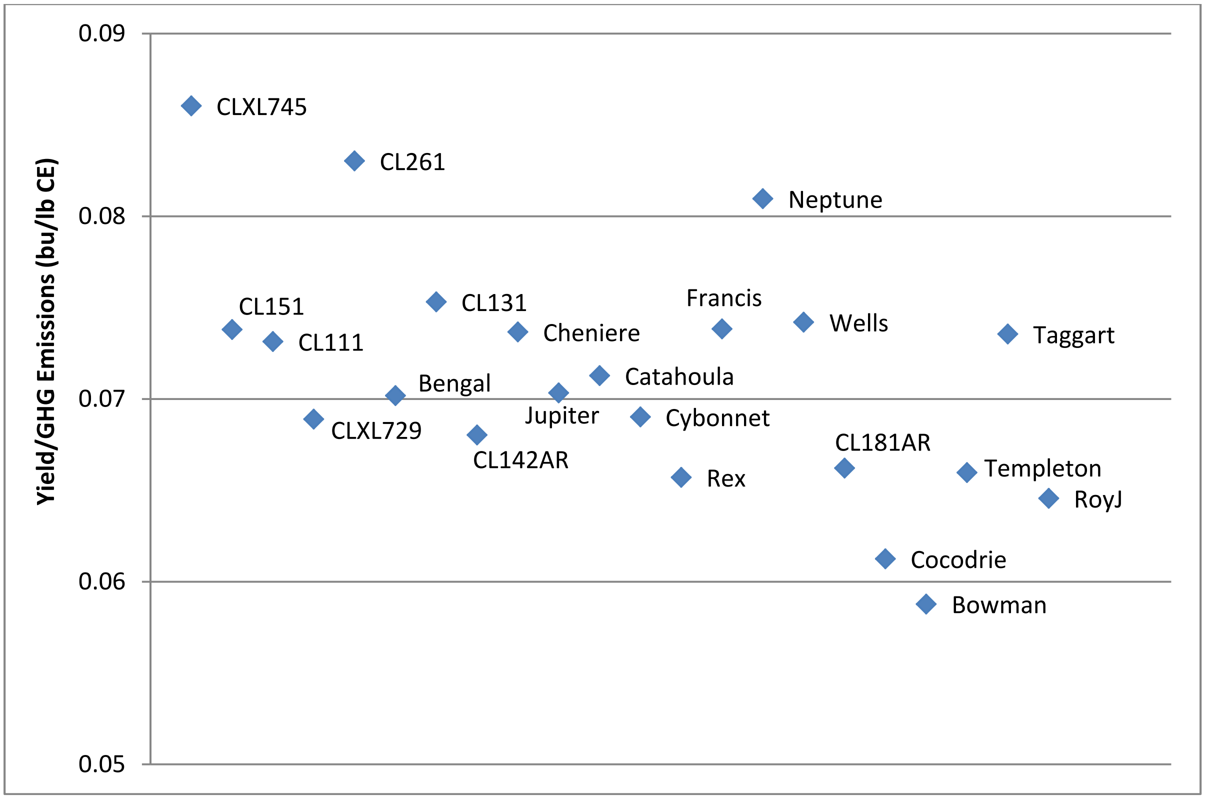


Figure 26. Yield/GHG Emissions (bu/lb CE) Ratio for Rice Varieties at the Keiser ARPT Station in 2010

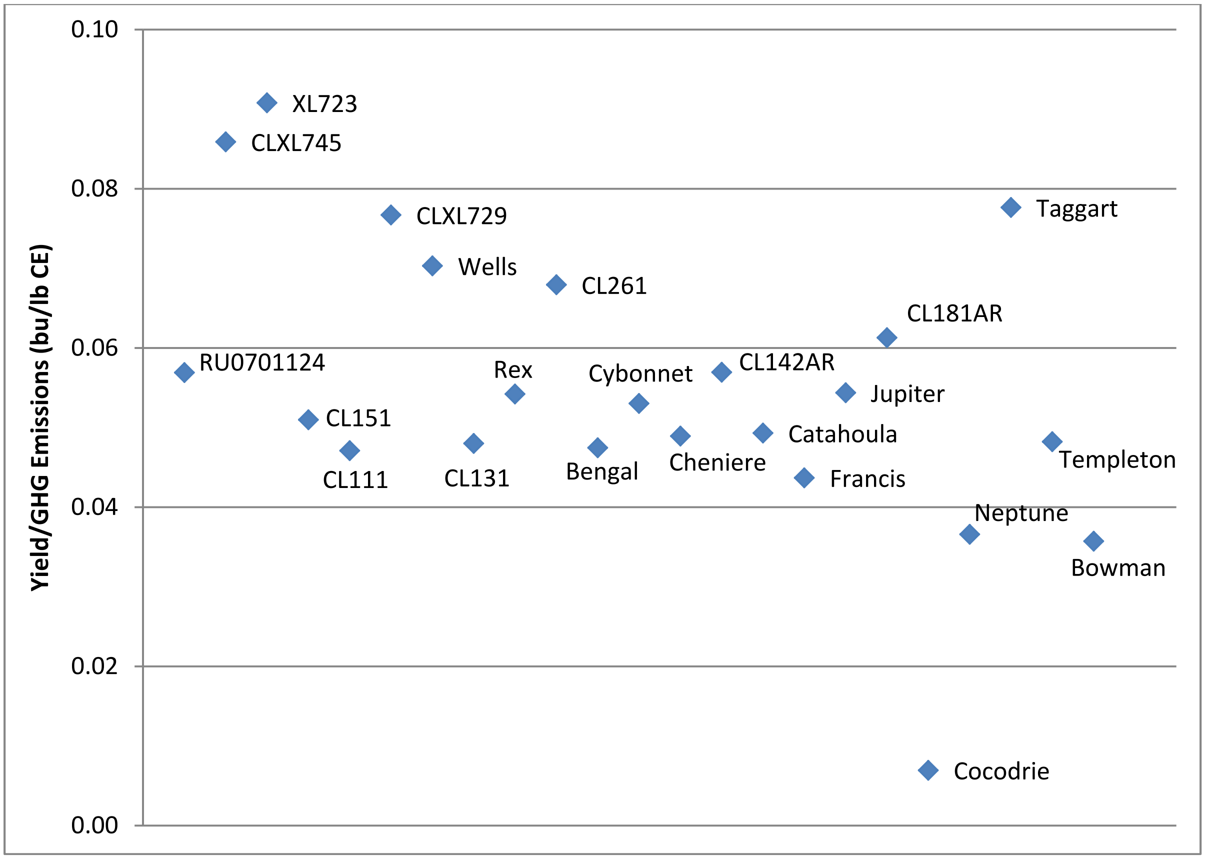


Figure 27. Yield/GHG Emissions (bu/lb CE) Ratio for Rice Varieties at the Newport ARPT Station in 2010

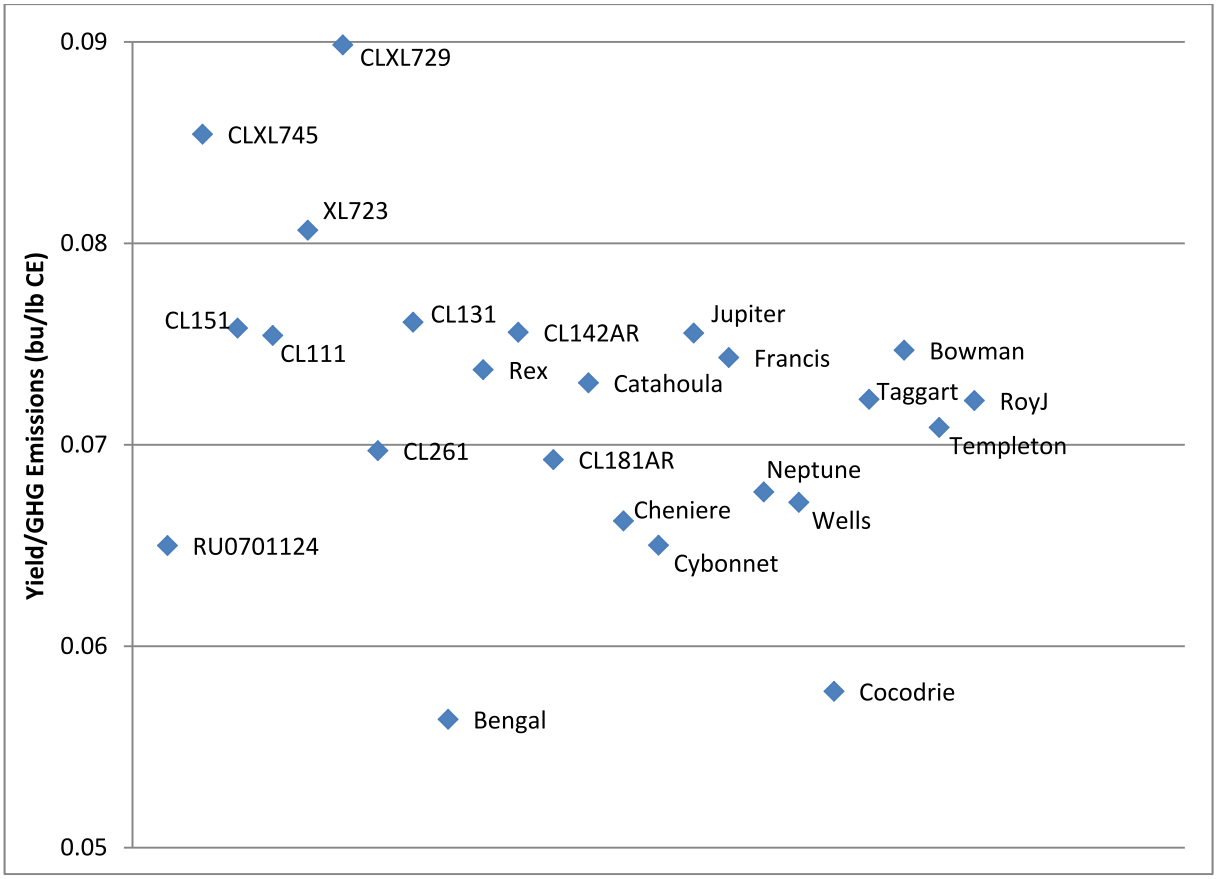


Figure 28. Yield/GHG Emissions (bu/lb CE) Ratio for Rice Varieties at the Colt ARPT Station in 2010

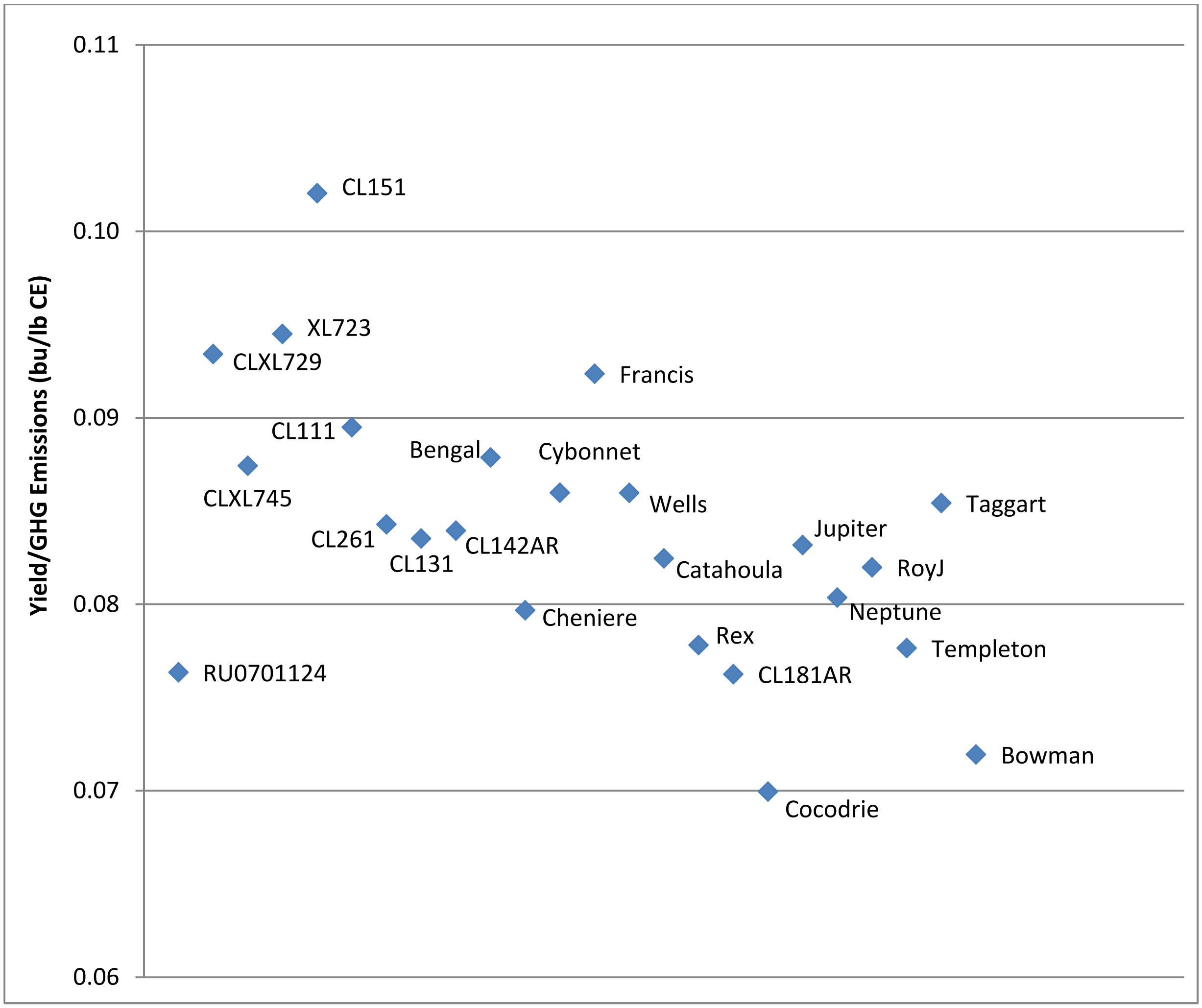


Figure 29. Yield/GHG Emissions (bu/lb CE) Ratio for Rice Varieties at the Coring ARPT Station in 2010

Rice varieties located higher on the Y axis on the above six figures (24-29) are more ghg use efficient than the ones on the bottom. Figures 24 through 29 illustrate that the three Hybrid rice varieties are the varieties with the highest efficiency in GHG emissions. GHG emission use efficiency in Hybrids is attributed to the genetic potential of these varieties for shorter life cycle and a higher yield in rice production. Hybrid rice varieties have on average shorter period under flood (shorter life cycle) and higher yields across all six ARPT stations during the growing year of 2010.

Unlike for water use efficiency where total water use is mainly dependent on number of days on flood, total GHG emissions are influenced by two major factors: 1) number of days under flood and 2) cultivar type (conventional & hybrids). Therefore, on a per ac bases, hybrid rice varieties emit on average more GHG than conventionals across all six ARPT stations; however, their rice yield is high enough to make hybrids among the most efficient varieties in GHG emissions for the majority of the ARPT stations.

V. CONCLUSION

A. Summary

This study has empirically estimated the water-use and GHG emissions per acre and per bushel on the most commonly cultivated rice varieties in Arkansas. Rice varieties were then grouped under conventional, Clearfield and hybrid varieties to compare between each group and find out whether hybrid rice varieties are more environmentally beneficial in terms of water use and GHG emissions.

The hypothesis of this study was that hybrid rice varieties use less water and emit less GHG per acre and bushel.

The study found that on average hybrid rice varieties use less water per acre because of their shorter life cycle (shorter period under flood). However, statistical results indicate that on average the amount of water per acre used by hybrids is not statistically different from that of conventional and Clearfield rice varieties. Efficiency measures, on the other hand, show that hybrid rice varieties are significantly different from conventional and Clearfield varieties, meaning that hybrids use significantly less water per bushel of rice.

Regarding GHG emissions per acre, the study found that hybrid rice varieties are not significantly different from conventionals but they are statistically different from Clearfield varieties in that hybrids emit more GHG. Estimates of GHG emission use efficiency, on the other hand, indicate that hybrid rice varieties emit significantly less GHG per bushel of rice.

The combination of (average) shorter life cycle and (average) higher rice yield per acre give hybrids an upper hand on efficiency estimates, both water-use efficiency and GHG emission use efficiency. Rice varieties with such attributes are what could best fit the current situation where global market demand for rice is continuously increasing while water reserves and GHG emissions are becoming a serious problem.

This study also concluded that same rice varieties have different life cycle length and yields across locations. This finding is important when advising rice producers in regards to the most efficient rice variety for their farm based on the location.

It is important to emphasize that Arkansas rice producers as well as rice producers around the world should make their decision on cultivar selection not only based on how much input (water-use/ac) per acre a variety uses, but how efficiently the variety is using that input. The efficiency is critical given the fact that rice producers in Arkansas and around the world are not only facing resource constrains (low water reserves & high GHG emissions) but also a market with increasing demand for rice.

B. Limitations of the study

Despite the careful and detailed work carried out to make this study and its results as representative as possible, there are same limitations and indeed room for improvement to this project. Firstly, because of the time constraint, this study only estimated yield/water use and yield/ GHG emissions but not yield/cost. The economic aspect is critical to this study in order to help rice producers in their decision on which rice cultivars they should cultivate.

Secondly, the data on GHG emissions from diesel (tractor operation), fungicide, herbicide, pesticide, fertilizer (Sum of N-P-K application) and N_2O (Correlated with nitrogen fertilizer application) from McFadden et al. (2011) were average estimates on a per cultivar type (conventional, Clearfield, & hybrid) and not in a per variety basis. More variety specific data would have resulted in more representative estimations.

Finally, data on methane emission from Rogers et al. (2012) was limited to only year, one location and one rice variety. Field data on methane emission for a number of more years, locations and rice varieties would be necessary for more representative estimations on methane emissions.

C. Future Research

There are certain areas of this study that could be improved by future research. First and foremost, data need to be collected on rice price and input prices (including costs on carbon emission permits and water use) to estimate yield/cost ratio. Secondly, more variety specific data on GHG emissions from diesel (tractor operation), fungicide, herbicide, pesticide, fertilizer (Sum of N-P-K application) and N_2O (Correlated with nitrogen fertilizer application), need to be collected in order to improve the estimation of GHG emissions. Another area of improvement would be to have field data on methane emission for a number of more years, locations and vice varieties for more representative results.

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VII. APPENDIX

The Ecoinvent database, put out by The Swiss Centre for Life Cycle Inventories (The Ecoinvent Centre) comprises LCI data covering all economic activities. Each activity dataset describes an activity at a unit process level. Data quality is maintained by a rigorous validation and review system. The report at hand reports the data quality guidelines applied. The Ecoinvent LCI datasets are intended as background data for Life Cycle Analysis (LCA) studies where problem- and case-specific foreground data are supplied by the LCA practitioner. The Ecoinvent datasets may also be useful as background datasets for studies in material flow accounting and general equilibrium modeling. To handle the increased number of datasets, and the resulting increased demand for quality control and review, an editorial board has been established at Ecoinvent. It is made up of more than 50 editors, all experts in their fields. Each editor covers an area of economic activity (e.g. agriculture, mining, chemicals production, etc.), a specific geographical region, a specific type of emission, or specific database fields such as uncertainty, to ensure consistent reporting in the datasets across different industrial activities. Each new dataset passes at least three editors, at least one for the economic activity and at least two cross-cutting editors. The database administrator functions as chair of the editorial board, which thereby functions as a critical review panel according to ISO 14040. The review process and all reviewer comments are documented and stored by Ecoinvent. The names and final review comments of the editors are stored in the datasets. The current list of editors is available at the Ecoinvent web-site.

The focus of the Ecoinvent database is on the compilation of the basic building blocks (LCI datasets), representing the individual unit processes of human activities and their exchanges with the environment, and the combination of these LCI datasets through the use of system models in life cycle inventory analysis, thus constructing life cycle inventories. Nevertheless, the Ecoinvent database also contains data on impact assessment (LCAI) methods and results of applying these methods to the LCI data.