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Full Length Research Paper

Propagation of Farash (*Tamarix aphylla)* as affected by cutting lengths under low polytunnel and open air

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A research study was conducted on *Tamarix aphylla* in August, 2008, in the experimental area of Department of Forestry, University of Agriculture Faisalabad, Punjab to find out the impact of vegetative propagation of Farash (*T. aphylla*) through different size of cuttings in open air and under low polytunnel. In this study, 2", 4" and 6" long cuttings were planted in shade in polythene bags, with nine holes, 3" wide and 7" long, made in each bag for irrigation purpose. The data was recorded twice a month on sprouting percentage, height of plant, root length and number of root branches for two months after initial planting in the month of August. Sprouting percentage and height of plants were maximum in T_3 (6" long cuttings) and minimum in T_1 (2" long cuttings) in both open air and low polytunnel, but overall the success rate was much higher under the low polytunnel. The measurement of roots length and number of roots branches was maximum in T_1 than T_3, in open air and low polythene tunnel.

Key words: *Tamarix aphylla*, cuttings, growth, open air, polytunnel.

INTRODUCTION

Within the Tamariacacea family, there are 4 genera and 289 species (The Plant List, 2010). This family thrives in temperate conditions and can be found distributed as such in Europe, Asia and Africa within their maritime deserts and sandy tracts. This family is not abundant on Indian subcontinent where its representation is 20% of all species spread between Srilanka, India, Pakistan, Bangladesh, Bhutan and Myanmar (Kundu, 2009). Having thought to have its origins in the Central Sahara, it then spread throughout North Africa, Egypt and the Middle East spreading to India, Afghanistan and Pakistan. The spread also covered the areas of Eriteria, Kenya and Ethiopia (CABI, 2015). Tamariacacea is a small family of about 4 genera and 289 species (The Plant List, 2010) temperate in distribution, usually found in sandy tracts and maritime deserts of Asia, Africa and Europe. On the Indian subcontinent (comprising Bangladesh, Bhutan, Myanmar, Nepal, Pakistan, Sri Lanka and India), the family Tamaricaceae is poorly represented (20% of all species) (Kundu, 2009). Qaisar

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(1982) stated that in Pakistan it is represented by 4 genera and 35 species. The native range of *T. aphylla* extends over the Middle East, North, East and Central Africa, and parts of West and South Asia. The species is thought to have originated in the Central Sahara, from where it spread to Pakistan, India, Afghanistan, the Middle East, Egypt and North Africa, as well as to Eritrea, Somalia, Kenya and Ethiopia (CABI, 2015; Orwa et al., 2009).

T. aphylla is evergreen, moderate sized and fast growing tree of upto 18 m height with an erect tapering trunk and smooth branches. Department of Agriculture and Fisheries (2013) concluded that it is heat, salt, draught and frost tolerant. Mature trees of *T. aphylla* have dark grey to black and rough stem of up to 1 m in diameter but immature trees have light grey trunks. Department of Land Resources Management (2014) concluded that even because of pendulous needles and branches, it is not a true pine or conifer. Silvery grey appearance on tree foliage of whitish coating is because of salt secreting glands from the needles. Small, white and pink flowers occur in dense racemes. Biophysical limits of *T. aphylla* are 0 to 1200 m above sea level, mean annual rainfall is 250 to 500 mm and mean annual temperature is 10 to 50°C. *Tamarix aphylla* grows naturally in canals, riverbanks, coastal plains, salt marshes, salty deserts and sand dunes. It can grow positively in saline soil and expand in occasional inundation areas than never flooded ones. It flourishes on loamy soils and can grow easily on stiff clays and sand. Nowadays, *T. aphylla's* wood can be used in different ways. Soft branches and leaves also provide a good quality of forage especially in dry time scale of the year. Its wood is flammable and can be used for firewood and charcoal (calorific value, 4835 kcal/kg) but catches fire slowly because of salt contents especially in small branches (Orwa et al., 2009). Its wood is used as fuel in United States and has been proposed for fence posts (Guler et al., 2007). *T. aphylla* have close-grain wood which is helpful in making carts, tool handles, ornaments, furniture, wheels, carpentry and fruit boxes (Orwa et al., 2009). On the other hand, it has been found to be a suitable raw material for making particle boards and can be used as biomass for sugar production (Sadegh et al., 2012; Hashemi, 2011).

There are different ways to propagate or multiply a plant. In Tamariacacea, there are 120 species but this study will focus on *T. aphylla*. A plant can be grown from their seeds or cutting off a portion of an established plant (Welch-Keesey and Lerner, 2009) and in the same way *Tamarix* species can naturally be reproducde from seeds and their broked stem fragments. The successful rate of vegetative propagation is quite higher especially when branches broken up by floodwater carry downstream (Crushes, 2008). A cutting is any detached plant part which, under favorable conditions, will produce a new plant identical to the parent plant (Hamilton and Midcap, 2003). A new plant grown form the cuttings of a parent plant which can grow faster and avoids all difficulties then growing from a seed. Vegetative propagation through cuttings or asexual reproduction is still very productive method so evergreen needled trees can also reproduce by parent plant cuttings (Welch-Keesey and Lerner, 2009). In open air, the viability of *T. aphylla's* recalcitrant seed is very low not more than a week, their germinative capacity keep reducing with the passage of time and therefore for better results immediate sowing is the only solution (Orwa et al., 2009). So, the yield of a tree produced from a cutting can be greater than a tree produced from seed. Boles produced by cuttings have better quality and less tapered (Hudson, 2009). Hybridization between superior species, as well as creating orchards of improved trees, has been examined in research. In order to realize genetic goals in tree species, several generations of tree breeding are required and each generation can last for 15 to 50 years depending on the species. Within the past few decades, genetic improvement of tree species has accelerated within the forest industry. Currently, the dilemma is how to speed up this process.

Asexual propagation (vegetative reproduction through cuttings) is one of the methods to solve this question. Until 1971, there were only three propagation programs introduced to this world (Ritchie, 1991), but now this process is successful as a nursery management tool (Hudson, 2009). Arrington (2015) stated that one of the many main advantages of asexual reproduction is the advantage of speed because it does not consider the gamete formation process and another is that the offspring are clones of the parents. The size of length of cuttings can differ according to different plant species (Edson, 1991). McCormack (2006) suggested that different cutting lengths can affect the prosperous rooting in *Morus alba*. So, it is very important to consider the age and size of planting material for initial survival and formation of seedlings (Haq, 1992) and establishment of cuttings and the early life stages of a plant are critical for the establishment of high seedling mortality. The root growth depends on node position, cutting length and leaf area factors and the success of rooting from cuttings depends on the factors like environmental, genotype and physiological state (Ahmed et al., 2011). So, it is vital to upgrade the use of local species by vegetative means (Weber and Stoney, 1986; Arriaga, 1994; Leakey et al., 1994), because propagation by seedlings took a very long time (Ahmed et al., 2011). Desired results from cuttings may affect if environmental conditions are not supplied properly (Hamilton and Micap, 2003). A cover can be used for the existence and initial formation of plants. Humid conditions are quite suitable for the rooting process of *M. alba* and umbrella of greenhouse with plastic cover (Ahmed et al., 2011). Trujillo (2002) also favored plastic cover for the success of cuttings in the nursery. So it is quite settled that polythene cover really

Table 1. Sprouting percentage of *Tamarix aphylla* plant as affected by cuttings size in open air and under low polytunnel.

Time interval after planting (days)	Treatments								Mean
	Open Air				Low Polythene Tunnel				
	T_1 (%)	T_2 (%)	T_3 (%)	Mean	T_1 (%)	T_2 (%)	T_3 (%)	Mean	
15 Days	17.15	28.20	29.10	24.82[e]	21.22	68.07	77.55	55.61[b]	40.21[c]
30 Days	19.22	45.30	48.28	37.60[d]	23.28	80.85	85.10	63.07[a]	50.33[b]
45 Days	21.10	58.10	62.02	47.07[c]	21.10	85.66	86.85	64.54[a]	55.80[a]
60 Days	21.10	58.10	63.23	47.47[c]	21.10	85.66	86.85	64.54[a]	54.83[a]
Mean	19.64[c]	47.42[b]	50.65[b]	39.24	21.67[c]	80.06[a]	84.08[a]	61.94[a]	56.00

T_1: 2" long cuttings; T_2: 4" long cuttings; T_3: 6" long cuttings; %: percentage.

affects the different parameters of a plant.

In 1823, *Tamarix* species were first introduced into the United States but now they are planted as windbreaks, ornamental and for stream bank stabilisation (Crushes, 2008). *T. aphylla* recognised as windbreaks, erosion control, sand dune problems and as an ornament. However, it is planted in the hot deserts of Iran to control sand dunes problems (Sadegh et al., 2012).

MATERIALS AND METHODS

Study site

The experiment was carried out at experimental area of the Department of Forestry, University of Agriculture Faisalabad. Latitude 36 to 26° and Longitude 73 to 06°E.

Cutting preparation and planting

Three different sizes of branch cuttings (2", 4" and 6" long) of Farash (*T. aphylla*) were prepared from six-year-old healthy trees in the first week of August 2008. These cuttings were then planted and irrigated immediately in the polythene bags of 3" × 7" size which were filled with sandy loam soil. Half of these bags were placed in the open air, while the remaining half was placed under the low polytunnel. There were two experiments (open air block and under low polytunnel block) were organised in accordance with Randomized Complete Block Design (RCBD) with three replications each. The data on sprouting percentage and height of plant were recorded after 15, 30, 45 and 60 days but root length and root branches data was recorded right after 60 days. There were three treatments in each replica and three treatments were labeled as T_1 for 2" long cuttings; T_2 for 4" long cuttings and T_3 for 6" long cuttings. There were 50 polythene bags in each treatment (T_1, T_2 and T_3) which makes 150 in each replica of open air and under polytunnel, making a total of 900 bags for the whole experiment. The data were subjected to analysis of variance and comparison among the treatments by the Least Significant Difference Test at 5% probability level (Steel et al., 1997).

RESULTS AND DISCUSSION

Sprouting percentage

It is vital to find out the survival percentage of plants by the propagation of different size of stem cuttings in different environmental conditions. The maximum sprouting after 15 days was observed in T_3 (77.55%) under polytunnel while in open air it was only 29.10% (Table 1). Overall, after 30 days, there was a negligible increase in the sprouting percentage, thus thirty days are adequate for assessing sprouting. The results of the present study showed that the cutting size and polythene cover influence the sprouting of tree cuttings at nursery stage. These findings are also in line with those of Mebrathu and Hanover (1990), Cobbina (1990), Haq (1992), Mitchell (1998), and Trujillo (2002).

The sprouting percentage in all treatments (T_1, T_2 and T_3) was much higher under low polytunnel than in open air and after 60 days the most successful treatment was T_3 (6" long cuttings) under low polytunnel with 86.85% (mean value 84.08%) sprouting and in open air it was only 63.23% (mean value 39.24%) (Figure 1). This significant figure clearly shows that the environmental conditions (polytunnel) do affect the sprouting percentage of *T. aphylla*. Rafay et al. (2015) revealed that the sprouting percentage was maximum with 6" cuttings under low polythene tunnel are maximum than others and in different mediums. So the results indicate that the low polytunnel is better for propagating *T. aphylla* plants from branch cuttings.

Height of plants (cm)

After 15 days, the height of plants exposed to the open air was less being 2.23 cm for T_3 (6" long cuttings), 1.98 cm for T_2 (4" long cuttings), and 1.52 cm for T_1 (2" long cuttings). The plants were much taller in first 15 days when kept under low polytunnel being 3.21 cm for T_3, 3.10 cm for T_2 and 3.22 cm for T_1 (Table 2). Overall, after 30 days, there was no difference in the height of plants in open air but under low polytunnel T_3 have shown a significant height than other treatments. After 60 days, the results for plant height clearly shows (Figure 2) that under low polytunnel plants flourished and developed more vigorously with a mean difference of 3.54 cm than in open air (Table 2). Rafay et al. (2015) concluded that

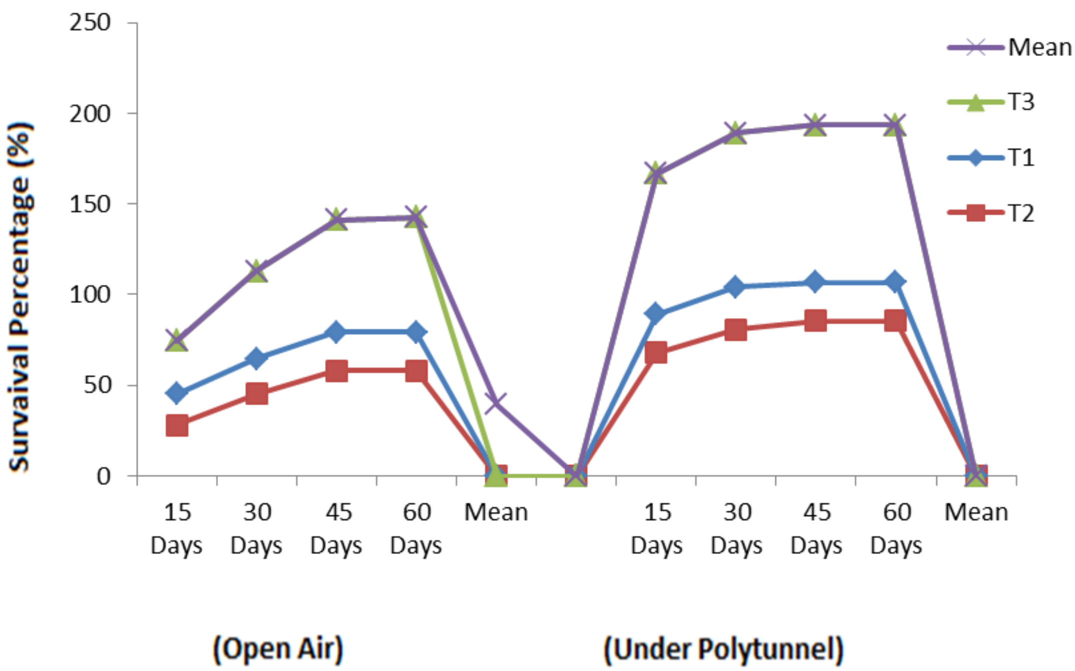

Figure 1. Sprouting percentage of *Tamarix aphylla* plant as affected by cuttings size in open air and under low polytunnel.

Table 2. Height of *Tamarix aphylla* plants (cm) as affected by cuttings size in open air and under low polytunnel.

Time interval after planting (days)	Treatments								Mean
	Open Air				Low Polythene Tunnel				
	T_1(cm)	T_2(cm)	T_3(cm)	Mean	T_1(cm)	T_2(cm)	T_3(cm)	Mean	
15	1.52	1.98	2.23	1.91^{g}	3.22	3.10	3.21	3.17f	2.54^{d}
30	4.69	4.89	4.98	4.85^{e}	7.33	8.65	9.35	8.44^{d}	6.65^{c}
45	8.23	8.63	9.22	8.69^{d}	10.55	12.22	14.78	12.52^{b}	10.60^{b}
60	9.65	10.75	11.03	10.47^{c}	13.96	16.45	17.52	15.98^{a}	13.23^{a}
Mean	6.02^{e}	6.56d^{e}	6.86^{d}	6.48	8.76^{c}	10.10^{b}	11.21^{a}	10.025	8.25

T_1: 2" long cuttings; T_2: 4" long cuttings; T_3: 6" long cuttings; cm: centimetre.

under low polythene tunnel the height of plants with 6" long cuttings achieved maximum height. These results also match the findings of Khan (2007).

Root length (cm)

The maximum root length of 20.14 cm was recorded in T_1 (2" long cuttings) under polytunnel. Even the mean value of T_1 in open air and under polytunnel is 19.63 cm which is higher than T_2 and T_3 mean values which are 18.67 and 18.24, respectively (Table 3). Length of roots were much better grown in the plants under low polytunnel (mean value 19.56 cm) than in the open air (mean value 18.14 cm) (Table 3). The results from T_1 shows that root length can be developed in a better way, under polytunnel (Figure 3). The reason might be conservation of moisture and heat/temperature under the sheet cover, enhancing growth of plant roots. These results agree with the findings of Trujillo (2002).

Root branches

The numbers of root branches were counted immediately after the completion of 60 days. The maximum number of root branches (21.23) were produced by T_1 (2" long cuttings) in open air (Table 4). On the other hand, plants grown under polytunnel had slightly less root branches (18.75) than in open air. It is shown (Figure 4) that T_1 (2"

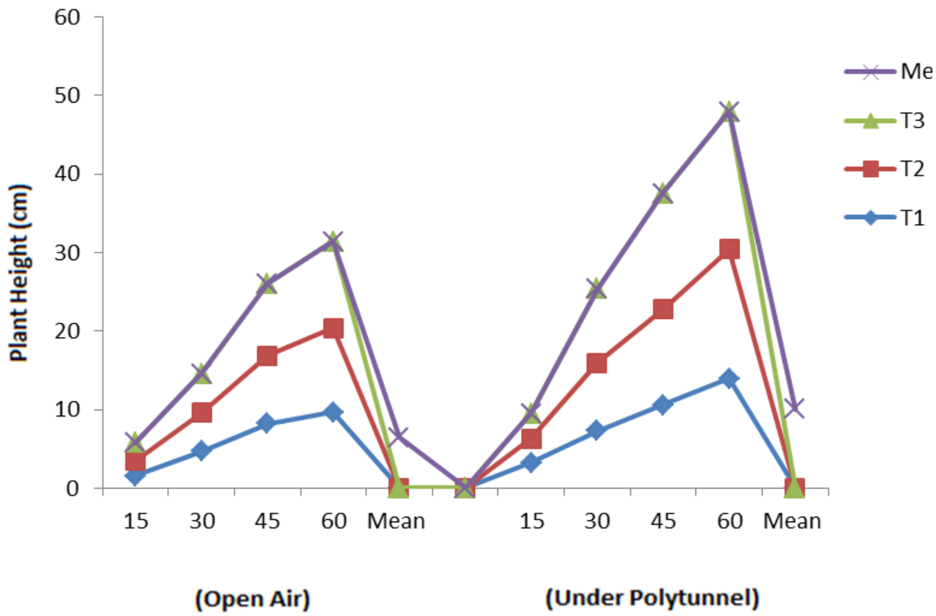

Figure 2. Height of *Tamarix aphylla* plants (cm) as affected by cuttings size in open air and uner low polytunnel.

Table 3. Root length (cm) of *Tamarix aphylla* as affected by cuttings lengths in open air and under low polytunnel.

Blocks	Treatments			
	T_1 (cm)	T_2 (cm)	T_3 (cm)	Mean
Open air	19.12	18.13	17.16	18.14
Polytunnel	20.14	19.22	19.32	19.56
Mean	19.63	18.67	18.24	18.85

T_1: 2" long cuttings; T_2: 4" long cuttings; T_3: 6" long cuttings; cm: centimetre.

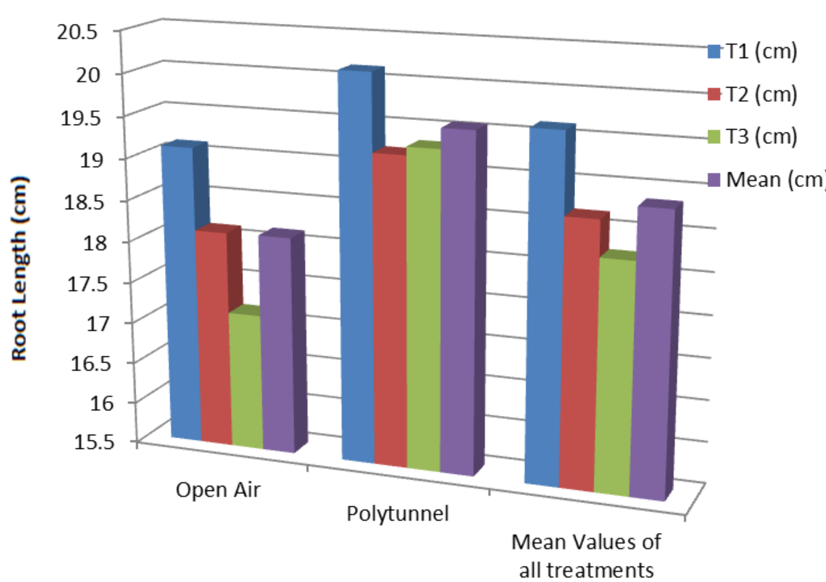

Figure 3. Root length (cm) of *Tamarix aphylla* as affected by cuttings lengths in open air and under low polytunnel.

Table 4. Number of root branches of *Tamarix aphylla* as affected by cuttings length in open air and under low polytunnel.

Blacks	Treatments			Mean
	T_1	T2	T3	
Open	21.23[a]	18.45[b]	16.21[c]	18.63
Covered	18.75[b]	18.10[bc]	20.24[ab]	19.03
Mean	19.99[a]	18.27[b]	18.22[b]	18.83

T_1: 2" long cuttings; T_2: 4" long cuttings; T_3: 6" long cuttings.

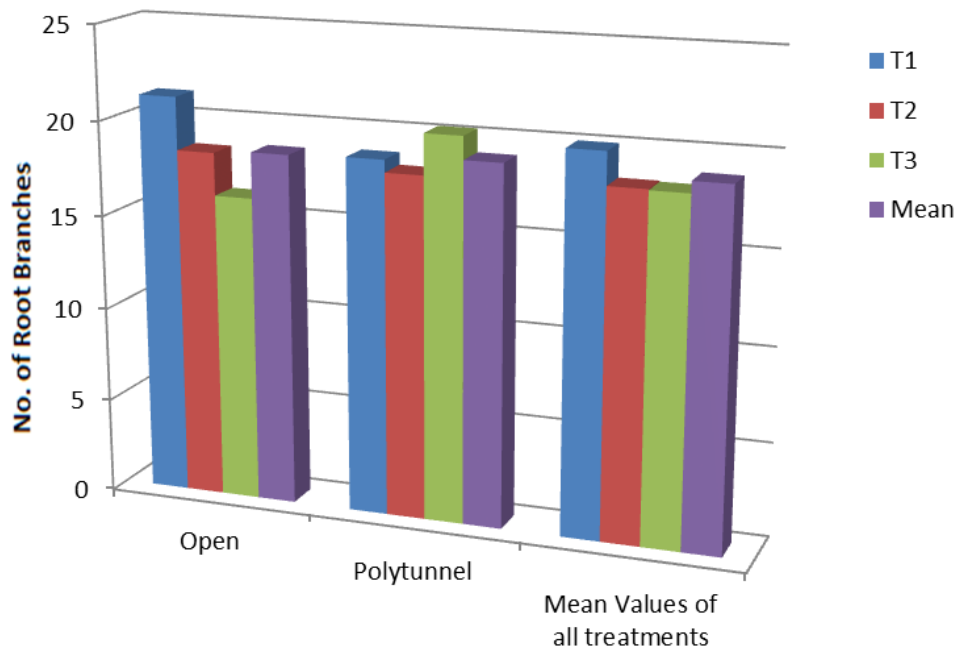

Figure 4. Number of root branches of *Tamarix aphylla* as affected by cuttings length in open air and under low polytunnel.

long cuttings) in open air produced more roots than the the longer cuttings possibly because there was more space available to grow for them as compared to larger cuttings. Irfan (2011) concluded that 2" long cuttings produced more branches than others and in different mediums. Different researchers have previously observed that shorter cuttings lead to the development of more and better roots (Foster et al., 2000). It shows again the success rate of T_1 with the number of root branches (mean value 19.99) is higher than other treatments (T_2 and T_3) is as similar to the results of measurement of roots length.

Conclusion

Although seedlings still costs less in most regions of the world, propagation through cuttings could be the best alternative to it to prepare more vigorous plants and more flowering in some cases in less period of time. The overall growth of plant cuttings under polytunnel was better as compared to the open air. The reason that under polytunnel, moisture was conserved and proper temperature for plant growth was maintained which resulted in the best results of sprouting percentage, plant height and root growth except the number of root branches. The numbers of root branches were higher in the open air than under low polytunnel which can be the result of small space available. All the growth parameter indicates that the performance of T_3 treatment (6" long cuttings) is better than all other sizes of cuttings. So, keeping in view the conclusion, planting of 6" long cuttings of *T. aphylla* under low polytunnel is recommended for nursery raising.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Consortium of maize and cowpea in organic farming - dry grain production

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Intercropping of maize and cowpea is widely used by Brazilian family farmers. The aim of this work is to compare the grain yield of two maize cultivars, and one cultivar of cowpea in organic system. Treatments of monoculture of cowpea (Poços de Caldas) and maize ('BR106' and 'AG1051') and intercropping were used. A randomized block design with four replicates in an area under conversion to organic production system was used. The experiment was conducted in the period of October 2012 to March 2013, corresponding to the periods of spring/summer. The maize alone was on average, 26.5 cm taller and grain yield was 28% higher than in the intercropping. The cowpea intercropped with maize 'AG 1051' was 3.8 cm taller than the intercropped with 'BR 106'. In monoculture, the cowpea presented more (0.7 and 1.2 grain per pod when intercropped with 'AG 1051' and 'BR 106', respectively). The cowpea monoculture resulted in 2.4 pods per plant than in intercropping and productivity was 5.4 times higher than that of the intercropping. The cowpea intercropped with 'BR 106' was efficient, while that with 'AG1051' was inefficient in terms of land equivalent coefficient.

Key words: *Vigna unguiculata, Zea mays*, land equivalent coefficient.

INTRODUCTION

In Brazil, the consortium of corn and common bean (*Phaseolus vulgaris* L.) is very relevant, especially among family farmers. In the semi-arid region of northeastern Brazil, this practice is higher among maize and cowpea

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(*Vigna unguiculata* L. Walp) crops. Meanwhile, in the North of Rio de Janeiro, there is a large production of cowpeas, however, usually in monoculture.

Corn is one of the main cereals produced in the world and the most cultivated in Brazil, but it has enormous contrast of productivity between the different regions of the country. Corn crop production in Brazil in 2013/2014 was 79,905.5 thousand tons (CONAB, 2014). According to Freire Filho et al. (2011), cowpea production in 2009 in Brazil was approximately 523,890 tonnes. Cowpea plays a key role in organic production due to its symbiotic relationship with nitrogen-fixing bacteria.

Corn and cowpea bean, in general, present low productivity in family agriculture, both in intercropped and monoculture systems. Several problems may be associated with this and one of the factors is the use of cultivars unsuitable for the type of system. On the other hand, family farmers are currently looking for new techniques or agricultural systems, and one of the alternatives is organic farming with consociated systems. It is worth emphasizing that when the consortium is compared between crops and monoculture, the main advantage of the intercropping system is the more effective use of non-renewable resources (Brooker et al., 2015).

Organic farming seeks to utilize cultural practices such as intercropping, crop rotation, green manuring, biological control of pests and diseases, and nutritional balance and excludes the use of chemicals (Cieslik et al., 2009). When the producer decides to change the production system in an area where the conventional production system was used for an organic system, this area goes through a process called conversion or transition process. At the beginning of this process, there is usually a reduction in productivity, making it difficult to use this practice.

The objective of this work was to compare the response of two maize cultivars, intercropped with cowpea in a conversion area, from conventional to organic systems, by analyzing the development and yield of dry corn and cowpea beans.

MATERIALS AND METHODS

The experiment was carried out at the Research Support Unit of the Center for Agricultural Sciences and Technologies, State University of Norte Fluminense Darcy Ribeiro (CCTA/UENF), Campos dos Goytacazes– RJ, 21°44 '47" South latitude and 41°18'24" West longitude, with altitude of 12 m in the period of October 2012 to March 2013, corresponding to the spring/summer periods (Figure 1). The study was carried out in the field in the spring/summer period. The climate of the region is classified as Aw (Köppen), that is, humid tropical climate, with rainy summer, dry winter, average annual temperature of about 24°C, with maximum temperatures of about 40°C in summer.

The soil where it was installed was classified as Cambisol Hapic, and after the soil sampling, the 0 to 20 cm depth and subsequent chemical analysis with the following chemical were obtained: pH (H_2O) = 5.3; P = 4 mg dm^{-3}; K, Ca and Mg = 2.3; 38.2 and 36.0 $mmol_c$ dm^{-3}; Fe, Cu, Zn and Mn = 109.8; 2.5; 5.0; and 69.0 mg dm^{-3}; M.O. = 26.9 g dm^{-3} and CTC and SB = 120.0 and 78.5 $mmol_c$ dm^{-3}, respectively.

Factorial arrangement (2 x 2) + 1 whose factors and levels were: corn cultivars ('AG 1051' and 'BR 106') and cultivation system (monoculture and consortium with cowpea), was used. Besides these treatments, one more treatment with monoculture of cowpea was installed. The experimental design adopted was of randomized blocks with four replicates.

All experimental units were 5 m in length, and the consortium system was 6.4 m wide with eight rows. Monoculture of bean cowpea was 3.6 m wide with six rows, while monoculture maize was 3.2 m wide with four rows. As a useful area, for maize in monoculture and in consortium, the two central lines were considered, being 0.5 m at their extremities, 6.4 m², while the cowpea beans were 1.5 m from the ends of two central lines with a floor area of 2.4 m² in the monoculture and 3.2 m² in the consortium (Figure 2).

The consortium consisted of a row of cowpea between double rows of maize (1C:2M). The row spacing used, regardless of the cultures, was 0.80 m. Soil preparation was mechanized by performing a plowing at 20 cm depth, followed by two harrows. Maize and cowpea had density of 4.0 and 8.0 plants per meter, respectively.

In the area, two fertilizations were carried out with bovine manure, applying 1 L per linear meter of furrow as Guedes et al. (2010). The dry manure used in fertilization had the following characteristics: N, P_2O_5, K_2O, Ca, Mg and C = 1.18; 0.87; 1.20; 0.85; 0.55 and 10.89%; Fe, Cu, Zn and Mn = 7; 20; 140 and 68 mg dm^{-3}. Three manual weeding was carried out in all the plots. All the experimental areas received additional irrigation by sprinkling according to the water requirement of the crops.

To avoid pest infestations in both crops, spraying was carried out according to organic production systems: in the corn crop, an aqueous extract with dry leaves of neen (*Azadiracta indica*) was applied to control the caterpillars; in the cowpea culture, three sprays were applied at four days interval with neutral detergent aqueous solution to control the aphids (*Aphis* spp.). For the control of coleoptera (kitty, *Diabrotica speciosa*), three applications of shredded kit were made according to Martinez (2003). The applications were satisfactory in the control of insect pests. The evaluations of maize and cowpea were done in the two central lines of each experimental unit, that is, in the useful area, using the lateral lines as a border. The maize crop evaluations were used for all plants of the useful area, totaling 32 plants. When in the R2 stage, the height of the plant and the diameter of the stem were evaluated. When the grains reached the R7 stage (physiologically ripe), the weight of 100 grains and the yield of grains were evaluated.

In the cowpea culture, sixteen plants of the useful area of each experimental plot were evaluated, at the point of physiological maturation: plant height, number of leaves and length of main branch and, when the plants were dry: the number of seeds per pod, the number of pods per plant, the weight of one hundred grains and productivity.

In order to compare consortia and monocultures, the area equivalence index (AEI) was used to estimate the area required for monoculture yields equal to that obtained in intercropping (Moura, 1984). The AEI is derived from the equation:

$$AEI = CA/MA + CB/MB = IA + IB$$

CA = Cowpea bean yield in consortium; MA = cowpea bean yield in monoculture; CB = corn yield in consortium; MB = corn yield in monoculture; IA = individual index for cowpea beans; IB = individual

Figure 1. Map of the Research Support Unit of the Center for Agricultural Sciences and Technologies at the campus of the Northern Fluminense State University, Darcy Ribeiro (CCTA / UENF), Campos dos Goytacazes – RJ.

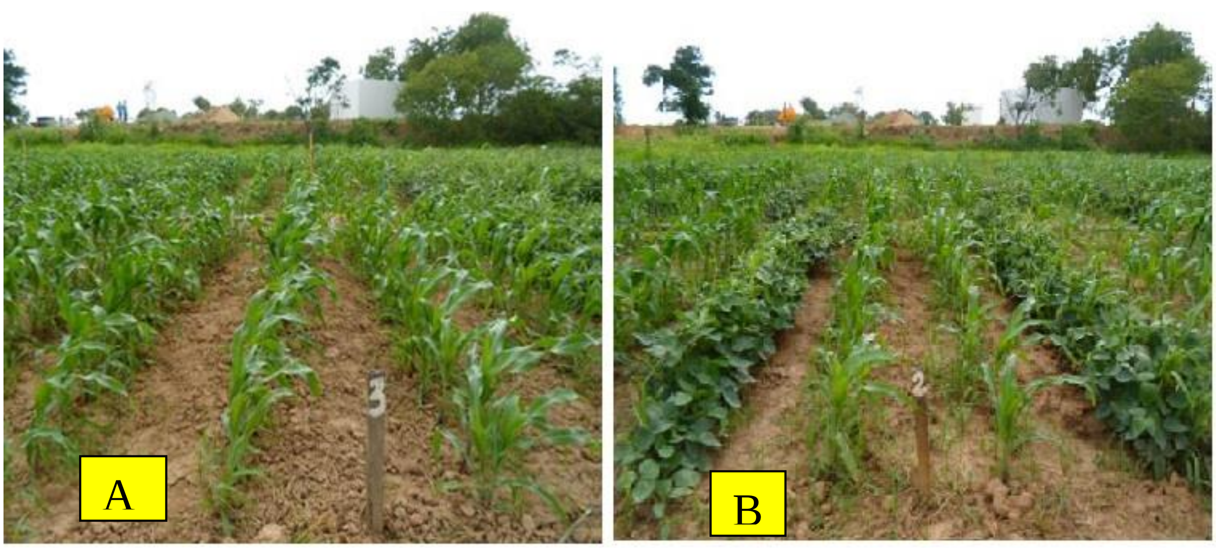

Figure 2. Corn monoculture ('AG 1051') (A) and maize consortium with cowpea (B).

index for corn.

The individual consortium is considered to be efficient when the AEI is greater than 1.0. For statistical analysis of maize variables, the experiment was considered as a factorial arrangement (2 x 2). Data were submitted to analysis of variance by the F test and, when interaction between factors was verified, the unfolding was performed. Meanwhile, for the analysis of cowpea variables, the experiment was considered to contain three treatments: cowpea in monoculture, in consortium with corn 'AG 1051' and in consortium with 'BR 106'. The analysis of variance was performed by the F test and when the effect of the treatments was significant, at a 5% probability level, the means were compared by the Tukey test, also at a 5% probability level.

Statistical analysis were performed with the aid of the computational app and performed with the aid of the computational application SAEG (Sistema para Análises Estatísticas e Genéticas) (Gomes et al., 1990).

RESULTS AND DISCUSION

The monoculture of Aguiar and Moura (2003) showed heights of corn plants higher than that observed in this experiment, where the plant height of 'AG 1051' and 'BR 106' varieties were 241 and 284 cm, respectively, under soil conditions of low fertility and with chemical fertilization. Both works were installed in soil with low fertility, but in this work, it was totally managed in an

Table 1. Plant height (AP) stem diameter (DC), weight of hundred grain (PCG) and grain yield (PRO) of corn cultivars grown in monoculture (Mono.) and intercropping (Cons.) with cowpea ('Poços of Caldas`).

Corn cultivation	AP (cm)			DC (mm)		
	Mono.	Cons.	Mean	Mono.	Cons.	Mean
'AG 1051'	232.1	212.8	222.5^a	22.0	22.0	22.0^A
'BR 106'	255.4	221.6	238.5^a	22.1	21.5	21.5^A
Mean	243.7^a	217.2^b	230.5	22.1^a	21.5^a	21.8
CV (%)		9.4			7.1	
		PCG (g)			PRO (kg ha^{-1})	
'AG 1051'	19.7	19.5	19.6^A	6.330	4.411	5.371^A
'BR 106'	20.8	19.4	19.4^A	5.209	4.591	4.900^A
Mean	20.2^a	19.6^a	19.9	5.769^a	4.501^b	5.135
CV (%)		5.8			17.3	

Averages followed by the same letters, uppercase in the column and lowercase in the row, do not differ by test F (p > 0.05).

organic way, using only cattle manure in the fertilization. In addition, the area was in the process of conversion to the organic production system, influencing the lower corn growth. Santos et al. (2010) compared production systems with organic fertilization or chemical fertilization. It was verified that the organic fertilization provided smaller, less developed corn plants with less production. Maize plants were, on average, 26.5 cm higher ($p < 0.05$) than the consortium plants (Table 1). On the other hand, there was no significant difference between cultivar heights (Table 1). Possibly, corn intercropped with cowpea increased less due to competition with fabaceae. Viegas Neto et al. (2012) also observed a significant reduction ($p < 0.05$) in corn plant height in a corn and bean intercropping system, in the row.

Aguiar and Moura (2003) obtained heights of corn plants higher than that observed in this experiment, where the plant height of 'AG 1051' and 'BR 106' varieties were 241 and 284 cm, respectively, under soil conditions of low fertility and with chemical fertilization. Both works were done in soil with low fertility, but in this work, it was totally managed in an organic way, using only cattle manure in the fertilization. In addition, the area was in the process of conversion to the organic production system, influencing the lower corn growth. Santos et al. (2010) compared production systems with organic fertilization or chemical fertilization. It was verified that the organic fertilization provided smaller, less developed corn plants with less production.

It is interesting to consider that, in intercropping, intercropping species usually differ in height, among other morphological characteristics, that can make plants to compete for light energy, water and nutrients. The division of the solar radiation incident on the plants, in a consortium system, is determined by the height of the plants and the efficiency of light interception. The shade caused by the highest crop reduces both the amount of solar radiation to the lowest crop and its leaf area (Flesch, 2002). Thus, within certain limits, reduction in maize height, when in consortium, may be beneficial to cowpea, because it certainly reduces the shading and negative effects on the Fabaceae.

There was no significant effect ($p > 0.05$) of cropping system and of maize cultivars on stem diameter (Table 1). The corn plants presented approximately 21.8 mm of stem diameter.

On the other hand, Viegas Neto et al. (2012) verified a significant reduction in stalk diameter in a corn intercropping system. Santos et al. (2010) verified that among seven maize cultivars, 'AG 1051' stood out in all variables, presenting a significantly larger stem diameter of 23.3 mm. However, in this work (Table 1), as already mentioned, there was no difference between cultivars and between cropping systems for stem diameter for the weight of one hundred grains of maize (Table 1) with no difference in effects (p > 0.05) in cultivation system and maize cultivars. The weight of one hundred grains remained as an average of 19.9 g.

The values of one hundred grains obtained (Table 1) were lower than those observed in the literature (Aguiar and Moura, 2003; Távora et al., 2007), which is possibly related to the low availability of nutrients, due to the fact that only organic fertilization was used in the first year of conversion to the organic system. F were lower than those observed in the literature (Aguiar and Moura, 2003; Távora et al., 2007), which is possibly related to the low availability of nutrients, due to the fact that only organic fertilization was used in the first year of conversion to the organic system or the weight of one hundred grains of maize by Aguiar and Moura (2003) under conditions of low fertility soils and mineral fertilization which were 25.3 g for 'AG 1051' and 23.1 g for 'BR 106'. Távora et al.

(2007) obtained 30.2 g for hybrid corn 'Cargill-435', in a system consortium with cowpea and using a plant population similar to this work.

Regarding the average yield of maize grains, there was no significant effect (p> 0.05) of maize cultivars (Table 1) with a mean of 5,135 kg ha^{-1}. Contrary to the current study (Table 1), Aguiar and Moura (2003) obtained 4,210 and 2,836 kg ha^{-1}, respectively, for 'AG1051' and 'BR 106' in low fertile soils with mineral fertilization; 'BR106' produced 32.6% less than 'AG1051'.

'BR 106' is an open pollinated variety, while 'AG 1051' is a double hybrid, which generally has higher yields. However, BR 106 has lower cost of seeds, since it can be produced by the producer itself, does not require high production technology, has the capacity to adapt to different environmental conditions, among other aspects, therefore favoring its adoption, and contributes to the choice of this variety by family farmers.

However, in an analysis by Santos et al. (2009b) on review of several studies, concluded that the hybrid 'AG1051' was shown to be promising for family farming. When comparing 'AG 1051' with 'BR 106', it was found that, even in conditions of low soil fertility, the hybrid had a grain yield higher than the variety.

The crop system significantly affected (p <0.05) corn grain yield (Table 1). Monoculture yielded 28% more maize grain than the consortium (Table 1). The reduction in maize productivity in the consortium (Table 1) was possibly caused mainly by reduction in the population of maize plants, which in the consortium was approximately two thirds of the monoculture population. However, on average, both 'BR106' and 'AG1051' were negatively affected by the insertion of cowpea into the system, as they presented lower plants (Table 1) and did not fully express their productive capacity by area (Table 1).

In general, the relationship between population density and crop productivity is direct. However, there are some crops that have high phenotypic plasticity, alter their production components as a function of spatial arrangement without modifying productivity (Mauad et al., 2010), and this characteristic can vary among cultivars of the same species.

In an organic production system of intercrop with cowpea, Guedes et al. (2010) found that the maize crop did not suffer losses in productivity and recommended that the sowing of the cowpea should be done three weeks before the maize in consortium between 'AG1051' and 'Mauá' cultivars. On the other hand, Flesch (2002) observed in the intercropping system of maize and beans, that the anticipated or simultaneous crops do not interfere with maize productivity. According to Portes (1984), corn is more demanding in light than beans, in order to reach maximum productivity, making solar radiation possibly the most important factor for the productive equilibrium of the system, which depends on the season of sowing of one crop relative to the other, and sowing density, which are related to the interception of light by the canopy of corn, and the amount of light reaching the bean canopy.

Cowpea intercropped with 'AG 1051' maize was 3.8 cm higher (p<0.05) than the 'BR 106' intercropped. Meanwhile, monoculture cowpea presented intermediate height which did not differ significantly from that in consortium with maize cultivars (Table 2).

The height of the 'Poços de Caldas' cowpea varies from 52 to 68 cm according to Bezerra et al. (2008). Thus, the values obtained (Table 2) were close to the lower limit of the cultivar, which is certainly related to the conversion process by which the experimental area was submitted. The number of leaves and length of the main branch did not present significant effects (p <0.05) of the treatments (Table 2).

Regarding the number of grains per pod, the values obtained (Table 2) were lower than those found by Silva (2015), who evaluated the types of cultivar system averaging 13.8 (Silva and Neves, 2011), 14.3 and the average found by Freire Filho et al. (2011) was 14.0 grains per pod. However, the average found in this study (Table 2) was close to the average observed by Silva et al. (2014), evaluating the agronomic potential of eight cultivars of cowpea, obtaining an average of between 5 and 8 grains per pod. In monoculture, the number of grains per pod was superior (p <0.05) to the consortia, producing 0.7 and 1.2 more grains per pod than when in consortium with AG 1051 and BR 106, respectively (Table 2).

According to Silva and Neves (2011), for manual harvesting, it is preferable to obtain more grains per pod and, consequently, the longer pod length. However, in semi-mechanized and mechanized crops, large pods are not very desirable. For these authors, smaller pods with smaller numbers of grains and, consequently, lighter ones, are preferred because they allow better sustentation, reducing the possibility of folding and breaking of the peduncle for the last two types of harvest. For the number of pods per plant, cowpea monoculture resulted in an average of 2.4 pods more than the plants in consortium with maize (p <0.05) (Table 2). In general, the numbers of pods per plant obtained in the experiment (Table 2) are similar to those reported in the literature. Santos et al. (2009a) found an average value of 10 pods per plant, while Silva et al. (2014), evaluating the agronomic potential and physiological quality of seeds of eight cultivars of cowpea, obtained from 12 to 22 pods per plant.

The weight of 100 grains was not significantly affected by the treatments (p> 0.05) (Table 2), with an average of 18.2 g. According to Silva and Neves (2011), the preference of the consumers for the weight of 100 grains is about 18 g. Távora et al. (2007) in a consortium system of corn and cowpea obtained an average value of 18.5 g. Silva et al. (2014) found a mean of 19.5 g, a similar result

Table 2. Plant height (AP), number of leaves per plant (NF), length of main branch (CRP), number of seeds per pod (NGV), number of pods per plant (NVP), weight of hundred grain (PCG) and productivity (PRO) of cowpea ('Pocos de Caldas') in monoculture and intercropping with corn cultivars 'AG1051' and 'BR 106'.

Farming system	AP (cm)	NF	CRP (cm)
Monoculture	53.1 AB	17.3 A	101.0 A
Consortium with 'AG1051'	56.0 A	16.4 A	100.1 A
Consortium with 'BR 106'	52.2 B	19.5 A	101.0 A
Mean	53.7	17.7	100.0
CV (%)	15.3	40.4	22.4

	NGV	NVP	PCG (g)	PRO (kg ha^{-1})
Monoculture	9.4 A	14.7 A	18.1 A	2.989 A
Consortium with 'AG1051'	8.7 B	13.0 B	18.4 A	657 B
Consortium with 'BR 106'	8.2 C	11.5 B	18.1 A	450 B
Mean	8.8	13.1	18.2	406
CV (%)	12.1	30.6	5.4	20.2

Averages followed by the same letters, uppercase in the column and lowercase in the row, do not differ by test F (p > 0.05).

Table 3. Individual index relative (IA and IB) and land equivalent ratio (IEA) of cowpea ('Pocos de Caldas') intercropped with corn cultivars 'AG1051' and 'BR 106'.

Relative individual index	Corn cultivars	
	'AG 1051'	'BR 106'
IA (cowpea)	0.22	0.15
IB (Corn)	0.70	0.88
AEI	0.92	1.03

presented by Freire Filho et al. (2011).

Bean cowpea productivity was significantly influenced (p <0.05) by the consortium, with a reduction in productivity. On average, monoculture productivity was approximately 5.4 times higher than that of the consortium, being related to the lower number of pods per plant and grain per pod (Table 2).

Hamd-Alla et al. (2014) in their results obtained results contrary to those presented here, where they observed higher corn grain yield in consortium with cowpea as compared to single crop. This was possibly due to the lower competitive ability of the cowpea, relative to maize, by the factors of production, especially solar radiation. In addition, the population of plants in the consortium was one-third of the population in monoculture because of the ratio of two rows of maize to one of cowpea in the consortium. As already mentioned, the consortium consisted of a line of cowpea between double rows of corn (1C: 2M).

Silva and Neves (2011) evaluated twenty genotypes of cowpea and obtained yields varying from 658 to 1,070 kg ha^{-1}, while Silva (2015) obtained a productivity average of 752 kg ha^{-1}, with no statistical difference between cultivation systems. The consortium of cowpea bean with 'BR 106' was considered to be efficient, since the value of the AEI was higher than 1.0 (Table 3). However, the IEA of 'AG 1051' was less than 1.0, indicating that the consortium of this hybrid with cowpea was inefficient (Table 3). The relative individual indices (Table 3) show that the cowpea in the consortium produced 22 and 15% of that produced in the monoculture, respectively, in the consortia with 'AG1051' and 'BR106'. However, corn in consortium with cowpea had productivity of 70 and 88% of that obtained in monoculture. Thus, 'AG1051' was more negatively affected by the consortium, but less affected the cowpea, while 'BR106' was less affected by the consortium, but more negatively affected the cowpea. Therefore, only the consortium with the 'BR106' can be considered efficient.

Other authors obtained higher AEI, pointing to more efficient consortium systems than the one obtained in this experiment. Flesh (2002) evaluated intercropping consortia of corn and beans, using poultry manure in fertilization. The author obtained AEI ranging from 1.18 to 1.67. Guedes et al. (2010) evaluating the consortium of cowpea 'Mauá' and corn 'AG-1051', in organic cultivation, obtained AEI of 1.67, while Fernandes (2012) evaluating cowpea consortium (‘Siriri’, ‘Radiante’ and ‘Pérola’) and corn (‘AL Bandeirante’, ‘BR 106’ and ‘Sol-da-Manhã’) in an agro-ecosystem managed under ecological bases in the Dourados, Mato Grosso do Sul, obtained an average of AEI with the cultivar ‘BR 106’ of 1.22.

The AEI obtained in the experiment (Table 3), which is much lower than those observed by other authors, is possibly related to the area where the experiment was conducted, which is in the process of conversion to the organic production system. Certainly, the effects of corn competition on cowpea in the consortium were higher due to the system conversion condition, which led to lower numbers of grains per pod, pods per plant and, consequently, lower cowpea productivity (Table 2).

In the study developed by Santos et al. (2016), they obtained higher results from IEA, where the arrangement and density of plants in the area, with larger proximities between the root systems of the crops, together with a larger population of string bean plants and less corn, resulted in greater agronomic gains, contributing to a higher IEA.

On the other hand, Takin (2012), evaluating the consortium between maize and cowpea, found that the highest IEA occurred in cultivation with the row arrangement of maize for a row of cowpea and two rows of maize for a row of cowpea, 1.77 and 1.75, respectively.

Conclusion

The consortium of cowpea with the variety, BR 106 for marketing purposes of grain was considered efficient. Because it has the capacity to adapt to the different environmental conditions, among other aspects, this favor its adoption and contributes to the choice of this variety by family farmers. The hybrid AG1051 suffered from the cowpea competition and did not express its productive capacity. Thus, the IEA of AG 1051 were lower than 1.0 showing that the consortium of this hybrid with cowpea was inefficient.

In contrast to the results presented, there are possible recommendations to know more deeply, the physiological, biological, chemical and genetic characteristics of the species in areas of organic production, since this system of production is more dynamic and directly influence all the variables of production when compared with the monoculture area.

The main limitations of the study were shown in the low yields achieved in this study, due to the management applied between the transitional system for organic cultivation, given that the technological level is still insufficient for this level. Another limitation is the low level of knowledge of the conversion process to the organic production system, directly influencing the growth of the plants.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Corn productivity in integrated crop-livestock system: Effect of different forage masses post-grazing

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Forage management in integrated crop-livestock system is a complex activity that increases profitability, when well performed, therefore consequently influencing future crop productivity. This study aimed to evaluate the agronomic performance of corn cultivation in the integrated crop-livestock system using the no-tillage system in different forage masses post-grazing. The experiment was conducted in the municipality of Mata, which is located in the state of Rio Grande do Sul, during the agricultural years of 2009/2010, 2010/2011, 2011/2012, 2012/2013 and 2013/2014, under no-till with corn in the summer and black oats plus ryegrass in the winter for grazing. The experimental design was made up of randomized blocks, using four heights of forage mass post-grazing: 0.10, 0.20, 0.30 m conventional grazing and without grazing. For the evaluation of the remaining dry mass of forage, a destructive cut was made at 5 cm from the soil at 28 days after the animals left. The evaluations of plant height, cob insertion height, number of grain rows, number of grains per cob, mass of one-thousand grains, and corn grain yield were performed. The average values of remaining forage mass were 1.52, 2.26, 2.44, 8.56 and 1.41 Mg ha^{-1} for the different grazing managements, in which corn productivity were 7.74, 8.82, 7.94, 9.22 and 7.70 Mg ha^{-1}. In absolute terms, the winter pasture management of 0.2 m high presented the best results in terms of corn grain productivity.

Key words: Soil coverage, forage, grazing height, income components, zero tillage.

INTRODUCTION

The production of food, bio-energy, fiber, wood and other goods are some of the many obstacles currently faced by researchers, technicians and farmers (Veiga et al., 2011). In order to meet modern-day demands, appropriate production systems with the least possible use of external inputs, environmental contamination and greenhouse gas emission must be adopted. No-till and integrated crop-livestock system are management alternatives with

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greater rationality of inputs employed that maintain and even increase production (Santos et al., 2008). These alternatives increase organic matter, which improves soil quality and aggregation (Conceição et al., 2005).

The integrated crop-livestock system is one of the most promising strategies for developing production systems that are more sustainable and have reduced input use because it assumes the continued use of agricultural land and improvement of soil quality over time (Rao et al., 2003). According to Veiga et al. (2011), this system integrates multiple biological, economic and social factors that interrelate and determine its sustainability. Additionally, ICL systems can improve nutrient cycling, reduce soil erosion, improve water use, interrupt pest and disease cycles as well as reduce investment risks through economic diversification (Allen et al., 2008).

Successful integration between systems depends on the employed stocking rate variable, its direct and indirect effects on the amount of forage as well as the nutrients that cycle in it (Carvalho et al., 2005). Overcrowding in grazing systems reduces the increment of the straw on the ground in direct consequence of managing smaller heights of forage plants, resulting in reduced productive potential of plants, problems with straw addition, compaction and soil erosion (Anghinoni et al., 2011). On the other hand, moderate grazing management grants plants the ability to grow and resprout, which is due to greater light interception compared to overcrowding (Souza et al., 2009).

In addition to pressure from grazing conferred by adjusting animal stocking and/or remaining height, the type of mulch can also modify the system, particularly nutrient cycling, decomposition rate and the addition of organic carbon to the soil. Forage legumes provide a greater increase of nitrogen on the successor crop, therefore ensuring cost reduction by means of nitrogen fertilization (Collier et al., 2006; Albuquerque et al., 2013). However, the use of grasses in the ICLS, in addition to allowing greater forage intake for grazing, can also contribute to nutrient cycling at a proportional rate or even higher depending on nitrogen management, carbon/nitrogen relation and lignin in the aerial part (Alvarenga et al., 2001; Doneda et al., 2012).

In small properties that adopt the integrated crop-livestock system, corn crops stand out as successors of the grazing period due to their numerous uses, such as in animal feed and green or conserved forage. Corn crop production reaches anywhere from 12000 to 13000 kg ha^{-1} of grains in commercial fields in Brazil. Additionally, in experimental conditions and by farmers who have adopted advanced technologies, it is even possible to obtain a production of approximately 15700 kg ha^{-1} (Mundstock and Silva, 2005). However, what is observed in practice are in fact considerably low and irregular yields, which average around 4795 kg ha^{-1} of grain (CONAB, 2016).

With the constant evolution of the agricultural sector since the introduction of No-till (NT), management rotation/crop succession and currently the integrated crop-livestock system (ICLS), the need for further studies in these areas that act in integrated fashion grows similarly. Therefore, the objective of this study is to evaluate the agronomic performance of corn crops in the integrated crop-livestock system in no-till farming in different forage masses post-grazing.

MATERIALS AND METHODS

The study was conducted on a farm during the agricultural years of 2009/10 to 2013/14, at the Central Depression of Rio Grande do Sul (103 m height, latitude 29°07 ' 34 "S and longitude 54°27 ' 29"). Climate is 'Cfa' type in the Köppen classification (Peel et al., 2007), with rainfall and annual average temperatures ranging between 1,558 and 1,762 mm and 17.1 and 17.9°C, respectively. The soil of the experimental area is classified as Rhodic Paleudalf (Embrapa, 2013) with physical-chemical features obtained through sampling in the 0.2 m layer for the implementation of the experiment. Sampling revealed the following values: pH 5.5 water; organic matter of 5,0 g kg^{-1}; P-Mehlich-1 of 49,4 mg dm^{-3}; 155,4 mg dm^{-3} of K; 1,31 $cmol_c$ dm^{-3} of Ca^{+2}; 0,37 $cmol_c$ dm^{-3} of Mg^{+2}; and $CTC_{pH\ 7,0}$ of 8,23 $cmol_c$ dm^{-3}, sand, clay and silt of 557, 195 and 248 g kg^{-1}, respectively (Tedesco et al., 1995).

The experimental design comprised of randomized blocks with three replications and five treatments, totaling 15 experimental units (EU) with dimension 14 m × 15 m. Treatments consisted of four heights of forage mass post-grazing: forage mass height of 0.10 m (M-10); 0.20 m (M-20) and 0.30 m (M-30) continuous grazing (CG), with an area of 500 m^2 and intensity of free grazing for the animals and control treatment without grazing (TWG).

The experiment was conducted in mid-April of 2009, in an area of 3000 m^2 and in a system integrating grain production with livestock production. The pasture component was implanted in April for the respective agricultural years and made up of a consortium of black oats (*Avena strigosa* Schreb.) and ryegrass (*Lolium multiflorum* Lam.) in the proportion of 70 kg ha^{-1}, 25 kg ha^{-1} of viable seeds, respectively. These seeds were sown in total area coverage and the corn crop of the previous crop was then mowed on the seeds, avoiding the sorting.

The mineral fertilizer used in the corn crops and forage was based on the recommendation for the respective crops according to the manual of liming and fertilization (CQFS-RS/SC, 2004), and obtained through soil sampling prior to the deployment of each crop. The nitrogen fertilization cover for the corn crops was carried out at two different times, comprising of the phenological stages V4 and V8 (fourth and eighth leaves), and for grazing, this fertilization was conducted in three moments and applied in the phenological stage of oat crop tillering and after each grazing (Weismann, 2007).

For the characterization of the vertical structure of the pasture, the monitoring of the height was carried out through the ruler method (sward stick), which was adapted from Barthram (1985), in which an overhead projector marker moves through a graduated ruler until it touched the leaf surface canopy. This monitoring was carried out before the entry of the animals, during grazing and after the departure of the animals to ensure the desired height was maintained. Grazing were carried out around 70, 100 and 130 days after the emergence of pastures for the different heights of forage mass post-grazing of the respective five years. The period for the entry of the animals into the first pasture occurred when the forage reached an average height of 0.40 m and the remaining grazing were performed at intervals of 28 days, using lactating cows of the Jersey breed with 2.4 animal units per EU.

Measurement of the remaining biomass of forage was conducted 28 days after the last grazing, collecting three samples through destructive cuts of pasture in random places and delimited by a metal square of 0.25 m^2, which was obtained by cutting with scissors and adjacent to the ground. Afterwards, the remaining biomass of forage were dried in an oven with forced air circulation of 65°C for 72 h and then weighed on a precision balance.

Subsequently, desiccation of the pasture was performed using glyphosate herbicide at the dosage of 3 L ha^{-1} of commercial product, respecting an interval of 15 days to perform sowing in no-till system. Hybrid sowing occurred on 11/17/2009, 12/14/2010, 12/10/2011, 11/25/2012 and 12/13/2013 for the respective agricultural years, and had 0.60 m spacing between rows. The emergence of the seedlings occurred five days after sowing, with a final density of 70,000 plants ha^{-1}.

Grain harvest was performed manually in the phenological stage R6 (physiological maturity) in an area of 2.8 m^2 with three samples in each sub-plot, which occurred from mid-March to the first fortnight of April of the respective agricultural years of when the evaluations were performed. The evaluations performed were:

Cob insertion height, number of grain rows, number of grains per cob, mass of one-thousand grains and grain productivity corrected for 13% humidity.

The results were submitted to analysis of variance using the Tukey test at 5% probability of error. The statistical software GENES (Cruz, 2013) was used.

RESULTS AND DISCUSSION

Results of the remaining dry forage mass of the winter period can be seen in Table 1, on the grounds that the different heights of forage mass post-grazing became the substrate for sowing the corn crop. In the five-year evaluation of the RDFM of winter, there were differences between post-grazing heights.

In this evaluation period, the average amount of mulching that remained until the time of corn sowing ranged, respectively, from 1410 to 8560 kg ha^{-1} for conventional grazing and without grazing, and possessing an average 3240 kg ha^{-1} of mulching that was on the ground at the time of corn sowing (Table 1). Different grazing pressures allowed the development of quantities of plant residue on the soil surface, ranging from 1850 to 5400 kg ha^{-1}, from the largest to smallest grazing pressure, respectively, and being 6050 kg ha^{-1} in the area without grazing (Flores et al., 2007) (Table 1).

In the integrated crop-livestock system, the themed research is tied to the establishment of the ideal amount of straw in order to ensure adequate soil coverage for successor crops, which are sown in periods that frequently have dry spells. Additionally, straw coverage mitigates the impact of mechanical pressure of trampling (Braida et al., 2006). One of the requirements for the success of the no-tillage system (NTS) is the favorable formation of straw coverage on the soil surface (Pariz et al., 2011). The success of theno-tillage system also depends on the annual addition of straw coverage to cover the ground and must not be less than 8000 kg ha^{-1} (Lovato et al., 2004; Nicoloso et al., 2006). Depending on the crop that will be used in succession and the remnant of winter forage straw, this goal can be achieved. However, to maintain and/or increase the soil organic carbon content in the NTS, the amount of stover must be increased from 10000 to 12000 kg ha^{-1} per year (Bayer, 2001).

Nevertheless, the remaining straw forage (Table 1) did not affect the results of the straw found in this study, reinforcing the importance of crop rotation, especially when leaving favorable amounts of straw at the end of the grazing cycle. Regarding the productivity of corn grains in the agricultural year of 2009/10, it was possible to observe a difference between the different masses of forage post-grazing (Table 1). The most grazed treatments (10-M and CG) resulted in lower grain productivity when compared to the other treatments, which did not differ statistically between themselves.

Grain yields varied from 9600 to 11600 kg ha^{-1}, respectively, for CG and 30-M, with an average yield of 10640 kg ha^{-1} (Table 1). Results of smaller grain yields were repeated in the agricultural year of 2010/11, for CG and 10-M, and 5300 5300 kg ha^{-1}, respectively, and the average productivity of the treatments were 6260 kg ha^{-1} (Table 1). In order to mitigate the loss of productivity in periods of water deficit during sowing, soil mulching is essential, as it helps maintain hydrothermal features (Resende et al., 2005). This is confirmed in the agricultural years 2010/11 and 2011/12, since these years suffered water deficits, where the difference of income ranged from 1900 and 1400 kg ha^{-1} for CG and NG for the respective agricultural years evaluated (Table 1).

Studies that link different grazing intensities found that the higher the grazing intensity, the lower the yield of corn grain, with a difference of 1300 kg ha^{-1} between the most grazed versus the least grazed treatment, of which was associated to greater soil compaction in areas of greater grazing intensity (Journal et al., 2006).

For the agricultural years 2012/13 and 2013/14, climatic conditions favored better performance for different heights of forage mass post-grazing and without grazing, with average yields of 8300 and 9980 kg ha^{-1} for the respective agricultural years (Table 1). Furthermore, it is possible to observe that the corn grain yield of the CG was equal to other treatments that maintained a greater supply of straw at the end of the grazing cycle (Table 1).

In the average of the five agricultural years evaluated, corn grain yield ranged from 7700 to 9220 kg ha^{-1} for CG and NG, respectively, with a difference of 1520 kg ha-^{1} for the area with the lowest soil coverage areas without grazing (Table 2). These results corroborate with the literature, such as by Nicoloso et al. (2006) and Trogello et al. (2012), who report differences in 1300 and 2000 kg

Table 1. Average remaining dry forage mass (RDFM) and grain productivity (GP) grown in no-tillage system in integrated crop-livestock system, in five agricultural years and in different heights of forage mass post-grazing.

Height of forage mass post-grazing	Agricultural year					
	2009/10	2010/11	2011/12	2012/13	2013/14	Average
RDFM (kg ha^{-1})						
10-M	1100^{c}	2200^{cd}	1900^{b}	1200^{c}	1200^{d}	1520^{b}
20-M	2400^{b}	2900^{bc}	2100^{b}	1900^{b}	2000^{c}	2260^{b}
30-M	2200^{b}	3600^{b}	2000^{b}	2100^{b}	2300^{b}	2440^{b}
NG	9200^{a}	8100^{a}	10100^{a}	7300^{a}	8100^{a}	8560^{a}
CG	550^{c}	2000^{d}	2100^{b}	1200^{c}	1200^{d}	1410^{b}
CV (%)	8.13	7.52	3.92	5.680	2.95	-
GP (kg ha^{-1})						
10-M	9920^{b}	5510^{c}	6130^{bc}	7860^{cd}	9160^{b}	7710^{b}
20-M	10860^{a}	6650^{ab}	6240^{b}	8750^{ab}	11470^{a}	8780^{ab}
30-M	11600^{a}	6590^{b}	6110^{bc}	7440^{d}	8130^{b}	7950^{ab}
NG	11150^{a}	7210^{a}	7090^{a}	9190^{a}	11410^{a}	9210^{a}
CG	9630^{b}	5200^{c}	5730^{c}	8240^{bc}	9730^{ab}	7710^{b}
Average	10634	6216	6264	8301	9983	-
CV (%)	2.58	3.56	2.49	2.4	6.52	-

*Averages followed by the same letter in the same column do not differ by the Tukey test at 5% probability. CV: Coefficient of variation.

ha^{-1}, respectively, from the lowest to the highest grazing intensity. Regarding the productivity of corn grains conducted in five years, they indicate that among the grazed areas, the height of forage mass post-graze of 20-M was the one that presented the best average yield in this evaluated period, with 8820 kg ha^{-1} (Table 2).

The average height of the cob was influenced by different forage masses after grazing (Table 2). Continuous grazing provided the lowest CIH, although it differed statistically from M-10 and NG, which did not differ from the other post-grazing forage masses (Table 2). The evaluation of this variable is very important since it is related to lodging, which leaves the taller plants more susceptible. Notwithstanding, the cob insertion height is a very important parameter in mechanized harvesting because it has significant effect on total grain loss. However, Junior et al. (1997) highlight that the CIH should be above 1.0 m in mechanized harvesting, and the CIH below this height, especially the CG average (Table 2). This cob insertion height is not influenced by the use of green manure in soil coverage (Santos et al., 2010).

For the number of grain rows, there were statistical differences in the agricultural years 2010/2011 and 2012/2013, and in the remaining agricultural years this variable was not influenced by the different masses of post-grazing forage. In the five evaluated agricultural years, it is possible to observe that in the average NGR there was an interaction between the different post-grazing forage masses, resulting in CG having lower NGR, and not being different than the M-10 of which did not differ from the other treatments (Table 2). For Valle et al. (2013), the NGR is more influenced by genetic character, population, plant population used and doses of nitrogen (Carmo et al., 2012) than predecessor cover crops (Albuquerque et al., 2013).

The different post-grazing forage masses influenced the number of grains per cob in the agricultural years 2010/2011 and 2012/2013, and in the remaining crop years this variable was not influenced by the different treatments (Table 2). The average of the variable NGC of the five years evaluated did not differ between M-10 and CG, of which did not differ from the NG and M-30 that were statistically equal to M-20 (Table 2). For Bravin and Oliveira (2014), the NGC is an important variable because it is directly related to corn productivity. When there are no limitations in the system, the NGC is greater when there is adequate availability of nitrogen for the plants in the soil (Soratto et al., 2011), which results in major gains of production.

The thousand-grain weight, which is an important component of productivity, presented significant differences in three of the five agricultural years evaluated (Table 2). In the average of the different post-grazing forage masses in five years, there were no statistical differences between the treatments. This is the production component less affected by changes in management and fertilization practices, with a feature

Table 2. Cob insertion height (CIH), number of grain rows (NGR), number of grains per cob (NGC), mass of a thousand grains of corn (MTG), grown in no-tillage system in integrated crop-livestock system in five agricultural years, in different heights of forage mass post-grazing.

Agricultural year	Height of forage mass post-grazing					CV (%)
	M-10	M-20	M-30	NG	CG	
CIH (m)						
2009/2010	0.89^{ab}*	0.90^{a}	0.82^{bc}	0.78^{c}	0.62^{d}	7.59
2010/2011	0.98^{c}	1.07^{ab}	1.10^{a}	1.13^{a}	1.03^{c}	4.2
2011/2012	0.98^{a}	0.90^{ab}	0.96^{ab}	0.94^{ab}	0.82^{c}	5.29
2012/2013	1.0^{b}	1.03^{ab}	1.03^{ab}	1.04^{a}	1.01^{ab}	2.64
2013/2014	0.93^{b}	0.98^{a}	0.99^{a}	0.97^{ab}	0.85^{c}	4.21
Average	0.96^{ab}	0.98^{a}	0.98^{a}	0.97^{ab}	0.87^{b}	-
NGR						
2009/2010	15^{ns}	15	15	15	14	6.74
2010/2011	13^{b}	14^{ab}	14^{ab}	15^{a}	13^{b}	6.07
2011/2012	14 ns	15	14	15	13	9.98
2012/2013	13^{ab}	13^{ab}	14^{a}	13^{ab}	12^{b}	7.77
2013/2014	12 ns	13	13	13	12	7.1
Average	13.4^{ab}	14.0^{a}	14.0^{a}	14.2^{a}	12.8^{b}	-
NGC						
2009/2010	508 n^{s}	541	496	515	506	9.43
2010/2011	292^{b}	372^{a}	326^{ab}	352^{a}	292^{b}	8.32
2011/2012	479 n^{s}	507	517	507	479	5.76
2012/2013	285^{b}	382^{a}	341^{ab}	367^{a}	285^{b}	13.13
2013/2014	495 n^{s}	529	496	503	528	17.48
Average	411.8^{b}	466.2^{a}	435.2^{ab}	448.8^{ab}	418.0^{b}	-
MTG (g)						
2009/2010	288^{b}	289^{b}	311^{a}	273^{b}	272^{b}	2.34
2010/2011	384^{ab}	380^{b}	354^{c}	402^{a}	382^{b}	1.85
2011/2012	344 n^{s}	342	345	340	342	2.42
2012/2013	325^{a}	304^{b}	320^{ab}	321^{ab}	329^{a}	2.1
2013/2014	266 n^{s}	284	282	245	293	10.87
Average	321.4^{ns}	319.8	322.4	316.2	323.6	-

*Averages followed by the same letter on the same line do not differ by the Tukey test at 5% probability. CV%: percentage variation coefficient. NS = Not significant.

more influenced by the hybrid, nutrition and climatic conditions (Ohland et al., 2005).

Conclusion

Superior productivity of corn in integrated crop-livestock system was found for 0.2 and 0.3 m high pasture forage management. The ungrazed system provided the most remaining forage mass for sowing corn, and consequently increased crop productivity. The treatments M-20 and M-30 were ideal for the realization of direct seeding in grazed areas.

CONFLICT OF INTERESTS

The authors declare no conflict of interest in the publication of this manuscript.

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Use of spermidine reduced the oxidative damage in onion seedlings under salinity by modulating antioxidants

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This research studies the role of spermidine (Spd) in conferring tolerance in onion seedlings under oxidative sress, caused by NaCl. Stress condition was applied on two months old onion seedlings by adding 10 gL^{-1} of NaCl, where 100 μM of Spd was sprayed twice daily before counting the stress duration. Under salinity stress, seedlings were observed for 7 days, and data were measured on relative leaf water, proline, reactive oxygen species (ROS), lipid peroxidation (as malondialdehyde, MDA), amine oxidases, enzymatic and non-enzymatic antioxidants in leaves. Salinity stress decreased the relative water content (RWC), where Spd application delayed the loss of RWC. Contrariwise, Spd increased the proline content in salinity stressed seedlings up to five days. Salinity increased the contents of superoxide ($O_2^{\cdot-}$), hydrogen peroxide (H_2O_2) and MDA continuously and significantly with stress duration. More importantly, application of Spd decreased the ROS and MDA contents in stressed seedlings more effectively, up to three days of stress. Spd maintained higher activities of polyamine oxidase (PAO) and diamine oxidase (DAO) under salinity. Higher activities of superoxide dismutase (SOD), ascorbate peroxidase (APX), monodehydroascorbate reductase (MDHAR) and glutathione reductase (GR) in presence of Spd over salinity during the study period, suggested their ROS scavenging role under salinity stress. Conversely, glutathione peroxidase (GPX) and dehydroascorbate reductase (DHAR) played important role in reducing the oxdative stress for 3 to 5 days. Spd also maintained higher reduced glutathione (GSH), ascorbic acid (ASA) and their redox homeostasis in leaves during the study period. Thus, Spd observably confirms better tolerance in short term salinity.

Key words: Spermidine, oxidative damage, salinity, antioxidants, onion seedlings.

INTRODUCTION

Onion is the most important spice crops in Banglaesh. However, the production of this crop is hampered in coastal soil of southern districts of Banladesh. Tidal flash of sea water increases soil salinity which is a major environmental stress affecting plants growth and productivity of the crop. In plants, salinity causes oxidative stress by producing reactive oxygen species (ROS) such as superoxide radicals ($O_2^{\bullet-}$), singlet oxygen (O_2), hydroxyl radicals ($^{\bullet}OH$) and H_2O_2 (Hasegawa et al., 2000; Apel and Hirt, 2004). Higher ROS causes damage to cell organells like proteins, DNA, lipids, pigments and carbohydrates which ultimately lead to cell death (Apel and Hirt, 2004; Gill and Tujeta, 2010). Conversely, higher methylglyoxal (MG) production under salinity causes potential damage to the cell organells (Yadav et al., 2005a, b). Hence, higher concentration of ROS and MG under stress is essentially needed to be reduced in cell, to survive and grow.

To survive under such situation, plants hold antioxidant system in cell to reduce the oxidative damage by ROS (Gill and Tujeta, 2010). Plants have both enzymatic and non-enzymatic antioxidants which take part in scavenging of ROS produced during various environmental stresses. Among the enzymatic antioxidant in plants, superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPX), glutathione *S*-transferase (GST), ascorbate peroxidase (APX), monodehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR) and glutathione reductase (GR) are important. On the other hand, non-enzymatic antioxidants like ascorbic acid (ASA) and reduced glutathione (GSH) play important role in maintaining the enzymatic activities (Rohman et al., 2016; Gill and Tujeta, 2010). Alternatively, glyoxalase-I (Gly-I) and glyoxalase-II (Gly-II) detoxify MG in cell (Yadav et al., 2005b). It has been repeatedly reported that, enzymes both the antioxidant and glyoxalase system are important to lessen the toxicity of ROS and MG under stress (Singla-Pareek et al., 2008; Noctor et al., 2012; Saxena et al., 2011).

Spermidine, a triamine of polyamine (PA) group, plays important role in growth and development of plants (Martin-Tanguy, 2001). PAs are also well known for their antioxidant properties as well as their cell membrane stability (Zhao and Yang, 2008). Due to cationic nature, PAs are reported to stabilize protein, DNA and lipids of cell membrane (Bouchereau et al., 1999). In addition, they have been reported to have defensive role under abiotic stresses (Alcázar et al., 2006). Importantly, cellular level of PAs shows positive correlation with plant tolerance towards environmental stresses (Nada et al., 2004; He et al., 2002; Shen et al., 2000; Roy and Ghosh, 1996; Besford et al., 1993; Krishnamurthy and Bhagwat et al., 1989). Yiu et al. (2008) reported Spd mediated higher activities of antioxidant enzymes in welsh onion (*Allium fistulosum* L.), under submerged condition.

Previously, enhanced activities of glyoxalases and GSTs in onion (*Allium cepa* L.) by exogenous Spd under salinity were reported, where the activities of the enzymes were upregulated with lower MG content (Islam et al., 2016). Therefore, exogenous Spd might have important role in reducing of ROS and regulating of related physiological activities under salinity. Considering these, we applied exogenous Spd to examine its role in maintaining ROS and related physiological activities, by measuring enzymatic and non-enzymatic antioxidants in onion under saline stress.

MATERIALS AND METHODS

Plant material and stress treatment

Seedlings of two months old (*Allium cepa* L. var BARI Piaj-3) were used as plant material. They were grown in plastic bucket (30 L), under green house of Bangladesh Agricultural Research Institute (BARI), and the seedlings were imposed to salinity stress by adding NaCl saline solution (10 gL^{-1}). An EC meter (Hanna 993310) was used to measure salinity level. Spermidine at 100 μM concentration was sprayed twice daily. Saline was added until the level became 16 dSm^{-1}, to attain salinity level of 16 dSm^{-1}.

When the salinity level attained 16 dSm^{-1}, addition of both saline water and Spd was stopped, and salinity duration was counted. Soil surface was sealed with polythene to maintain the soil moisture. This condition was maintained for seven days. A control without salinity and Spd was maintained under same condition. Data were meassused at 1, 3, 5 and 7 days of stress, in fully expanded leaves on different parameters.

Measurement of relative water content

Relative water content (RWC) was calculated according to the method of Barrs and Weatherley (1962). Data on fresh weight (FW), turgid weight (TW) and dry weight (DW) of leaves were recorded. The below formula was used to calculate RWC:

$$RWC\ (\%) = (FW-DW) \times 100/(TW-DW)$$

Measurement of $O_2^{\bullet-}$ generation rate and H_2O_2

Superoxide radical generation rate was measured according to Rohman et al. (2016). Method of Yu et al. (2003) was used in measuring H_2O_2.

Measurement of lipid peroxidation

Heath and Packer (1968) method was monitored to measure the level of lipid peroxidation, which was assayed as melondialdehyde (MDA), a peroxidation product of polyunsaturated fatty acid of the membrane lipid.

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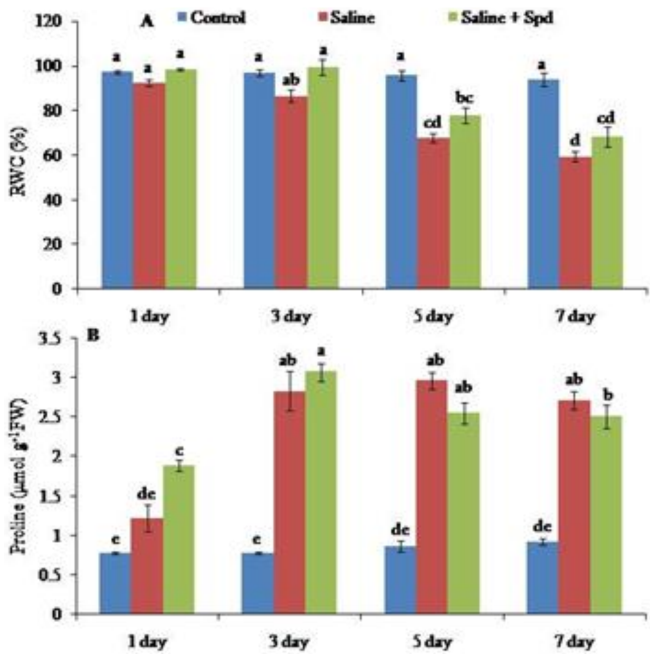

Figure 1. Changes in relatve water and proline contents in leaves of onion seedlings by Spd under salinity stress. Values present in the bars are mean ± standard error (SE). Similar letters between the bars are not significant at P≤5%.

Determination of proline

Ninhydrin was used to produce prolin's reaction which was used to estimate proline following the method of Bates et al. (1973).

Extraction and measurement of ascorbate and glutathione

Half gram of fresh onion leaves were homogenized in 3 ml extraction buffer containing 5% meta-phosphoric acid and 1 mM EDTA. Homogenates were centrifuged at 11,500×g for 15 min by 4°C, and the supernatant was used in analysis of ascorbate and glutathione. Method of Huang et al. (2005) was used to measure ascorbate while Yu et al. (2003) was used to assay for glutathione pool.

Determination of protein

Content of protein was determined according to Bradford (1976) where, BSA was used as standard.

Enzyme extraction and assays

Half gram of leaf tissue was homogenized in 1 ml of 50 mM K-phosphate buffer (pH 7.0), which contains 100 mM KCl, 1 mM ascorbate, 5 mM β-mercaptoethanol and 10% (w/v) glycerol. The homogenates were centrifuged at 11,500×g for 10 min, and the supernatants were used for determination of enzyme activity. All process was carried out below 4°C.

Diamine oxidase (DAO, EC*:* 1.4.3.6) and polyamine oxidae (PAO, EC*:* 1.5.3.11) activities were measured by the method of Gao et al. (2005), with few modifications. Fresh samples of onion leaves were homogenized in 100 mM phosphate buffer (pH 6.5) and the homogenate was centrifuged for 20 min at 4°C by 10,000×g. The supernatant was used for enzyme assay. The reaction mixture contained 2.5 ml of phosphate buffer (100 mM, pH 6.5), 0.2 ml of 4-aminoantipyrine/N,N-dimethylaniline reaction solution, 0.1 ml of horseradish peroxidase (250 Uml^{-1}), and 0.2 ml of the enzyme extract. The reaction was initiated by addition of 0.1 ml Putrescine final concentration of 20 mM) for DAO determination and 0.1 ml Spd (final concentration of 20 mM) for PAO determination. The change of absorbance at 550 nm per minute by 0.001 was considered as, one unit enzyme activity.

Superoxide dismutase (SOD, EC 1.15.1.1) activity was assayed according to Spitz and Oberley (1989) based on the competition between SOD and an indicator molecule NBT for superoxide production from xanthine and xanthine oxidase. Activity of one unit was defined as, the amount of protein required to inhibit NBT reduction by 50%. The Catalase (CAT, EC: 1.11.1.6) activity was assayed by Csiszár et al. (2011) while extinction coefficient of 39.4 $M^{-1}cm^{-1}$ was used to compute the activity.

Ascorbate peroxidase (APX, EC: 1.11.1.11) activity was computed by Nakano and Asada (1981) while Glutathione peroxidase (GPX, EC: 1.11.1.9) activity was calculated by Elia et al. (2003). The activities of glutathione (GR, EC: 1.6.4.2) and monodehydroascorbate reductase (MDHAR, EC: 1.6.5.4) were assyed according to the methods of Hossain and Fujita (2010). In case of assay activity of dehydroascorbate reductase (DHAR, EC: 1.8.5.1), method of Nakano and Asada (1981) was monitored.

Statistical analysis

Data were analyzed by statistical software SAS (9.1 version) and the means were separated by Tukey's tests following randomized complete block design (RCBD). Value presented in table and figures are, mean of three independent experiments (each experiment consists of three replications). Probability level at P≤0.05 was considered as significant.

RESULTS

Changes in relative water content (RWC) and proline

The salinity reduced the leaf RWC gradually with stress duration, and at 5 and 7 days, RWC was significantly lower in the stressed seedlings than control (Figure 1A). Foliar application of Spd reduced the loss of water and restored the RWC in salinity stress seedlings by 7, 15, 14 and 14 % at 1, 3, 5 and 7 days, respectively. On the other hand, salinity stress significantly increased the proline content in onion seedlings (Figure 1B).

In salinity treated seedlings, the content was 0.55, 2.6, 2.4 and 1.9 fold higher over control seedlings at 1, 3, 5 and 7 days, respectively. Exogenous foliar spray of Spd further increased the content up to 5 days of stress and decreased subsequently.

Effect of Spd on ROS and lipid peroxidation

The formation rate of $O_2^{\bullet-}$ increased continuously and

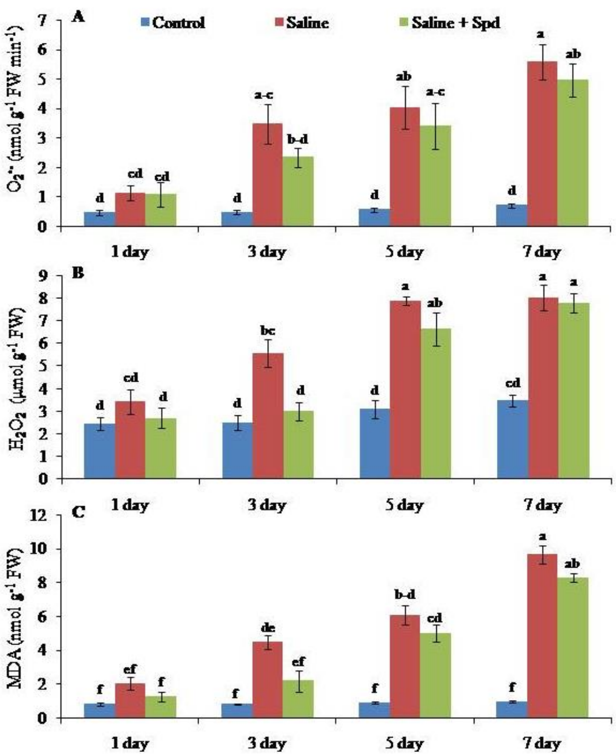

Figure 2. Changes in $O_2^{\bullet-}$ (A), H_2O_2 (B) and MDA (C) contents in leaves of onion seedlings by Spd under salinity stress. Values present in the bars are mean ± SE. Similar letters between the bars are not significant at P≤5%.

significantly with duration of stress (Figure 2A). As compare to control, $O_2^{\bullet-}$ generation rate was 2.4, 7.1, 7.1 and 7.8 fold higher in salinity stressed seedlings at 1, 3, 5 and 7 days, respectively. In Spd treated seedlings, the generation rate decreased by 5, 32, 16 and 11%, at 1, 3, 5 and 7 days, respectively. Similarly, H_2O_2 was increased sharply by salinity which was 1.4, 2.2, 2.5 and 2.3 fold higher compared to control at 1, 3, 5 and 7 days, respectively (Figure 2B).

Spd treatment also reduced the H_2O_2 content in onion seedlings over the content in the seedlings under salinity without Spd by 21, 46, 16 and 28% at 1, 3, 5 and 7 days, respectively. Lipid peroxidation was measured as MDA which sharply increased in onion leaves by salinity stress (Figure 2C). As compared to respective control, the content of MDA was 1.5, 4.5, 5.7 and 8.8 fold higher at 1, 3, 5 and 7 days, respectively. The Spd treatment reduced the content by 39, 51, 18 and 14% at 1, 3, 5 and 7 days of salinity stress, respectively, when calculated over salinity stress without Spd.

Changes in polyamine related enzymes

Under saline stress, the activity of polyamine oxidase (PAO) increased slightly up to 3 days and decreased afterward (Figure 3A). On the other hand, the activity of diamine oxidase (DAO) increased by saline stress where maximum (47% over control), increment was observed at 3 days of stress (Figure 3B). Spd increased both activities over salinity. However, both of the activities were the highest at 3 days of stress.

Changes in antioxidant enzymes

The activity of superoxide dismutase (SOD) increased under saline stress (Figure 4A). However, after 5 day of stress, it decreased. The increments of the activity under salinity over control were 20, 22, 47 and 25% at 1, 3, 5 and 7 days, respectively. Application of Spd in saline stressed seedlings further increased the activity over salinity by 10, 21, 20 and 25% at 1, 3, 5 and 7 days, respectively. However, CAT activity was almost similar in the seedlings both under salinity with or without Spd (Figure 4B).

Under salinity, the APX activity decreased after 3 day of stress (Figure 5A). Application of Spd increased the activity in the seedlings over salinity, where the increments were 23, 21, 19 and 39% at 1, 3, 5 and 7 days, respectively. Alternatively, saline stress increased the GPX activity (3, 32, 55 and 29% over control at 1, 3, 5 and 7 days, respectively) where the activity decreased after 5 days of stress (Figure 5B). Application of Spd improved the activity over salinity by 14 and 15% at 1 and 3 days, respectively; however, this activity decreased gradually.

The important enzymes, MDHAR, DHAR and GR of ASA-GSH cycle were also measured which maintain ASA and GSH. In this study, saline stress decreased MDHAR activity with duration, though, significant variation was not found between the activities under control and salinity (Figure 6A). Notably, application of Spd increased the activity over salinity, where increase was higher by 6, 19, 22 and 21% at 1, 3, 5 and 7 days, respectively. In contrast, salinity increased the DHAR activity over control. In application of Spd, the activity was found to increase stressed seedlings up to 3 days of stress (Figure 6B).

Saline stress also increased the activity of GR with stress duration (Figure 6C). As compare to control, the activity was higher by 5, 28, 40 and 38% at 1, 3, 5 and 7 days, respectively. Notably, application of Spd further increased the activity in stressed seedlings by 15, 23, 10 and 20% at 1, 3, 5 and 7 days, respectively.

Changes in ascorbate and glutathione

A continual decrease was observed in ascorbic acid (ASA) content under salinity stress (Figure 7A). As

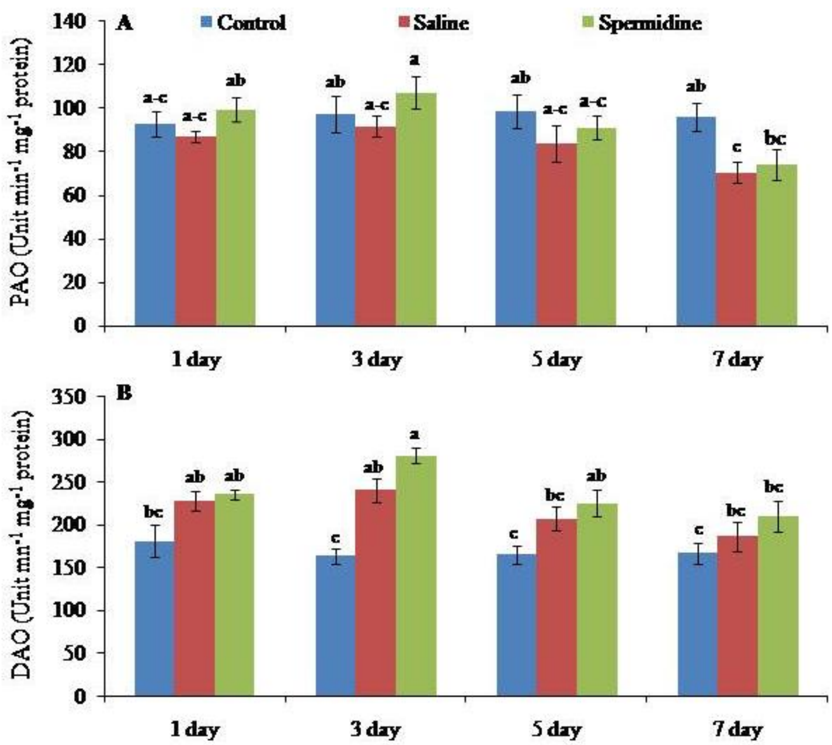

Figure 3. Changes in activities of PAO (A) and DAO (B) in leaves of onion seedlings by Spd under salinity stress. Values present in the bars are mean ± SE. Similar letters between the bars are not significant at P≤5%.

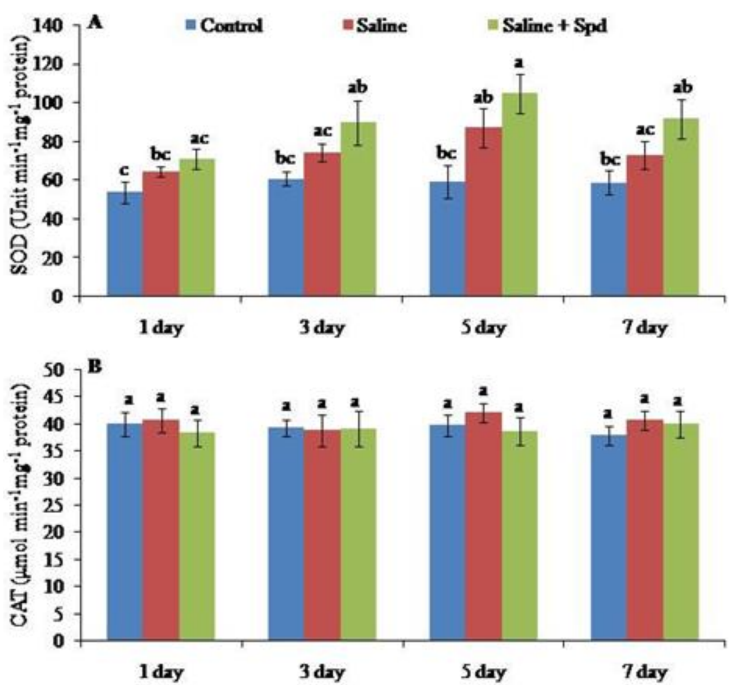

Figure 4. Changes in activities of SOD (A) and CAT (B) in leaves of onion seedlings by Spd under salinity stress. Values present in the bars are mean ± SE. Similar letters between the bars are not significant at P≤5%.

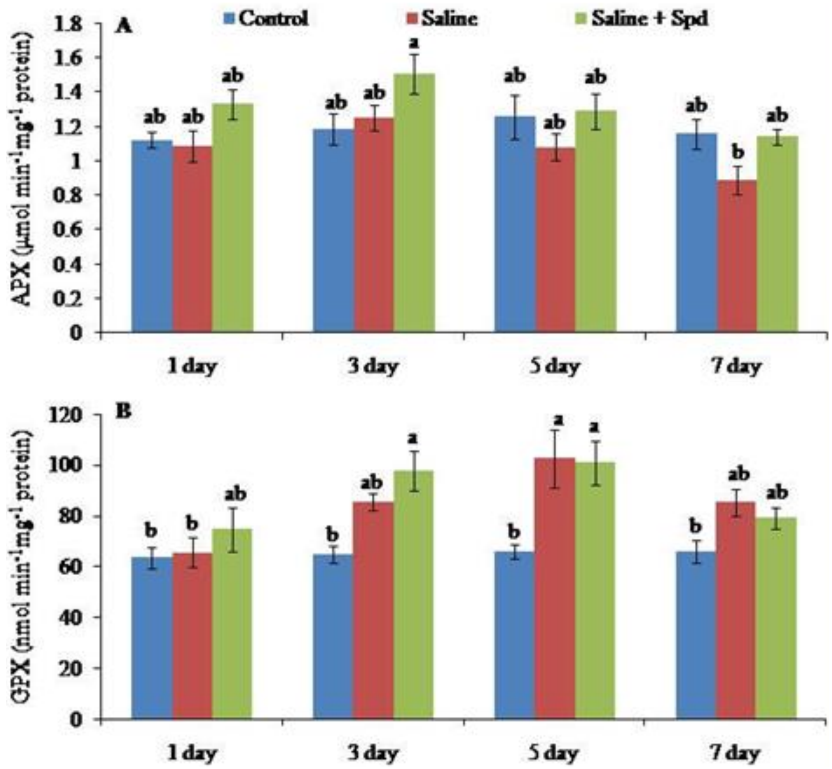

Figure 5. Changes in activities of APX (A) and GPX (B) in leaves of onion seedlings by Spd under salinity stress. Values present in the bars are mean ± SE. Similar letters between the bars are not significant at P≤5%.

compare to control, salinity reduced the ASA content by 15, 36, 43 and 60% at 1, 3, 5 and 7 days, respectively, while application of Spd maintained the ASA content higher over salinity by 7, 16, 16 and 17% in stressed seedlings correspondingly.

Contrary, the DHA contents were observed to increase continuously with duration of saline stress, and as compared to control, 32, 34, 33 and 52% higher DHA was found at 1, 3, 5 and 7 days, respectively (Figure 7B). The application of Spd in saline stressed seedlings also reduced the oxidation of ASA, resulting in decrease of DHA content (15, 17, 16 and 23% at 1, 3, 5 and 7 days, respectively) as well. Importantly, Spd maintained the ascorbate redox in saline stressed seedlings by 11, 18, 20 and 31% at 1, 3, 5 and 7 days, respectively (Figure 7C).

Saline stress also caused continual and significant decrease in GSH content in onion seedlings, while 7, 24, 51 and 62% reduction was observed at 1, 3, 5 and 7 days, respectively (Figure 8A). In presence of Spd, saline treated seedlings showed 8, 14, 40 and 57% higher GSH at 1, 3, 5 and 7 days, respectively. Conversely, salinity increased GSSG content significantly and continuously (Figure 8B). As compared to control, the content was 1.8, 2.4, 5.6 and 6.4 folds higher at 1, 3, 5 and 7 days, respectively. Application of Spd decreased GSSG in saline stress seedlings, maintaining higher glutathione redox (Figure 8C).

DISCUSSION

Leaf water relationship is a very important factor to maintain physiological and biochemical processes in plants. In this study, salinity caused loss of leaf water in onion seedlings (Figure 1A). Osmotic adjustment in plants is very essential to maintain structure and function of cell components (Lambers et al., 2006; Hasegawa et al., 2000) while exogenous Spd increased the leaf water content (Figure 1A).

The osmotic adjustment in presence of Spd might be due to proline synthesis. Proline accumulation in onion seedlings was correlated with RWC (Figure 1B). Previously, exogenous Spd was also reported to increase with proline content and RWC in other plants under salinity stress, which demonstrated that osmolyte level, was modulated by PAs (Roychoudhury et al., 2011; Duan et al., 2008). Proline functions as an osmoprotectant for osmotic adjustment as well as scavenger of ROS (Yancey et al., 1982), and as compatible solute (Ashraf

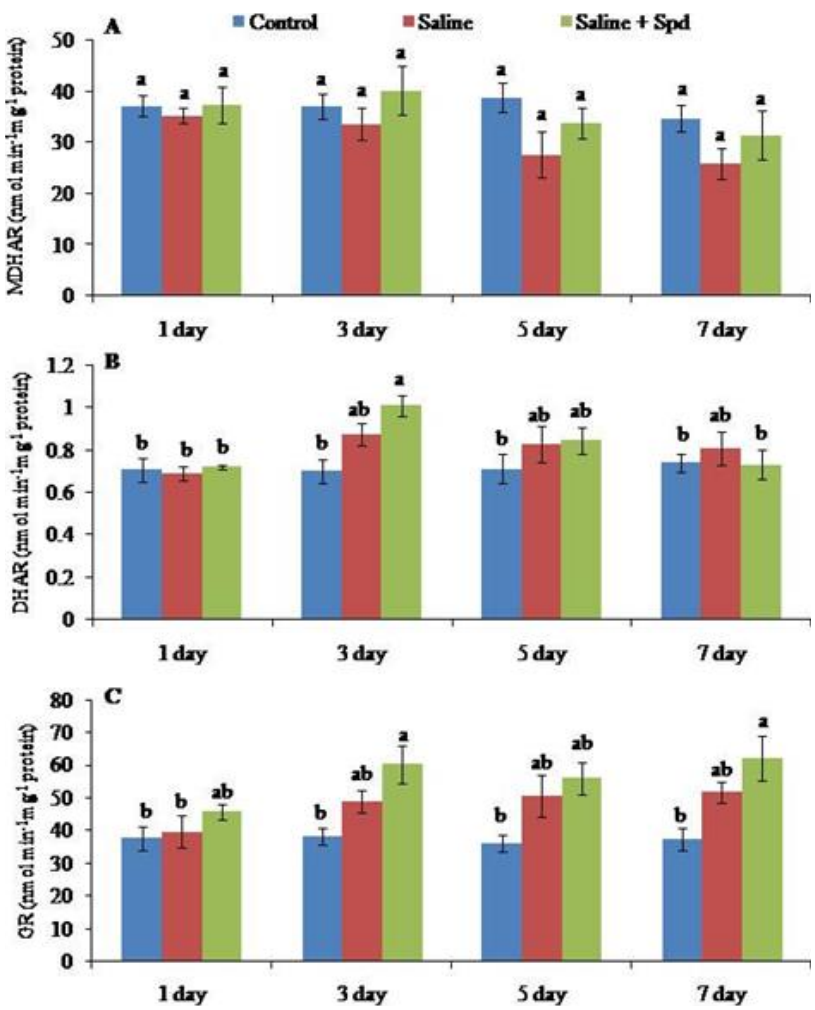

Figure 6. Changes in activities of MDHAR (A), DHAR (B) and GR (C) in leaves of onion seedlings by Spd under salinity stress. Values present in the bars are mean ± SE. Similar letters between the bars are not significant at P≤5%.

and Foolad, 2007; Kocsy et al., 2005). Proline biosynthesis in higher plants is preceded through polyamine cycle where Spd is very important to regulate the proline content (Szabados and Savoure, 2009; Sanchez et al., 2001). Previously, under drought stress, Li et al. (2014) reported that exogenous Spd promoted polyamine cycle. In this study, higher proline content by exogenous Spd could play important role in osmotic adjustment under salinity stress, which might be involved in membrane stability. However, decreased proline content after 5 days of stress might be due to insufficient Spd as its application was stopped before counting the stress duration.

Production of ROS like superoxide ($O_2^{\bullet-}$) and hydrogen peroxide (H_2O_2) is a common phenomenon in crop under abiotic stress including salinity (Huang et al., 2005; Noctor et al., 2002; Hernández et al., 2000), but at higher concentration, they are the major cellular components to cell death (Foyer and Noctor, 2005; Foyer et al., 1994). To protect the cell organells from the toxicity of ROS, plant deploy antioxidant activity (Gill and Tujeta, 2010). In this study, we observed profound increases in $O_2^{\bullet-}$ and H_2O_2 contents under salinity in onion seedlings (Figure 2A, B). ROS-scavenging enzymes as well as antioxidant molecules in plants protect cell organells by lessening the damage from $O_2^{\bullet-}$ and H_2O_2, where $O_2^{\bullet-}$ is first dismutated into H_2O_2 by the interference of SOD in different cell organells (Bowler et al., 1992).

In this study, exogenous Spd improved SOD activity in onion which was associated with lower $O_2^{\bullet-}$ generation. Therefore, SOD activity played an important role in dismutation of $O_2^{\bullet-}$ in onion seedlings under salinity stress. Melondialdehyde, a product of lipid peroxidation by ROS under environmental stresses including salinity,

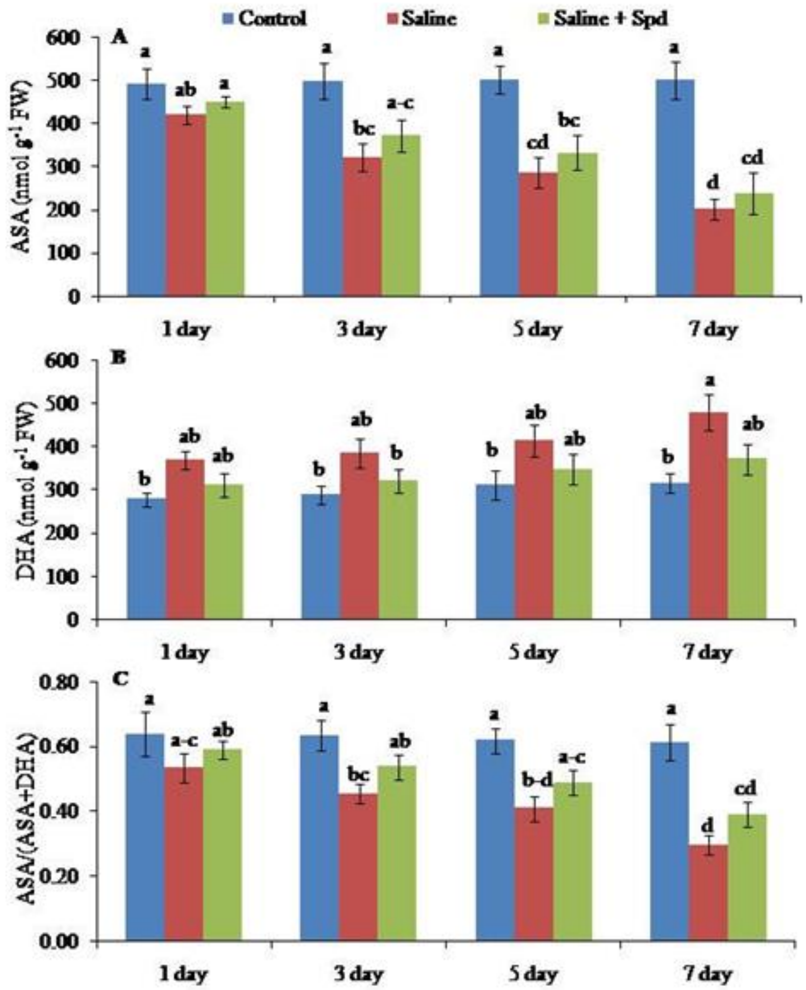

Figure 7. Changes in ASA (A), DHA (B) and Ascorbate redox [ASA/(ASA+DHA)] (C) in leaves of onion seedlings by Spd under salinity stress. Values present in the bars are mean ± SE. Similar letters between the bars are not significant at 5% level.

causes damage to plasmalemma and organelle membranes (Garg and Manchanda, 2009). In the experiment, both MDA and H_2O_2 were increased significantly (Figure 2B, C), which can cause membrane damage in onion. Higher MDA content under salinity in plants was also reported previously (Saleethong et al., 2011; Moschou et al., 2008; Rohman et al., 2016). Reduction of MDA in Spd treated seedlings might be resulting from comparatively lower concentration of $O_2^{\bullet-}$ and H_2O_2.

Superoxide dismutase deploys the primary protection against $O_2^{\bullet-}$ to reduced the oxidative damage. Exogenous Spd increased SOD activity which correlated negatively with $O_2^{\bullet-}$ generation (Figure 4A). Therefore, the increased SOD activity by the addition of Spd, dismutated the NaCl-stress which mediate higher $O_2^{\bullet-}$ in onion seedlings. However, the increased SOD activity by Spd addition up to 5 days of stress, suggested its better role under short-term salinity stress.

Excessive accumulation of H_2O_2 is one of the most important indicators of oxidative stress (Apel and Hirt, 2004). H_2O_2, produced by intervention of SOD, is highly cytotoxic (Gill and Tujeta, 2010). On the other hand, CAT is considered as the strongest decomposer of H_2O_2 (Scandalios, 2005). However CAT activity did not increase in the onion seedlings under saline stress (Figure 4B). Foliar application of Spd also failed to increase the activity in saline stressed seedlings. Unlike other H_2O_2 scavenging enzymes, enzymatic reaction of CAT is independent of other cellular substrates for instituting its activity (Scandalios, 2005). However, under salinity CAT activity almost unchanged in the presence or absence of Spd suggesting that, the enzyme did not play important role in decomposition of H_2O_2 under saline

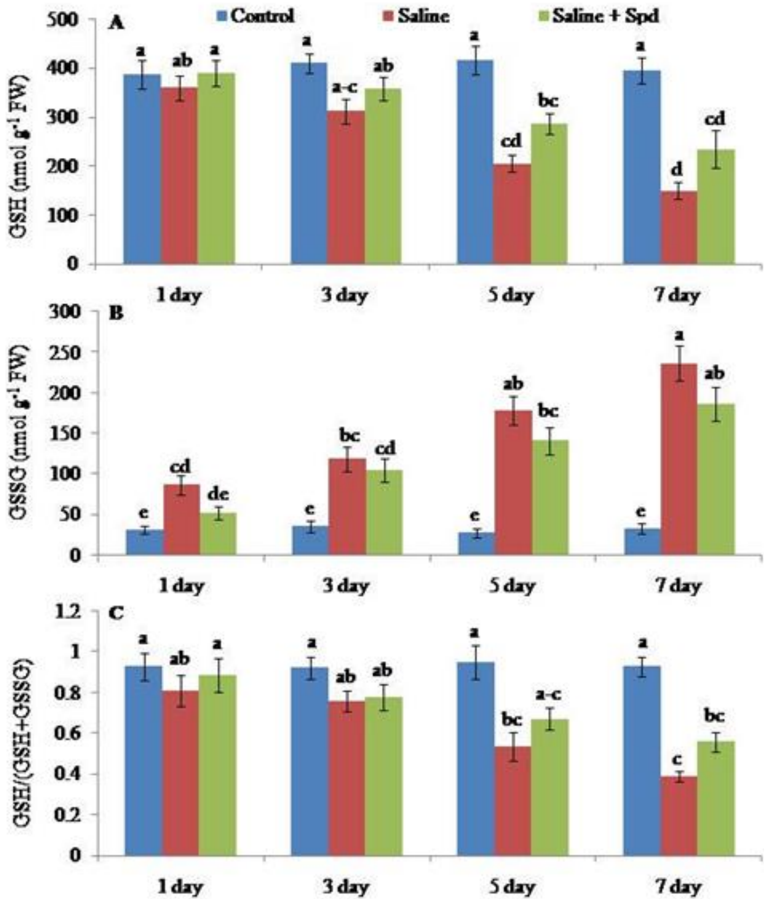

Figure 8. Changes in GSH (A), GSSG (B) and glutathione redox [GSH/(GSH+GSSG)] (C) in leaves of onion seedlings by Spd under salinity stress. Values present in the bars are mean ± SE. Similar letters between the bars are not significant at 5% level.

stress in onion sedlings.

The activity of APX increased in salinity stressed seedlings (Figure 5A). To reduce H_2O_2 to water, APX needs ASA to generate monodehydroascorbate which disproportionates to ASA and DHA (Apel and Hirt, 2004). Salinity stress might inactivate the APX activity by reducing ASA content (Figure 7A). Exogenous Spd enhanced the activity by increasing ASA content which indicates the H_2O_2 scavenging role of Spd. GPX activity which increased remarkably, suggestes the role of H_2O_2 metabolism in onion seedlings. Application of Spd treatment increased the activities of GPX up to 5 days of stress, suggesting the role of Spd in converting H_2O_2 into H_2O more efficienty in early days of salinity stress (Figure 5A, B).

Ascorbic acid plays an important role by maintaining enzymatic activity of ascorbate-glutathione cycle and thus improves plant tolerance to adverse environmental conditions including salinity stress by effectively reducing ROS, produced under stress conditions (Apel and Hirt, 2004; Shalata and Neumann, 2001; Nakano and Asada, 1981). In this study, the content of ASA decreased gradually and significantly with duration of salt stress resulting in more oxidation to generate GSSG (Figure 8A, C). In ascorbate-glutathione cycle, ASA is maintained by MDHAR and DHAR enzymes with ASA the key reductant in plant cells for H_2O_2 metabolism (Mehlhorn et al., 1996; Nakano and Asada, 1987). The increased contents of DHA in this study resulted in the oxidation of ASA (Figure 7B). Conversely, higher activity of DHAR is use in maintaining ASA contents under salinity. Spd-induced MDHAR and DHAR activities suggested higher maintenance of ASA and its redox in onion seedlings (Figure 6A, 6B, 7C).

On the other hand, GSH participates in scavenging of ROS either directly or indirectly in ascorbate-glutathione and thus it is a key non-enzymatic antioxidant (Noctor et al., 2002). The essential role of GSH is due to its capability to restore ASA through reduction of DHA, passing through the ascorbate-glutathione cycle (Apel and Hirt, 2004). GSH is also used in glyoxalase to detoxify cytotoxic MG by acting as a substrate. Furthermore, in plant cells, GR is the key enzyme for maintaining GSH, which is also necessary in speeding up scavenging H_2O_2 (Saha et al., 2015).

Salinity stress caused a significant decrease in GSH levels at 3, 5 and 7 days saline stress (Figure 8A), and at the same time, GSSG levels also increased significantly at 1, 3, 5 and 7 days saline stress (Figure 8B). Spd treatment significantly decreased the level of GSSG by GR mediated recycling which ultimately maintained higher GSH content (Figure 8A, B). Hence, the results suggested the contribution of Spd in maintaining glutathione redox during the stress period. This result was collaborated with other recent findings, where exogenous PAs including Spd upregulated the GR activity under salt stress (Erat et al., 2008).

Conclusion

Considering the above results, saline stress caused over production of ROS and MDA in onion seedlings. Application of foliar Spd reduced ROS and MDA through up-regulating activities of SOD, APX, GPX, MDHAR, DHAR and GR as well as maintaining ASA and GSH. Importantly, many of the enzymatic antioxidants showed higher activities at 3 to 5 days of stress.

However, the CAT activity remaind almost unchanged under salinity stress with or without Spd application. In this preliminary study, we used only one dose of Spd. Multiple dose can be examined for further study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Private initiatives in rural irrigated agriculture towards sustainable livelihoods in Nadowli-Kaleo District, Ghana

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At the dawn of the 21st Century, the goal of achieving poverty reduction became a global concern. Diverse livelihood public interventions such as the provision of community dams since then have been implemented in rural settings including Nadowli-Kaleo District of the Upper West Region, Ghana to promote food security through dry-season farming. However, the objectives of these interventions have not been realized. Rather, rural farmers engaged in irrigation farming have resorted to the initiation and utilization of private water systems prompting the examination of factors accounting for the choice of irrigation operations. A case research design was adapted in the conduct of the investigation. Five communities were selected as cases based on a set of criteria namely, the presence of an open-access dam and on-going private irrigation schemes. Factors accruing to the preference for private water systems to that of open-access community dams for irrigation included contamination of dam water by other users such as funeral undertakers, water vendors and fishermen, as well as drying up of dam water. Although irrigation engagement tremendously benefits irrigation operators and consumers through provision of fresh vegetables for household consumptions and income generation, irrigation operations are however saddled with the destruction of irrigation crops by animals, financial inadequacies and limited knowledge of farmers in irrigation agronomy. Measures proposed to propel the productive capacity of rural irrigation farmers comprise: creation of irrigation fund for farmers, entrepreneurship training in basic agronomic techniques in irrigation farming, giving awards to irrigation farmers on Farmers' Day Celebrations, establishment of block irrigation systems, and proper management of existing community dams.

Key words: Agriculture, rural irrigation, private initiatives, sustainable livelihoods, irrigation systems.

INTRODUCTION

Irrigated agriculture has a track record of making giant gains in livelihoods empowerment globally. Whereas only 20% of the global agricultural land is irrigated, about 40% of the world food supply is generated from irrigation

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(Mandri-Perrot and Bisbey, 2016). Irrigation promotes farm cultivation throughout the year and also has an advantage of regulating water supplied to the crop since the water is synthetically managed. When irrigation is efficiently combined with other farm inputs such as adequate and appropriate crop fertilizer, and enhanced varieties of seed, the produce per acre of irrigated land outstrip what is generated from rain-fed agricultural land of the same size (Inkoom and Nanguo, 2011; Namara et al., 2011). Irrigated agriculture therefore creates room for an all year round intensified and diversified agriculture through increased farm produce and earnings, agricultural wage employment and reduction in poverty either directly or indirectly (ADB et al., 2007).

The scale of irrigation development can range from millions of hectares such as that found on the Indo-Gangetic Plain to that of a farmer operating on a couple of hectares using water from a well. The motivation for undertaking irrigation also ranges from inspiration of international politics to an individual's desire for a better life (Rydzewski, 1990). The benefits accruing to irrigation and its utilization especially in the area of food supply however varies on continental, regional and country basis. For instance, while 60% of food output in Asia emanates from irrigated agriculture, only 9% of Sub-Saharan Africa's total food supply is based on non-rain fed agriculture. As much as 98% of the total food output of Egypt thrived on irrigation (Lipton et al., 2003).

The global annual water withdrawal for irrigation is estimated at 2672 km^3. On continental basis, Asia leads with 76% of total irrigation water abstraction (2026 km^3/year), followed by Americas 15% (397 km^3/year), Africa with 6.5% (171 km^3/year) and Oceania 0.3% (9 km^3/year). Also, irrigation water use per unit of surface area (density) is largest in arid regions with high cropping intensity such as Pakistan, Egypt, India, and Mexico which have relatively high drought risks (Podimata and Yannopoulos, 2015).

The Continent of Africa especially Sub-Saharan Africa is lagging behind in terms of investment and development of the irrigation sector. In 1961, the total irrigated land in Africa was approximately 7.4 million ha. This increased to 13.6 million in 2008 representing 6% of cultivable land (World Food Programme (WFP) and FAO, 2010). Moreover Madagascar, South Africa and Sudan make up two-thirds of the irrigated area in Sub-Saharan Africa. The performance of the sub-Continent is by far the least compared to any other region in the world. Whereas China and India expanded their irrigated area by 25 million ha and 32 million ha, respectively over a forty year period, that of the Sub-Saharan region of Africa was only 4 million ha within the same period (ADB et al., 2007).

The rate of increase of land under irrigation in Africa reached its peak in the mid-1970s with an annual growth rate of 2.3%, but has however slowed down since then (Miyoshi and Nagayo, 2006). Irrigation development in developing countries especially Sub-Sahara Africa has therefore been dwindling due to a continual decline in the flow of investment fund to the sector by the World Bank, development partners and other external donor agencies. For instance, the allocation of Official Development Assistance (ODA) to the agricultural sector including irrigated agriculture in Sub-Saharan Africa dropped from 17% in 1980 to 6% in 2008 (Sakaki and Koga, 2013). Such changing modalities by external donors have been nurtured by the realization that irrigation programmes and investment in developing countries have not realized the expected impact of improving agricultural production. This reduction in irrigation investment was possible by means of a structural adjustment policy to address poor investments by anti-agricultural policies (World Bank, 2007).

In Ghana, there is huge potential of land and water resource available for intensification of agriculture under irrigation. Ministry of Food and Agriculture (MOFA) and Ghana Irrigation Development Authority (GIDA) (2012) estimated the irrigation potential of the country to be between 500,000 ha and 2.3 million ha. However, there is apparently low scale of overall development in the sector (Miyoshi and Nagayo, 2006). For instance land under actual irrigation stands at 206,868 ha, out of which 10,668 ha is formally developed and 186,000 ha are developed by individuals engaged in private micro and small scale irrigation farming while 10,200 ha are utilized for commercial purposes. The total land under irrigation represents only 2.8% of the 7.5 million ha of agricultural land under cultivation in Ghana. Water drawn from the renewable water resource is less than 2%, and less than two-thirds of the drawn water is actually developed for irrigation (MOFA and GIDA, 2012).

Irrigation in Ghana is often synonymous to public or communal irrigation systems and schemes mostly managed by Ghana Irrigation Development Authority (GIDA) and Irrigation Company of Upper Regions-ICOUR (Namara et al., 2010). Several research archives with regards to irrigation abounds, and mostly such literature connoting to irrigation operations especially in Ghana are either focused on urban and waste water irrigation activities, or geared towards formal (government and development partners led) irrigation schemes in rural areas. However, local governments and development partners have not reaped the expected benefits of encouraging dry-season farming by way of communal irrigation systems (small dams) establishment. Even though informal (private initiatives) irrigated agriculture dominates the irrigation sector in Ghana (Drechsel et al., 2006) constituting about 89.9% of the irrigated land (MOFA and GIDA 2012; MOFA, 2011), little has been achieved to augment and sustain the efforts of rural farmers engaged in dry-season informal irrigation.

Problem statement

The economy of the Upper West Region is dominantly agrarian. About 77.1% of households' livelihoods in the region are dependent on agriculture whereas as much as 91.4% of the populace engaged in agriculture are households in rural communities. In the study area (Nadowli-Kaleo district), which is entirely a rural district, 83.4% of households' livelihoods are dependent on farming (Ghana Statistical Service, 2013). These agricultural activities especially crop farming are highly dependent on rainfall. However, the seasonal nature of rains in the study district, thus short rainy season (mostly from June to September) and extended dry seasons (mostly from October to May) coupled with harsh dry-winds render the farmers jobless during the off-rainy seasons (Inkoom and Nanguo, 2011). This has become a perennial problem resulting in food shortages, malnutrition, and inadequate income for basic needs and services among others (Namara et al., 2011). For instance, the sixth round report of the Ghana Living Standard Survey depicted the Upper West Region as the poorest region in the country with 70.7% of its population being poor and the region with the highest extreme poverty of 45.1%. In its findings, poverty was more pronounced in rural savannah and predominantly among farmers (Ghana Statistical Service, 2014a).

Though most farmers realize bumper harvest during the rainy season, such farm produce quickly dissipate as the dry season prolongs due to the high dependence on such harvested produce as sole source of livelihood. In a move to sustain themselves during the dry seasons, these farmers engage in intra-regional rural-urban migration for greener pastures, while others migrate to southern parts of the country where there is prolonged and double maxima rainfall for all year round farming activities (Inkoom and Nanguo, 2011; Kpieta et al., 2013). Others especially the aged with no aim of movement stay back idle in the rural communities during the dry seasons.

In ameliorating the issue of perennial seasonality of rainfall, local governments in partnership with Non-Governmental Organisations and other development partners such as World Bank and International Fund for Agricultural Development (IFAD) responded through the establishment of communal surface irrigation systems in the form of small reservoirs (dams and dugouts) for crop irrigation in farming communities during dry seasons (Dinye and Ayitio, 2013; Inkoom and Nanguo, 2011; Kpieta et al., 2013; Namara et al., 2011). Preliminary survey in the study district (Nadowli-Kaleo) revealed that these communal water systems provided by the local government in the form of dugouts and dams are not utilized for the intended purpose of irrigated agriculture. Rather, rural farmers who are engaged in irrigated agriculture in sustaining their livelihoods during the dry season have resorted to the initiation and utilization of private water systems for crop irrigation.

In undertaking the study and bearing in mind the research problem, the researchers therefore sought to provide answers to the following questions: (i) what factors influence the choice of irrigation operations?; (ii) how does irrigation engagement affect rural livelihoods?; and (iii) what factors hinder private irrigation development in the study district?

Resultantly, there was the need to examine appropriate irrigation systems and practices that are relevant in improving and sustaining rural livelihoods in Nadowli-Kaleo district of the Upper West Region. Specific objectives in achieving the main objective included: (i) to uncover the factors influencing the choice of irrigation operations in the study district; (ii) to assess the effects of rural irrigated agriculture to livelihoods; and (iii) to examine hindrances to private irrigation development in the study district.

A research on private irrigation operations and reasons for the preference of private water systems to that of community dams in rural irrigated agriculture in Nadowli-Kaleo district is therefore relevant in identifying the lapses that mar the maximization of irrigation potentials in rural areas. Since irrigated agriculture is eminently glued to the achievement of the Sustainable Development Goals (SDGs) especially SDG 1: "End Poverty in all its Forms Everywhere"; and SDG 2: "End Hunger, Achieve Food Security and Improved Nutrition, and Promote Sustainable Agriculture" (ICSU and ISSC, 2015), a paradigm shift in the traditional approaches to development within the irrigation arena will tremendously accelerate the minimization of poverty and its other forms if not totally annihilate them. It will heighten the achievement of food security and improved nutrition as well as the promotion of sustainable agriculture. For instance, the World Food Programme (WFP) and FAO (2010) posited that about 870 million people are chronically undernourished, and by 2050 the population of the world would have been 9.1 billion thereby demanding a 60% increase in global food production to feed this population. It is therefore estimated that 90% of the required global food production (of which developing countries takes up 80%) needs to be generated from increment of yields and crop intensification while 10% (of which developing countries constitute 20%) will be produced from an expanded arable land. Ending global and national poverty therefore demands special and radical attention on ending poverty and hunger in rural areas since most of the urban poor are negative externalities of rural-urban migration.

Theoretical underpinnings of the research

The study was positioned within certain theories namely: Tragedy of the Commons theory, Game Theory, Theory of Access, and Neoliberal theory bearing in mind the research problem, objectives and methodology.

Tragedy of the Commons theory

The theory was propounded by Hardin (1968) who asserted the necessity of abandoning the commons (freedoms) in breeding. Though the theory was propounded in the context of the growing population and its foreseeable issues at the time, it is equally applicable in any instance where society appeals to individuals exploiting a common resource to restrain themselves for the general good by means of their conscience. Individuals who are locked into the logic of the commons are free only to bring on universal ruin; once they see the necessity of mutual coercion, they become free to pursue other ulterior motives. Moreover, the author posited that every new enclosure of the commons involves the infringement of somebody's personal liberty. The author therefore proposed an alternative to the commons by way of institution of private property coupled with legal inheritance.

Game theory

This theory deals with the formal study of conflict and cooperation. It is concerned with improved strategic decision-making where several players make choices that potentially affect the interests of other players (Nuemann, 1928). The theory is applicable whenever the actions of several agents are interdependent. These agents may range from individuals, firms, groups, or a combination of them.

Theory of access

It embodies a wide range of social relationships that can constrain or enable people to benefit from resources (Ribot and Peluso, 2003). Ribot and Peluso (2003) further discussed that access analysis involves firstly identification and mapping out the flow of the particular benefit of interest; followed by identification of the mechanisms by which different actors involved gain, control, and maintain the benefit flow and its distribution; and finally an analysis of the power relations underlying the mechanisms of access involved in instances where benefits are derived. Access framework therefore analyses specific resource conflicts to understand how those conflicts can become the very means by which different actors gain or lose the benefits from both tangible and intangible resources (Ribot and Peluso, 2003).

Neoliberal theory

Proponents of this theory advocates for a free market system which allows the occurrence of efficiency, economic growth, income distribution and technological progress since the intervention of the state in promoting such phenomena will aggravate the economic performance (Kotz, 2015).

METHODOLOGY

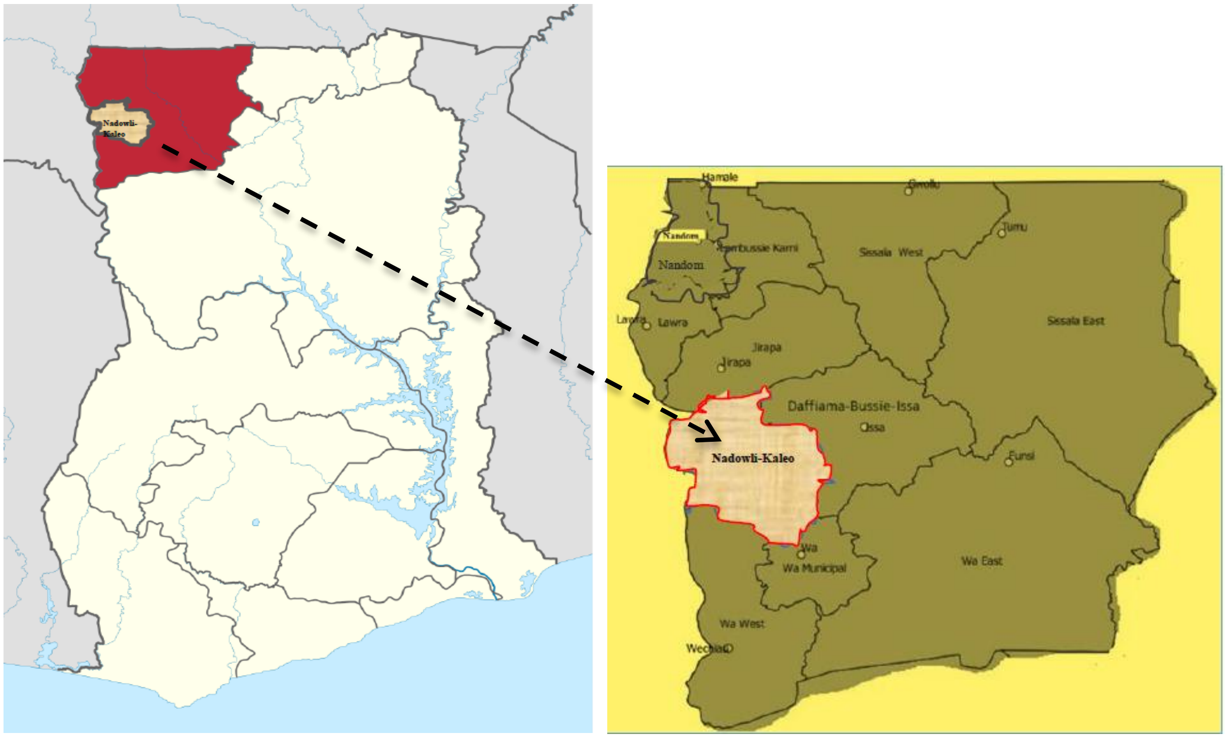
Geographical scope

Geographically, the research was conducted in Nadowli-Kaleo District, a rural district in the Upper West Region of Ghana. Nadowli-Kaleo District is one of the 11 administrative districts of the Upper West Region with Nadowli as the capital. The district lies within latitude 10° 20' and 11° 30' North and longitude 3° 10' and 2° 10' West (Figure 1a, b). The district shares its northern border with Jirapa and Lambussie-Karni Districts; Southern border with Wa Municipal and Wa West District; Western border with the country Burkina Faso, and Eastern border with Daffiama-Bussie-Issa District (Ghana Statistical Service, 2014b). The district is centrally situated within the Upper West region of Ghana and covers a total land area of 1,132.02 km^2. The distance between the District and regional capitals covers about 40 km. The District has a mean annual temperature of 32°C and a mean monthly temperature ranging between 36°C around March to 27°C around August. Annual rainfall is confined to four months (July to September) and is also unevenly distributed (Ghana Statistical Service, 2014b).

Selection of study area

The interest to undertake this research was triggered by a preliminary review of studies conducted by researchers on irrigation utilization in the Upper West Region. The reviewed articles revealed that formal and public irrigation schemes are underutilized in the region (Inkoom and Nanguo, 2011). Inferences from the reviewed papers further revealed that two of such underutilized irrigation facilities in the region situated at Sankana and Goli are within Nadowli-Kaleo district. The major reasons being attributed to the underutilization was the charging of water user fees and the application process people had to go through to qualify for the dams' utilization. According to the findings of the researched papers, such factors therefore deterred people from accessing the facilities for irrigation (Acheampong et al., 2014; Inkoom and Nanguo, 2011).

These revelations on the public irrigation schemes therefore propelled the researchers to enquire more about irrigation development and utilization across the entire Nadowli-Kaleo district. The investigations were intended to ascertain whether such underutilization pertains only to the two cited irrigation facilities or reflective across the whole district. In view of this, the researchers visited the Planning Unit of the District Assembly to access information on the other existing facilities and their locations. A study of the district profile from the District's Medium Term Development Plan revealed that there were about thirteen (13) facilities across the district including the two cited by other researchers. Some of the communities with community dams and dugouts included: Duong, Goli, Kaleo, Kalsegra, Konkonpari, Kulpieni, Kuuri, Loho, Nadowli, Saan, Sankana, Takpo, and Zang among others. Information from the Planning Unit also revealed that the only facilities where access was restricted were the two located at Sankana and Goli. However access to the other dam facilities across the district was open to all in the respective communities. To confirm this, enquiries were made through phone calls with Assembly members of the respective communities as well as personal visits to these facilities to verify the authenticity of their existence. It was intriguing and worth noting that even though irrigation was on-going in some of the visited communities, the open-access community dams and dugouts were not utilized for the intended purposes of irrigation especially by private irrigation



(a) (b)

Figure 1. Nadowli-Kaleo District in (a) National Context (b) Upper West Regional Context.

operators. Such anomalies therefore prompted a further explorative study into rural irrigation operations in Nadowli-Kaleo District.

Selection of study cases

Five community dams and dugouts within the district were selected for the study based on certain developed criteria which included: the presence of a community dam/dugout; and the existence of on-going private initiated irrigation activities. Communities where these facilities were located are namely: Duong, Kaleo, Kalsegra, Nadowli, and Saan as shown in Figure 2.

Sampling

The non-probability sampling method was more appropriate for the study since some units of the study population had zero chances of being selected and the probability of selection could not be accurately determined (Babbie, 2016); besides, there was no sample frame of registered irrigation farmers from which a sample could be selected. The researchers further employed the expert (purposive), convenience and snowball non-probability sampling techniques in the collection of empirical data. Expert (purposive) sampling technique was used to collate data from key institutions as well as District Assembly and Unit Committee members engaged in promoting agricultural development in the district. Convenience sampling technique was applied in selecting the first respondent (irrigation operator) in each of the studied communities. The Snowball sampling technique was then employed to access data from the other irrigation operators through recommendation from the interviewed respondents, other community members as well as personal observation by the researcher. Personal observation was employed to remedy instances in which the respondents were not in a position to recommend others.

Data collection and analysis

The empirical research pertained to more of qualitative as compared to quantitative, and the study was carried out in a rural setting involving farmers who had low literacy levels; hence the collation of data by means of focused-group discussions, face-to-face interviews with the use of structured and open-ended questions as well as direct observation including picture taking and voice recordings for transcription. In each of the selected communities of study, three categories of interviews were conducted based on the study variables consideration. These categories included: irrigation operators on the context of one-on-one interviews; non-irrigators in the form of focused-group discussions (consisting of a mixture of men and women); and community leaders (Assembly and Unit committee members) which also took the form of one-on-one interviews. In all, thirty irrigation operators were interviewed for the entire study. Additionally, five focused-group discussions were conducted for non-operators with one discussion in each of the selected communities while seven Assembly members and key informants were interviewed. These interviewed persons were based on the availability and willingness of the respondents to offer the needed information. Moreover, key institutions including Agriculture Department, Works Department, and Planning Unit of the District Assembly were contacted for information on their contributions to irrigated agricultural development in the study district. The gathered data were analysed using the coding process, which involved sifting through data and sorting them into themes, pattern or the concepts it reflect. The aim of the coding was to look for connections and patterns in the

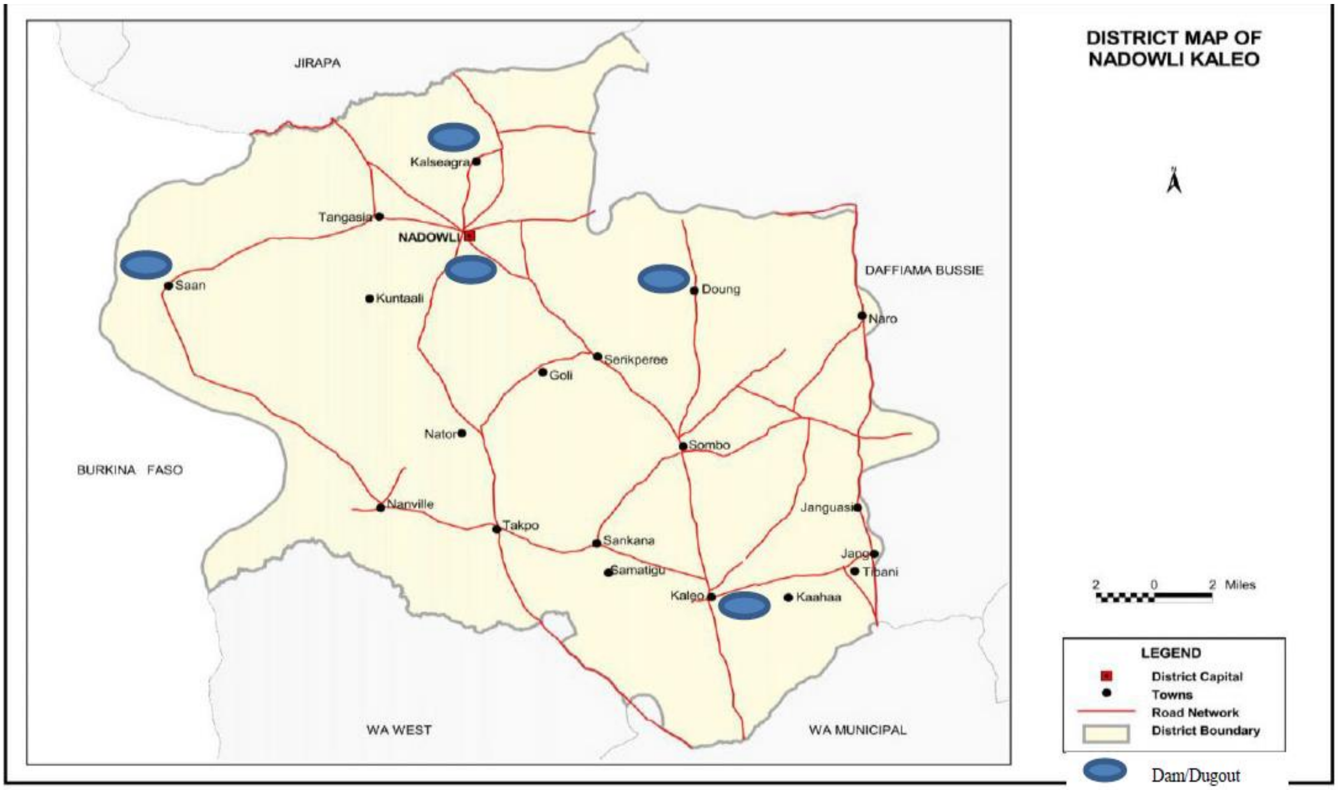


Figure 2. Map of Nadowli-Kaleo District with studied cases.
Source: Ghana Statistical Service (2014b) with Authors' Insertion (2017).

data from which the findings were generated. An analytical framework was also used to minimize subjective views of the researcher as much as possible.

RESULTS AND DISCUSSION

The findings of the study were categorized under themes based on the various objectives of the research namely: factors influencing the choice of irrigation operations; effects of irrigation operations on rural livelihoods; and factors hindering private irrigation development in the study district.

Overview of studied community dams

Duong

The earth dam was established in the 1970s and currently serves a projected population of 2,751 persons. The dam is patronized by the community for different purposes including animal watering, fishing, domestic chores and construction activities among others. However, water from the community dam facility is not utilized for crop irrigation although dry-season farming has been going on yearly (Field Study, 2017).

Kaleo

The community earth dam was constructed in 1963 for a population of 2,500 persons with a targeted irrigable area of 12 hectares (Acheampong et al., 2014). With a current projected community population of 4,564 persons, the community dam is utilized for varied purposes such as industrial activities and animal watering, other than crop irrigation.

Kalsegra

The earth dam facility was first established in 1989 through the community initiative. It was later on rehabilitated in 2015 by the local government with funding from the World Bank, Ghana Irrigation Development Authority (GIDA) and the Government of Ghana under the auspices of Ghana Social Opportunities Project (GSOP). The dam currently serves a projected population of 3,108 persons who utilize the dam water for diverse purposes including swimming (undertaken by children), fishing, animal watering as well as construction and other industrial activities. The crop irrigation component for which the earth dam was rehabilitated is however not activated by the community (Field Study, 2017).

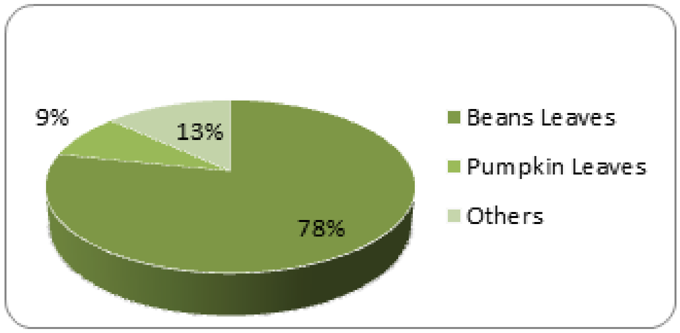


Figure 3. Types of crops grown on irrigated fields (in percentage).
Source: Field Study (2017).

Nadowli

The community dam was initiated in the year 1999 and completed in 2000 but has not been rehabilitated since its construction. With a projected community population of 4,579 persons, the community earth dam is currently resorted to by community members for different purposes including fishing, animal watering, water for construction and industrial activities among others (Field Study, 2017). However, farmers in the community who are engaged in dry-season farming do not utilize water from the dam facility for crop irrigation though cluster of vegetable gardens are sited closer to the dam (Field Study, 2017).

Saan

The community dugout was created in the 1980s to serve varied needs including crop irrigation. It serves a community population of 2757 persons. Although crop irrigation is scantily undertaken in the community, the dam water is not patronized by farmers for such irrigation activities.

Forms of rural private irrigation operation

Types of crops grown on irrigated fields

Based on aggregate of irrigated crops from the field study, the mostly grown single crops include beans leaves (78%), and pumpkin leaves (9%) as shown in Figure 3. The major crops (grown beans and pumpkin leaves) are mostly cooked as sauce with 'Tuozafi' which is a local delicacy in the district. The dominant crops grown are therefore dependent on the demand by the consumers, availability and the maturation period. For instance, beans leaves take an average of one month to mature for consumption, and as such can be cultivated about four times within the irrigation season. However, vegetable crops including tomatoes, okra, eggplant and cabbage which take about three (3) months to mature are only grown once within the irrigation period although such crops are re-harvested 2 to 3 times during the season. Moreover, crops like banana, plantain, and oil palm which are of southern origin are sparsely grown in certain areas of the district especially in Nadowli. These crops are mostly irrigated on seasonal wetlands thereby affirming Blench (2006) findings of the cultivation of such crops in the Upper West Region.

Source of water for irrigation

Water sources for rural irrigated agriculture is dominated by temporary shallow wells (ponds) representing 86.6%, with the others being stream (6.7%) and borehole water (6.7%) as illustrated in Figure 4. The temporary wells are mostly located within the fenced crop field. Average distance from the water source to the farthest part of the crop field is about 60 m. From observation, water from boreholes was used to irrigate backyard gardens at the home level, whereas the temporary wells were purposely constructed for irrigation located far away from houses on lowlands and areas liable to flood (seasonal wetlands). Consumers of rural irrigated produce are conscious of the quality of water used for irrigating crops and often verify the source of irrigation water before purchase of irrigated vegetables. This is also attributable to the homogeneity of population in rural areas making it easier for inhabitants to identify one another. These findings however opposes Bougnom and Piddock (2017) assertion that the use of wastewater for irrigated agricultural lands is increasing globally, since the use of freshwater for irrigated agriculture is still gaining grounds in rural areas.

Equipment used for watering crops

Materials used for watering irrigated crops are key determinants for the scale of irrigation operations in the study district. Regarding the empirical study, the

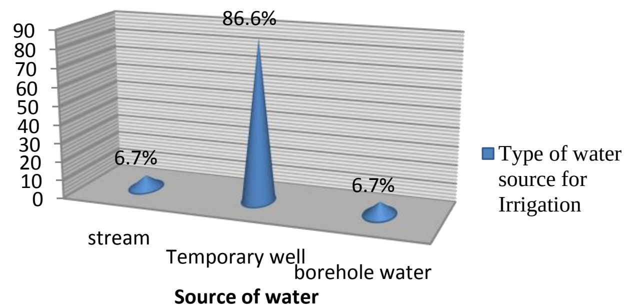


Figure 4. Water sources for crops irrigation (in percentage).
Source: Field Study (2017).

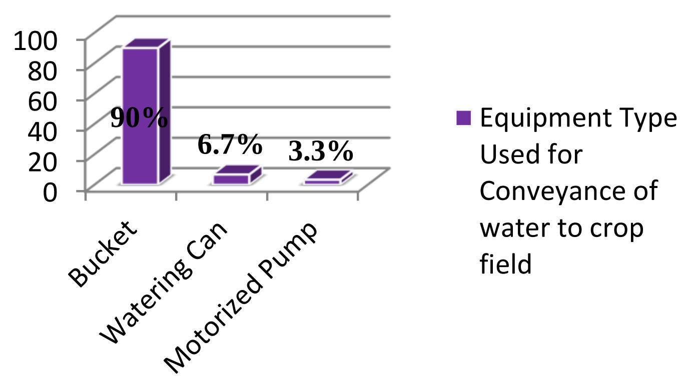


Figure 5. Types of materials used for watering crops.
Source: Field Study (2017).

equipment used for transmission of water from the water reservoir for crop irrigation were predominantly rubber and metal buckets (90%). Other watering equipment included watering can (6.7%) and motorized pump (3.3%). Averagely, irrigation farmers use about 2½ h daily to water crops. The duration of time spent in watering a crop field is influenced by the size of the watering material, the types of crops grown and the nature of land under irrigation. Figure 5 illustrates the percent patronage of materials used for watering crops.

The type of equipment used for watering depends on the financial capacity of the irrigation operator. Farmers with better financial status patronize the use of pumping machines and watering cans while farmers in financial distress adapt to the use of buckets for crop watering.

Factors influencing the choice of irrigation operations

The field study revealed astonishing reasons for the preference of private water systems to that of open-access communal dams and dugouts for irrigation. The empirical findings within this theme in the study district therefore counteract Acheampong et al. (2014) and other researched propositions that the development of small dams and dugouts generate high satisfactory performance in terms of irrigation utilization. These empirical findings include:

Contamination of dam water by other users

The use of clean water for rural irrigation farming in the studied communities is a paramount priority to the farmers as a result of the requisite standard demanded by consumers due to the nature of the irrigation produce (mostly green leaves) being patronized and the high homogeneity of population in the studied settlements. The use of polluted water for vegetables irrigation is an eyesore to consumers. On the contrary, the multipurpose functions and open-access usage of the community dams and dugouts by competing users resulted in the contamination of the water facilities by their activities thereby making water from such facilities unwholesome for vegetable crop irrigation. Due to the communal ownership of the dams and dugouts in the studied cases, restrictions pertaining to who and what the dam facility is to be used for does not exist and as such there are several users in each community who utilize the dams and dugouts for diverse purposes other than irrigation. Users of these community dam facilities included: funeral undertakers, water vendors, nomadic herdsmen, fishers, children and animals which resort to such reservoirs as swimming pools, and car washers among others. In Nadowli for instance, the community dam is a resort by funeral undertakers for the washing of clothes and cloths used for wrapping the dead during funerals as well as vehicles used for such purposes. An irrigation operator in Nadowli recounting his preference for self-initiatives to that of the open-access dam is quoted to have said:

“Anytime there is a funeral in this community, the vehicle that is used to carry the dead body is usually washed in the dam water. Also, the clothes that are used to cover the dead during funerals are washed in the dam. Other drivers have also been washing their vehicles here (referring to the dam). As a result, if consumers know that the green leaves we sell are irrigated with water from the dam, they will not buy it”.

The use of the dam for fishing is also a deterrent to irrigation farmers in utilizing such water for crop irrigation. Frequent fishing activities in the community dams and dugouts through the use of crude methods culminate in muddiness of the water after such fishing expeditions.

Moreover, children and animals which resort to the dams and dugouts as swimming pools in Kalsegra for instance, often defecate and urinate in the water during usage. These bizarre actions by other users of the communal water reservoirs therefore compel farmers to initiate their own water systems for irrigation utilization during the dry season where the usages of self-water systems could be controlled, therefore upholding Hardin’s (1968) proposition in ‘Tragedy of the Commons’ theory that the unguarded utilization of a common resource often result in the exploitation and abuse of that common resource if such is unchecked. It also affirms Neumann’s (1928) argument in ‘Game theory’ that in the utilization of a common resource, its competing and varying users adopt diverse strategies to maximize the benefits of such commons irrespective of the consequences of their actions on fellow users. The multipurpose functions of the public dams and dugouts therefore defeat the irrigation motive behind the constructions. However, these claims and explanations given on dam water contamination have not been scientifically proven to ascertain the content and level of pollution within the water facilities.

Drying up of water from dams and dugouts

Regular availability of water is a major prerequisite for the success of irrigation farming in the dry season. However, volume of water in these communal facilities diminishes as the dry season progresses due to siltation and the loss of water by evaporation as a result of absence of tree cover. Also, the unregulated demand of water from the dams and dugouts for multiple purposes such as industry and construction, domestic and household chores as well as animal watering among others also culminates in the drying up of water from such facilities. Such actions therefore make dam facilities as unsustainable and unreliable sources of water for continuous irrigation during the dry season. Alternatively, irrigation farmers construct their own water systems to maintain regular water access for crop watering. For instance, an irrigation farmer in Kalsegra is quoted to have said:

“…..I do not want to be chasing the dam water as it dries up, so I decided to construct my own system so that I can have full control over its usage”

Another farmer also puts it:

“When the water dries-up, because of the open-access nature of the dam, I cannot scoop it alone. So I decided to dig my own shallow well so that when it dries-up, I can scoop it myself” (female irrigation operator)

Whereas other developing countries such as India (Siebert et al., 2010), Kenya (Keller, 2001) among others are drifting from conventional systems such as open surface water to emerging groundwater systems for rural irrigation using improved technological implements, successive governments in Ghana are still glued to the promotion of the former mostly in the form of community dams for rural irrigation.

Absence of complementary irrigation equipment

The presence of necessary implements propels the utilization of community dams and dugouts for irrigation. From the field study, irrigation farmers distant the crop fields from the community dams and dugouts due to the absence of suitable soils within the catchment areas of the water reservoirs for vegetable cultivation. For instance, the land around the dams and dugouts are either rocky (as in the case of Kaleo), sandy (as in the case of Kalsegra) or hardy (as in the case of Nadowli). Also, irrigated farms are distant from community dams and dugouts to minimize siltation of such water facilities. Moreover, farmers distant their crop fields from the dams and dugouts to prevent intrusion of animals which drink from the water facilities. Even though farmers distant the crop fields from the dams and dugouts for the outlined reasons, there is no corresponding provision of water harvesting implements such as canals, pipes and pumps among others to propel water from the dams and dugouts to the irrigated crop fields (Namara et al., 2011) due to technical and engineering negligence (Acheampong et al., 2014). As such, farmers resort to the initiation and utilization of private water systems within the crop fields for irrigation. One such irrigation farmer (name withheld) is quoted to have said:

"As for me I do not use water from the dam for irrigation because the land around the dam is not fertile. As such, I farm on the other side of the water bank, and because of that I cannot climb the high bank and fetch water from the dam with my bucket and climb it again to water my crops. So I decided to construct my own water system".

Access to land

Land ownership in the study district is dominated by the freehold system (97%), thus land is majorly owned by families and not individuals. This implies that in cases where a non-title holder of land intends to utilize land for a specific purpose, all the family members entitled to the land need to approve the request before such could be granted. From the empirical study, knowledge of this cumbersome process of land acquisition for temporary usage deters individuals from seeking lands around community dams and dugouts for irrigation farming during the dry season and as such only those whose lands are within the catchment areas of the respective community dams and dugouts can utilize the water for irrigation. Although the dams and dugouts are communally owned and openly accessible to the respective communities, access to the surrounding lands (catchment areas) is restrictive. Farmers therefore resort to initiating private water systems on their own lands for irrigation utilization. A respondent in Kaleo puts it:

"I do not understand what these government people have done. How do they expect every community member to gather around this small area for farming? Is that how rainy season farming is carried out? So, imagine I am interested in farming but do not own land around the dam site, what will I do?"

A fisherman at one of the dam site is quoted to have said:

"Since I do not have land around the dams, I prefer to fish in the dams so that I can also benefit from it. Why do I have to go through this long procedure to get a small piece of land around the dam to farm on, when I know I will have to release it during the rainy-season?"

This study outcome avows Ribot and Peluso's (2003) 'Theory of Access' which explains that people use different mechanisms to gain, control, and maintain the utilization of resources. It also resonates with Elimnh's (2013) assertion of the vital role land resource plays in the production of crops for farmers whose livelihoods depend on it.

Effects of rural irrigated agriculture on livelihoods

This theme of the research objective sought to examine the effects of irrigation engagement to the livelihoods of farmers and the community at large. These include:

Food supplement for household consumption

The dry season is also known as the 'lean season' in the study district and the Savannah regions as a whole due to hardships encountered by subsistence farmers during the period resulting in malnutrition which is mostly visible in stunted growth especially among children. During these periods, subsistence farmers who engage in farming as the main source of livelihood highly depend on their stored food produce. Such produce therefore serve various purposes such as food and collaterals among others. An engagement in irrigation farming during the dry season is definitely a relief and asset enhancement to the farmers. These irrigated outputs mostly in the form of fresh vegetables which are often rare during the dry season boost up the nutritional content of households' diet. Also, such irrigated produce complements the other staple produce for the rest of the season thereby buttressing Inkoom and Nanguo (2011) and other researchers' submission that farmers engage in irrigation farming during the dry season to increase food supply.

Employment and income generation

Economically, irrigation farming enhances the financial assets of farmers and households who engage in it. Such income is generated from the sales of harvested irrigation produce. Since few farmers are engaged in the cultivation and supply of fresh vegetables in the dry season and the demand for such produce is often high, commercialization of fresh vegetables becomes a lucrative enterprise for farmers. Average monthly income generated from the sale of vegetables is estimated at GH¢150.00. Comparatively, if such vegetables are grown in the rainy season for commercialization, the demand is often minimal since more people are engaged in the production. Income generated from the sales according to the irrigation operators is used for the provision of family needs such as health insurance premium payment, hospital bills, purchase of foodstuff, and payment of children's school fees among others. A distance education tertiary student responded:

"…dry season farming is very beneficial to me because it is from the sale of these irrigated vegetables that I get money to support my distance education at the tertiary level and also pay my siblings school fees as well".

These findings endorse Eneyew et al. (2014) assertion that irrigation operations enhance employment opportunities and increased income for the operators. The finding also avers Elimnh's (2013) assertion that irrigation farming improves income although the level of income varies among farmers and regions.

Social worth and sense of fulfilment

According to the Australasian Faculty of Occupational and Environmental Medicine (2010), working improves general health and well-being and reduces psychological distress. The absence of work therefore leads to a range of psychological problems such as depression, anxiety and low self-esteem especially among young people. The lack of work (unemployment) also increases mortality rates, cardiovascular diseases, and lung cancer among others.

Engagement in a productive activity such as irrigation farming during the dry season when most farmers are redundant therefore bequeaths a sense of worth and fulfilment to the irrigation farmer.

Reduction in rural migration

The movement of rural farmers from the savannah grasslands to the rural forest and semi-deciduous lands in the country for temporary or permanent settlement is the result of rainfall failure in the migration source. The innovation of initiating private water systems for irrigation farming during the dry season positively curtails the perennial exodus of rural farmers for greener pastures elsewhere. This empirical study outcome therefore reinforces Dinye and Ayitio (2013) as well as Kpieta et al. (2013) claims that irrigation development in rural savannah minimizes the migration of farmers in the source areas.

Felling of trees for gardening

The protection of irrigated crop fields from animals and theft demands the securing of the farmlands through fencing. Due to the absence of funds to purchase metal fencing nets, rural farmers engaged in dry season irrigation resort to the felling of trees for gardening. Such practices therefore negatively affect the environment and further deteriorate the ecosystem steadily resulting in desertification (Akudugu et al., 2016).

Hindrances to private irrigation development in Nadowli-Kaleo District

Destruction of irrigated crops by invaded animals

Since irrigation takes place during the dry-season (characterized by dry land with dried and stale grasses), animals including cattle, goats, sheep among others which are reared through the extensive system in the dry-season often search for fresh and green grasses to graze. Such grasses can only be found on wetlands and probably around water bodies. During such moments, animals which go to the dugouts to drink water mostly in the afternoons in the absence of farmers invade the irrigated lands which are often fenced with dry grasses, stocks and sticks. Such invasions therefore culminate in the destruction of irrigated crops which are often the only greenery areas visible to the animals. The invasion of animals on irrigated farmlands located around dugouts and dams was also a major factor which deterred farmers from engaging in irrigated cropping within the peripheries of such water bodies. A respondent in Saan (one of the studied communities) is quoted to have said:

"You know, during the dry season there are no green grasses. The only places where green leaves can be found are wetlands, areas around the dams and the irrigated crops. Therefore because our fences are not strong (mostly in the form of sticks and stocks), the animals especially the Fulani cattle usually invade the irrigated fields and destroy the crops during the afternoon and in the night time when we are not available".

Inadequate financing capacity

Intensification of agriculture through irrigation is highly anchored on the financial capacities of the operators. Such funds are essential to purchase the needed farm inputs and implements such as fertilizer, watering machines, pipes and pumps and fortified fencing materials such as metallic nets among others. From the field study, self-financing was the main source for funding irrigation farming in the study district. Alternative and external means of funding were non-existent and not explored as well. Such limitations inhibited the farmers' ability to expand irrigation operations resulting in micro scale farming and output. This finding therefore buttresses Elimnh's (2013) view that access to credit for financing investment and farm operations is crucial for the commercialization of smallholder agriculture.

Limited knowledge in irrigation agronomy

The management and agronomic practices in irrigated farming are quite variant with the rain-fed agriculture. Although irrigation farmers are enthused with their farming activities, such farmers do not however possess the requisite knowledge and skills for dry-season farming due to the artificial form of applying water to the crops. Such agronomic practices include the quality and volume of water requirement for specific crops, pest and disease control, mulching, fertilizer application, and suitability of soils for varied vegetable crops among others. Also, with a gradual drift in demand for exotic vegetables such as cabbage and eggplants by consumers especially in the district capital, knowledge on the growth of such crops is therefore necessary. From the perspective of irrigation operators however, such services are not rendered by the Agricultural Extension Officers. In a triangulated response from the Agriculture Department on why monitoring, supervision and offer of extension services to farmers were not undertaken, logistical constraints was the reason cited for the negligence of responsibilities.

Strategic measures for rural irrigated agricultural maximization

Based on the study findings and ensued issues, the researchers put forth measures to be adopted by policy makers, local governments, other development think tanks and for further discourse in propelling the productive capacity of rural farmers engaged in irrigated agriculture.

Establishment of irrigation fund for farmers

The researchers propose the establishment of a fund purposely dedicated to irrigation development. Access to financial capital is a crucial inhibiting factor for rural irrigated agricultural intensification in the study district. The researchers however discovered that donor funding from the World Bank, FAO, and IDA among others for the promotion of irrigation development are expended in the acquisition of land, payment of compensation fees and the construction of community dams and dugouts of which the expected irrigation benefits are unattainable. The researchers therefore submit an alternative solution in which such donor funds or proportions of it could be consolidated into a funding pool from which persons with interest in irrigation farming could apply or seek assistance. This will ensure value for money and enhance accountability and transparency since the beneficiaries could easily be traced and held responsible in cases of financial malfeasance. At the district level, the fund could be managed by a Unit of GIDA or the Agriculture Department. On the other hand, such funds could be accumulated and channelled into the acquisition of irrigation machinery for farmers who demonstrate interest in irrigation farming at subsidized prices and payments made on instalment basis.

Training of irrigation farmers in basic agronomic practices

Due to the limited knowledge in irrigation agronomy by farmers coupled with logistical constraints of Agricultural Extension Officers for mobile servicing of farmers, thereby resulting in stagnant yields, the researchers propose the establishment of demonstration farms at substation level and the organization of periodic trainings to boost the knowledge and capacity of irrigation farmers. This initiative could be undertaken by the Agriculture Department in collaboration with the entire District Assembly and factored into the district budgetary allocations. At the demonstration farm units, stationary officers could offer training services for cluster of irrigation farmers through demonstration exercises on the farmlands. These training services could be rendered probably at the beginning of each irrigation season especially for new entrants coupled with intermittent refresher trainings in the course of the season. Such trainings could cover areas of concern such as the use of low-cost and efficient irrigation technologies, water volumes and application methods, as well as pests and disease control among others especially in the aspect of vegetable production. Also, helplines of the extension officers could be made available to farmers for enquiries in times of need.

Facilitation of the establishment of block irrigation systems

The construction of open-access community dams for irrigation in principle expects all farmers within a community to converge around a single water system and utilize the water for farming. In practice, this approach to dry season farming has been fiercely resisted by members of the studied communities through the various actions meted out notwithstanding the conflict of interests and emanating issues of accessibility with regards to the utilization of the dam facilities. To ameliorate such incessant and recurrent issues in the utilization of existing and subsequent community dams, the researchers recommend the establishment of block water systems for rural irrigation farming. This initiative could be made possible through feasibility studies and mapping out of suitable areas for potential irrigation schemes in communities within the district. Such studies could be undertaken through a collaborative effort of the engineering units of the Agriculture Department and Works Department of the District Assembly in consultation with chiefs as well as Assembly and Unit Committee members of the respective communities. The government, together with development partners and NGOs interested in supporting irrigated agriculture could then channel their resources towards creation of block water systems at these potential sites such as permanent wells and boreholes for groundwater irrigation probably powered by solar energy. These potential irrigation sites could then be utilized by farmers with interest in irrigation. In cases where persons interested in irrigation farming do not have access to land, such persons on their own or together with the assembly or unit committee members could then liaise with the land owners for parcels of land to farm at convenient terms of agreement. These prospects could further be explored for instance on pilot basis to ascertain its impact and relevance and if the need be, amendments made to it.

Granting of awards to irrigation farmers on Farmers' Day Celebration

It is proposed that consideration should be given to the inclusion of irrigation farming as one of the categories for Farmers' Day Celebration Awards at the district level. Farmers are mostly not enthused in undertaking dry season farming due to its labour intensive nature. The inclusion of such awards for irrigation farmers who have shown dexterity in irrigation farming in the course of the year would serve as incentives in propelling people to venture into irrigation farming during the dry season. This could be made possible by adapting similar protocols that are followed for the award of best farmer for any category such as farm visits to irrigation sites to ascertain the truth prior to the selection, grading and screening, shortlisting and final presentation of awards on the day of celebration.

Proper management of existing community dams

The researchers recommend the rehabilitation of existing community dams through the creation of canals as well as provision of pumping machines and pipes to propel water from the dams to the irrigation fields. Moreover, there is an urgent need for the enactment and enforcement of bye-laws by the District Assembly in collaboration with community chiefs to safeguard the usage of the dams and dugouts. Such legislations will minimize the hazardous impact of human activities on these water facilities. Perpetrators who are tried and found guilty should be rigorously sanctioned to serve as deterrent to other community members.

Conceptualizing rural irrigated agriculture towards sustainable livelihoods

From the illustration in Figure 6, irrigated agriculture is carried out either by individual initiative or induced by the government and development partners through the establishment of irrigation systems. The choice of type of irrigation engagement is further influenced by mechanisms including:

i) Availability and access to livelihood assets such as human, social, financial, natural, and physical capital.

ii) The institutional arrangement and government set-up including the policies, laws, customs, and cultural beliefs among others. These mechanisms either enhance the livelihood assets available to an individual and the community at large or worsen the state of exposure to issues of vulnerability.

iii) Livelihood vulnerability causative factors include: seasonal rains, unemployment, and price fluctuation of produce among others.

Moreover, there is a corresponding interaction among these influencing factors. For instance, the institutional arrangements and set-ups such as fiscal policies of government can either enhance livelihood assets such as increased financial capital and physical assets or intensify livelihood vulnerability such as unemployment. The main reason for undertaking this study is in reference to the issues emanating from the utilization of these respective irrigation systems namely: private and government/donor irrigation systems. In the study district, government and donor funded irrigation systems meant for dry-season farming are deserted. Farmers engaged in irrigation rather resort to the initiation of private systems. Certain ascribed theories namely: Game theory, Tragedy of the Commons, Theory of Access and Neoliberal theory therefore sought to explain why the phenomenon under study exists.

This raises concerns including: why the non-utilization of donor facilities; and why the preference for self-initiated irrigation facilities by farmers engaged in dry-season farming? These concerns are further translated into objectives that drive the focus of the research including: uncovering the factors that influence the choice of irrigation operations, an assessment of the effects of irrigation operations on livelihoods, and examination of the hindrance to private irrigation development. Based on the study objectives, empirical outcomes are generated with strategic measures put forward to strengthen irrigation intensification. Implementation of the strategic measures will culminate in the achievement of desirable sustainable livelihood outcomes such as perennial employment, food security, and availability of regular income which will eventually enhance the livelihood assets of farmers and communities as illustrated in Figure 6.

Conclusion

Restricting access to the use of communal water systems for irrigation through the implementation of regulatory mechanisms such as charging of water user fees and filing of application letters as stipulated by the Irrigation Development Authority of Ghana, or adopting the open access mechanisms to community dams utilisation for irrigation as explored by the current study demonstrate that treading the path of establishing communal water

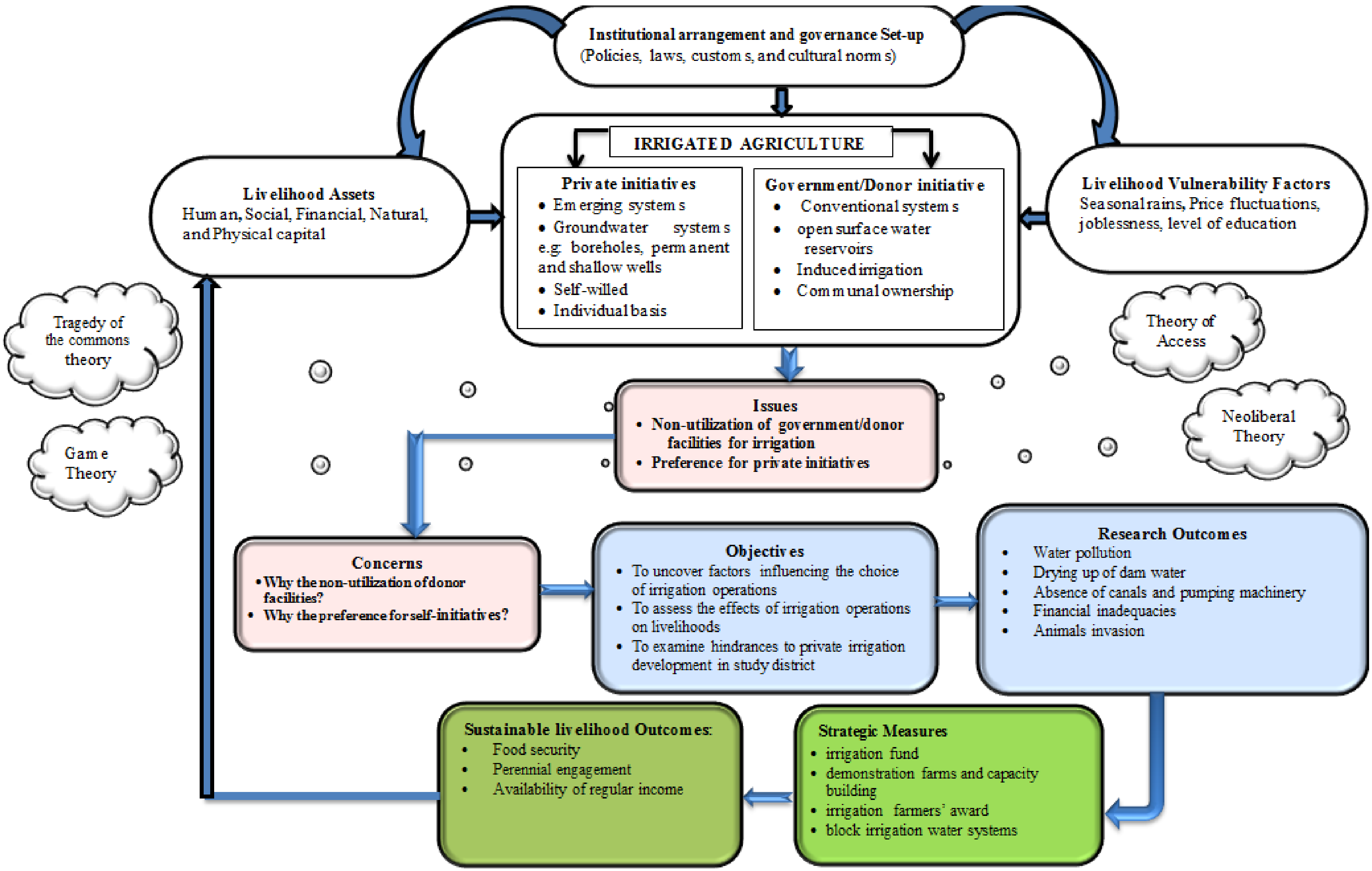


Figure 6. Conceptualizing rural irrigated agriculture towards sustainable livelihoods.
Source: Authors' Construct (2017).

systems for irrigation have not produced the desired benefits. This therefore necessitates the need for a paradigm shift and reorientation in the approaches to developing and promoting irrigation especially for rural communities in northern Ghana. The multi-purpose functions of public communal surface water reservoirs (dugouts and dams) are inappropriate for irrigated farming since there are competing conflicts of interests in the utilization of such facilities. The prospects of groundwater development for irrigated farming on individual bases need further exploration.

As opined by Davis (2006), any genuine social transformation of an area must be initiated from within the society even if the results of cross-fertilization of the generated ideas are from external societies. The conscious promotion of private initiatives in rural irrigation can therefore produce a tremendous positive impact on the livelihoods of rural people most of whom fall within the class of peasant farmers especially during the prolonged dry season periods. Moreover, it will reduce burden on government's expenses in areas such as during acquisition of lands, compensation of displaced persons, procurement processes and construction costs. It will also ensure ownership and sustainability of irrigation projects, enhance peer learning and heighten innovations and creativity in agriculture. There is therefore the need for a dispassionate discussion devoid of political colouring on the prospects of the current government's 'One Village One Dam' policy aimed at promoting rural irrigation in northern Ghana since the viability and sustainability of such initiative is anchored on a situational analysis of similar existing projects.

CONFLICT OF INTERESTS

There is no conflict of interest between the authors.

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