International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 19 No. 4 Mar. 2017, pp. 806-812

http://www.ijias.issr-journals.org/

Effect of two watering systems on sorghum productivity in Burkina Faso, West Africa

Pane Jeanne d'Arc Coulibaly[1], Daniel Okae-Anti[2], Badiori Ouattara[1], Thomas Gaiser[3], and Michel Papaoba Sedogo[1]

[1]Institut de l'Environnement et de Recherches Agricoles (INERA), Centre de Recherches Environnementales, Agricoles et de Formation de Kamboinsé, Burkina Faso

[2]Department of Soil Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, Ghana

[3]University of Bonn, Germany

ABSTRACT: Sorghum is the staple crops in the Saharan areas of West Africa. Like other crops, its production is highly dependent on the improved crop seed varieties and on water use efficiency (WUE) and nitrogen use efficiency (NUE). The objective of this study was to assess the effect of sorghum root growth and water and nitrogen use efficiency on grain yield and harvest index under rainfed and drip irrigation conditions. The study was conducted in the Central region of Burkina Faso in 2014. The improved seed variety Sariaso 14 was sown. 60 kg ha^{-1} of nitrogen was applied. A randomized split-split-plot design with four replications was used. The results showed that the two watering systems had significant effects on sorghum WUE, NUE, root growth, grain yield and harvest index. Root growth was found to be twice higher in the rainfed condition than in the irrigation one. On the other hand, WUE and NUE were higher by 92 and 26% respectively in the irrigated plot. Irrigation was found to improve grain yield and harvest index by 44% and 56% respectively. Irrigation is considered more beneficial for farmers given the erratic distribution of rainfall.

KEYWORDS: Burkina Faso, sorghum, irrigation, rainfed, WUE, NUE.

1 INTRODUCTION

Sorghum is the main staple crops in the semi-arid regions of West Africa. Like other crops, its production is highly dependent on the use of improved crop seed varieties and on the efficient use of water and nitrogen ([1]; [2]). According to reference [3], the improved seed variety has high production; it is also early maturing, drought resistance, or high yielding potential.

In arid and semiarid regions, water and nitrogen are the factors that limit plant productivity ([4]; [5]). Some findings show that water and nitrogen use by plant are correlated: low nitrogen input enhanced drought tolerance and therefore improved water use efficiency [6]. These authors advised the use of low concentration of nitrogen under water stress condition. Reference [7] in their study reported also the negative impact of increasing nitrogen application in severe drought stress.

WUE and NUE are two critical important concepts used to estimate crop productivity. WUE is a yield determinant factor under stress condition [8], while NUE is a concept assessing crop production systems [9]. According to reference [10], WUE is dependent on the quantity of water used to produce grain while NUE is most due to the amount of nitrogen applied and to water management practices.

In Burkina Faso, sorghum production is essentially in rainfed. And yet, in this rainfed agriculture, there is variability in rainfall during the growing season such as the irregularity of rains leading to droughts and dry spells, the occurrence of some heavy rains leading to floods and thus losses of some crops. Managing water and nitrogen in this rainfed agriculture is a key challenge for food production.

Despite their drought tolerance and their high ability to produce higher grain yield, improved seed varieties of crops including sorghum production depend much on the availability of water. According to references [11] and [12], water stress mostly affects crop production; it can involve great economic losses. Water is thus the agent driver of soil nutrients to plants [13]. The objective of this study was to assess the effect of sorghum root growth, WUE, and NUE on grain yield under two watering systems, rainfed and irrigation.

2 MATERIAL AND METHODS

2.1 STUDY SITE DESCRIPTION

The experiments were carried out in 2014 in the Central region of Burkina Faso at Saria research station. It is situated at 82 km south west of the capital, in an agro climatic zone with annual rainfall between 700 and 900 mm. According to the last 35 years rainfall data collected, the average annual rainfall is 811.4 mm with mean rainy days of 63. The soils are mainly Luvisol [14], with granite rock as parent material. These soils have upper horizons of sandy loam to loamy sand texture and generally continuous and massive structure. The rainfed agricultural system is based on cereals, mainly sorghum and millet, grown in association with cowpea.

2.2 METHODOLOGY

Two experiments were laid out in 2014 on two different growing seasons: the first sown in July 5th (rainfed experiment) and the second in October 20th (irrigated experiment in dry season).

The rainfed experiment received rain water only.

Concerning the irrigated experiment, drip irrigation system was used and water has been applied using an approximate estimate of the rate of an unstressed sorghum canopy's potential evapotranspiration, PET (3-4 mm day^{-1}) from October to February according to the meteorology station.

2.3 TREATMENTS APPLIED

Two water regimes have been applied to the irrigated experiment: 100% of potential evapotranspiration (well-watered treatment) and 50% of potential evapotranspiration (water stress treatment). The amount of water applied for the well-watered treatment was 50% of potential evapotranspiration at the beginning of the experiments (from germination to four weeks after emergence), 100% of potential evapotranspiration from four weeks to the grain filling period and 50% of potential evapotranspiration from grain filling period to maturity. For the water stress treatment, the amount of water applied was 50% of potential evapotranspiration during the entire period. Water was applied twice per day in equal amounts. The rainfed experiment has been only watered with rain water.

60 kg ha^{-1} of urea representing the recommended dose to fertilize sorghum crop in Burkina has been used. This amount of urea has been applied in two equal half doses to the plants.

Improved sorghum seed variety *Sariaso* 14 (110 to 115 days) has been sown.

2.4 EXPERIMENT DESIGN

This study was led in a randomized split-split-plot arrangement in complete block with four replications. The main plot treatment was water levels while the sub-plots treatment was N levels and genotypes. The main plot size was 28.6 m x 7 m and the sub-plot size was 6.4 m x 7 m. The sowing density was 0.8 m between sowing lines and 0.4 m between seed hills. The outer 2 lines and 2 seed hills, each side, were excluded from sampling, resulting in 4 lines by 12 seed hills.

2.5 HUSBANDRY PRACTICES

The experiment areas were ploughed with tractor and harrowed manually before planting. Basal applications of P at 23 kg ha^{-1} and K at 14 kg ha^{-1} were applied using triple super phosphate (TSP) and muriate of potash (KCl) respectively.

2.6 MEASUREMENTS

Soil water content: soil water content has been determined at the beginning and at the end of the experiments by gravimetric method. Gravimetric method has been used for this determination in all treatments. Soil samples were taken every two weeks within the four middle lines and in three locations. The samples from the three locations were then mixed to take one composite sample. These samplings were done in the entire treatments in six horizons (0-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm) with a graduated drill. The samples were weighed, oven dried at 105 ^{o}C for 24 hours and weighed again. Soil water content was estimated as the percentage of the difference between the wet and the dried weight divided by the dried weight.

Root profile: the profile wall method [15] was used to determine roots growth and distribution in all treatments.

Yield and yield components: For the estimation of yield and yield components, the total of seed hills was first counted. After, the straw was cut down, weighed, dried and weighed again. The whole panicles were harvested and weighed. The empty and full panicles were also counted and weighed. Then, the full panicles were sun-dried, threshed, winnowed and the grains weighed.

Water use and water use efficiency: The total water consumption (ET) or water use during these experiments was calculated according to water balance equation given below by references [16] and [17]:

$$ET = P + I + SW - R - D.$$

Where ET is the total soil water consumption (include soil evaporation and plant transpiration);

P (mm) is the rainfall and I (mm) is irrigation amount, R (mm) is the surface runoff; D (mm) is the water drainage below the crop root zone. SW (mm) is the soil water change from sowing to maturity. In our experiment, R and D are assumed to be not significant. This led to: ET (mm) = P + I + SW.

Experiment 1 (rainfed experiment): ET (mm) = P + SW

Experiment 2 (irrigated experiment in dry season): ET (mm) = I + SW

WUE has been calculated according to the equation: WUE (kg ha^{-1}mm^{-1}) $= \frac{Grain\ yield}{WU}$

Where ET (mm) or WU (mm) is the total soil water consumption

Nitrogen use and nitrogen use efficiency: Laboratory analysis was performed to assess the amount of nitrogen removed by sorghum crop by analyzing the residues (stem, root and grain) by the Kjeldahl method. The formula used to estimate NUE is that of references [9] and [18].

$$\text{NUE (\%)} = \frac{Nitrogen\ removed\ by\ crop}{Nitrogen\ applied} \text{x } 100$$

Statistical analysis: All data obtained from the measurements were subjected to analysis of variance (ANOVA) using XLSTAT version 2016 software. The means of the main effects were compared using Student – Newman - Keuls' multiple range tests at 5% of probability level. A two tailed test was subsequently used to compare the means when p. values ≤ 0.05.

3 RESULTS

The analysis of variance performed on the data from the two watering systems shows the following results on water use and water use efficiency, and on nitrogen removed by crop and nitrogen use efficiency (Table 1).

With regards to water use and water use efficiency, the analysis of variance indicated high significant influence of watering system (P. < 0.0001). By this analysis, it was found that the high use of water contributed to the low efficiency use of water (Table 1). This table displays that while the irrigated experiment consumed less water (316 mm) to produce large WUE (7.34 kg ha^{-1} mm^{-1}), the rainfed experiment consumed more water (878 mm) to produce low WUE (1 kg ha^{-1} mm^{-1}). Irrigated experiment used water efficiently by 92% more than the rainfed experiment (Table 1).

Table 1: Effects of watering system on sorghum WUE and NUE

Watering system	WU (mm)	WUE (kg ha^{-1} mm^{-1})	N crop (g)	NUE (%)
Rainfed	878 a	1 b	3.4 b	6 b
Irrigation	316 b	7.34 a	7.1 a	10 a
p.	***	***	**	**

Within rows, means followed by the same letter are not significantly different at P. < 0.025.
The irrigation amount is obtained by the mean value between 50% and 100% PET representing the water use (WU)
WUE: water use efficiency N crop: nitrogen removed by crop
NUE: nitrogen use efficiency
***: significant*
****: high significant*

With regards to nitrogen fertilization (Table 1), the application of 60 kg ha^{-1} of nitrogen influenced significantly N uptake by sorghum crop and NUE (P. < 0.025) in the two watering systems. Nitrogen removed by crop and its efficient use was 26% higher in the irrigated experiment than in the rainfed one.

The effect of these two watering systems on soil water content has been also assessed in the horizon 0 to 120 cm. The results presented in Table 2 showed that in the first 60 cm of layer, there was no significant difference between soil water content from the rainfed experiment and that of the irrigated one. But from 60 to 120 cm of soil depth, the rainfed experiment was found to have the highest soil water content (twice more than the irrigated one).

Table 2: Soil water content

	Depth (cm)					
Watering systems	0-20	20-40	40-60	60-80	80-100	100-120
Rainfed	11.3 a	14.8 a	16.7 a	16.5 a	15.9 a	15.3 a
Irrigation	9.6 a	10.8 a	13.1 a	11.9 b	12.5 b	11.5 b
p.	*	*	*	**	**	**

Within rows, means followed by the same letter are not significantly different at P. < 0.025.
**: non-significant*
***: significant*

Sorghum root numbers and rooting depth have been evaluated on the two watering systems (Figure 1). The analysis of variance showed highly significant influence (P. < 0.0001) of these different watering systems on sorghum root numbers and rooting depth.

Under rainfed experiment, root numbers and depth were twice more important than in the irrigated experiment.

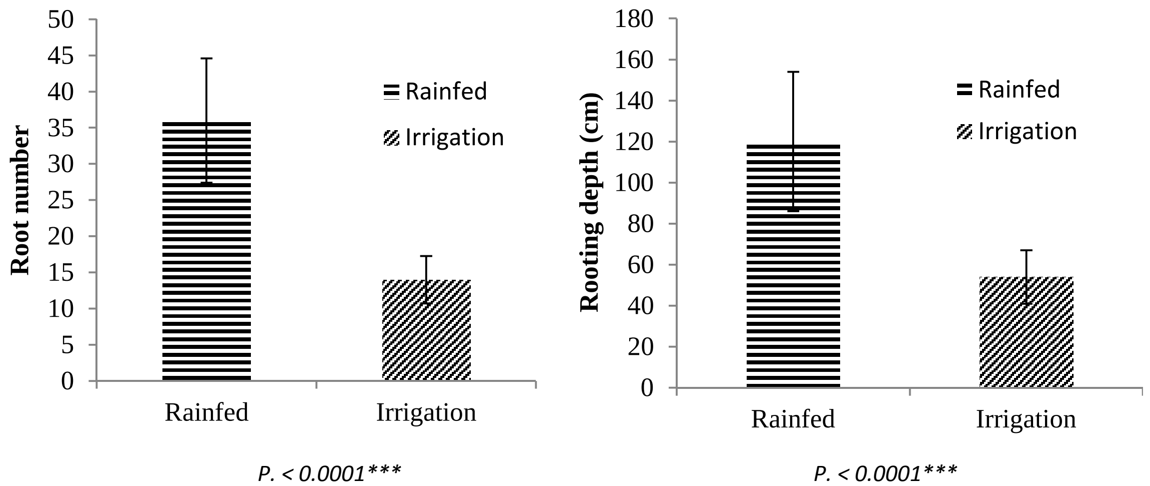

Figure 1: Effects of watering system on sorghum root growth

****: highly significant*
The bars on the graphs represent the errors bars

Yield and yield components have been assessed. The two watering systems had no statistical difference on straw yield. But, significant difference was noted in grain yield and harvest index (p. < 0.025). It was observed that sorghum grain yield and harvest index were 44% and 56% respectively higher under irrigation than under rainfed condition.

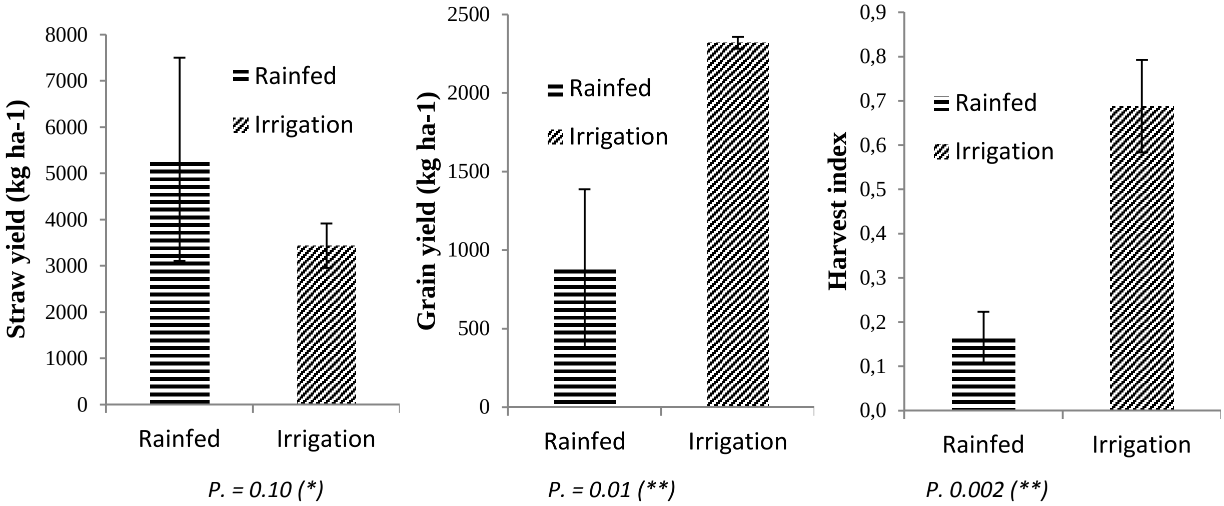

Figure 2: Effects of watering system on sorghum straw yield, grain yield and harvest index

**: non-significant*
***: significant*
The bars represent the standards errors

4 DISCUSSION

By the two experiments, it was observed that the irrigated experiment used less water compared to the rainfed experiment. However, water and nitrogen have been used more efficiently in this irrigated experiment than in the rainfed one. The efficient use of water and nitrogen in the irrigated experiment was due to water management practice. In drip irrigation system, water is uniformly distributed around root zone. This water dissolves nitrogen and then the nutrient is easily and efficiently used by plants. The low WUE and NUE observed in the rainfed experiment comparatively to the irrigated one agrees with that of reference [19] who found WUE and NUE greater in their study sites where irrigation was applied. These authors indicated that the rainfed experiments recorded the lowest WUE and NUE. The low values of WUE and NUE in the rainfed condition were due to the fact that, under rainfed condition, nutrients could be lost through leaching as the amount of water was found great in the deeper soil layer in this experiment. This nitrogen leaching could occur mainly at the beginning of the experiment when rooting system was not yet well developed. Reference [20] noticed that runoff, leaching, denitrification, and volatilization may be the mechanisms by which nitrogen is lost from the soil. But for these authors nitrogen losses from the soil were mainly due to the volatilization.

The study revealed that rainfed experiment recorded the highest amount of soil water content in the deeper horizons. Moreover, root numbers and rooting depth were highly important in this experiment. The high root growth in the rainfed experiment was thus linked to water content into the soil. These observations highlighted the fact that a part of water during the rainfed experiment has been stored at greater depths of soil while water from the irrigated experiment stayed superficially around the roots zone. The high moisture found in the rainfed experiment at the deeper layers allowed more roots growth and subsequent development. Despite this high roots growth in the rainfed experiment, WUE and NUE were greater in the irrigated experiment indicating that the roots system extracted water and nutrients more efficiently in the irrigated experiment. The high WUE and NUE in the irrigated experiment were therefore due to the availability of water around root zones but not to the rooting depth. This result contrasted those of references [21] and [22] who found that crop nutrients uptake from the soil to fill plant needs and to improve crop production was mostly due to the rooting depth.

Similarly to WUE and NUE, grain yield and harvest index were also found to be higher in the irrigated experiment than in the rainfed experiment. By these experiments, it was noted that sorghum productivity is linked to high WUE and NUE but not to high root growth as was indicated by the findings of reference [23]. These authors linked sorghum crop productivity to its root numbers and rooting depth. From reference [9], it was learned that WUE and NUE are two critical important concepts used to estimate crop productivity. According to Reference [8],WUE is a yield determinant factor under stress condition while NUE according to reference [9] is a concept assessing crop production systems. These two factors being high in the irrigated experiment led to increase grain yield and harvest index respectively by 44% and 56% than in the rainfed one. References [24] and [25] demonstrated a link between WUE and sorghum yield; WUE increased when grain yield increased. Also, harvest index was found to increase under high NUE [26].

5 Conclusions

Cropping sorghum under drip irrigation experiment contributed to enhance sorghum productivity through the efficient use of water and nitrogen. The great water use and root growth in the rainfed experiment did not improve sorghum grain yield compared to the drip irrigated experiment where grain yield has been much improved with low water use and low root growth and development. Given the erratic rainfall in rainfed agriculture, sorghum production under irrigation could be beneficial for farmers.

Acknowledgements

The lead author is grateful to the West African Science Service Center on Climate Change and Adapted Land Use programme for providing funds for her PhD study. She is also grateful to the staff of the Institut de l'Environnment et de recherches Agricoles (INERA)/Kamboinsé especially to her field assistants and to the laboratory assistant who contributed a lot to the success of her study during data collection and their analyses. She is also grateful to Dr. Pare Jean for his support during the drafting of this manuscript.

References

[1] N. D. Mueller, J. S. Gerbe, M. Johnston, D. K. Ray, N. Ramankutty, and J. A. Foley, "Closing yield gaps through nutrient and water management*", Nature*, vol. 490, n°7419, pp. 254-257, 2012.

[2] A. Rahimi, F. Sayadi, and H. Dashti, "Effects of water and nitrogen supply on growth, water-use efficiency and mucilage yield of isabgol (Plantago ovata Forsk)", *Journal of soil science and plant nutrition*, vol. 13, n°2, pp. 341-354, 2013.

[3] A. G. Timu, R. Mulwa, J. Okello, and M. Kamau, "The role of varietal attributes on adoption of improved seed varieties: the case of sorghum in Kenya", *Agriculture & Food Security*, vol. 3, n°1, pp. 1-7, (2014).

[4] C. A Jaleel, P. Manivannan, A. Wahid, M. Farooq, R. Somasundaram, and R. Panneerselvam, "Drought stress in plants: a review on morphological characteristics and pigments composition", International Journal of Agriculture & Biology, vol. 11,n°1, pp. 100–105, 2009.

[5] M. Aslam, M. S. I. Zamir, I. Afzal, M. Yaseen, M. Mubeen, and A. Shoaib, "Drought stress, its effect on maize production and development of drought tolerance trough potassium application", *Cercetări Agronomice în Moldova,* vol. 46.*,* n°2, 154 p., 2013..

[6] B. Liu, C. Liang, M. Li, D. Liang, Y. Zou, and F. Ma, "Interactive effects of water and nitrogen supply on growth, biomass partitioning, and water-use efficiency of young apple trees", *African Journal of Agricultural Research,* vol. 7, n°6, pp. 978-985, 2012.

[7] E. Gholinezhad, A. H. Aynaband, , A. Noormohamadi, G. I. Bernousi, "Study of the effect of drought stress on yield, yield components and harvest index of sunflower hybrid iroflor at different levels of nitrogen and plant population", *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, vol. 37, n°2, 85 p., 2009.

[8] A. Blum, "Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress", *Field Crops Research*, vol. 112, n°2, pp. 119-123, 2009.

[9] P. Fixen, F. Brentrup, T. W. Bruulsema, F. Garcia, R. Norton, and S. Zingore, "Nutrient/fertilizer use efficiency: Measurement, current situation and trends, Managing Water and Fertilizer for Sustainable Agricultural Intensification, 8 p., 2015.

[10] R. Monclus, E. Dreyer, M. Villar, F. M. Delmotte, D. Delay, J. M. Petit, C. Barbaroux, D. Thiec, C. Bréchet, and F. Brignolas, "Impact of drought on productivity and water use efficiency in 29 genotypes of *Populus deltoids* × *Populus nigra*", *New phytologist*, vol. 169, n°4, pp. 765-777, 2006.

[11] H. Nazarli, M. R. Zardashti, R. Darvishzadeh, and N. Solmaz, "The effect of water stress and polymer on water use efficiency, yield and several morphological traits of sunflower under greenhouse condition" *Notulae Scientia Biologicae*, vol. 2, n°4, pp. 53-58, 2010.

[12] T. Boutraa, A. Akhkha, A. Abdulkhaliq, and A. M. A. Al-Shoaibi, "Effect of water stress on growth and water use efficiency (WUE) of some wheat cultivars (*Triticum durum*) grown in Saudi Arabia" *Journal of Taibah University for Science*, *vol.* 3, pp. 39-48, 2010.

[13] V. Gonzalez-Dugo, J. L. Durand, and F. Gastal, "Water deficit and nitrogen nutrition of crops. A review. *Agronomy for sustainable development*, vol. 30 n°3, pp. 529-544, 2010.

[14] *FAO "*World reference base for soil resources—a framework for international classification*,* correlation and communication", *World Soil Resources Report,* vol. 103, 2006.

[15] D. Sauerbeck, *W. Böhm: Methods of Studying Root Systems. Bd. 33 der "Ecological Studies-Analysis and Synthesis", herausgegeben v. WD Billings et al., Springer-Verlag, Berlin-Heidelberg-New York 1979, ISBN,3-540-09329-X, 188 S., 69 Abb., Leinen DM 69,–.* Zeitschrift für Pflanzenernährung und Bodenkunde, vol. 143, n°3, pp. 362-363, 1980.

[16] P. Bandyopadhyay, S. Mallick, and S. Rana, "Water balance and crop coefficients of summer-grown peanut (*Arachis hypogaea* L.) in a humid tropical region of India,. *Irrigation Science*, vol. 23, n°4, pp. 161-169, 2005.

[17] S. M. Ismail, K. Ozawa, and N. A. Khondaker, "Influence of single and multiple water application timings on yield and water use efficiency in tomato (var. *First power*)", *Agricultural water management*, vol. 95, n°2, pp. 116-122, 2008.

[18] F. Brentrup, and C. Pallière, "*Nitrogen use efficiency as an agro-environmental indicator*. in *Proceedings of the OECD Workshop on Agrienvironmental Indicators,* March 2010.

[19] J. T. Bushonga, E. C. Millera, J. L. Mullocka, D. B. Arnalla, and W. R. Rauna, "Irrigated and Rain-fed Maize Response to Different Nitrogen Fertilizer Application Methods", *Journal of Plant Nutrition*, 2016 (just-accepted).

[20] M. A. Monem, W. L. Lindsay, R. Sommer, and J. Ryan, "Loss of nitrogen from urea applied to rainfed wheat in varying rainfall zones in northern Syria", *Nutrient cycling in agroecosystems*, vol. 86, n°3, pp. 357-366, 2010.

[21] A. P. Wasson, R. A. Richards, R. Chatrath, S. C. Misra, S. V. Sai Prasad, G. J. Rebetzke, J. A. Kirkegaard, J. Christopher and M. Watt, "Traits and selection strategies to improve root systems and water uptake in water-limited wheat crops", *Journal of Experimental Botany*, Vol. 63, n°9, pp. 3485-3498, 2012.

[22] B. M. Atta, T. Mahmood, and R. M. Trethowan, "Relationship between root morphology and grain yield of wheat in north-western NSW, Australia". *Australian Journal of Crop Science*, vol. 7, n°13, pp. 2108-2115, 2013.

[23] E. R. de Souzaa, A. A. de Assuncão Montenegroa, S. M. G. Montenegrob, J. de Arimatea de Matos, "Temporal stability of soil moisture in irrigated carrot crops in Northeast Brazil", *Agricultural water management*, vol. 99, n°1, pp. 26-32, 2011.

[24] M. M. Hussein, and A.K. Alva, "Growth, Yield and Water Use Effeciency of Forage Sorghum as Affected by Npk Fertilizer and Deficit Irrigation", *American Journal of Plant Sciences*, vol. 5, pp. 2134-2140, 2014.

[25] J. P. Broeckelman, G. J. Kluitenberg, K. Roozeboom, and I. A Ciampitti, "Grain Sorghum Yield Response to Water Availability", *Kansas Agricultural Experiment Station Research Reports*, vol. 1, n°2, pp. 1-5, 2015.

[26] A. Jr. Bufogle, P. K. Bollich, J. L. Kovara, R. E. Macchiavelli, and C. W. Lindau, "Rice variety differences in dry matter and nitrogen accumulation as related to plant stature and maturity group 1". *Journal of plant nutrition*, vol 20 n°9, pp. 1203-1224, 1997.