Evaluation of Super Absorbent Polymer (Hipro-Aqua) on the Growth, Yield and Quality of Tobacco *(Nicotiana tabacum L.)* Under Various Irrigation Regimes

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Declaration

I do hereby declare that this thesis entitled, "Evaluation of Super Absorbent Polymer (Hipro-Aqua) on the growth, yield and quality of Tobacco *(Nicotiana tabacum L.)* Under Various Irrigation Regimes**",** was written by me and that it is the record of my own research work. It is neither in part nor in whole been presented for another degree elsewhere.

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Abstract

Drought is the most important limiting factor in the production of crops in agriculture; it is becoming an increasingly severe problem, sharpening its ends due to dynamic changes in climatic variables. Tobacco is one of the major cash crops that is being grown by many farmers, but its production potential is often constrained by the scarcity of water and poor productivity of sandy soil. In order to counteract the problem of water scarcity, the researcher hereby sought to investigate on the effects of a novel technology towards water conservation and potential production of tobacco in Zimbabwe. The addition of water-saving superabsorbent polymer (SAP) in soil can improve soil physical properties, crop growth and yield and reduce the irrigation requirement of plants. This experiment was conducted on a flue-cured tobacco variety 'T75' at Tobacco Research Board, Zimbabwe during the 2015-2016 season. The experimental design was a split-plot with two factors including four irrigation regime (providing 40%, 60%, 80% and 100% from consumptive (ET crop) of tobacco) as main plots and four levels of SAP (0, 75, 150 and 225 kg/ha) as subplots in a randomized complete block design with three replications. Irrigation level and SAP had significant effects on growth parameters of tobacco (leaf length and leaf width) of tobacco leaves, with the highest (77.19cm) leaf length at SAP rate of 150kg/ha under irrigation regime of 80% and the lowest (60.72cm) being at 0kg/ha SAP rate of under 40% irrigation regime. Also there was significant effect of the treatment application of different rates of SAP under different irrigation regimes on yield parameters (fresh and dry cured leaf yield), with the highest (2 017kg/ha) dry cured leaf yield of tobacco at SAP rate of 150kg/ha under 80% irrigation regime and the lowest (653kg/ha) dry cured leaf yield of tobacco at 225kg/ha under 40% irrigation regime. The quality of tobacco (% nicotine, % sugar content and grade index) was also influenced by the treatment applications of SAP rates under different irrigation regimes, with the highest (3.05%) nicotine content attained at an SAP rate of 150kg/ha under irrigation regime of 80%. The results indicate that 150 kg/ha of SAP under 80% irrigation regime produced the desirable outcomes on the growth, yield and quality of tobacco, signifying the importance and role of SAP in moisture retention and its positive contribution towards those parameters.

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CHAPTER 1

1.1 Introduction and Justification

Tobacco (*Nicotiana tabacum* L.*)* is Zimbabwe's most valuable agricultural commodity, accounting for about 26% of agricultural GDP and 60% of agricultural exports. (Aneseeuw *et al.*, 2012). Once the world's second largest flue-cured tobacco exporter in 2000, Zimbabwe is now the world's sixth-largest exporter, ranking behind Brazil, India, the United States, Argentina and Tanzania (TIMB, 2013). Indeed tobacco is an export cash crop that contributes significantly to the country's revenue and her capacity to capitalize on tobacco production has made her a significant player in the global tobacco industry (Manyeruke and Mangwanya, 2011).

Zimbabwe has recorded and set a quality standard through the production of good yields of high quality (Mazarura, 2014). In the 2015-2016 season, average annual yield of tobacco in Zimbabwe were 190 million kg with a total average export revenue of US$604.7 million. Tobacco (*Nicotiana tabacum* L.*)* is a high value crop whose production dates back to the colonial era in Zimbabwe (Mazarura, 2004). Zimbabwe had established an international reputation of producing a high quality crop with high nicotine content that compete favorably on the world market; however the trend is declining in terms of the quality of the produce due to a number of factors which entails on water, soil and crop plant management (TIMB, 2012).

The Chinese buy about 40 percent of Zimbabwe's tobacco, mainly the mahogany grade and Western Europeans about 35 percent of the golden leaf contributing to the influx of revenue to the nation (Tianze, 2015). Tobacco is grown for its leaf where nicotine one of the alkaloids, a major economic product of tobacco is extracted (Tayaoub *et al*, 2015). Also other compounds such as solanesol and a variety of beneficial alkaloids which have different uses in chemical and medicinal industries, preservative galleries and fuel industries are extracted giving a wide and broad spectrum of tobacco usage in the local industry and abroad (Mazarura, 2004*).* Tobacco is used in food processing industry, cosmetic industry, chemical industry, pharmacy and mainly in tobacco industry as raw materials for other tobacco production systems (Kulic *et al*., 2008).

Again, tobacco production has since been seen at an increase from the 1990s with the highest yield and tonnage being around the year 2000, (Marowa etal 2014). The 2000-2008 period was largely dominated by the land reform programme which was seen to yield high tonnage per every production season (FAO, 2008). Large-scale farms were sub-divided and land allocated to indigenous farmers (Chiremba and Masters, 2008). This rapidly increased the number of growers thereby increasing the potential tobacco production base (Alden-Wily, 2010).

The 2009-2015 production era was characterized by rapid recovery of production and increase in grower base from the year 2009 to the 2015/2016 growing season, which had the following trends (ZTA; 2014). In the year of 2008, the volume of flue cured tobacco which was produced amounts to 58.5 million kilograms which was worth US$174.4million. The trend kept on increasing due to the increase in active growers which were coming into the tobacco production, with the year of 2010, having a rise in the volume of tobacco flue cured production of 123.5 million kg fetching US$355.7 million, (TIMB; 2014). In 2012 the tonnage of flue cured yield increased to 144.5million, with US$540 million of revenue. Also 166.7 million kg at US$610 million in 2013 was seen, with the highest metric tonnage observed in the 2015-2016 season with the total tonnage of 190 million kg (Herald, 2016).

Also in terms of the production base for the growing units for the 2015-2016 season, the estimated number of active growers rose up with 80% being small-scale farmers with (up to two hectares) growing 120 000 hectares, producing 180 million kg valued at US$670 million.

However tobacco productivity has been at a decrease in terms of quantity produced and the quality thereon regardless of the influx of tobacco growers into the farming industry. So the production issue has been constrained by various challenges among them pests and diseases, some of the economically important pests being the following; the adult stage of fungus gnat (*Bradysia spp)* which feed on roots causing stunted growth (Reynolds *et al*, 2015). Another important pest is the cutworm (*Agrotis spp)* which feed on stems at the soil level, leaving deep cuts which will result in plants lodging later in the field (Masuka et *al*., 2010). Among the most important seedbed diseases is Pythium root rot which is caused by (*Pythium myriotylum*) which results in wilting and subsequent death of the seedlings which become more prevalent recently due to the wide usage of the float bed system of raising tobacco seedlings (TRB, 2015). Root not nematodes (*Meloidogyne javanica*) infects plant roots causing stunted and irregular plant growth (Vovlas *et al*, 2005). Tobacco mosaic virus infects leaves causing mosaics of dark-green and chlorotic light-green areas, curling, mottling, blistering of leaves and the entire plant may be dwarfed (Masuka et *al*., 2010).

Apart from diseases and pests that have been detrimental to tobacco production, production of tobacco has been constrained largely by the shortage of adequate water to facilitate production recently (FAO Report, 2010). Also due to the extension services provided, tobacco production has extended to other parts of Zimbabwe which do not have favorable condition for maximum production of the cash crop-tobacco. However farmers in these areas are encountering the major problem of water shortage to meet the water requirements of tobacco per production cycle, let alone the water scarcity problem being worsened by the dynamics of climate change. Regardless of other measures which tobacco growers are using to minimize the adverse effects of water shortage in different marginal areas of Zimbabwe such as water harvesting, growing of drought tolerant cultivars of tobacco, use of mulches for moisture conservation among the rest, these efforts are not yielding good results to farmers due to lack of facilities for water harvesting, lack of enough residues for mulching and also the inconsistency of breeding lines which are succumbing to genetic and environmental alterations (World Bank, 2008 and Nnadi et al, 2014).

So with all this in mind, the production of tobacco so as to attain best results in terms of yield is by addressing the problem of water shortage in tobacco growing regions in Zimbabwe by the use of a novel substance which is Super Absorbent Polymer (SAP), which is a substance that functions in retaining water in the rhizosphere and hence increase water use efficiency in tobacco production. Super Absorbent Polymer (SAP) is a substance which helps in the retention of water in the soil zone, this was seen after its application on lawns and in plantation agriculture (Nnadi and Brave; 2011).

A number of reasons have been put forward to explain these observations: better soil aeration, thereby enhancing microbial activity (Abd EI-Rehirn *et al*, 2004); delaying dissolution of fertilizers; increasing sorption capacity or favoring the uptake of some nutrient elements by the plants (Evangelou *et al*, 2014).

Moreover, the use of SAP leads to increased water use efficiency since water that would have otherwise leached beyond the root zone is captured (Yazdani *et al*, 2007). While increasing the amount of available moisture, SAP compound help reduce water stress of plants resulting in increased growth and plant performance (Baker, 1991 and Allahdadi, 2002). This compound also is claimed to reduce fertilizer (NPK) leaching. This seems to occur through interaction of the fertilizer with the polymer (Ghamsari, 2008). SAP application into agriculture is also being considered as a potential carrier for insecticides, fungicides and herbicides (Bakass and Lallement, 2002).

However, looking at all those positive impacts of SAP in the production of tobacco, this has prompted the researcher to undertake this research to rectify on the shortfalls of some of the other efforts farmers are doing in moisture conservation, by studying on the other best alternative which can help growers to maximize on production with the available water reserves. So it is against this background that the researcher has intended to carry a study on the evaluation of the effect of Super Absorbent Polymer application on the growth, yield and quality of tobacco (*Nicotiana tabacum.*L) under various irrigation regimes to determine the best management strategy towards water conservation in tobacco production especially in marginal areas where tobacco is being grown with too little amount of water which are below the water requirements of the crop.

1.2 Overall Objective

- To evaluate the effect of Super Absorbent Polymer (HiPro-Aqua) application on the growth, yield and quality of tobacco *(Nicotiana tabacum L.)* under various irrigation regimes.

Specific Objectives

1.2.1 To evaluate the effect of different SAP application levels under various irrigation regimes on growth parameters of tobacco, leaf length and width of tobacco under field conditions.

1.2.2 To determine the effect of different SAP application levels under various irrigation regimes on the yield of tobacco, fresh and dry leaf yield measured in kg/ha.

1.2.3 To assess the effect of different SAP application levels under various irrigation regimes on the quality parameters, percent nicotine, sugar content and grade index of tobacco.

1.2.4 To evaluate the effect of different SAP application levels under various irrigation regimes on the Water Use Efficiency (WUE) of tobacco.

1.3 Hypotheses

1.3.1 There are significant differences on the effects of SAP application under various irrigation regimes applied on growth parameters (leaf length and width) of tobacco

1.3.2 There are significant differences on the effects of SAP application under various irrigation regimes on yield (fresh and dry leaf yield).

1.3.3 There are significant differences on the effects of SAP application under various irrigation regimes on the quality of tobacco (percent nicotine, sugar content and grade index) of the cured tobacco leaf.

1.3.4 There are significant differences on the effects of SAP application under various irrigation regimes on the Water Use Efficiency (WUE) of tobacco.

CHAPTER TWO

2.0 Literature Review

2.1 Economic Importance of Tobacco in Zimbabwe.

Zimbabwe has a total land area of 39.6 million hectares, of which 9% of it (4.31 million hectares) is arable and agriculture is being done on 39.9% of total area of land (15.8 million hectares) (Government of Zimbabwe (GoZ), 2001 and FAO, 2001) The commodities from the agricultural produce contributing to agricultural Gross Domestic Product (GDP) include tobacco (25%), maize (14%), cotton (12.5%), beef and fish (10%), sugar and horticulture (7%) and livestock (24%) Rukuni *et al* (2012). Tobacco farming and growing is the major employer of the country's labour force, accounting for 65% of the rural population. (FAO, 2012). The majority of the rural population are producers, but the potential productivity of farmers has been affected by the changes in rainfall patterns and distribution which has led to the fluctuations of tobacco produce in the nation, (Rugabe and Chambati, 2001). As can be seen from trends in tobacco farming, growers are becoming unnumbered, both active and those under contract farming across all agro ecological regions of Zimbabwe, (TIMB, 2014).

Agriculture is the backbone of Zimbabwe’s economy and it plays a pivotal role in Zimbabwe’s economy (FAO, 1999 and UN - Zimbabwe, 2010). About 70 percent of the Zimbabwean population depends on agriculture for food, income, and employment (UN - Zimbabwe, 2010). Tobacco is one of the crops grown in Zimbabwe and supplies raw materials required by some manufacturing and processing industries in Zimbabwe. In 2009, tobacco contributed at least 56 percent of the total agricultural export earnings of the nation and thus contributing at least 10 percent of the Gross Domestic Product (ZTA, 2015). Some of the world’s finest flavour tobaccos come from Zimbabwe especially the flue cured tobacco varieties (Marowa *et al*., 2015). This is mainly because of the country’s favourable soil and climatic conditions besides great management practices as a result of continuous research in tobacco production (Edwards, 2005). At one point, the country’s tobacco exports accounted for 20% of the world's flue-cured tobacco (ZTA, 2013). The revenue obtained from tobacco exports alone constituted up to 30 percent of the total revenue obtained from exports; (Zimbabwe Tobacco Association (2013). The report further pointed out that tobacco production utilized only about 3 percent of the nation’s arable land and at peak production the industry employed about 50% of all people employed in commercial agriculture, (Marowa *et al;* 2014). However, this estimate did not include other activities and downstream industries that exist to service the tobacco industry and again the extension of tobacco growing into marginal areas (ZTA, 2013). Tobacco has also been a springboard for the production of other crops in the country (Huni, 2014 and Marowa *et al*, 2015). It is one of the crops which brings good returns to farmers and offers a ready market for Zimbabwean farmers, (Ruzivo Trust; 2013). Income from tobacco is used by growers to develop their farms, cattle production and irrigation schemes (Huni, 2014). There is therefore no doubt that tobacco is important in Zimbabwe's agriculture and the national economy at large (Richardson, 2013).

Tobacco is an annual, short day and self-pollinated crop which belongs to the family Solanaceae and the genus *Nicotiana* (Hasani *et al.*, 2008). Only two species of this genus (*Nicotiana tabacum* L. and *Nicotiana rustica L.*) are widely cultivated all over the world (Taj, 1994). Tobacco is one of the few crops entering the world trade entirely on the dry leaf basis and is the most widely grown commercial non-food plant in the world (Marowa and Rukuni, 2015; and Taj, 1994). It is used in the manufacture of cigarettes, cigars and biddies among other products (Taj, 1994). Due to increased prices of fuel, labour and other inputs, the cost of producing quality flue-cured tobacco has risen (Woras *et al*, 2008). Farmers therefore need to be efficient in their production practices to attain high yields of high quality for maximum profits. Adoption of best management practices (BMPs) is therefore imperative for tobacco farmers to realize the highest profits (Marowa and Rukuni, 2015). This review will therefore focus on water management as well as yield components of a flue cured tobacco variety as influenced by the use of Super Absorbent Polymer compound, since water has been reported to affect yield and quality of tobacco in Zimbabwe.

2.2 Production trends of flue cured tobacco in Zimbabwe

Although Zimbabwe has continuously been reported as the country which produces well graded tobacco with less chemical residues and also as the major producer of tobacco in the world (TIMB, 2005; FAO, 2011; ZTA, 2013), there has been some fluctuation in the volume of flue-cured tobacco produced and sold in the past two decades. Tobacco production in Zimbabwe increased from 1995 to 2000 when the area harvested increased from 82000 hectares to 92000 hectares with 2000 commercial growers producing 230000 metric tons recorded in the year 2000 (TIMB, 2005). Production decreased in 2001 to 2005 mainly due to the decrease in the area harvested from 72 000 ha to 27 000 ha (Marowa and Rukuni, 2015). From the production season of 2006, regardless of other improvements in agronomic practices and extension advisory services, production continued to decrease on an increasing rate due to the problem of inadequate rainfall distribution and again growing of tobacco in regions which were not producing it, (FA0, 2011). The increase in production (from 133,866,041 kg in 1990 to 215,983,208 kg in 1998) could be attributed to the increase in the area harvested and improved agronomic practices in 1998 although the 2001 average yield has yet been reached to date (FAO, 2003).

This implies that there is a lot to be done in improving agronomic practices and area under tobacco production. Poor management of insects, diseases and weeds could also be some of the cause of the observed low yields, but the most limiting factor which contributed to the loss in produce had been noted as water shortage across all tobacco growing regions. Water stress in plants has got detrimental effects towards the normal growth of the plant and its integrity. However water stress causes a decrease in the total produce per hectare, by compromising the healthy and integrity of the plant. Therefore managing overall demand through a focus on water productivity is an important consideration which is an imminent study under review in this paper.

2.3 Effects of water scarcity on tobacco production in Zimbabwe

Water stress, is one of the major constraints that limit the maximum production of tobacco in Zimbabwe, (Chandler and Bartels; 2003). The problem of water shortage in plants as a drought phenomenon has chemical – physical signalling which occurs within the plant’s system which compromises in the organization of a number of large and small bio-molecules, such as nucleic acids, proteins, carbohydrates, fatty acids, hormones, ions, and nutrients (Dhanda; 2012). So the influence of water shortage in the plant lead to compromised state of the membranes, leakage of cell contents, and then finally leading to the death of the plant (Simontacchi *et al*., 2015). Given the trends in the demand for water in agriculture in Zimbabwe due to population growth, income growth and percent increase in tobacco growers as have been said earlier on – a recurring challenge for agricultural water management is the question of how to do more in terms of production with less water volumes- that is optimising on production by utilising the inadequate water volumes so as to maximise on tobacco production (GoZ., 2014).

So the single most important way of managing water shortage in tobacco production is through increasing tobacco production with respect to water, (FAO (2012). Increase in crop yields (production per unit of land) is the most important source of crop water productivity increase, Fuglie and Wang (2012). Yield increases are made possible through a combination of improved water control, improved land management and some other agronomic practices, USDA (2016). This includes the choice of genetic material, and improved soil fertility management and plant protection. With the fast decline of irrigation on water potential and continued expansion of population and economic activity in the country especially the agricultural sector, though there have been an influx of farmers into tobacco, but the major constraint has been to water availability sufficient enough to promote tobacco farming (GoZ Report., 2014). Therefore, the stress on agricultural development in the present world has shifted to the sustainable use of water for sustainable production in agriculture, (Hulela, 2003). The major goal being of creating revenue and earn a good standard life.

With the understanding of unpredictable and erratic rainfall, it is therefore important to take practical steps to contain this problem (Yellisetty, 2015). Tobacco has a minimum threshold amount of rainfall that will enable it to mature and produce yields to its maximum potential possible (Bita and Gerats, 2013). More often despite this minimum threshold of rainfall being achieved tobacco wither and die before maturity (Bryan *et al*, 2013). Farmers are currently employing several strategies to combat water shortages, through water harvesting, growing of drought tolerant crops, mulching and intercropping, but all these efforts are up to no avail (Alam, 2015).

Faster growth and the maximization of yield concept provides a way for sustained growth of tobacco despite harsh conditions in Zimbabwe with the aim of achieving good results if not optimal yield (Lipson, 2015). Generally, though not in all situations rains are heavier at the early stages of growth or at the onset of rains. It is therefore very important to take advantage of this and boost growth by minimizing the loss of water beyond reach of tobacco rhizosphere through the application of the aforementioned substance –Super Absorbent Polymer

2.4 Super Absorbent Polymer (SAP)

Superabsorbent polymer (SAPs) is a unique group of materials that can absorb over a hundred times their weight in liquids and upon absorbing the water they would not release the water easily under pressure especially from the pressure exerted by the top soil or any other variable in the soil medium, (Smartech Global Solutions Company, 2003). Also documentation from the same report affirmed that, early commercial versions first emerged in the United States in the early 1970s in the form of starch/acrylonitrile/acrylamide based polymers, with applications originally focused in the agriculture/horticulture markets where they were used as hydrogels to retain moisture in the surrounding soil during growing and transportation. Again, cross-linked polyacrylates and modified cellulose ethers were also commercialized along with starch-grafted cross-linked polyacrylates, (Plastermart, 2003). By 1985, the worldwide use of SAPs was an estimated 12,000 metric tons, two thirds being used in Japan. Agricultural uses for seed coatings/potting compounds and water retention in arid planting areas rely on SAP's hydrogel properties.

Superabsorbent polymers are cross-linked polymers, which can absorb large volumes of liquid and retain it with them, (Gerad (2011). This is realized by increase in volume of the polymer (Buchholz and Graham, 1997; Kazanskii and Dubrovskii, 1992). Superabsorbent polymers were first developed by USDA in 1970s for applications in agriculture to improve the water holding capacity of soils to promote seed germination and plant growth and now finds extensive application in disposable pads and sheets, towels used in surgery, adult incontinence and female hygiene products (Liu and Guo, 2001). Superabsorbent polymers can be classified into two types: based on charge – non-ionic and ionic (Buchholz and Graham, 1997) and based on its affinity towards water – hydrophobic (Atta et al., 2005; Jang and Kim, 2000) and hydrophilic. Ionic SAPs are further classified into cationic and anionic (Buchholz and Graham, 1997).

2.4.1 Chemical Structure of Super Absorbent Polymer

SAPs contain long polymeric chains which are slightly cross-linked (Liu and Guo, 2001, Gerad 2011). Superlative water absorbing property of SAPs arises from electrostatic repulsion between charges on the polymer chains and osmotic imbalance between the interior and exterior of the polymer (Ono et al., 2007; Liu et al 2010). Besides, certain functional groups in the polymeric chain also forms hydrogen bonding with water molecules (Xie et al., 2007). The swelling of the polymer is limited as the polymer chains are cross-linked (Liu and Guo, 2001; Hamidi and Rafiei 2015) and this cross-linking makes these polymers insoluble in water (Buchholz 2014; Mahmid et al, 2014).SAPs are prepared by two principal processes – bulk solution polymerization and suspension polymerization (Buchholz and Graham, 1997; Buchholz, 2014). SAPs are quantified for practical features using the following methods – water absorption capacity, swelling rate, swollen gel strength, wicking capacity, sol fraction, residual monomer and ionic sensitivity (Zohuriaan-Mehr and Kabiri, 2008; Mahmood et al, 2014).

According to Ahmed et al; (2015), he asserted that water absorbing capacity or swelling of the polymer can be controlled by two methods -type and degree of cross linking between polymeric chains and morphology of the SAP. Xie et al. (2009) and Ahmed et al, (2015), discussed that the water absorbing property of the SAPs can be greatly affected by type of cross-linking agent used. Ahmed et al 2015 and Sadhegi, 2012, discussed that, the cross linking agent varies the polymeric chain length – that is, longer polymer chains have more network space and thus increases water absorbing capacity (Liao, 2014). Besides, the length of polymeric chain also affects its water absorption capacity – smaller polymer chains have more polymer ends which do not contribute to water absorption (Han, 2015; Liu, 2012).

Morphological property like porosity also affects water absorption of SAPs (Isık and Kıs, 2004; Kabiri and Zohuriaan-Mehr, 2004; Turan and Çaykara, 2007). Another morphological property - particle size, also affects water absorption of SAP. Bhardwaj et al. (2007) discusses that the smaller the average grain sizes of SAP, the larger the water absorption capacity. Also SAPs undergo controllable volume changes in response to small environmental conditions such as temperature, pH and ionic strength (Beltran et al., 1991; Gudeman and Peppas, 1995; Liu et al., 1995).

2.5 Effect of SAP on Water Use Efficiency of Tobacco

Eneji etal (2013) and Yazdani etal (2007) discussed that application of superabsorbent polymer is an effective management practice in tobacco production in soils with low water holding capacity where rain or irrigation water leach below the root zone within a short period of time leading to poor water use efficiency by crop. According to Islam etal (2011) and Bedi and Sohrab (2004), they brought the notion that in arid and semi-arid regions of world, intensive research on water management is being carried out and use of superabsorbent polymers may effectively increase water use efficiency in crops.

Tobacco growth and scheduling of irrigation is normally done at four to five weeks after planting and normally this is around the phase of grand growth of September-planted irrigated tobacco which coincides with the hottest and driest period of the year that is October (TRB, 2014).

Guiwei et al. (2008) reported that amendment of soil with superabsorbent polymers prolonged the duration of water evaporation from the soils especially those soils where tobacco is dominantly grown which has got large pore spaces. So the amount of irrigation necessary to maintain crop growth under conditions of high evapotranspiration may leach nitrogen out of the root zone to the detriment of cured leaf quality. However, the interval and number of irrigations depends upon soil type, weather and cultivation type, but these are normally frequent and have negative implications on the gross productivity of the farmer. Thus soil conditioning with superabsorbent polymers could be an innovative facet in the field of agriculture, which works as water storage reservoirs and helps in the extension of irrigation cycles in order to save and utilise available water reserves. Research evidences suggested that problems associated with traditional micro irrigation and the factors which are catalyst in practicing efficient irrigation techniques can be taken care of by conditioning the soil with superabsorbent polymer.

In term of water conservation and optimize water use efficiency where water scarcity is a common problem, superabsorbent polymer can be used as a water conservator in agriculture (Alessandro, 2008). Water use efficiency and dry matter production also responds positively to the application of super absorbent polymer in the range lands and landscape designs (Woodhouse and Johnson, 1991).

2.6 SAP Effect on Soil Physical Properties

The potential benefit of polymers on water storage also depends on the soil texture, (Khumar (2015). Coarse textured soils which have large pores like sand tend to retain less water than fine textured soils (clay soils). The amount of water that may be retained by incorporating the superabsorbent polymer would be greater in coarse textured soil than in fine textured soil, thus this study holds its integrity in tobacco production since tobacco favours growing in course textured soils, being the sand or sand loamy soils. Conversely, porosity increased with increasing SAP doses for clay loam and sandy soil, (Uz et al., 2008). Ekabafe et al. (2011) reported an increase of 171 to 402% in water retention capacity when polymers were incorporated in coarse sand. Addition of polymer to sand soil decreased water stress and increased the time to wilt (Karimi et al., 2009). Isalam et al. (2011) reported that total N content at 0-15 cm soil depth increased slightly under low superabsorbent polymer dose but it increased remarkably by 19.3, 36.6 and 35.8%, respectively for medium, high and very high superabsorbent polymer doses on researches which were done at Tobacco Research Board.

Eslamian and Kazemi (2008) observed that use of superabsorbent polymer led to increase in the water holding capacity of the soil. By application of superabsorbent polymer, high water retention capacity and protection against drought was observed, Nazrali et al. (2011). Drought stress leads to production of oxygen radicals, which results in increased lipid peroxidation and oxidative stress in the plant, but with the use of superabsorbent polymer could reserve different amount of water in itself and ultimately increases the soil ability of water retention and preserving and at last in water deficiency more the superabsorbent polymer mixed in the soil, more would be the water retention and improved soil moisture.

2.7 Effect of SAP on Root Activities of Tobacco.

With an increase in concentration of SAP, there is a significant increase in the root parameters like root length, root volume, root fresh and dry weight at harvest in tobacco due to proper maintenance of water by hydrophilic polymer for longer duration. Volkamar and Chang (2005) reported that hydrophilic polymer at 1.87 g $plant^{-1}$ increased root biomass of Coker tobacco as compared to control which was in support to what was found after the harvesting was done in all treatment plots. Similarly, Sendur et al. (2001) concluded that SAP significantly increased root length as well as root dry weight as compared to control which was in accordance with findings in Zimbabwe at Tobacco Research Board in 2016 on tomato bioassays which were conducted. Zhang et al. (2005) observed SAP significantly increased root biomass over control. Keshavars et al. (2012) reported that superabsorbent polymer is added to the soil media before planting so as to enhance root development to deeper depths, which was the notion which also helped the determination of the application time of the compound-SAP. So with all those highlighting facts and studies undertaken it totally holds water especially for the results which were obtained in this study undertaken in tobacco, applying all those beneficial aspects of the compound till the best is achieved in all the agronomic activities entailing to make farming a profitable enterprise in the alternating Elnino - Lanino dynamics of climate change.

CHAPTER THREE

3.0 Materials and Methods

3.1 Study site

The study was carried out at Kutsaga Research Station. Kutsaga lies in Natural Region IIa (Agritex, 2005; Vincent and Thomas, 2004) at an altitude of 1 479 metres above sea level (Akehurst, 2009). Geographically, the site is found on latitude 17^{o} 55`S, longitude $31^{o}$ 08`E (FAO, 2006). Mean annual rainfall varies between 800-1000mm and normally falls from November to March (Rukuni and Eicher, 2006). Average temperature in summer and winter are 32˚C and 18˚C respectively (FAO, 2009). The area has light, well drained, sandy soils of granite origin and resembles those found in most tobacco growing areas in Zimbabwe. The soils are very low in clay content and have low water holding capacity. They are slightly acidic with a pH of about 5.2. The seedbed site used in this study was a north facing slope as recommended (TRB Handbook, 2014), which is better exposed to the sun and usually more protected from the prevailing cold winds in winter.

3.2 Experimental Design

The experiment was conducted as a split plot arranged in a Randomized Complete Block design (RCBD) with three replications. Four different irrigation levels (I_1=100%, I_2= 80%, I_3= 60% and I_4 =40%) of evapotranspiration (*ETc*) were allocated to main plots. Four levels of superabsorbent polymer (S_1=0 ($kgha^{-1}$), S_2= 75 ($kgha^{-1}$) and S_3= 150 ($kgha^{-1}$) and S_4 = 225($kg^{-}1$) were allocated to sub plots. Irrigation was applied to meet 40%, 60%, 80% and 100% evapotranspiration (*ETc*). Evapotranspiration (*ETc*) was calculated based on class A pan data as follows (James *et al.* 1982):

$$ET0=Kpan\ (Ep)$$

$$ETc=Kc\ ET0$$

Where ET_0 is potential evapotranspiration from a reference crop, *Kpan* is the pan coefficient, *Ep* is evaporation from a pan and *Kc* is a dimensionless plant coefficient.

Table 3.1: Treatment Combinations

Irrigation Regimes	Super Absorbent Polymer Levels			
$I_{1\ 100\%}$	0kgha^{-1}	75kgha^{-1}	150kgha^{-1}	225kgha^{-1}
$I_{2\ 80\%}$	225kgha^{-1}	150kgha^{-1}	75kgha^{-1}	0kgha^{-1}
$I_{3\ 60\%}$	150kgha^{-1}	225kgha^{-1}	0kgha^{-1}	75kgha^{-1}
$I_{4\ 40\%}$	75kgha^{-1}	0kgha^{-1}	225kgha^{-1}	150kgha^{-1}

3.3 Soil Characteristics

Before laying out of the experiment, random soil samples from the experimental plots were taken up to a depth of 0-20 cm through the Z- sampling procedure and all the samples were mixed together to form a composite sample and brought to the laboratory for analysis. Mechanical and chemical analyses of the soil were done to assess the physical and chemical properties of soil and the results of analysis have been presented in the following tables. This was done to in order to see the contribution of soil constituencies and the additive advantage brought by the application of SAP into the soil.

Table 3.2: Water relations in the experimental Soil under Study

Water relations in the experimental soil under study

Constant Depth (cm)	Field capacity% (by vol.)	Wilting Point% (by vol.)	Available water%	Bulk Density
0-15	12.1	4.1	8.0	1.62
15-30	11.2	4.3	6.9	1.64
30-45	10.6	3.9	6.7	1.67
45-60	10.4	3.8	6.6	1.68

Table 3.3: Physical and chemical characteristics of the soil

Physical characteristics %		Chemical characteristics	
Coarse sand	46.2	pH 8	32
Fine sand	38.4	EC (ds/m)	3.25
Silt	11.8	Ca (mg/100g)	0.15
Clay	3.6	Na (mg/100g)	0.29
Texture class	Sandy	K (mg/100g)	0.21
$CaCO_3$ %	12.1	Cl (mg/100g)	0.47
Organic matter %	0.31		

Table 3.4: Irrigation water analysis

					Soluble Cations (meq/l)				Soluble Anions (meq/l)		
EC (ds/m)	pH	SAR (meq/l)	RSC (meq/l)	TDS Ppm	Ca^{++}	Mg^{++}	Na^{+}	K^{-}	Cl^{-}	SO_4^{-}	$CO_3 + HCO_3$
0.8	7.8	3.45	-1.3	512	2.1	1.3	4.5	0.1	3.6	2.3	2.1

3.4 Seed material and variety description

Pure seed lots of the Kutsaga flue cured tobacco variety T 75 was used in this study and was supplied by the Plant Breeding Division of the Tobacco Research Board (TRB), Kutsaga Research Station. T 75 is a tall plant with very close internodes. Leaves are broad and long, darker green and slightly more pointed and heavier bodied than those of K RK26 giving the variety a compact and bushy appearance. When topped to leave no more than 20 leaves per plant top growth is good.

3.5 Experimental Procedure

3.5.1 Nursery Management

Nursery management commenced on the first of June 2015 and the starting point was the clearing of seedbed site. This was followed by bed construction in the seedbed. A bed measuring 20 metres long and 1.05m wide was constructed. Two courses of 11.25cm farm bricks were used and were set in position without mortar. The bed was lined with a 250 micrometre gauge black plastic. The bed was filled with water to a depth of 10cm to flatten the plastic against the bottom and the sides of the pond to avoid wrinkles.Pine bark 100% composted was the medium used in the float tray system. Float trays were filled with the growth medium. This was followed by dibbling creating dibbles or holes in which the seeds were sown by hand using a dibbler. This was followed by sowing in the tray by hand. The trays were then floated in the ponds in the seedbed.

Kutsaga float bed fertiliser (4.5% N,:2.1% P_2O_5:4.7% K_20) was then applied at 25, 50 and 75mg N/L of water in the seedbed at 7, 14 and 35 days after sowing. Ammonium Nitrate (34.5% N) at 100mg N/L of water was applied to the trays at 42 days after sowing. Water was refilled and replaced in ponds regularly to allow new air circulation so that oxygen levels would be replenished and proper root respiration promoted. This was also done to replenish the reduced water levels and avoid seedling wilting. Spore kill with the active ingredient (*Didecylmethylammonim chloride* 120g/L*)* was used to control algae at a rate of 0,3ml/L for one hectare seedbed. Ridomil gold with the active ingredient (*mefenoxam*45.3%) was used as a preventive treatment, 35 days after sowing at the rate of 213 g/hectare bed against Pythium root rot. Trimming of seedlings was done using a clipper to ensure uniformity of the seedlings and to enhance hardening before transplanting. Before transplanting seedlings were then hardened by depriving them of nutrients and water for 14 days. At the end of the hardening process, 48 hours before transplanting, a chemical called Baytan plus Triademenol 15% WP was applied with a dilution rate of 165g/100L of water and an application rate of 2litres per square metre to prevent sore shin disease caused by *Rhizoctonia solani*.

3.5.2 Land preparation

Deep ploughing was done using a tractor to a depth of 40cm, immediately following the rains (April). The land was then harrowed using a disc harrow to allow a fine tilth to be obtained of vegetation before actual planting was done. Agricultural lime ($CaCO_3$) was applied as a broadcast at 1000kg per hectare to correct soil pH. Flat-topped ridges were constructed which allowed maximum penetration of early rains. The height of the ridges was about 20cm. The soil was loose and friable allowing easy root penetration. Fumigation was done two weeks before planting to control soil borne pathogens especially nematodes. Ethylene dibromide was used as a pre-planting fumigant at an application rate of 125ml/100m ridge.

3.5.3 Planting of tobacco seedlings

Water planting with water of the tobacco seedlings was done 12 weeks after sowing. The size of the planting hole was 20cm and chlopyrifos 48% EC was then applied at the rate of 50mls/25L of water in every planting hole. Chlopyrifos was applied at the base of the plant to prevent cutworms (*Agrotis sergetum*). Float seedlings were pulled after hardening when they were 8-12cm long and pencil thick. Planting stations were marked in each ridge with a hoe, 56cm apart. The distance between ridges was 120cm. Fertiliser application was done to the respective treatments, Fertiliser was applied right onto the planting holes following the standard fertiliser recommendations according to the Tobacco Research Board fertiliser bulletin. Seedlings were then planted to a depth of 5cm.

3.5.4 Fertilization in the field

Compound C (6N:15P:12K) was applied as a basal fertiliser at two weeks after planting at a rate of 600kg per hectare. Double banding was done using a spade at least 10cm on both sides of the plant. Ammonium Nitrate (34.5% N) was applied as top dressing fertilizer at a rate of 150kgs per hectare. Dolloping sticks were used to create a hole into the ground less than 5 cm below surface and 10 cm away from the plant before placing fertilizer in the hole. The first split application was done at 3 weeks after planting at the rate of 100kgs and at three weeks after topping at a rate of 50kgs per hectare.

3.5.5 Weeding

Land was kept weed-free especially during the first 4-5 weeks following planting since the crop cannot tolerate weeds. During the period from two weeks after planting manual weeding was done by means of hand hoeing. Weeds were removed early and crops were kept weed-free during their period of major growth.

3.5.6 Topping and Suckering of tobacco

Topping was done when 10 percent of tobacco plants had reached the required leaf number of eighteen leaves and the top most leaf was 15cm in length. Suckercides N-Decanol and pendimethalin were applied at the rate of 8 and 5mls respectively per every topped plant. The remaining un-topped plants were then topped 7 to 10 days later.

3.6 Data Collection

3.6.1 Leaf Length and Width

Leaf length and width of the tobacco plants were obtained by measuring and calculating the mean leaf length and mean leaf width per plot. A metre rule was used to measure both the leaf length and leaf width. Measurements were done at 11 weeks after planting. The plants that were assessed was tagged on the third leaf to allow more data to be collected as well as for consistence measurements. The middle row in a three row plot was the assessment row measuring 1.2mx 16.8m. Leaf dimensions of 10 plants within each assessment row were taken. The overall experimental plot was 220 metres by 16.8 metres giving a total plot size of 3696m$^{2.}$ The total area of assessment rows was 816m^2 since each assessment row was 16.8m and there were 48 assessment rows.

3.6.2 Root Length of Tobacco

Root length of tobacco was measured by destructive method which involved the uprooting of the mature tobacco plant and the washing of the roots to get rid of the soil. Then a metre rule was used to measure and determine the length of the sampled plants in the net plot. The length was measured in centimetres.

3.6.3 Fresh Leaf Yield (kgha^{-1})

Green leaf yield of each treatment in the net plot was taken just after each picking. All the leaves on the plant were harvested, which resulted in a total of nine pickings for the eighteen leaves which were harvested. The total green leaf yield was calculated by the formula:

Fresh leaf yield (kg ha^{-1}):

$$= \frac{\text{Fresh weight. Plot}^{-1}\text{ (kg) x } 10000 \text{ m}^2}{20.16\text{m}^2}$$

(Khan *et al*, 2008)

3.6.4 Dry Leaf Yield (kg ha^{-1})

To record data concerning leaf yield, the weight of cured leaf in each treatment was taken after each picking. Curing was done using the rocket barn, which is the recent modified system of curing tobacco. The sample for dry leaf yield determination was from the assessment row only as the net plot. The total cured leaf yield was calculated by the following formula:

Cured leaf yield (kg ha-1)

$$= \frac{\text{Cured wt. plot}^{-1}\text{ (kg) x 10000 m}^2}{20.16\text{m}^2}$$

(Khan *et al*, 2008)

3.6.5 Nicotine content of dry (cured) tobacco leaves

Nicotine content of the cured leaves was determined by the method of using mass spectrometry. Cured tobacco leaf samples of one kilogramme were taken for each treatment. Leaves were then cut into small pieces and pulverised into powder form. The dried powder (0.1 g) was extracted three times with about 5mls of methanol by sonication method for 30 minutes. It was then filtered and the filtrate was evaporated near to dryness by an evaporator. The extract was passed through the cleanup column, which was filled with cotton in the bottom. An activated silica gel (10 g) soaked with solvent was loaded into the cleanup column of about 5 cm, which was then topped with 1.5 cm of anhydrous sodium sulfate. Five milliliters of solvent were added to wash the sodium sulfate and the silica gel.

The extracts (1 ml of each sample) were then separately transferred into the column, and the vessel was rinsed twice with 2 ml loaded solvent, which was also added to the column. Sixty milliliters of loaded solvent were added to the column and allowed to flow through the column at a rate of 3–5 ml/min, and the eluent was collected. The collected eluent from the cleanup procedure was re-concentrated to 2 ml by using K-D concentrator. Finally the extract (2 ml) from leaves was filtered through a 0.45 ml Millex HA filter (Millipore, Molsheim, France) prior to GC–MS analysis. The methanol extract (1 ml) was diluted with 5 ml of methanol and the samples were filtered through 0.45 lm membrane filters (Molsheim, France) prior to GC–MS analysis. The GS-MS analysis produced values of nicotine concentration in leaf samples and it was expressed as a percentage of the dry leaf weight before analysis. Leaf quality: The amount of sugars in the leaves was also evaluated by the Analytical chemistry services division. Values for sugar and nicotine contents were compared to find if they match with the required ratio of 6:1 which is the desired sugar to nicotine ratio for a desired, chemically balanced high quality tobacco leaves.

3.6.6 Sugar Content (%)

Reducing sugars percentage was calculated as follows from the results which were obtained from the analysed sample (1kg) of cured dry leaf of tobacco:

$$\% \text{ Reducing Sugars} = \frac{25 \times 100 \times 0.05}{\text{Titrate} \times \text{wt. of sample}}$$

(Steel and Torrie, 1980).

3.6.7 Grade Index

Leaf maturity was shown by a change in colour from green to yellow. Tobacco was reaped ripe to ensure maximum yield and desirable quality. 1-2 leaves per plant per week was reaped to allow uniform curing and this assists in grading. This ensures that only tobacco of similar stalk positions is reaped. Uniform loading of the leaves into the ban was done to ensure adequate airflow, which is necessary for top-quality cures.

Leaves were sorted according to the type, colour, size, texture and blemish and then graded in terms of the reaping groups, quality, colour and defects (Flue-cured tobacco production field guide, 2011). Under the different reaping groups, the tobacco leaves were classified as priming's (P), lugs (X), leaf (L), strips/scrap (A) as well as short leaf (T). Under quality, the classes of tobacco were fine (1), good (2), fair (3), low (4) and poor (5). The colour classes of the tobacco leaves were lemon (L), orange (O), light mahogany (R), dark mahogany (S), green (G) and pale lemon (E). Under defects, the leaves were classified as badly handled (BAD), funked (FD), mouldy (LD), mixed (MD), stem rot (SAD) and split (SD). Thus the tobacco classification was according to the major leaf classification symbols used in Zimbabwe (Flue-cured tobacco production field guide, 2014).

The Grade index (%) was then calculated by the following formula:

$$\text{Grade index} = \frac{\text{(Weight (kg) of cured upper grade leaves in a treatment)}}{\text{(Total weight (kg) of cured leaves in a treatment)}} \times 100\%$$

(Idrees and Khan, 2001)

3.6.8 Water Use Efficiency (WUE) of tobacco.

Water use efficiency (WUE) was calculated by the following formula (Michael, 1978):

$$\text{Water Use Efficiency (kg/ha/cm)} = \frac{Y}{WR}$$

(Joy *et al*. 173)

Where, Y = Cured leaf yield (kg ha-1), WR = Total amount of water used by the crop (cm).

$$WR = IR + ER + \Sigma_{ni=0} \frac{M_{sj}-M_{hj}}{100} A_1D_1$$

Where, IR = Total irrigation water applied (cm), ER = Effective rainfall (cm), Msj = Moisture content (%) at transplanting time in the jth layer of soil, Mhj = Moisture content (%) at harvest time in the jth layer of soil, Aj = apparent specific gravity of the jth layer of soil, Dj = depth of the jth layer of soil (cm).

3.6.9 Data analysis

Split plot analysis of variance was done using GenStat 14th Edition for all the data collected and the means were separated using the Least Significant Difference (LSD) at 5% level of significance.

CHAPTER 4

RESULTS

4.1 Effect of different SAP application rates on Leaf Length of tobacco under different irrigation regimes.

Both SAP application rate and irrigation rate had significant effect on tobacco leaf length (Appendix 1), however the effect was confounded within the significant ($p < 0.05$) SAP rate and irrigation regime interaction. There was interaction ($p < 0.05$) between different super absorbent polymer application rates and different irrigation regimes application on the leaf length of tobacco. There was significant differences ($p < 0.05$) between SAP application and irrigation regimes on the leaf length of tobacco. Results of this study have shown that the highest (77.19cm) leaf length was attained from the application of SAP at the rate of 150kg/ha under irrigation regime of 80% followed by the application of 75kg/ha SAP under 80% irrigation regime with (72.14cm) and there was significant difference between the treatment with 0 $kgha^{-1}$ and the other different rates of SAP which includes 75kg/ha and 225kg/ha. Conversely the application of 0kg/ha of SAP under 40% irrigation regime had statistically the least (60.72cm) leaf length (Fig 4.1).

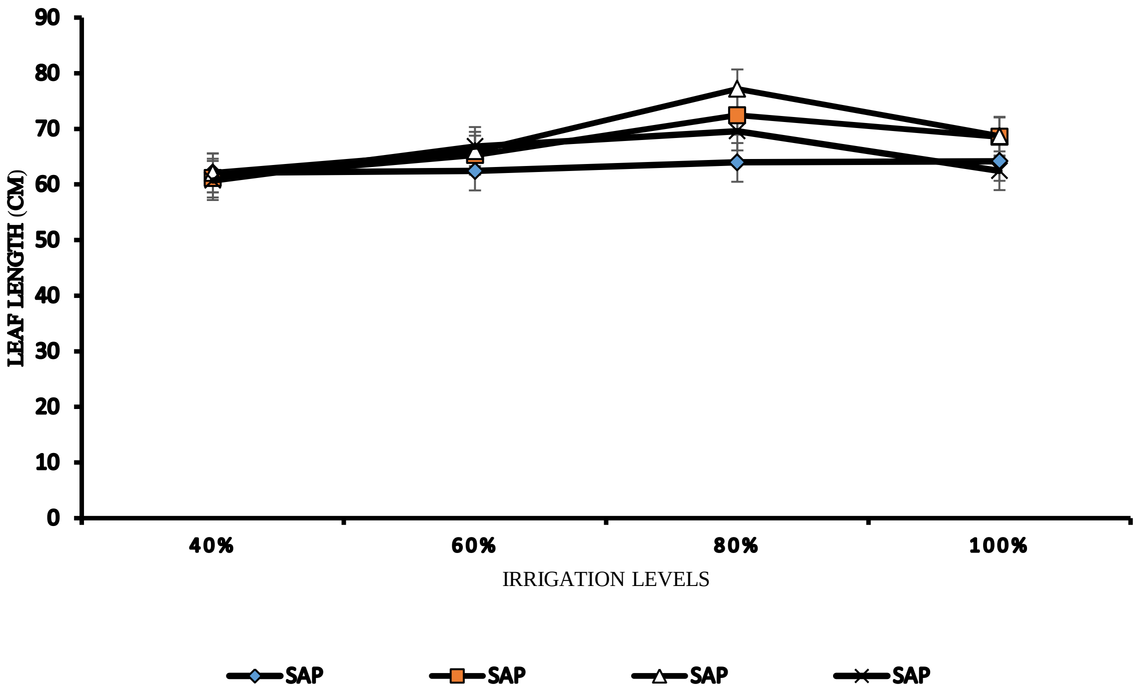

Figure 4.1: Effect of different SAP application rates on Leaf Length of tobacco under different irrigation regimes. Error bars indicate standard error

4.2 Effect of different SAP application rates on Leaf Width of tobacco under different irrigation regimes.

There was interaction ($p < 0.05$) effects between different super absorbent polymer and different irrigation regimes application on the leaf width of tobacco. There was significant differences ($p < 0.05$) between SAP application and irrigation regimes on the leaf width of tobacco. The highest (46.02cm) leaf width was attained from the application of SAP at the rate of 150kg/ha under irrigation regime of 80% followed by the application of 75kg/ha SAP under 80% irrigation regime with (45.34cm) and there was significant difference between the treatment with 0 $kgha^{-1}$ and the other different rates of SAP which includes 75kg/ha and 225kg/ha. Conversely the application of 75kg/ha of SAP under 40% irrigation regime had statistically the least (29cm) leaf width signifying the importance of adequate water availability in plant growth (Fig 4.2).

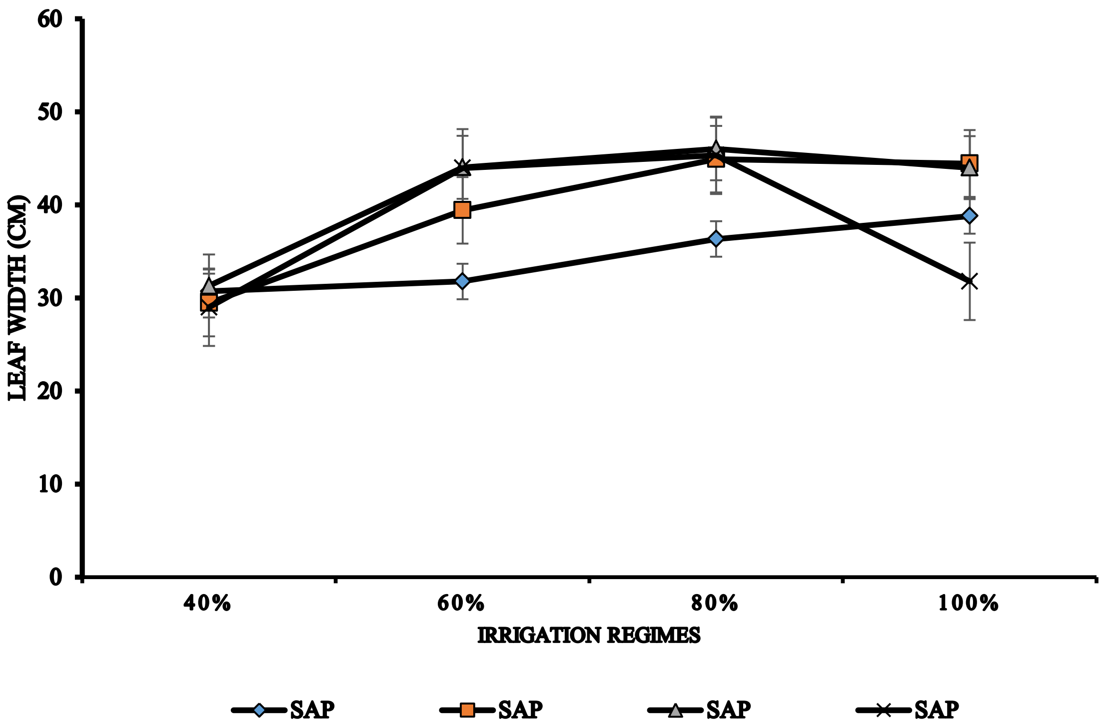

Fig 4.2 Effect of different SAP application rates on Leaf Width of tobacco under different irrigation regimes. Error bars indicating standard error.

4.3 Effect of different SAP application rates on the Root length of tobacco under different irrigation regimes

There was no interaction ($p > 0.05$) between different SAP application rates and different irrigation regimes on the root length of tobacco. However there was significant ($p < 0.05$) difference of different irrigation regimes on tobacco root length. The root length which recorded longer (42.70cm) was obtained at 100% irrigation regime, whilst the minimum (34.93cm) root length was obtained at 40% irrigation regime signifying the importance of water in the growth and expansion of tobacco root system (Table 5).

Table 5. Effect of different SAP application rates on the Root length of tobacco under different irrigation regimes

Irrigation Regime	**Means**
100% Irrigation Regime	42.70^{a}
80% Irrigation Regime	37.24^{b}
60% Irrigation Regime	36.55^{b}
40% Irrigation Regime	34.93^{b}
LSD	3.752
Cv %	5.0
Grand Mean	37.86
P value	$P < 0.010$

* Numbers with different (a, b) letters are significantly different from each other.

4.4 Effect of different SAP application rates on Fresh Leaf Yield of Tobacco under different irrigation regimes.

There was interaction ($p < 0.05$) between different super absorbent polymer rates and different irrigation regimes application on the fresh leaf yield of tobacco. There was significant differences ($p < 0.05$) between SAP application and irrigation regimes on the fresh leaf yield of tobacco. The highest fresh leaf yield of tobacco (7 558kg/ha) was attained at 80% irrigation level with the SAP application rate of 150kg/ha, followed by the application of 75kg/ha SAP under 80% irrigation regime with (7 020kg/ha). Conversely the application of 75kg/ha, 0kg/ha and 225kg/ha of SAP under 40% irrigation regime had statistically the least (3 480kg/ha) of fresh leaf yield of tobacco.

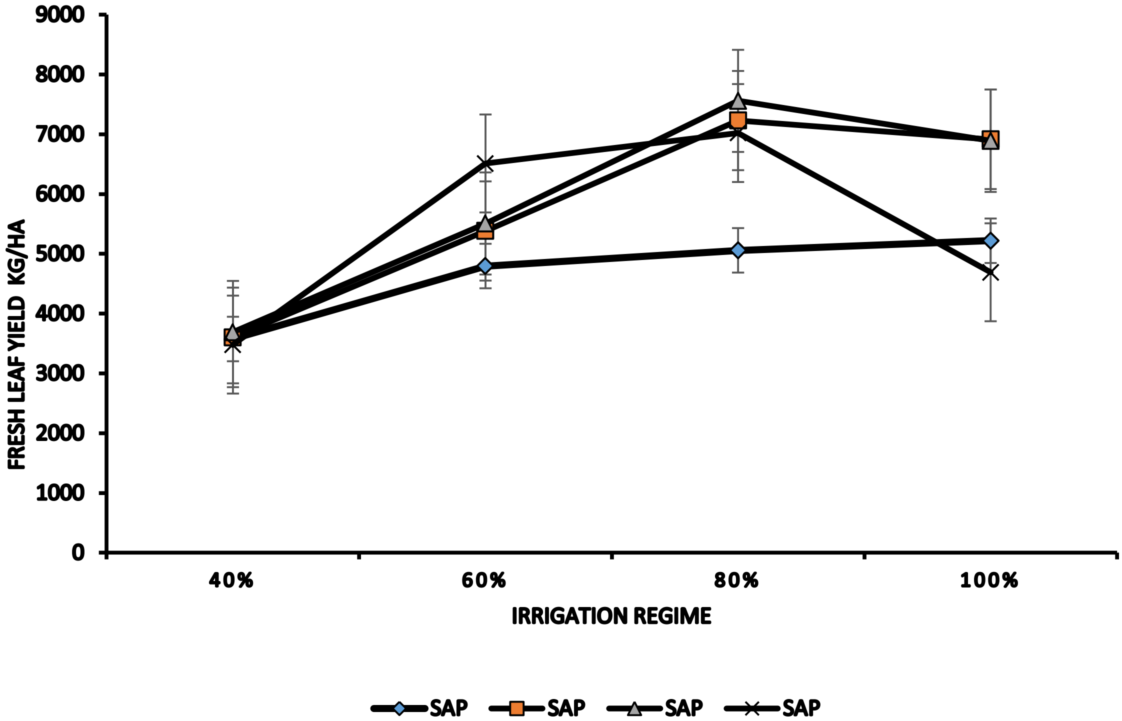

Fig 4.4 Effect of different SAP application rates on Fresh Leaf Yield of Tobacco under different irrigation regimes. Error bars indicate standard error

4.5 Effect of different SAP application rates on Dry Leaf Yield of Tobacco under different irrigation regimes

There was an interaction ($p < 0.05$) between the application of different SAP rates and different irrigation regimes on the dry leaf yield of tobacco. There was significant differences ($p < 0.05$) between different SAP application rates and irrigation regimes on the dry leaf yield of tobacco. The highest (2 017kg/ha) dry leaf yield of tobacco was attained at 80% irrigation level with SAP rate of 150kg/ha and SAP rate of 75kg/ha yielding more cured leaf yield per hectare. The lowest (653kg/ha) dry leaf yield of tobacco was attained at 225kg/ha under 40% irrigation regime. A gradual decrease of yield was seen especially on SAP rate of 225kg/ha with the 100% field capacity. Although there was significant differences between the treatments on 100% Irrigation regime, the total saleable yield was at a decrease.

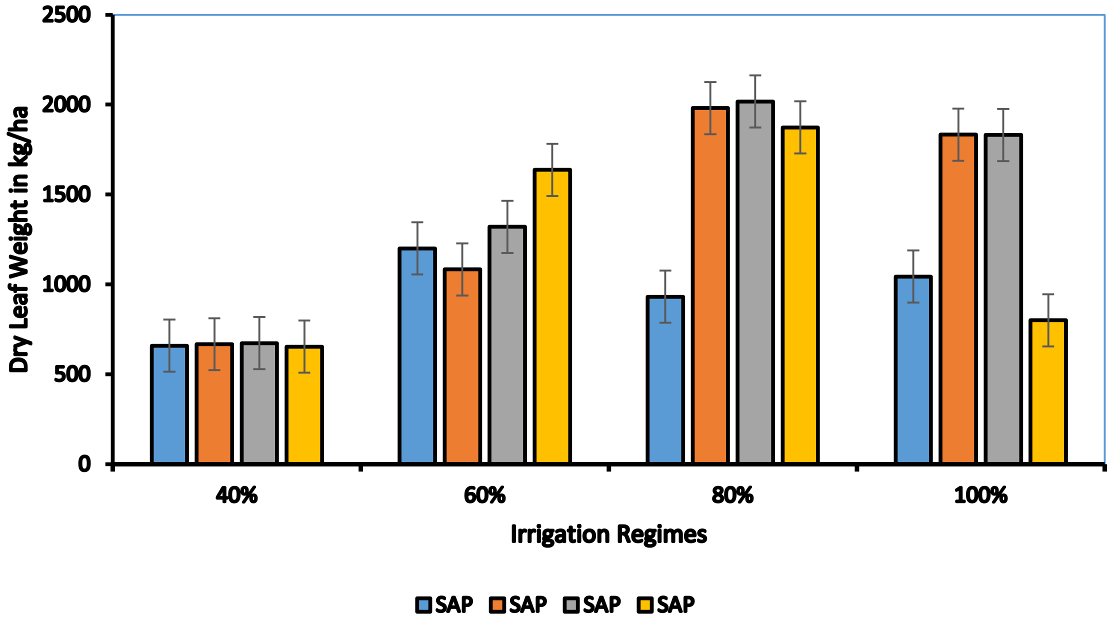

Fig 4.5 Effect of different SAP application rates on Dry Leaf Yield of Tobacco under different irrigation regimes. Error bars indicating standard error

4.6 Effect of different SAP application rates on % Nicotine Content of dry (cured) tobacco leaves under different irrigation regimes.

There was interaction ($p < 0.05$) between different SAP application rates and different irrigation regimes on nicotine percentage of the tobacco variety under the study. There was significant ($p < 0.05$) difference between different SAP rates under different irrigation regimes. The highest (3.55%) nicotine content recorded of dry weight was on the application of 80% irrigation regime and 150kg/ha of SAP, followed by (3.05%) which was obtained at 75kg/ha application under the same irrigation regime of 80%. Conversely the least (1.05%) nicotine value was found at 150kg/ha under the 40% irrigation regime. Trends were the same for the highest rate of SAP at 100% of irrigation level, whereby the response of nicotine percent after analysis was found to decrease.

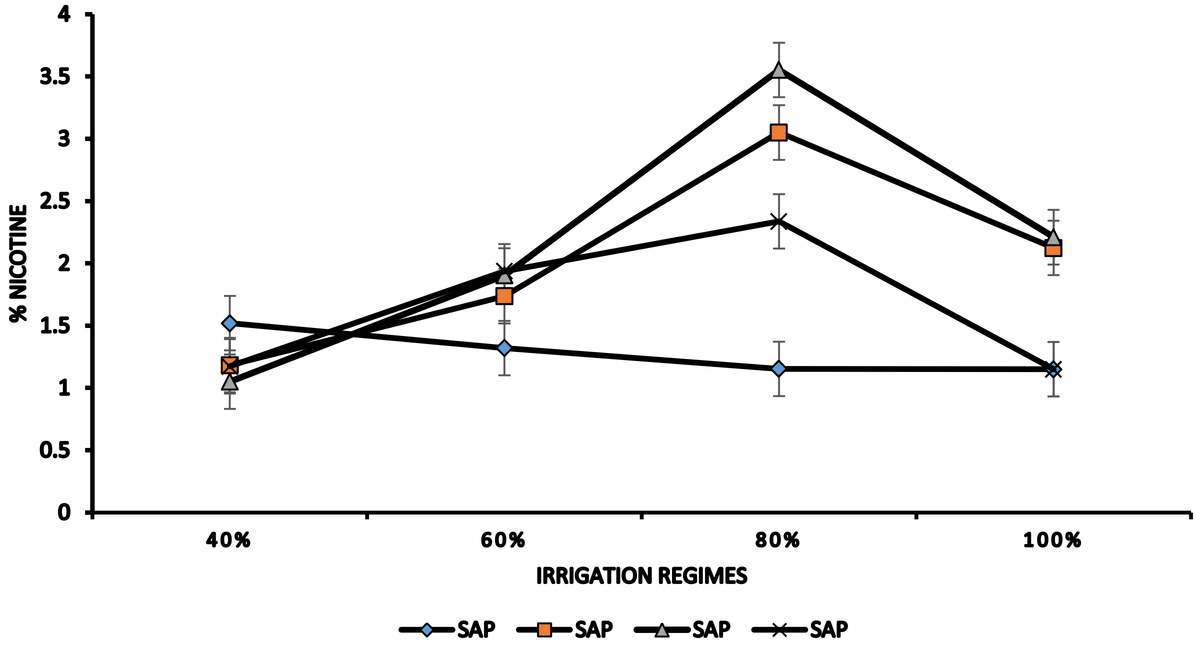

Fig 4.6 Effect of different SAP application rates on % Nicotine Content of dry (cured) tobacco leaves under different irrigation regimes. Error bars indicate standard error

4.7 Effect of different SAP application rates on % Sugar Content of dry (cured) tobacco leaves under different irrigation regimes.

There was an interaction ($p < 0.05$) between different irrigation levels and different SAP application rates on the percent sugar content of the cured leaf of tobacco. There was significant ($p < 0.05$) effect between different SAP rates and different irrigation regimes. However there was no significant effect ($p > 0.05$) on the effect of different irrigation regimes on the total sugar content of tobacco. The highest (17.8%) sugar content percentage value was found at 80% irrigation regime and SAP application rate of 150kg/ha, whilst the least (13.88%) sugar content value was obtained at 40% irrigation regime with an SAP rate of 75kg/ha.

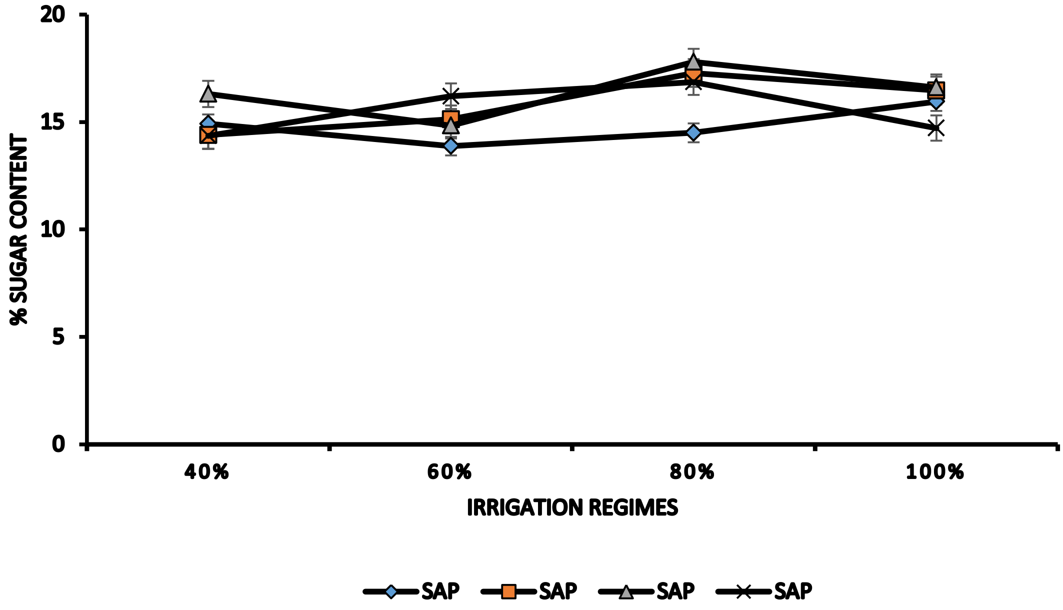

Fig 4.7 Effect of different SAP application rates on % Sugar Content of dry (cured) tobacco leaves under different irrigation regimes. Error bars are indicating standard error.

4.8 Effect of different SAP application rates on Grade Index of dry (cured) tobacco leaves under different irrigation regimes.

There was interaction ($p < 0.05$) on irrigation levels and SAP compound on the grade index of tobacco. Also there was significant differences ($p < 0.05$) between the application of SAP and different irrigation regimes. The best (80.67%) grade that was obtained was found between 80% irrigation level and SAP application of 150kg/ha. The least (42%) grade was found at 40% irrigation regime and 225kg/ha of SAP. The same trend was also shown at 100% irrigation level, but the most declining variable being that at 225kg/ha with the 100% irrigation level.

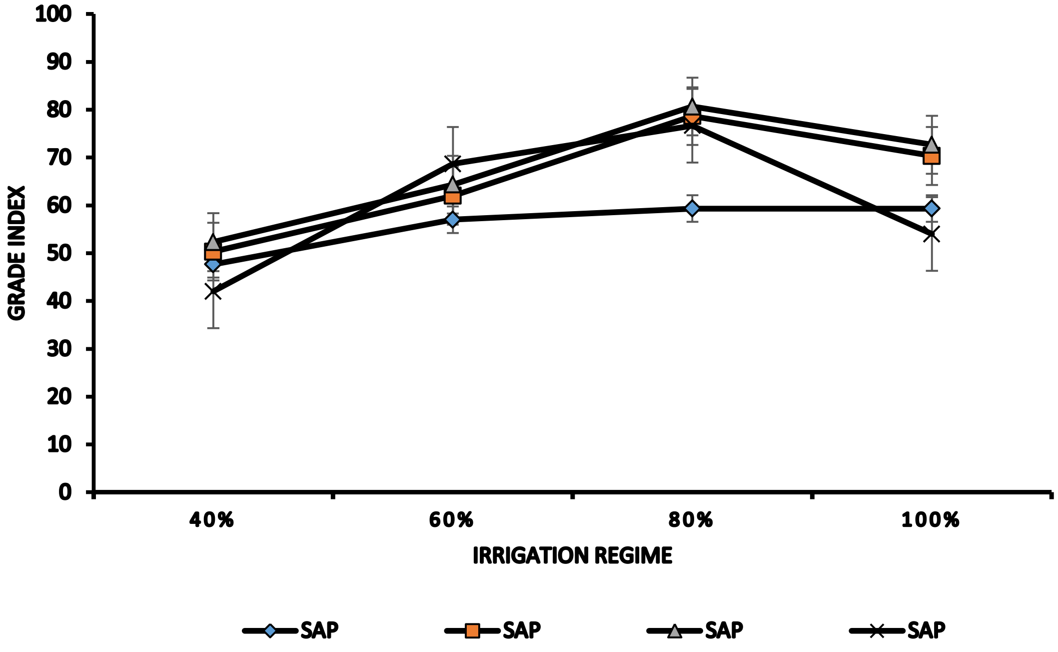

Figure 4.8 Effect of different SAP application rates on Grade Index of dry (cured) tobacco leaves under different irrigation regimes. Error bars indicate standard error.

4.9 Effect of different SAP application rates on Water Use Efficiency (WUE) of tobacco under different irrigation regimes.

There was interaction ($p < 0.05$) on irrigation levels and SAP compound on the water use efficiency of tobacco. Also there was significant differences ($p < 0.05$) between the application of SAP and different irrigation regimes. The best (79.84%) WUE which was obtained from this study was on 75kg/ha application of SAP at 60% irrigation regime. The lowest (39.16%) WUE which was obtained from this study was on 0kg/ha application of SAP at 40% irrigation regime.

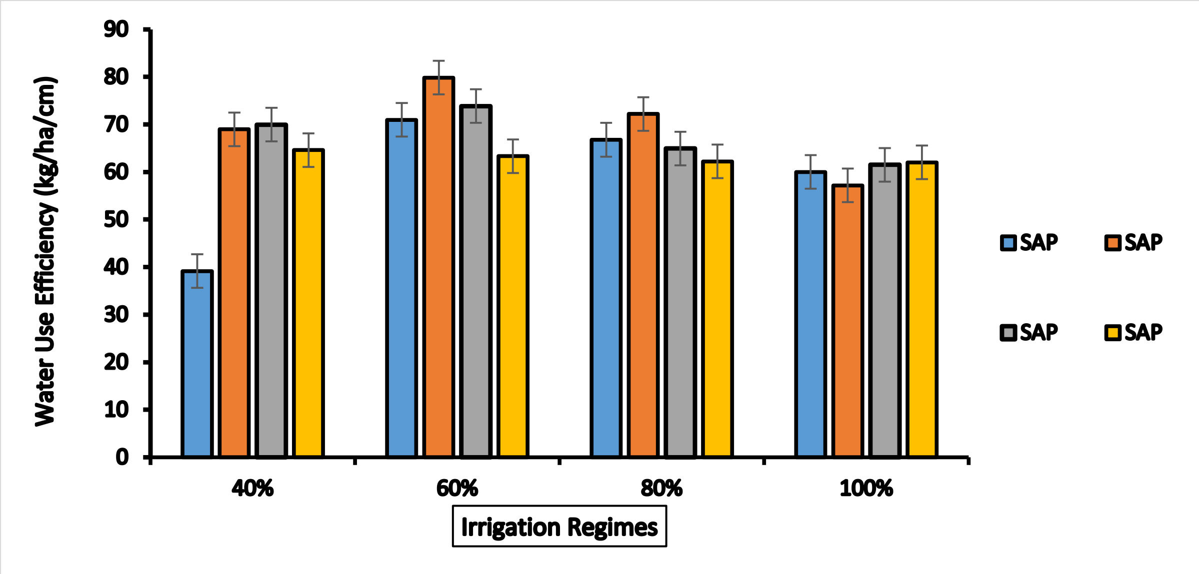

Fig 4.9: Effect of different SAP application rates on Water Use Efficiency (WUE) of tobacco under different irrigation regimes.

CHAPTER 5: Discussion

5.1 Effect of different SAP application rates on Leaf Length of tobacco under different irrigation regimes.

Leaf length is very important to cigarette processors and manufacturers since it affects the lamina to stem ratio. A high ratio of lamina to stem is desirable in manufacturing cigarettes (Edwards, 2005). The observed differences amongst the treatment combinations in relation to leaf length of the variety under review was taken to be attributed to the effect of the treatment combinations at par pertaining to other agronomic practices administered on the experimental plots. T75 standing as a newly improved variety of the flue cured genera, this variety exhibited its best potential in terms of leaf length as a component of yield at treatment combinations: Super-absorbent polymer rate of 150 kg/ha under 80% irrigation regime. This results and observation was garnered by the influence of the retaining ability and capacity of SAP for the prime component of potency-water. Although the variety T75 had been bred for yielding and giving the best outcomes from the farming enterprises by smallholder farmers, its potential agronomic attribute and performance could not be realised without addressing the vital component of growth- water. Thus the application of SAP into the soil helped in the retention of water and nutrients which also helped the plant to be able to endow both water efficiency, nutrient efficiency and by and large radiation efficiency due to the improved size of the leaves garnered by rapid expansion and elongation from adequate water availability in the rhizosphere.

Again at other (SAP rates of 75kg/ha and 225kg/ha under different irrigation regimes of 40% and 100% respectively) administered treatment combinations the leaf length of tobacco was not so much influenced due to the effect of both extremes. The possible cause of the undesired results from some other treatment combinations was due to the influence and effect of the genetic potential of the variety T75, its favourable agronomic practices to achieve its potential and perhaps the period when this variety was grown. So this means that, though the study was aiming at looking for the retention ability of SAP towards water conservation, it also helped the researcher in coming up with the best rate of SAP application and a fairly water saving irrigation regime of 80%, which on its on plays a major role towards water saving and utilisation of an irrigation deficit management practice in tobacco production countrywide.

5.2 Effect of different SAP application rates on Leaf Width of tobacco under different irrigation regimes

The geometric mean and plant architecture in terms of its canopy cover of a plant is mainly influenced by the length and width of the plant's leaves. These have different factors which influence the growth (i.e. expansion and elongation) of the leaf. In tobacco production the most important yield component is the leaf, so most of the agronomic practices are administered in order to have the best leaf size and quality at the end of the production cycle. So besides some of the most imminent factors which influence the growth and expansion of the tobacco leaf, water is one of the most prime important factor which alters the growth and expansion of the tobacco leaf. However, the researcher sought to address the water shortage problem by studying on the water retention capacity of a soil additive SAP, yet at the same time observing the influence of the retained water towards the growth and expansion of the leaf.

From all the treatment combinations which include the irrigation regime and SAP levels, the leaf width had no significant effect at 40% irrigation regime with all levels of SAP. This might be due to the lack of the adequate available water relative to the plant's water requirements, where it probably strives above a 50% irrigation regime. There was a significant increase in leaf width up to 60% irrigation regime with the best result of leaf width attained at 225kg and 150kg SAP levels. This treatment combination was statistically significant from the standard.

At 80% irrigation regime versus other rates, there was not much difference in performance, so these treatment combinations except the standard were not statistically significant from the lower regime of 60%. This means that water requirements of tobacco has got a certain threshold which needs to be attained so as to reach the maximum potential of growth and expansion of the leaf.

Irrigation and the application of SAP had dramatic effects on the morphological traits under review. With the increase of irrigation water of 60% and 80%, the inherent morphological trait was improved. This happens because of the reason that all vital and metabolic activities of the tobacco plant depend mainly on the availability of water. Any kind of water stress reduce tissues pressure potential which leads to reduced water potential in the meristem tissues then this lead to plasmolysis, reduction of cell expansion and cell division which all cause decreased protein cell wall synthesis (Hopkinson, 2005). Under drought stress conditions, cell elongation in higher plants is inhibited by reduced turgor pressure. Reduced water uptake results in a decrease in tissue water contents. As a result, turgor is lost. Likewise, drought stress also trims down the photo assimilation and metabolites required for cell division. As a consequence, impaired mitosis, cell elongation and expansion result in reduced growth hence there is a compromised state of the leaf width due to lack of normal expansion capabilities of the leaf.

5.3 Effect of different SAP application rates on the Root length of tobacco under different irrigation regimes

The application of SAP under different irrigation regimes had no significant effect on the root extension and elongation process. However the irrigation regimes had a significant effect on the total length of root growth, with 100% irrigation regime giving the best root length. The main reason why root length is of paramount importance in tobacco production is due to the type of moisture movement in the sandy loamy soils, which goes vertically. Hence there is need for long root length so as to be able to utilize all the moisture supplied into the soil. The bidirectional movement of water in and out of roots implies that water does not meet differential resistance to flow through non suberized roots moving in both directions (Caldwell *et al.*, 1998). However, most water exchange occurs in the young and distal portions of the root system (Caldwell *et al.*, 1998), and properties of this area affect HR (hydraulic retention) patterns and water flow differently (Warren *et al.*, 2007; Scholz *et al.*, 2008). So by this phenomenon highlighted it is so important to have roots which can extend in length so as to have the ability to access water and at the same time enhancing plant growth. By application of SAP high amounts of water can be collected, stored, and then released gradually for crop growth over duration between two irrigation or rainfalls. Therefore, the application of SAP is a suitable method in irrigation deficit conditions because these materials moderate the negative effect of deficit water and so the irrigation period of a crop can be increased by their application (Dabhi *et al.,* 2013). It has been reported that SAP consumption under drought stress reduces the damage caused by stress in the cytoplasmic membrane and subsequently decrease leakage of cell contents. Moreover, SAP reduces the production of destructive biomarkers and reactive oxygen species by increasing the water availability and thereby antioxidant enzymes activity decreases. These factors reduce the costs implied by supporting plants to neutralize the negative impacts of drought stress and finally enhance plant growth and yield (Rahmani *et al*., 2009; Islam *et al*., 2011; Pouresmaeil *et al*., 2013).

5.4 Effect of different SAP application rates on Fresh Leaf Yield of Tobacco under different irrigation regimes.

The effect of different irrigation regimes and SAP application in different rates on the fresh yield of tobacco was quite pronounced at 80% irrigation level with both 75kg, 150kg and 225kg of SAP having the highest and remarkable amount of fresh yield of tobacco leaf.
The fresh leaf yield of tobacco (T75), at 40% irrigation level with all the rates of the SAP compound applied was not statistically significant from each other, and also the total leaf yield as computed per hectare was very low, reaching almost 3000kg of fresh leaf yield. This is because, although the SAP soil additive was added, the amount of water for absorption was far much below the water requirements of the tobacco crop, leading to a compromised state of both anabolic and catabolic processes necessary for growth of the plant.

The first signs of water shortage due to the application of 40% irrigation regime under low amounts of SAP in tobacco is the reduction of turgor pressure leading into the reduction of growth of cells namely in the stem and leaf. The growth of cells is the most important process being affected in water stressed environments. The reduction of cell growth leads to the reduction of plant height and reduction of leaf size hence leading to decrease in total fresh leaf yield per hectare. By reducing turgor pressure due to water shortage, cell growth is reduced due to the pressure inside the cell. Thus, there was a significant relation between the reduction of cell size and reduction of water in plant tissues. Because of this, the first tangible effect of drought on the plants is the small size of leaves or low size of plants. By reducing leaf area, sun light absorption and photosynthesis level of the plant is reduced and it leads to the reduction in production of dry matter and plant yield (Hong-Bo et al., 2008). The results of this study showed that applying SAP to the lack of using it had positive and significant ($P<0.05$) effect on most of the tested attributes in irrigation interval. In the current study, by applying 75kg of SAP, considering the economics of the agricultural enterprise at 80% irrigation level had the highest fresh yield which was achieved. This is because water availability in adequate amounts facilitates leaf expansion and hence result in big leaves, resulting in high fresh yield of tobacco per hectare.

5.5 Effect of different SAP application rates on Dry Leaf Yield of Tobacco under different irrigation regimes

Dry leaf yield was significantly affected by irrigation, superabsorbent, and their interaction between irrigation× super absorbent. The application of 40% irrigation regime coupled with all the rates of SAP had the least tonnage in terms of the dry leaf yield of tobacco. This may be due to the effect of reduced number of leaves per plant, individual leaf size and leaf longevity by decreasing the soil's water potential, which is the main chief factor in leaf elongation and expansion. Leaf area expansion depends on leaf turgor, temperature, and assimilating supply for growth which is a phenomenon encountered when water is administered in adequate amounts as was seen on the application of 150kg/ha of SAP under 80% irrigation regime.

So lack of adequate water amounts within the soil zone caused reduction in leaf area and its expansion through reduction in photosynthesis and important metabolic process in the plant. Reduction of production in fresh and dry biomass production is a common adverse effect of water stress on crop plants. It can be concluded that plant leaf area, fresh and dry leaf yield can decrease noticeably with increasing water stress. So bearing that in mind, then current results showed that, adequate water supply although under a deficit irrigation strategy, produced good dry leaf yield as compared to treatments which had no adequate water amounts.

5.6 Effect of different SAP application rates on % Nicotine Content of dry (cured) tobacco leaves under different irrigation regimes.

Percentage of nicotine is one of the most important traits in the production of tobacco. When tobacco grows in field with abundant waters percentage of nicotine decreases in leaf (Sifola and Postiglione, 2002), which is a desired trait, that explains the reason why the trend of nicotine percentage by weight at 100% irrigation regime and the provision of 225kg/ha of SAP had the least amount of nicotine that was obtained from the chemical analysis of the experimental plots leaves.

Balance of nicotine and carbohydrate synthesis depends on activity of an enzyme called nitrate reductase (Weybrew *et al*, 2004). In highly irrigated, N is leached and its absorption by tobacco will be decreased. Therefore, lack of N inhibits the activity of this enzyme (*Nitrate reductase*) leading to production of more carbohydrates and less nicotine in leaf (Reynolds and Rosa, 1995). Synthesis of nicotine takes place in root areas of tobacco when the water is not available enough, root system deepens and expand in soil causing more nicotine synthesis which backs off the highest rate of nicotine content which was obtained at 80% irrigation regime and the 150kg/ha and the 75kg/ha since there was no any significant difference in terms of total percent nicotine by mass that was obtained between these SAP rates.

5.7 Effect of different SAP application rates on % Sugar Content of dry (cured) tobacco leaves under different irrigation regimes.

In the lowest irrigation regime, irrigation in 60% soil water depletion, the percentage of sugar was decreased. A way that plant can resist drought is to decrease its osmotic pressure in order to increase its pressure plant have to dissolve some of its polymers. This process turgids cell causing higher pressure potential to cope with lack of water. In drought stress hydrolysing enzymes such as amylase increases. Amylase then dissolve starch, which is the main ingredient of tobacco leaf, to reducing sugar leaving less amount of starch in leaf (Layton and Nielsen, 1999). This results confirm the findings of Sifola *et al*. (1998) and Philips *et al*. (1991), who reported that tobacco produced in water rich field in comparison to dry field contained high amount of carbohydrate and less alkaloids. Although there was interaction between the treatment factors and level combinations, the 80% irrigation regime proved too work fairly well due to the noticed highest amount of sugar percentage that was obtained.

5.8 Effect of different SAP application rates on Grade Index of dry (cured) tobacco leaves under different irrigation regimes

The possible explanation that can be provided for the grade index which was obtained on the tobacco variety T75 in light with the administered SAP compound and the irrigation regimes is that; grade index is entirely affected by the availability of adequate water amounts within the soil-plant- atmosphere continuum. Water availability at all times helps to avoid plasmolysis let alone wilting of the tobacco leaves hence this will avoid also the problem of false ripening hence there is improved normal maturity of the leaves hence improving on the grade index of the tobacco leaves. Again in terms of drought exposition of tobacco leaves to inadequate water amount as shown by the irrigation regime of 40% and all the rates of SAP compound which were administered, the grade of tobacco remained lower since wilted leaves are very hard to cure hence they produce poor quality leaves hence lower grade index.

Too much of water quantity within the rhizosphere of the tobacco plant compromise the metabolic processes within the plant which is seen at 100% irrigation regime and 225kg/ha. This has an overall effect on the chemical constituencies when water goes beyond the normal plant water requirements.

5.9 Effect of different SAP application rates on (WUE) of tobacco leaves under different irrigation regimes.

From the results which were obtained from the water use and yield per hectare computations, the relative and added advantage attained due to the application of SAP as a novel strategy towards the efficiency of water usage in the irrigation process of tobacco was enormous. So the most pronounced WUE in the administered treatment combinations of irrigation and SAP application was found at the application of 75kg/ha of SAP under the irrigation regime of 60%. Crop water use efficiency of tobacco had a positive relationship with the application of different SAP rates under the rates of different irrigation regimes applied. The dynamic interrelation between SAP and irrigation affected both tobacco yield and actual evapotranspiration. The response of WUE of tobacco to the application of SAP under different irrigation regimes changes depending on the rate of the SAP rate applied and the different irrigation regimes administered.

Chapter 6:

Conclusions and Recommendations.

6.1 Conclusions

Based on the results of this experiment, SAP application rates under different irrigation regimes application in a deficit management practice in arid and semi-arid climates is an effective strategy for suitable utilization of scarce water resources. Although this method may cause some decrease in yield on some rates of SAP application which are found on the extreme ends, an appropriate strategy of application will increase the efficiency of water use, without substantial reduction in crop yield. In addition, SAPs are suitable materials for adequate supply of crop water requirement and prevention from water and nutrients loss from the rhizosphere. In regard to the results and data collected and analysed, the application of SAP rates under different irrigation regimes improved the growth parameters (leaf length and width) of tobacco with the highest (77.19cm) leaf length attained from the application of SAP at the rate of 150kg/ha under irrigation regime of 80% followed by the application of 75kg/ha SAP under 80% irrigation regime with (72.14cm). Conversely the application of 0kg/ha of SAP under 40% irrigation regime had the least (60.72cm) leaf length. Also the quality indexes recorded showed a positive relation with the application of different SAP rates under different irrigation regimes. In the present study, the use of polymers in the rate of 150 kg/ha increased the amount of tobacco dry leaf yield by 12% and the amount of water use efficiency by 14% compared to control treatments. Overall, irrigation SAP application at 150kg/ha under an irrigation regime of 80% proved to be the suitable alternative moisture conservation strategy for crop production in areas affected by drought stress in Zimbabwe, since this strategy helps to improve the substantial yield of tobacco per unit measure of water used.

6.2 Future recommendations

I recommend that farmers adopt this technology which involves the use of 150 kg/ha SAP under an irrigation regime of 80% in order to maximise on the potential growth, yield and quality of tobacco.

Although the study revealed some important findings in regard to the positive influence of SAP under different irrigation regime, the following areas must further be explored:

1. Economic analysis on the use of SAPs as a soil amendment in agricultural fields
2. Conduct second and third year field trials for this experiment and to understand the physiological characteristics with other crops
3. Understand the life cycle of SAPs in soil

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List of Appendices

Appendix 1 Analysis of variance of the leaf length of tobacco.

Variate: Leaf Length

Source of variation	d. f.	s. s.	m. s.	v. r.	F pr.
Block stratum	2	2.907	1.453	0.44	
Block. IRRIGATION stratum					
IRRIGATION	3	526.613	175.538	53.59	<.001
Residual	6	19.655	3.276	0.69	
Block. IRRIGATION. SAP stratum					
SAP	3	191.843	63.948	13.43	<.001
IRRIGATION.SAP	9	208.479	23.164	4.87	<.001
Residual	24	114.263	4.761		
Total	47	1063.759			

Appendix 2 Analysis of variance of the leaf width of tobacco.

Variate: Leaf Width

Source of variation	d. f.	s. s.	m. s.	v. r.	F pr
Block stratum	2	4.293	2.147	1.55	
Block. IRRIGATION stratum					
IRRIGATION	3	1138.849	379.616	273.85	<.001
Residual	6	8.317	1.386	1.09	
Block. IRRIGATION. SAP stratum					
SAP	3	318.408	106.136	83.28	<.001
IRRIGATION.SAP	9	493.091	54.788	42.99	<.001
Residual	24	30.585	1.274		
Total	47	1993.545			

Appendix 3 Analysis of variance of the root length of tobacco

Variate: Root Length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	241.48	120.74	8.56	
Block. IRRIGATION stratum					
IRRIGATION	3	409.07	136.36	9.67	0.010
Residual	6	84.63	14.11	0.32	
Block.IRRIGATION.SAP stratum					
SAP	3	59.09	19.70	0.45	0.721
IRRIGATION.SAP	9	624.51	69.39	1.58	0.179
Residual	24	1056.20	44.01		
Total	47	2474.98			

Appendix 4 Analysis of variance of the Fresh weight of tobacco (kg/ha)

Variate: Fresh Weight

Source of variation	d. f.	s. s.	m. s.	v. r.	F pr.
Block stratum	2	160424.	80212.	0.75	
Block. IRRIGATION stratum					
IRRIGATION	3	63749400.	21249800.	199.47	<.001
Residual	6	639184.	106531.	0.54	
Block. IRRIGATION. SAP stratum					
SAP	3	11346115.	3782038.	19.25	<.001
IRRIGATION.SAP	9	16553912.	1839324.	9.36	<.001
Residual	24	4715601.	196483.		
Total	47	97164637.			

Appendix 5 Analysis of variance of the Dry weight of tobacco (kg/ha)

Variate: Dry Weight

Source of variation	d. f.	s. s.	m. s.	v. r.	F pr.
Block stratum	2	8679.	4340.	0.17	
Block. IRRIGATION stratum					
IRRIGATION	3	6798453.	2266151.	88.89	<.001
Residual	6	152958.	25493.	0.76	
Block. IRRIGATION. SAP stratum					
SAP	3	1782546.	594182.	17.70	<.001
IRRIGATION.SAP	9	3705810.	411757.	12.26	<.001
Residual	24	805755.	33573.		
Total	47	13254200.			

Appendix 6 Analysis of variance of the Nicotine content of tobacco (%)

Variate: Nicotine (%)

Source of variation	d. f.	s. s.	m. s.	v. r.	F pr.
Block stratum	2	0.39874	0.19937	7.80	
Block. IRRIGATION stratum					
IRRIGATION	3	10.45269	3.48423	136.25	<.001
Residual	6	0.15343	0.02557	0.29	
Block. IRRIGATION. SAP stratum					
SAP	3	5.75744	1.91915	22.00	<.001
IRRIGATION.SAP	9	8.19265	0.91029	10.44	<.001

Residual	24	2.09343	0.08723		
Total	47	27.04838			

Appendix 7 Analysis of variance on the Sugar content of tobacco (%)

Variate: Sugar (%)

Source of variation	d. f.	s. s.	m. s.	v. r.	F pr.
Block stratum	2	1.0549	0.5275	0.33	
Block. IRRIGATION stratum					
IRRIGATION	3	22.0564	7.3521	4.66	0.052
Residual	6	9.4584	1.5764	1.79	
Block. IRRIGATION. SAP stratum					
SAP	3	15.5037	5.1679	5.87	0.004
IRRIGATION.SAP	9	26.0154	2.8906	3.29	0.010
Residual	24	21.1147	0.8798		
Total	47	95.2036			

Appendix 8 Analysis of variance on the Grade Index of tobacco (%)

Variate: Grade Index

Source of variation	d. f.	s. s.	m. s.	v. r.	F pr.
Block stratum	2	2.375	1.188	0.10	
Block. IRRIGATION stratum					
IRRIGATION	3	4065.500	1355.167	110.44	<.001
Residual	6	73.625	12.271	3.01	
Block. IRRIGATION. SAP stratum					

SAP	3	983.000	327.667	80.24	<.001
IRRIGATION.SAP	9	986.500	109.611	26.84	<.001
Residual	24	98.000	4.083		
Total	47	6209.000			

Appendix 9: Analysis of variance on the Water Use Efficiency (WUE)

Variate: WUE

Source of variation	D.F.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	14.21	7.11	0.66	
Block. IRRIGATION stratum					
IRRIGATION	3	1118.40	372.80	34.70	<.001
Residual	6	64.45	10.74	0.50	
Block.IRRIGATION.SAP stratum					
SAP	3	772.72	257.57	12.03	<.001
IRRIGATION.SAP	9	1755.32	195.04	9.11	<.001
Residual	24	513.96	21.41		
Total	47	4239.06			