EFFECT OF POTASSIUM ON YIELD OF SUNFLOWER (*Helianthus annuus* L.) IN SOUTHWESTERN COASTAL REGION OF BANGLADESH

A Thesis

By

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Student ID.: MS-180811

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LIST OF ACRONYMS

Abbreviation	Full meaning
AEZ	Agroecological zone
Cm	Centimeter
CV	Coefficient of variation
DAS	Days after sowing
EC	Electrical conductivity
et al.	And others
etc.	Etcetera
G	Gram
K	Potassium
kg	Kilogram
LSD	Least significant difference
m^2	Meter squares
NS	Non significant
SRDI	Soil Resources Development Institute
t ha^{-1}	Ton per hectare
var.	Variety
%	Percent
@	At the rate of

CHAPTER I

INTRODUCTION

Bangladesh is a developing country crowded with the population of about 163.38 million (BBS, 2019) in the area of 147,570 square kilometer. Agriculture is the dominant sector of Bangladesh economy. In terms of GDP, it contributes about 14.23% (Economic Survey, 2018). Crop agriculture in Bangladesh is, however, constrained by a number of challenges every year.

The coastal area covers about 20% of our country and over 30% of the net cultivable area. Most of Bangladesh's coastal region lies on the southwest coastal region of the country and continuous to support crops productivity. But in the recent past, the contribution of crops to GDP has decreased because of salinity. Out of 2.68 million ha of coastal and off-shore lands, about 1.06 million ha of arable lands are affected by varying degrees of salinity (SRDI, 2010). About 53% of the coastal areas are affected by salinity (Uddin et al., 2011). The salt affected area has increased by 14600 ha per year (SRDI, 2001). SRDI had made a comparative study of the salt affected area among 1973 to 2009 and showed that about 0.223 million ha (26.7%) of new land has been affected by varying degrees of salinity during the last four decades and that has badly hampered the agro-biodiversity (SRDI, 2010).

It is regularly experiencing sea water submergence by tidal water, tidal surges and cyclones. In addition, it is now under threat of sea level rise due to climate change. Saline water intrusion, water logging, late drainage due to slow water recession, desiccation of soil in dry season and capillary rises from shallow saline ground water have bearing on soil salinity in this area (Gurung and Azad, 2013).

Soil salinity restricts normal crop production in the dry season in the southwestern coastal region of Bangladesh. Most of the land remains fallow after harvesting of *aman* rice (i.e. in the winter season) due to high soil moisture content, fresh and quality irrigation water limitations and increase of soil salinity. Most of the lands in the coastal regions are single cropped (Fallow-Fallow –Transplanted *aman*) and that is cultivated in monsoon, when soils became no saline.

As limited resources with high population, farmers have no scope to keep their land fallow. So, it is crucial matter to consider high salinity tolerance crops instead of vulnerable crops to salinity that ensures calorie intake, food security, poverty reduction, and economic growth. In order to overcome the present condition there is a scope to introduce saline and drought tolerant crops like wheat, maize, sunflower, sesame etc. in these areas. Among these crops sunflower will be a good choice.

Sunflower (*Helianthus annuus* L.) belongs to the family Asteraceae. It is one of the most important oil seed crops occupying the fourth place in the world grown on 22 million of ha of land producing about 33 million tons of sunflower seeds (Rodriguez et al., 2006). Sunflower is a short duration and photo-insensitive crop and therefore, it can be grown round the year provided there is no water stagnation. Besides, it is tolerant to drought and salinity. Thus, this crop can easily be cultivated in the southwestern parts of the country where a vast saline area remains fallow dry the dry period of the year (Kundu, 1996).

Again, acute shortage of edible oil has been prevailing in Bangladesh which has been met through imports, using a huge amount of foreign exchange every year. In Bangladesh 0.358 million tons of edible oil is produced against the annual demand of 1.6 million tons, while the remaining 1.242 million tons of the country's domestic requirements is met through imports

(Hossain, 2014). In order to meet the increasing demand of edible oil sunflower can be emerged as an important oilseed crop in Bangladesh.

The lower productivity of sunflower is mainly due to insufficient supply of nutrients; non-adoption of proper crop rotation and weed management practices. Hence, there is an urgent need to use balanced fertilizers with quantity to increase the sunflower productivity. The use of heavy amount of fertilizers not only increases the cost of inputs, but also creates soil and environmental pollution.

Potassium (K), one of the three primary nutrients, is absorbed by plants in larger quantities than any other element; expect N (Bukhsh et al., 2009). K plays a vital role as macronutrient in plant growth and sustainable crop production (Pettigrew, 2008). Potassium (K) is not only a constituent of the plant structure but it also has a regulatory function in several biochemical processes (Hasanuzzaman et al., 2018). It maintains turgor pressure of cell which is vital for cell expansion. It helps in osmoregulation of plant cell, helps in opening and closing of stomata (Bukhsh et al., 2010). It plays a key role in activation of more than 60 enzymes (Tisdale et al., 1990). Its application has primitive effect on growth and development (Brar and Singh, 1995) synthesis, carbohydrate metabolism, and enzyme activation. Potassium renders plant tolerance to different biotic and abiotic stress like salinity, drought, water logging, high temperature and ion toxicity (Reddy et al., 2004).

Salt tolerance is directly associated with potassium contents as it involves in osmotic regulation and competition with Sodium. Plant salt tolerance requires not only adaptation to Na^+ toxicity but also the acquisition of abundant K^+ whose uptake by the plant cell is affected by high external Na^+ concentrations (Zhang et al. 2010). Removal of exchangeable Na necessitates application of K to remove Na from the soil's exchange sites. There are increasing evidences that application of K fertilizers reduce the adverse effects of salinity in a variety of crops (Wakeel, 2013). Therefore, the improvement of crop production in saline soils could be achieved by balanced fertilization particularly efficient management of K and Zn fertilizers with suitable high yielding crop varieties.

But the problem is that there is no fertilizer recommendation (potassium) for sunflower in the southwestern part of Bangladesh. Therefore, the present research work was under taken keeping in mind the following objectives:

i. To evaluate the growth and yield response of sunflower at different rates of potassium.

ii. To find out the optimum rate of potassium for sunflower in the coastal soil of southwestern Bangladesh.

CHAPTER II

REVIEW LITERATURE

The purpose of this chapter is to review the past studies conducted by different researchers related to the present study. As far as possible it had been tried to review the available literature from different countries. Unfortunately, a very few of these studies were directly related to the present study. This chapter comprises of following section:

- Role of potassium in plants
- Effect of potassium on oil seed crops
- Distribution of different forms of potassium in soil
- Effect of salinity on sunflower
- Effect of potassium on sunflower (along with other nutrient)
- Effect of potassium on sunflower
- Effect of potassium on sunflower under saline condition

2.1 Role of potassium in plants

Hasan et al. (2017) reported that drought stress is a major catastrophe to plant productivity. Drought stress significantly reduces the crop yield and quality, and probably exceeds losses from all other stresses. Potassium (K^+) is an essential nutrient and affects the growth and development, and it also contribute significantly towards plants survival under drought stress.

Wang (2013) stated that potassium (K) is an essential nutrient that affects most of the biochemical and physiological processes that influence plant growth and metabolism. It also contributes to the survival of plants exposed to various biotic and abiotic stresses.

Jin et al. (2011) found that as stomatal closure is preceded by a rapid release of K^+ from the guard cells into the leaf apoplast, it is reasonable to think that stomata would be difficult to remain open under K-deficient conditions. Some studies also stated that K deficiency may induce stomatal closure and inhibit photosynthetic rates in several crop plants. Tsonev et al. (2011) stated that photosynthetic rate was decreased under drought stress in K-deficient plants.

Mian et al. (2011) stated that an increasing K supply corresponded with higher K^+ accumulation in plant tissue, which reduced the Na^+ concentration and resulted in a higher K^+/Na^+ ratio. Members of the HKT transporter (high-affinity K^+ transporter) family that mediate Na^+-specific transport or Na^+-K^+ co-transport play a key role in plant Na^+ tolerance mechanisms. HKT represents a primary mechanism in the regulation of Na^+ and K^+ homeostasis, as well as Na^+ exclusion.

Ashraf et al. (2011) found that exogenous application of K could effectively ameliorate the adverse effects of water logging on plants. K supplement under water logging not only increased plant growth, photosynthetic pigments and photosynthetic capacity, but also improved plant nutrient uptake as a result of higher K^+, Ca^{2+}, N, Mn^{2+} and Fe^{2+} accumulation. They also reported that exogenous application of K in soil and as foliar spray alleviated the adverse effects of water logging on cotton plants.

Holzmueller et al. (2007) observed higher K^+ concentrations decreased the internal competition of pathogens for nutrient resources. This nutritional status enables plants to allocate more resources to developing stronger cell walls for preventing pathogen infection and insect attack and to obtain more nutrients to be used for plant defense and damage repair.

Cakmak (2005) found that a close relationship between K nutritional status and plant drought resistance has been demonstrated. The roles of K in physiological and molecular mechanisms of plant drought resistance have been explored.

Egilla at al. (2005) stated that an adequate K status may facilitate osmotic adjustment, which maintains higher turgor pressure, relative water content and lower osmotic potential, thus improving the ability of plants to tolerate drought stress

2.2 Effect of potassium on oilseed crop

Parvej et al. (2015) stated that seed yield for soybean grown with low K averaged 3.4 Mg ha^{-1} and was 13 to 15% lower than the yields of soybean grown with medium and high K fertility. The yield loss associated with K deficiency was from fewer pods (16–25%) and seeds (22–30%) $plant^{-1}$, higher seed abortion (5–7%), and lower individual seed weight (8–10%) than soybean with medium or high K fertility. Seed K concentration increased with each increase in K fertility level averaging 15.8, 18.7, and 19.8 g K kg^{-1} for soybean grown under low, medium, and high K levels, respectively. Regardless of growth habit, the yield loss caused by K deficiency was attributed to the same primary mechanisms of reduced pod number and increased seed abortion.

Ren et al. (2013) found that optimal potassium (K) fertilization is beneficial for oilseed rape (*Brassica napus* L.) yield and quality. However, the discrepancy between the high K demand of winter oilseed rape and low soil fertility and insufficient potassium input has limited the sustainable development of oilseed rape production.

Slaton et al. (2010) found that Mehlich-3-extractable soil K ranged from 46 to 167 mg K kg^{-1} and produced relative soybean yields of 59 to 100% when no K was applied. Eleven sites had Mehlich-3-extractable K< 91 mg K kg^{-1} and all responded positively to K fertilization. Soybean grown in soil having 91 to 130 mg K kg^{-1} responded positively at nine of 15 sites. Mehlich-3 soil K explained 76 to 79% of the variability in relative yields and had critical concentrations of 108 to 114 mg K kg^{-1}, depending on the model.

Brennan and Bolland (2009) stated that canola required an average of 32% more applied K than wheat to produce 90% of the maximum grain yield. Applying increasing rates of K increased the rate of N required for 90% of maximum grain yield. Fertilizer K had no significant effect on the concentration of oil in canola grain or concentration of protein in both canola and wheat grain.

Brennan and Bolland (2009) stated that for all levels of N applied, significant grain yield responses occurred when up to 30 kg K/ha was applied, with no further significant grain yield responses occurring when 60 kg K/ha was applied. Application of K had no effect on the concentration of oil and protein in grain. Application of up to 30 kg K/ha significantly increased canola grain and oil yields (concentration of oil in grain multiplied by grain yield).

Fanaeia et al. (2009) concluded that potassium application improved physiological traits like water content (RWC), stomatal conductance (g), chlorophyll content (SPAD values). Potassium could ameliorate negative effects of water stress on grain yield and physiological properties and consequently improved them.

Jianwei et al. (2007) stated that seed yields were significantly affected by K application. Compared with the zero K treatment, plots treated with 150 and 300 kg K_2O/hm^2 produced 17.5 and 31.7% higher yields, respectively. The N utilization efficiency of rapeseed upland part was improved by 1.6% with 75 kg K_2O/hm^2, 7.7% with 150 kg K_2O/hm^2, 6.7% with 225 kg K_2O/hm^2, and 9.0% with 300 kg K_2O/hm^2.

Govahi and Saffari (2006) observed that K has no significant effect on dry matter production, number of primary and secondary branches, seeds per pod, seed yield and seed oil. But K has significant effect on 1000 seed weight with increasing levels of applied K (1.14%). The increase of 3.81% in oil yield was realized with increasing the rate of 0 t 60 kg K ha^{-1}.

Umar (2006) found that the water content of the leaf tissue was significantly increased by K application and the highest increase in RWC was 14.7%, and 22.8% under normal conditions, and by 8.7%, 19.9% and 17.7% under water stress conditions in mustard and groundnut, respectively. Water stress caused grain yield reductions and K application could enhance yield to a great extent. Production of above ground biomass, grain yield and RWC were highly correlated with the tissue K concentration, showing that concentration of K^+ in leaves played a vital role in increasing water stress resistance and stabilizing yield in the crops studied.

Casanova (2000) observed that soybean yield increases can be obtained with K fertilization when grown under conventional tillage when the fertilizer was banded or broadcast and sometimes when the K is applied in a foliar application. The positive yield response to K can be attributed to increases in most of the yield components. The number of pods per plant and the weight of individual seeds increased in response to K fertilization.

2.3 Distribution of different forms of potassium in soil

Odyuo et al. (2015) analyzed for some important physicochemical properties and different forms of potassium. Average values of various fractions of K viz., available K, water soluble K, exchangeable K, non-exchangeable K and total K in surface and sub-surface soils were 171 and 165, 12.4 and 9.2, 156, 879 and 918, 24.0 and 25.0 mg kg^{-1} respectively

Jatav et al. (2014) observed that the water-soluble K varied from 12.8 to 81.2 (mean of 31.3 mg kg^{-1}) and exchangeable K ranged from 9.4 to 186.9 mg kg^{-1} (mean 98.15), non-exchangeable K ranged from 285 to 3381 (mean of 1620 mg kg^{-1}). The 1N HNO_3 extractable K varied from 332.5 to 3440.0 mg kg^{-1}(mean 1694.3 mg kg^{-1}), under potato growing areas of Jalandhar district of Punjab.

Kundu et al. (2014) noticed the organic carbon content of the soils varied from 5.54 to 12.5 g kg^{-1} in surface soils, being higher than the values for sub-surface soils. The distribution of the different forms of the K in these soils, i.e., available, water soluble, exchangeable, non-exchangeable, total and lattice forms ranged from 86.9 to 132.4 mg kg^{-1}, 15.4 to 48.2 mg kg^{-1}, 68.9 to 80.9 mg kg^{-1}, 658.9 to 764.5 mg kg^{-1} 15579.2 to 17250.2 mg kg^{-1} and 14801.3 to 16361.0 mg kg^{-1} respectively, for surface soil and 98.5 to 135.6 mg kg^{-1}, 21.5 to 49.1 mg kg^{-1}, 72.9 to 92.2 mg kg^{-1}, 701.0 to 789.9 mg kg^{-1}, 15753.5 to 17303.2 mg kg^{-1} and 14951.3 to 16378.4 mg kg^{-1} respectively, for sub-surface soil of the Hooghly district of West Bengal.

Reza et al. (2014) noticed that water-soluble K ranged between 0.006 and 0.144 cmol kg^{-1}, exchangeable K between 0.07 and 0.54 cmol kg^{-1}, fixed K from 16.7 to 61.3 cmol kg^{-1} and total K from 17.4 to 63.6 cmol kg^{-1} in soils of horizons of different agro ecological regions of North-Eastern India.

Saini and Grewal (2014) reported the distribution of different forms of K in soils from different crop rotations in Haryana was studied by exposing profiles. The distribution of different forms of K i.e. water soluble, exchangeable, non-exchangeable and total K in these soils ranged from 8 to 58 kg ha^{-1}, 127 to 263 kg ha^{-1}, 442 to 828 kg ha^{-1} and 1.18 to 1.92% respectively.

harvest, head diameter and number of filled seed head^{-1} was well correlated with number of seed head and seed yield head^{-1}. Thus genotype Hysun-33 may be considered as best for saline and KU-SL-1 for non-saline soil.

Francois (1996) found that each unit increase in salinity above 4.8 dS m^{-1} reduced yield by 5.0%. These results indicate that sunflower is appropriately classified as moderately tolerant to salinity. Yield reduction was attributed primarily to a reduction in seeds per head. Oil concentration in the seed was relatively unaffected by increased soil salinity up to 10.2 dS m^{-1}. Sunflower appears to be well adapted for growth under moderately saline soil conditions.

Katerji et al. (1996) noticed that the stomatal conductance of sunflower was much higher and more severely affected by salinity and soil texture than the stomatal conductance of maize. Salinity had a more serious effect on the development of leaf area and canopy dry matter of sunflower.

2.5 Effect of potassium on sunflower (along with other nutrient)

Ertiftik and Zengin (2016) found that K application in the increasing doses increased yield components more than that of Mg. Together giving of the K and Mg in certain combinations took the yield components to maximum levels. The highest grain yields were obtained by the $K_{40}Mg_{40}$ in the first year (7313 kg ha^{-1}) and by the Mg60 in the second year (6510 kg ha^{-1}).

Chen and He (2011) found that for the maximum production of sunflower, the fertilization ratio among nitrogen, phosphate, and potash is 10.51: 5.78: 3, while the best economic yield's fertilization ratio among nitrogen, phosphate, and potash is 7.47: 4.49: 3.

Muzzammil et al. (2009) reported that all macro and micro-nutrient treatments significantly enhanced plant height, stem girth, head diameter, seeds per head, 100 seed weight, seed index and seed yield of sunflower. Further, as NPK, Zn and B doses increased from low to high significant differences of growth parameters were noticed. The seed yield of sunflower showed increasing response to traditional N broadcast application of higher fertilizer rates up to 120-60-60 NPK kg ha^{-1} but the values were low as compared to 90-45-45 NPK kg ha^{-1} where N applied through fertigation.

Patil et al. (2009) found that application of fertilizer dose 80:40:40 NPK $kgha^{-1}$ recorded higher in all growth and yield attributing characters and seed yield (1447.50 kg ha^{-1}) as compared with other fertilizer doses and control.

Malik et al. (2004) revealed that increasing levels of N, P and K increased yield and yield components of sunflower (plant height, head diameter, number of seeds $head^{-1}$, 1000 seed weight) but decreased the seed oil content.

Bikas and Gajendra (2002) stated that application of 80 kg N ha^{-1} significantly enhanced the plant height and dry matter accumulation, however application of P could not bring any change in final plant height and dry matter accumulation perhaps it reduced the dry matter accumulation significantly. At the same experiment application of K significantly enhanced the final plant height and dry matter accumulation. Application of P and K significantly improved the oil yield though these nutrients did not encourage the oil content in seed; this was due to the significant increase in seed yield with the application of P and K.

Reddy et al. (2002) reported that fertilizer combination of 100-60-60 NPK kg ha^{-1} + 500 kg gypsum and 0.2 per cent borax spray during flowering stage recorded significantly higher yield (2140 kg ha^{-1}) as compared to 50-30-60 NPK kg ha^{-1} in Vertisol with low available nitrogen and organic carbon and medium available phosphorus and potassium.

Renugadevi and Balamurugan (2002) found that seed treatment of sunflower seeds with Azospirillum species and phospho bacteria along with a fertilizer dose of 60:90:60 NPK kg ha^{-1} recorded maximum head diameter, seed yield per plant (51 g) and seed yield per ha (1183 kg).

Sadiq et al. (2000) revealed that the increase in levels of NPK increased days to flowering and maturity, plant height, head diameter and number of grains per disc. However, the increase in 1000 grain weight and grain yield per hectare was up to 80:50:50 kg/ha NPK level after which it dropped. On the basis of these findings, application of 80:50:50 kg NPK/ha is recommended for sunflower crop to obtain maximum grain yield under irrigated conditions.

Salehi and Malakooti (2000) observed that number of filled seeds per head (668 to 1177) and stalk yield (4755 to 6800 kg ha^{-1}) of sunflower significantly increased due to higher doses of nitrogen (120 kg ha^{-1}), phosphorus (120 kg P_2O_5 ha^{-1}) and potassium (60 kg K_2O ha^{-1}) fertilizers over no NPK fertilization during 1999 *Kharif* season.

2.6 Effect of potassium on sunflower

Li et al. (2018) conducted an experiment on oil and edible sunflower to study the effects of potassium (K) fertilization on seed yield and quality and to estimate the nutrient internal efficiency (IE) and nutrient requirement in sunflower production. All trials in edible sunflower and 75% trials in oil sunflower showed positive yield responses to K fertilization. Compared with control (without K fertilization), the application of K increased seed yield by an average of 406 kg ha^{-1} for oil sunflower and 294 kg ha^{-1} for edible sunflower.

Ullah et al. (2018) stated that potassium chloride was applied as a source for potassium, respectively. The results showed that palmitic acid concentration and stearic acid concentration were not affected by potassium application. Potassium applied at the rate of 90 kg ha-1 produced maximum biological yield (7178 kg ha^{-1}), grain yield (2074 kg ha^{-1}), oil yield (775 kg ha^{-1}), harvest index (28.87%) and oil percentage (37.32%). Application of potassium at the rate of 90 kg ha^{-1} could be recommended for higher oil and grain yield of sunflower.

Jyothi and Anjaiah (2018) observed that seed yield varied from 952.8 to 1430 kg ha^{-1}. Higher seed yield was recorded with K_{60} however; it was at par with K_{30} treatment. Maximum oil content and fatty acid contents record with K_{30} and protein content was found maximum with K_{60} treatment. Based on the results of investigation it can be concluded that among various levels of B and K application of boron @ 1kg ha^{-1} along with recommended dose (90:60:30) of N: P: K ha^{-1} was sufficient to get higher B:C ratio and net returns and also to prevent luxury consumption of K by sunflower crop cv. GK-2002 in sandy loam soils.

Torqueti et al. (2016) revealed that the application of KCl yielded the production of flower stems with greater height and larger capitulum diameter in relation to the supply of glauconite. Among the glauconite based fertilizers, the fine grained organo-mineral product provided the best flower charateristics. The postharvest commercial durability of the flower stalks was higher in plants that received the glauconite and fine grained organo-mineral glauconite. The fine grained organo-mineral glauconite surpasses all other alternative sources of potassium in relation to the agronomic characteristics evaluated.

Taher et al. (2013) found that increasing of Potassium levels significantly caused increasing in (seed number, 1000 seed weight and yield plant) both in fall and spring seasons. There was no effect for fertilization in oleic acid for both seasons.

Mollashahi et al. (2013) stated that the amounts of potassium fertilizers had significant effect on plant height, biological yield, seed yield and seed oil content. The highest amounts of all measured factors obtained from treatment of 150 kg ha^{-1} potassium.

Jaidi et al. (2012) observed that K application did not significantly improve plant height, head diameter, 1000-seed weight, seed yield, stalk yield and harvest index except number of seed $head^{-1}$, where application of K showed significant improvement. Among sunflower hybrids, S-278 produced significantly taller plants, heavier 1000-seed weight, higher seed and stalk yield, but lesser harvest index than that of Hysun-33. Both hybrids were, however, similar for head diameter and number of seed $head^{-1}$. Sunflower hybrid S-278 produced the highest seed yield when crop was fertilized with K @ 150 Kg ha^{-1} due to heavier 1000-seed weight. Similar trends were observed for stalk yield. Sunflower hybrid Hysun-33 produced the lowest seed yield when crop was grown with K. Hysun-33 produced the highest harvest index when crop was fertilized @ 100 Kg K_2O ha^{-1}. Similarly, S-278 produced the lowest harvest index when crop was fertilized @ 100 Kg K_2O ha^{-1}. It is therefore suggested that sunflower hybrid S- 278 should be cultivated with K application @ 150 Kg ha^{-1}.

Kapourchal et al. (2011) set an experiment to investigate the influence of different K sources (KCl and K_2SO_4) on sunflower yield. The treatments were consisted of 0 (standard), 50, 100, 150 and 200 kg/ha fertilizers each with four replicates. The obtained results indicated that by increasing potassium concentration in soil, its accumulation in plant tissues was also increased. So that the best yield was in 200Kg/ha level of K_2SO_4 treatment and the lowest yield was in the 50Kg/ha of the KCl treatment. Also, the sulphur content increased with increasing of K_2SO_4 fertilizer. This study may help the integrated nutrient management for oil seed crops especially the sunflower.

Soleimanzadeh et al. (2010) noticed that plants with higher levels of potassium showed higher resistance to drought stress conditions and higher yield and dry matter allocation to grain filling process i.e. harvest index.

Soleimanzadeh et al. (2010) showed that the drought stress decreased significantly plant height, head diameter, seed number per head, 1000-grain weight, biological yield, grain yield, harvest index and oil yield, but potassium increased significantly seed number per head, harvest index and oil yield. Finally, potassium application in dry lands that are exposed to drought stress could be helpful for oil yield improvement in sunflower.

Benlloch-González at al. (2010) stated that the effect of water stress on stomatal closure in sunflower plants has been found to be dependent on K^+ nutrient status. Stomatal conductance was reduced more markedly in plants with an adequate K^+ supply than in K^+ starved plants.

Akram et al. (2009) found that foliar application of potassium sulfate significantly improved growth, seed yield, photosynthetic and transpiration rates, stomatal conductance, water use efficiency, leaf turgor and enhanced shoot and leaf K^+ of the salt-stressed sunflower plants, but it did not improve leaf and root Na^+, Cl^-, Mg^{2+}, P, Ca^{2+}, N as well as K^+/Na^+ ratios.

Khan et al. (1999) reported that the highest 1000-seed weight (53.71 g) was obtained from the plot, fertilized with 150 kg potassium ha^{-1}, while the minimum 1000-seed weight (46.41 g) was obtained in common plots. The highest seed yield (4153 kg ha^{-1}) was also obtained in plots where 150 kg potassium per hectare was applied. The lowest seed yield was recorded in control plots (3402 kg ha^{-1}). It can be suggested from these results that potassium can be applied up to 150 kg ha^{-1} to obtain high seed yield of sunflower.

Ayub et al. (1999) found that leaf area per plant, stalk yield, number of grain per head, seed yield and oil content were affected significantly by K_2O levels. A significant increase in seed yield and oil content was observed up to 100 $kgha^{-1}$ but both these parameters were decreased beyond this limit. A decree of 26 to 20 percent in seed yield was noted by potassium application at the rate of 150 kg K ha^{-1} in the form of sulphate of potassium and muriate of potash respectively. The application of potash more than 100 kg per ha seems to be uneconomical to sunflower. Sirbu and Ailincai (1992) found a direct correlation between potassium and seed yield of sunflower.

De La and Benlloch (1980) observed that the uneven K distribution along the plant (higher K content in the higher internodes) was enhanced by GA3 treatment. Gibberellic acid increased the content of reducing sugars, especially in K deficient plants. An increase in the K level in the nutrient solution resulted in a decrease of the osmotic potential of stem segments. Osmotic potential differences within the elongating first inter node were increased by GA3 treatment.

2.7 Effect of potassium on sunflower under saline condition

Yin et al. (2015) showed that in the salted soil, the plant which had been disposed by K fertilizer had more advantages, the 1000 grain weight, fruit quantity of each oil sunflower and yield per plant and hectare all increased significantly. At the same time, the application of K fertilizer would increase the fat content and reduce the protein, increase the oleic acid and stearic acid, reduce the content of linoleic acid and palmitic acid.

Somayyeh et al. (2014) carried out an experiment to evaluate the effect of different doses of zinc sulphate and potassium sulphate on morphological characteristics of sunflower under saline conditions. The results showed that a morphological trait in irrigation treatments in both normal and salinity mode was significant at the five percent level and performance was significant at the one percent level. Above traits due to fertilizer treatment was significant at the one percent level, Interaction of irrigation conditions and fertilizer are significant at the five percent level. Average comparison of traits in the interaction of fertilizer and irrigation conditions showed that all traits measured have maximum amount in the treatment of 60 kg zinc sulfate and 250 kg potassium sulphate in normal irrigation conditions.

Delgado and Sánchez (1999) found that K supply in the absence of salinity increased significantly seedling biomass which reflects what is happening in the aerial part and root. This increase was proportionally higher in the stem than in the leaf with no variations in the foliar surface. In a saline environment, K supply did not markedly alter plant dry matter production, but increased foliar surface with moderate salt concentrations (50 mM) in the root environment.

From the mentioned review it is found that potassium had little response on growth and development and yield of sunflower but in few cases it has significant influence on yield and yield some yield attributes. Application of potassium with other nutrients variation or combined rates of NPK generally promoted the yield contributing characters of sunflower.

Again, the above review indicates that there are very few works on sunflower in Bangladesh compared to other countries and again almost no work on application of fertilizer on sunflower in southwestern coastal region of Bangladesh. As sunflower is thought to be great option to add in regular cropping pattern, research should be conducted to find out optimum dose of potassium for sunflower in southwestern coastal Bangladesh.

CHAPTER III

MATERIALS AND METHODS

This chapter comprises of the material used and the methods adopted during the course of present investigation entitled "Effect of Potassium on Yield of Sunflower (*Helianthus annuus* L.) in Southwestern Coastal Region of Bangladesh" which was carried out during *Rabi* season 2018-19.

3.1 Experimental site and soil characteristics

The field experiment was conducted at Pankhali, Dacope, Khulna (26 km away from Khulna University) during *Rabi* season 2018-19. The site was located in between 22°24' and 22°40' north latitudes and 89°24' and 89°35' east longitudes (Appendix-II). Dacope (second largest upazila) is surrounded by Batiaghata Upazila on the north, Pashur river on the south, Rampal and Mongla Upazilas on the east, Paikgachha and Koyra Upazilas on the west. Sundarbans on the southern part of this Upazila.Jhapjhopia, Dhaki, Sibsa, Chunkuri and Bhadra are the main rivers of this region.

The experimental site was located in Agro-ecological zone of 13 (Ganges Tidal Floodplain). These areas are dominated by medium to medium low lands, where flooding depth ranges from 0.3-0.9 m. The soil texture was clay type having soil pH 7.3 (almost neutral) and the organic matter content of this soil was 2.4% (medium). The salinity level of the site was increasing with the progress of dry period.

Table 1: Chemical properties of the experimental plot soil of Pankhali, Dacope, Khulna

	N (%)	P (µg/g soil)	K (meq/100 g soil)	Cu (µg/g soil)	Zn (µg/g soil)	B (µg/g soil)
Soil test value	0.124	31.34	0.35	107.42	1.51	1.16
Nutrient status	Low	High	High	Very high	High	Very high

3.2 Climatic conditions

Climatic data on daily air temperature (maximum and minimum), relative humidity and rainfall were recorded for the cultivation period (December, 2018 to April, 2019) from the Weather Station, Khulna. The experimental field was characterized by sub-tropical climate with moderately high temperature and heavy rainfall during the *Kharif* season (April to October) and low rainfall with moderately low temperature during the *Rabi* season (November to March).

Temperature: Throughout the experiment (December 2018 to April 2019) the maximum temperature of December 2018, January 2019, February 2019, March 2019 and April 2019 was 29°C, 31.2°C, 33.5°C, 34.5°C and 37.2°C respectively and the minimum temperature was 8.0°C, 9.5°C, 11.4°C , 14.4°C and 19.8°C respectively (Fig.1).

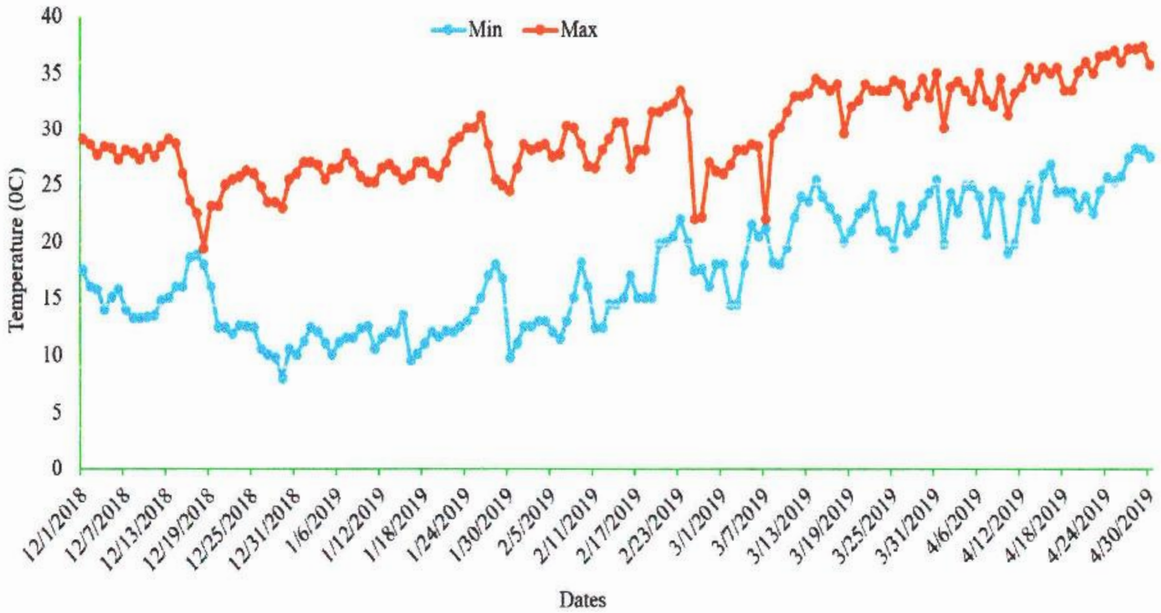

Figure 1: Maximum and minimum temperature pattern during the growing period (Dec'18-Apr'19) in the experimental area.

Relative humidity: The average relative humidity of December 2018, January 2019, February 2019, March 2019 and April 2019 was 79.5%, 76%, and 68.5%, 70% and 72% respectively (Fig.2).

Rainfall: As the experiment was held during *Rabi* season, the rate of rainfall was low. The average rainfall of December 2018, January 2019, February 2019, March 2019 and April 2019 was 3mm, 0mm, 6.03mm, 2.39mm and 3.4mm respectively. A heavy rainfall was held from 27 February (77mm) and 28 February (75mm). That heavy rainfall slightly destroyed the crop field (Fig.3).

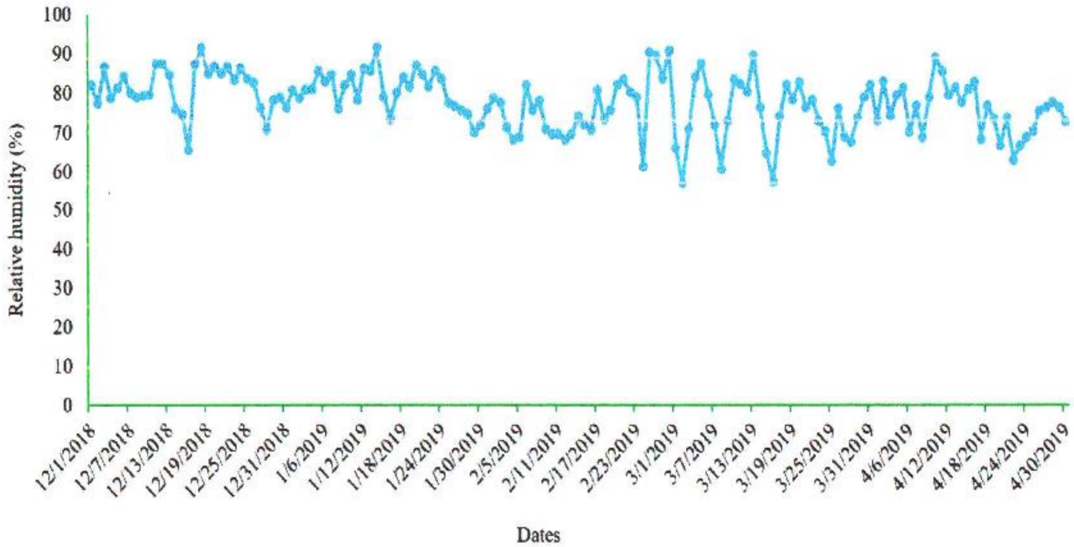

Figure 2: Relative humidity pattern during the growing period (Dec'18-Apr'19) in the experimental area.

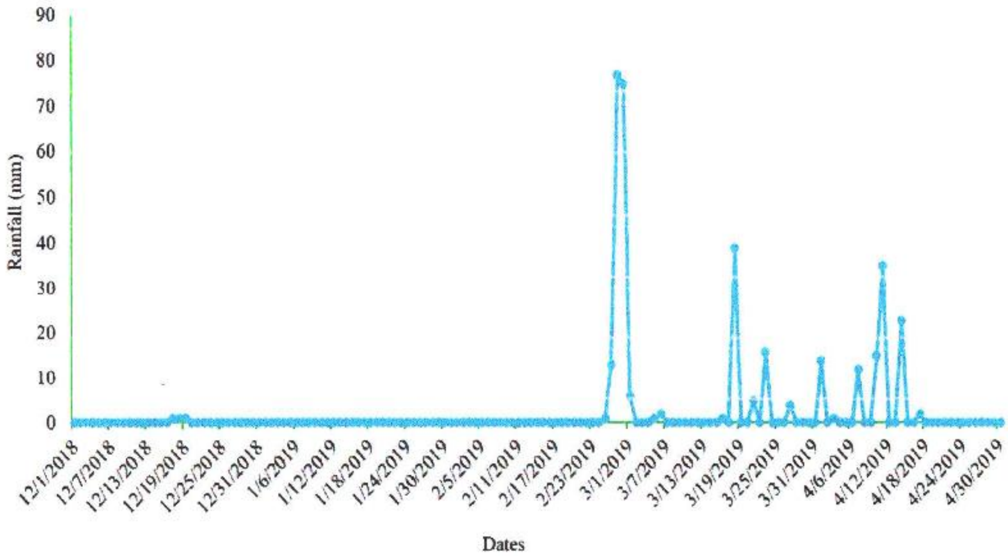

Figure 3: Rainfall pattern during the growing period (Dec'18-Apr'19) in the experimental area.

3.3 Water salinity

The salinity level of the water at different sources were presented in figure 4. The salinity levels of the river water was gradually increased with the progress of dry season. The water salinity in the canal, pond and river are more or less similar but after the heavy rainfall in the last week of February the salinity level was decreased and then increase but not beyond the limit. In the experimental plot canal was used as the source of irrigation. The canal was managed by disconnected it from the river during the middle of December.

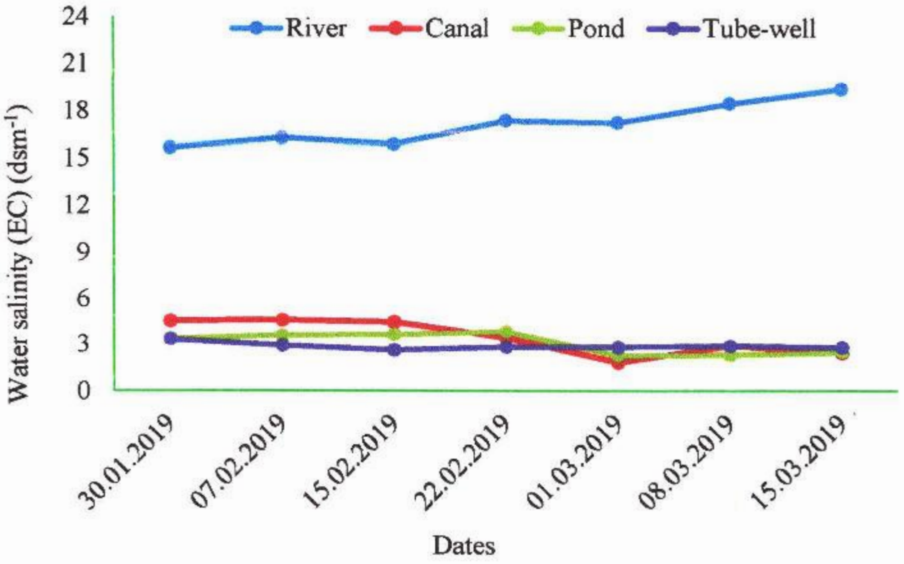

Figure 4: Salinity level of water at different sources with the progress of time

3.4 Experimental design and treatments

The experiment was laid out in a Randomized Block Design (RBD) with three replication. The entire experimental area at the farmers' field was divided into three sampling blocks representing the replications to reduce soil heterogeneity. Each block was divided into 7 unit plots with raised bunds as per the treatments. Thus, the total number of the unit plots was 21 (3×7). The size of each unit plot was 12 m^2 (4.0 m x 3.0 m). Plot to plot distance was 1.0 m and replication to replication distance was 1.5 m.

This research was done in seven treatments with three replications. Seven different rates of potassium were considered as treatment of the experiment. The details of the treatments are given below.

K_0= Control (No potassium added)

K_1= 40 kg ha^{-1}

K_2= 60 kg ha^{-1}

K_3= 80 kg ha^{-1}

K_4= 100 kg ha^{-1}

K_5= 120 kg ha^{-1}

K_6= 140 kg ha^{-1}

3.5 Planting materials

Sunflower hybrid variety Hysun-33 (hybrid) was used as planting materials in this experiment and the seeds were collected from the authorized dealer of Chuknagar, Dumuria, Khulna.

3.6 Fertilizer calculation and application

Fertilizers were applied by making holes at both sides (7-8 cm away) around 7-10 cm depth of the soil and then the holes were refilled by soil and pressed mildly. A little water was also given on the fertilizer hole. Nitrogen, phosphorus, and potassium were applied in the form of urea, triple super phosphate (TSP) and muriate of potash (MoP). Again calcium, zinc and boron were applied in the form of gypsum, zinc sulphate and borax.

Basal dose of fertilizer (one third of nitrogen and half of potassium and full dose of phosphorus, calcium, zinc and boron) was applied at the time of sowing, remaining half of potassium and one third of nitrogen was applied at 30 DAS and finally remaining one third of nitrogen was applied at 45 DAS. The doses of fertilizer were included in appendix-I.

3.7 Seed sowing and crop management

Seeds were sown on 8 December, 2018. Two seeds per pit were dibbled by maintaining line to line distance 70 cm and seed to seed distance 40 cm. Seed rate was 6 kg/ha. The experimental plots were irrigated lightly after seed sowing.

Before sowing no extra tillage operations were taken for land preparation and the moisture level during sowing time was ~ 40%. But there was no standing water at the time of sowing. The field was divided into unit plot size according to the design. All weeds, stubbles, crop residues were removed from the plots and were made ready for sowing. After sowing some cultural operations were carried out for crop management. Seedling emergence started after 3-4 days and completed within 1 weeks of dibbling. Thinning was done at 20 days after emergence to maintain one plant per pit. Earthing up along with weeding was done with the help of sapde to pill soil up around the base of a plants at 50 days after emergence for better root growth and plant support. Actually the rate of weed infestation was low. There was no need of using insecticide or fungicide as the fields were fortunately free from pest or diseases attack. But the field was always under a careful observation. To maintain desired soil moisture in the plots, irrigation was given when necessary. Three irrigations were provided by hose pipe from managed canal to the field following the mentioned date.

Irrigation schedule	Irrigation Date
First Irrigation	05.01.2019
Second Irrigation	25.01.2019
Third Irrigation	15.02.2019

A heavy rainfall was occurred on 27 February 2019 to 28 February 2019 and the field was waterlogged. The standing water was drained out immediately by using shallow pump and it was taken three days. After removal of excess water the field was remained saturated around next 15 days.

3.8 Harvesting and post-harvest operation

When 80% of the leaves as well as dorsal side of the disc turned yellowish and central disc florets dried up and shed off on touch of fingers, the crop was assessed to attain maturity. The crop was harvested on 2 April, 2019 (114 days after sowing). The head of the crop was harvested first followed by cutting the stalks with sickles, tagged separately as per the treatments. Later on the seeds were separated from the head manually. After separation, the seeds were winnowed to remove trashes and inert materials. The seeds were dried, cleaned, counted and weighed.

The schedule of all the pre-harvest and post-harvest operations which were done throughout the experiment was included in appendix-IV.

3.9 Details of data collection

3. 9.1 Growth parameters

Five plants from each plot were selected randomly and tagged for the purpose of recording various observations, measurement and collection of necessary data. Observations on growth parameter were recorded at different days after sowing (DAS) crop growth *i.e.,* 30, 60, 45, 60, 75, 90 DAS and at harvest.

3. 9.1.1 Plant height (cm): Plant height was measured from the base of the plant to the tip of the main shoot from tagged plants. The mean plant height was worked out and expressed in centimeters per plant.

3.9.1.2 Number of leaves per plant: The total numbers of green leaves produced per plant were counted from selected (tagged) plants and their average was taken as the number of green leaves per plant.

3.9.1.3 Plant diameter (cm): Plant diameter was measured for each selected plant, mean plant diameter was worked out and expressed in centimeters per plant.

3.9.1.4 Plant Biomass: Plant sample was collected at seedling, flowering and harvesting stage then oven dried and measured.

3.9.2 Phenological parameters

3.9.2.1 First heading and first flowering: First flowering and first heading date was counted.

3.9.3 Physiological parameters

3.9.3.1 Relative water content (%): Relative water content was measured by using following formula:

$$\text{Relative leaf water content (\%)} = \frac{Fresh\ weight\ (g) - Dry\ eright\ (g)}{Turgid\ weight\ (g) - Dry\ weight\ (g)}) \times 100$$

3.9.4 Yield attributes

The seven plants were randomly selected from each plot and tagged properly for the data collection, measurement and calculation of the following parameters:

3.9.4.1 Head diameter (cm) and circumference (cm): The diameter and circumference of the head was measured and expressed in centimeters per head.

3.9.4.2 Number of seeds head^{-1}: The head of selected plants were threshed, cleaned and the seeds were counted. The average was taken as the number of seeds per head.

3.9.4.3 Number of filled seeds head^{-1}: From the total number of seeds, the numbers of filled seeds per head were counted and the mean was recorded as number of filled seeds per head.

3.9.4.4 Number of unfilled seeds head^{-1}: From the total number of seeds, the numbers of unfilled seeds per head were counted and the mean was recorded as number of unfilled seeds per head.

3.9.4.5 Weight of hundred seeds (g): One hundred seeds were taken randomly from the produce of each net plot area and the weights were recorded and expressed in gram.

3.9.4.6 Seed weight plant^{-1} (g): The harvested heads were threshed. The seeds were separated, cleaned and weighed. The mean seed weight per plant was expressed in grams per plant.

3.9.4.7 Seed yield (t ha^{-1}): Based on the yield of the net plot area, the seed grain yield per hectare was calculated and expressed in kilogram per hectare.

3.9.4.8 Stover yield (t ha^{-1}): The leaves stem and head (after threshing) from each plot area were sun dried completely for a week and the weight was recorded. Based on the stover yield of the net plot area, stover yield per hectare was calculated and expressed in kilogram per hectare.

3.9.4.9 Harvest index (%): The harvest index was calculated by using the following formula

$$\text{Harvest index (\%)} = \frac{Seed\ yield\ (kg/ha)}{Biological\ yield\ (ka/ha)} x\ 100$$

3.9.5 Quality parameters

3.9.5.1 Oil content (%): The sampled seeds of each treatment were collected for determining oil content.

3.9.5.2 Oil yield (kg ha^{-1}): The oil yield per hectare was worked out by multiplying oil content and seed yield per hectare and was expressed in kilogram per hectare.

3.10 Chemical analysis

The percentages of oil content, seed moisture content and free fatty acid were determined following AOCS (American Oil Chemistry Society) widely used by BSTI (Bangladesh Standards and Testing Institution), Bangladesh.

3.11 Statistical analysis

The collected, calculated and recorded data on different parameters were compiled and statistically analyzed following the analysis of variance techniques (one-way ANOVA) by using 'Statistics 10' a statistical software. The significant differences among the treatment means were compared following all pair wise comparison by least significant different (LSD) at 5% level of probability.

CHAPTER IV

RESULTS

4.1 Effect of potassium on growth parameters of sunflower

4.1.1 Plant height (cm)

Data on plant height at different days after sowing (DAS) was measured and recorded. Different rates of potassium had no significant effect on plant height at various date of sowing (DAS) and at harvest (Table 2). Numerically the tallest plant at 30 DAS (23.95 cm), 45 DAS (43.90 cm), 60 DAS (74.63 cm), 75 DAS (120.27), 90 DAS (127.26 cm) and at harvest (125.33 cm) were recorded from 60 kg K ha^{-1} whereas, the shortest at different DAS and at harvest was obtained from without potassium added treatment (K_0).

Table 2: Effect of potassium variation on plant height of sunflower

Potassium rates (kg/ha)	Plant height (cm)					
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**	**At harvest**
0	22.50	42.78	71.21	112.83	121.87	120.40
40	23.61	43.20	73.23	119.07	126.32	124.78
60	23.95	43.90	74.63	120.27	127.26	125.23
80	23.52	43.87	74.41	119.78	127.02	124.84
100	23.38	43.52	74.51	119.40	126.20	124.33
120	23.43	43.94	74.23	119.80	126.40	124.30
140	23.31	43.73	74.36	119.50	126.03	123.84
Mean±SE	23.39±1.56	43.58±2.43	73.80±2.71	118.66±5.12	125.87±3.79	123.96±3.82
LS	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
CV (%)	*8.16*	*6.84*	*4.50*	*5.28*	*3.69*	*3.77*

ns= non-significant, LS= level of significance, CV= Co-efficient of variation and SE= Standard error

These results of plant height are similar to the findings of Ayub et al. (1999) where plant height was statistically similar in all treatments (50 kg ha^{-1}, 100 kg ha^{-1} and 150 kg ha^{-1}). But the finding of Mollashahi et al. (2013) does not support it as the result of variance analysis of their experiment showed that effect of potassium fertilizers was significant at 1% probability level on plant height. The results are in agreement with those of Ahmed (1993) and Al-Nawaz (1988) who reported that plant height was significantly affected by K_2O application.

4.1.2 Leaf number plant^{-1}

The data pertaining to the numbers of leaves plant^{-1} at different stages of growth were not significantly influenced by various rates of potassium are presented in table 3. Numerically the highest number of leaves plant^{-1} at 30 DAS (10), 45 DAS (16.11), 60 DAS (28.69), 75 DAS (33.47) and 90 DAS (28.57) were recorded from 60 kg K ha^{-1} whereas, the shortest at different DAS and at harvest was obtained from without potassium added treatment (K_0). The leaves number was increased with the increase of days and was highest in 75 DAS (for all treatment) and then reduced at 90 DAS. Though the highest number of leaves was found in potassium of 60 kg ha^{-1} for all DAS, but the number of leaves was reduced after adding potassium over 60 kg $ha^{-1.}$

Table 3: Effect of potassium variation on leaf number of sunflower

Potassium rates (kg/ha)	Leaf number plant^{-1}				
	30 DAS	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**
0	9.57	13.47	25.43	31.90	25.13
40	9.80	15.57	27.78	32.57	27.67
60	10.00	16.11	28.69	33.47	28.57
80	9.90	15.25	27.44	33.44	28.13
100	9.84	15.67	27.21	33.44	28.10
120	9.88	15.32	27.33	33.24	28.47
140	9.79	15.67	27.43	33.67	28.23
Mean±SE	9.82±0.61	15.30±2.13	27.33±2.13	33.10±0.80	27.76±1.41
LS	*ns*	*ns*	*ns*	*ns*	*ns*
CV (%)	*7.56*	*9.55*	*9.55*	*2.96*	*6.21*

ns= non-significant, LS= level of significance, CV= Co-efficient of variation and SE= Standard error

These results are similar to the works of Ayub et al. (1999). Their findings revealed that there is a significant effect of potassium on leaf but beyond this limit (50 and 100 kg ha^{-1}) leaf area per plant was decreased which is similar to the study.

4.1.3 Stem diameter (cm)

Significant variation was not found regarding stem diameter due to different potassium doses (Table 4). For 30 DAS (2.6 cm), 45 DAS (5.4 cm), 60 DAS (6.48 cm) and 90 DAS (7.70 cm), the maximum stem diameter was found in case of application of 60 kg ha^{-1} (K_2) and minimum stem diameter was found in case of control application (K_0) except 90 DAS. While at 75 DAS the maximum stem diameter was found in 60 kg ha^{-1} (K_2). At 30 DAS, 45 DAS and 60 DAS, the minimum stem diameter was found in K_0 (control). For 75 DAS, 90 DAS and at harvest the minimum stem diameters were found in 140 kg ha^{-1} (K_6), 120 kg ha^{-1} (K_5) and 100 kg ha^{-1} (K_4) respectively.

Table 4: Effect of potassium variation on plant diameter of sunflower

Potassium rates (kg/ha)	Stem diameter (cm)					
	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At harvest
0	1.78	4.62	5.60	8.60	8.46	7.52
40	.22	5.20	6.12	8.98	8.57	7.70
60	2.61	5.47	6.48	8.83	8.73	8.34
80	2.28	5.29	6.34	8.57	8.53	8.19
100	2.10	5.10	6.38	8.67	8.56	7.33
120	2.05	5.17	6.40	8.63	8.37	7.43
140	2.13	5.13	6.37	8.37	8.40	7.34
Mean±SE	2.17±0.36	5.13±0.33	6.24±0.48	8.66±0.42	8.52±0.45	7.70±0.50
LS	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
CV (%)	*20.28*	*7.84*	*9.37*	*5.93*	*6.52*	*7.95*

ns= non-significant, LS= level of significance, CV= Co-efficient of variation and SE= Standard error

This result is in good agreement with that of Ayub et al. (1999). They found non-significant effect of potassium on stem diameter. Non-significant effect K on plant diameter was also found by Ahmed (1993) while Ahmed (1989) had reported an increase in stem diameter with the application of K_2O.

4.1.4 Plant biomass (5 weeks after sowing) (g)

Application of different rates of potassium had no significant effect on production of plant biomass at seedling stage (Table 5). Data in table 4 showed that 60 kg K ha^{-1} (K_2) gave the maximum production of plant biomass (3.76 g) whereas control plot (K_0) gave the minimum production of plant biomass (3.11 g) at seedling stage.

4.1.5 Plant biomass at flowering (g)

There were no significant effects on production of plant biomass at flowering stage for application of different dozes of potassium. Numerically the amount of plant biomass at flowering stage ranged from 62.50 g to 71.00 g. The data (Figure 5) revealed that the maximum production of plant biomass (71.00 g) at flowering stage was found from application of 140 kg ha^{-1} K (K_6) whereas the minimum production of plant biomass (62.50 g) was found from plot where potassium was not added (K_0).

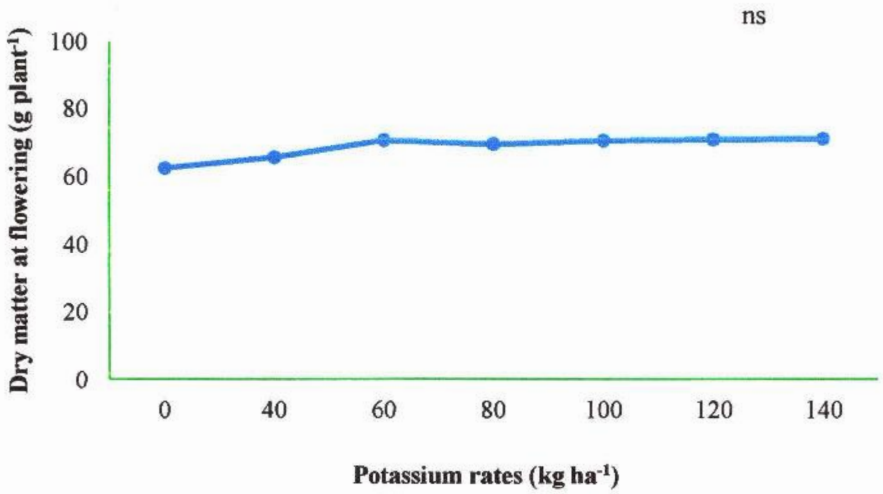

Figure 5: Influence of potassium on dry matter of sunflower at flowering stage

4.1.6 Total dry matter (t ha^{-1})

Variation in total dry matter among the studied treatment of potassium was statistically non-significant (figure 6). The ranges of total dry matter at different doses of potassium application were 7.13-7.97 t ha^{-1}. Result revealed that total dry matter was on highest (7.97 t ha^{-1}) in case of 60 kg K ha^{-1} (K_2) and lowest (7.13 t ha^{-1}) in case of control (K_0).

4.3 Effect of potassium on physiological parameters of sunflower

4.3.1 Relative water content

Relative water content of sunflower leaves were not significantly affected by different rates of potassium (Figure 7). It was found that the maximum relative water content (76.73%) was recorded from the treatment 60 kg K ha^{-1} (K_2) while the minimum relative water content (73.66%) was recorded from the control plot (K_0).

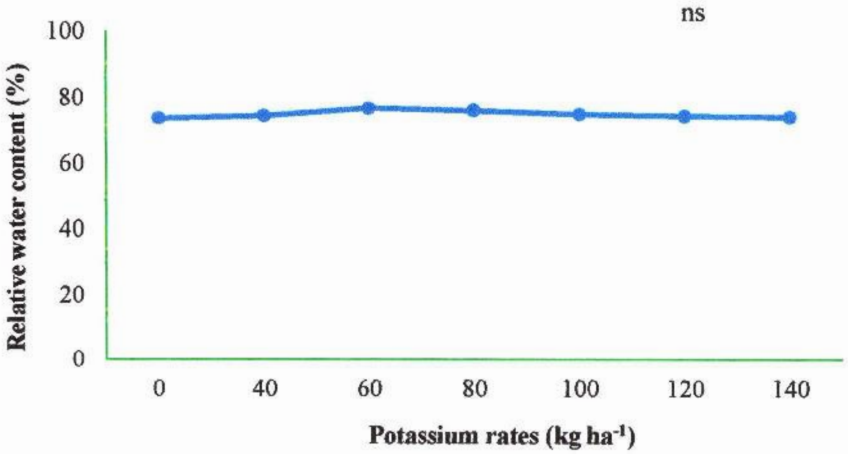

Figure 7: Relative leaf water content of sunflower at different rates of potassium

4.4 Effect of potassium on yield and yield attributes of sunflower

4.4.1 Head diameter (cm)

Head diameter of sunflower was non-significant with different levels of K application. Results have been presented in the table 4 indicated that head of sunflower with higher diameter (19.94 cm) was found in plot treated with K_2 60 kg ha^{-1} (K_2) and lower diameter (18.33 cm) was found in plot treated with K_0 (control).

Similar types of observations are also supported by Ayub et al. (1999) and Zaidi et al. (2012). Both of the case non-significant effect of potassium on stem diameter was found. These results are different to those of Ahmed (1989) who found significant effects of different potassium on sunflower.

4.4.2 Head circumference (cm)

Head circumference of sunflower did not show any significant variation among the potassium levels (Table 5). Numerically the highest head circumference (54.83 cm) was recorded from 60 kg K ha^{-1} (K_2) and the lowest head circumference (49.84 cm) was obtained from plots where potassium was not added. The head circumference in different doses of potassium application ranges from 49.84 cm to 54.83 cm.

Table 5: Effect of potassium rates on different parameters of sunflower

Potassium rate (kg/ha)	First heading (Days)	First flowering (Days)	Plant biomass (35 DAE) (g)	Head circum. (cm)	Head diameter (cm)
0	54.00	72.33	3.11	49.84b	18.33
40	53.67	70.33	3.19	51.88ab	19.25
60	53.00	70.67	3.76	54.83a	19.94
80	54.00	70.33	3.40	53.70ab	19.14
100	53.67	70.67	3.44	52.59ab	19.47
120	52.67	70.33	3.27	53.55ab	19.53
140	52.00	70.00	3.38	52.05ab	18.98
Mean±SE	*53.29±1.13*	*70.67±1.25*	*3.36±0.37*	*52.64±1.91*	*19.23±0.74*
LS	*ns*	*ns*	*ns*	*ns*	*ns*
CV (%)	*2.61*	*2.17*	*13.33*	*4.45*	*4.70*

ns= non-significant, LS= level of significance, CV= Co-efficient of variation and SE= Standard error

4.4.4 Filled seeds head^{-1}

Different rates of potassium had no significant influence on number of filled seeds head^{-1}. The maximum number of filled (1171.0) seeds head^{-1} was counted from 60 kg K ha^{-1} which was at par statistically similar to all other rates of potassium while the lowest one (910.7) was found in no potassium added treatment (K_0) .

4.3.5 Unfilled seeds head^{-1}

No significant variation was found in case of unfilled seeds at different rates of potassium. The lowest numbers of unfilled seeds (113.28) were counted from the plot where no potassium was added (K_0) whereas the highest number of unfilled seeds (148.05) were counted in plot treated with 120 kg K ha^{-1} (K_5) (Table 6).

4.3.6 Total seeds head^{-1}

Different rates of potassium had no significant influence on number of total seeds head^{-1}. The highest seeds head^{-1} (1297.7) was found from 60 kg K ha^{-1} (K_2) and the lowest seeds head^{-1} (1024.0) was found from without potassium addition (K_0) and the highest seeds head^{-1} (1297.7) was found from 60 kg K ha^{-1} (K_2). The range of total seed head^{-1} was 1024.0-1297.7.

The observation of Zaidi et al. (2012) is almost similar to this study where application of K significantly increased the number of seeds head^{-1} over control. However, all K levels except control produced statistically equal number of seeds head$^{-1.}$ The findings of Taher et al. (2013) show a slightly different results where that potassium application significantly affected the seed number head^{-1}.

4.3.7 Seed weight head^{-1} (g)

Seed weight head^{-1} was significantly influenced by the potassium levels. Results have been presented in the figure 8. The maximum (77.43 g) seed weight head^{-1} was found in 60 kg K ha^{-1} (K_2) and the minimum (58.33 g) seed weight head^{-1} was found in control plot (K_0). The results (69.62 g) found from 80 kg K ha^{-1} (K_3) was statistically similar with the results (69.67 g) of applying 140 kg K ha^{-1} (K_6). Again, the results (68.95 g) found from 100 kg K ha^{-1} (K_4) was statistically similar with the results (66.91 g) of applying 120 kg K ha^{-1} (K_5)

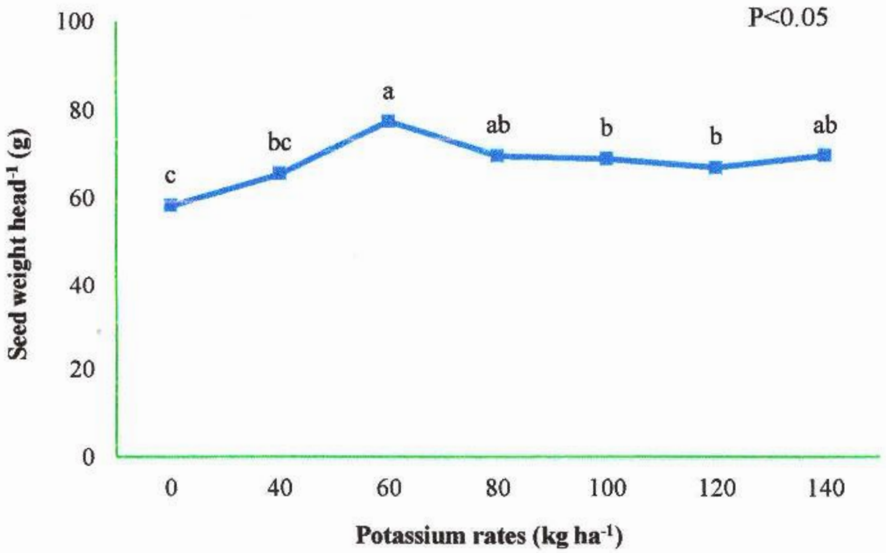

Figure 8: Effect of potassium on seed weight head^{-1} of sunflower

4.4.8 1000-seed weight (g)

There was no significant variation on 1000-seed weight (g) at different rates of potassium. When application of potassium was 60 kg ha^{-1}, the weight of 1000 seed was 72.33 g (maximum). Again, when potassium was not applied at all (control), the weight of 1000-seed was 64.67 g (minimum) (Table 6).

Statistical analysis of the research data of Ullah et al. (2018) indicated that increase in thousand grain weight occurred with increase in potassium levels. Sepher et al. (2002) stated that optimum amount of potassium supply enhanced the grain filling period which leaded to increase in grain weight. Again, from the study the highest 1000 grain weight was found from 60 kg ha^{-1} whereas from other study the highest 1000 grain weight was found from 90 kg ha^{-1} (Ullah et al. 2018) and 75 90 kg ha^{-1} (Khan et al. 1999).

4.4.9 Stover yield

The effect of potassium on stover yield of sunflower was non-significant (Table 6). The maximum stover yield (4.75 t ha^{-1}) was observed in 60 kg K ha^{-1} (K_2) In contrast, the minimum stover yield (4.46 t ha^{-1}) was observed in 40 kg K ha^{-1} (K_1). The ranges of stover yield were found from 4.46-4.75 for responses of different doses of potassium.

This results are in good agreement with Zaidi et al. (2012). That research revealed that application of K did not have significant effect on stalk yield, although it gradually increased with the increase in K application (Table 3). These results are in conformity with those reported by Ahmad (2009) that K application did not increase stalk yield.

Again, Taher et al. (2013) found that potassium application significantly affected the plant yield.

4.4.10 Seed yield (t ha^{-1})

Seed yield of sunflower at different rates of potassium showed significant variation (<0.001) (Figure 9). Application of potassium @ 60 kg ha^{-1} (K_2) produced the maximum seed yield (3.32 t ha^{-1}) which was statistically at par with the potassium application @ 80 and 100 kg ha^{-1} while the minimum seed yield (2.49 t ha^{-1}) was recorded from the control treatment (K_0). The results indicated that seed yield increased gradually by increasing potassium levels up to application @ 60 kg ha^{-1} and then decreased.

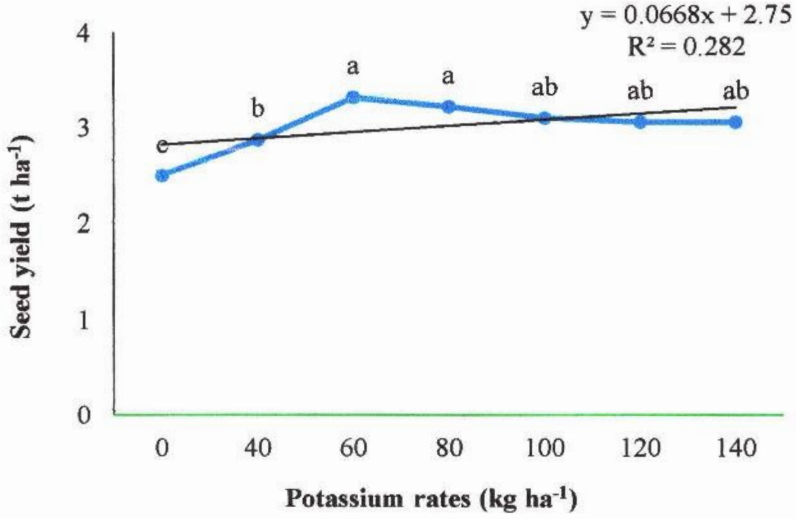

Figure 9: Effect of potassium on seed yield of sunflower

These results are in line with the findings of Mollashahi et al. (2013) and Ayub at el. (1999) recorded that K application had significant effect on seed yield of sunflower. The probable reason for high grain yield might be due to that potassium boosted the chlorophyll content, increased in leaf area, maximum number of grains per head and heavier thousand grain weight. Again, the seed yield was increased up to 60 kg ha^{-1}K whereas this rate was 90 kg ha^{-1} (Ullah et al. 2018).

4.4.11 Harvest index (%)

The data pertaining to harvesting index of sunflower as influenced by different potassium doses were presented in table 6. Harvest index had significant effect ($p<0.01$) on different level of K application. The highest harvest index (41.70%) was recorded from 60 kg K ha^{-1} (K_2) which was statistically at par with to 80 kg K ha^{-1} (K_3), 100 kg K ha^{-1} (K_4), 120 kg K ha^{-1} (K_5) and 140 kg K ha^{-1} (K_6) whereas, the lowest (34.97%) was recorded from control (K_0) treatment.

This results were also supported by Ullah et al. 2018 who also found significant difference among different doses of potassium on harvest index of potassium. The probable reason for increased in harvest index might be due to increase in grain yield kg ha^{-1}. The variation of starting of reduced stage among different researches is found due to variation among sunflower hybrids. It was found that the toxic level of potassium for sunflower as different for Hysun-33 and S-278.

4.4.12 Oil yield (kg ha^{-1})

Effect of potassium fertilizers had significant effect (*<0.01*) on oil yield (Figure 10). According to the data in figure 4, the maximum oil yield (1326.0 kg/ha) was obtained from treatment of 60 kg K ha^{-1} (K_2) which was statistically identical to 60 kg K ha^{-1} (K_2) while the minimum (943.2 kg/ha) was found from no potassium addition treatment (K_0).

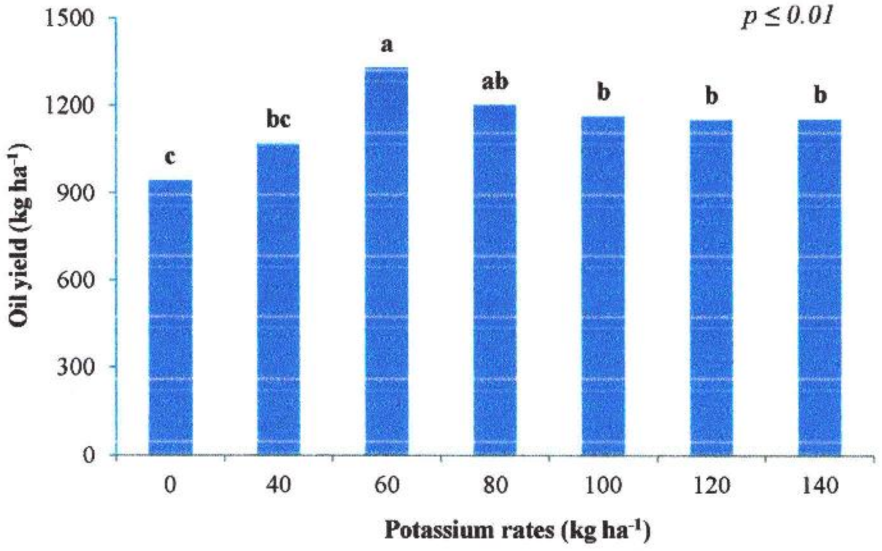

Figure 10: Influence of oil yield of sunflower at different levels of potassium

4.4.13 Oil content (%)

Statistically significant differences were not found regarding oil content of sunflower at different rates of potassium (Figure 11). The ranges of oil content at different doses of potassium application were 37.26-39.89%. The maximum oil content of sunflower (39.89%) was recorded from 60 kg K ha^{-1} (K_2) treatment whereas the minimum (37.26 %) was recorded from 80 kg K ha^{-1} (K_3) treatment.

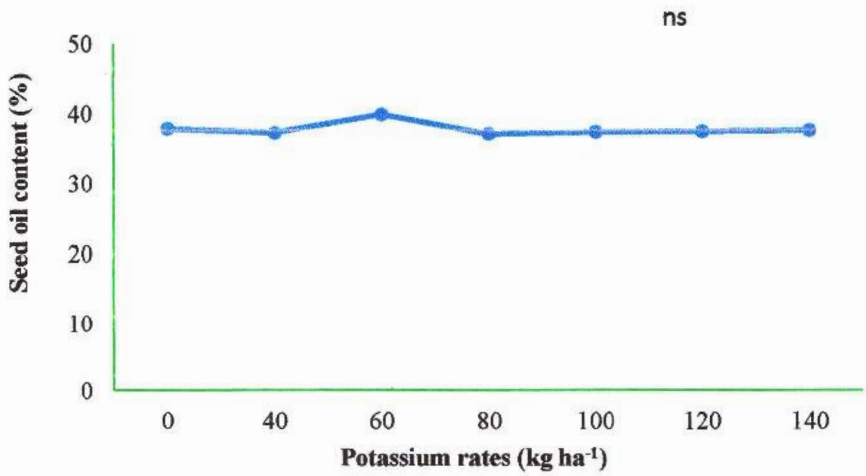

Figure 11: Oil content of sunflower seed at different levels of potassium

These results are conflicting with the results revealed by Ayub (1999) and Mollashahi et al. (2013) who found significant effect of potassium on oil content. But the similarity with our study is that up to a certain level oil content increased with potassium then declined.

4.4.14 Seed moisture content (SMC) (%)

SMC of sunflower at different rates of potassium showed no significant variation. The highest SMC (5.14) was obtained from 40kg K ha^{-1} (K_1) and the lowest SMC (5.05) was obtained from 140kg K ha^{-1} (K_6) (Table 6).

4.4.15 Free fatty acid (FFA) (%)

Free fatty acid (FFA) of sunflower at different doses of potassium was analyzed and no significant variation was found (Table 6). From table 4 it was found that 40 kg K ha^{-1} (K_1) provided highest FFA (1.79) whereas 120 kg K ha^{-1} (K_5) provided lowest FFA (1.67). FFA responding different doses of potassium was ranges from 1.67 to 1.79.

Table 6: Effect of potassium rates on yield and yield attributes of sunflower

Potassium rate (kg/ha)	Filled seeds $head^{-1}$	Unfilled seeds $head^{-1}$	Total seeds $head^{-1}$	1000-seed weight (g)	Stover yield ($t\ ha^{-1}$)	Harvest index (%)	SMC (%)	FFA (%)
0	910.7	113.28	1024.0	64.67	4.64	34.97c	5.12	1.74
40	1108.2	141.99	1250.2	68.00	4.46	39.18b	5.14	1.79
60	1171.0	126.70	1297.7	72.33	4.75	41.70a	5.06	1.70
80	1089.2	124.67	1213.9	69.67	4.71	40.57ab	5.19	1.71
100	1106.0	139.62	1245.7	69.67	4.50	40.89ab	5.10	1.69
120	1110.9	148.05	1259.0	69.00	4.55	40.25ab	5.10	1.67
140	1104.7	141.76	1246.5	69.33	4.57	40.15ab	5.05	1.73
Mean±SE	*1085.8±78.84*	*133.72±26.08*	*1219.6±83.85*	*68.95±3.65*	*4.58±0.26*	*39.67±1.05*	*5.10±0.11*	*1.72±0.08*
LS	*ns*	*ns*	*ns*	*ns*	*ns*	**	*ns*	*ns*
CV (%)	*8.89*	*23.89*	*8.42*	*6.48*	*6.87*	*3.26*	*2.57*	*5.89*

$^{**}p \leq 0.01$, ns= non-significant, LS= level of significance, CV= Co-efficient of variation and SE= standard error; data in each column of the table followed similar letter are not significantly different at $p \leq 0.05$ significant level according to LSD test.

4.5 Functional relationship among different parameters

4.5.1 Functional relationship between head diameter and total seed head^{-1}

There is a linear relationship between head diameter and total seeds head^{-1}. Usually with the increase of head diameter, the rate of seeds head^{-1} is also increased. If the disc area is large, there will be a chance to set maximum number of seeds. Again, if the disc area is small, there will be a chance to grow less seeds head^{-1}. Total seeds head^{-1} was plotted against head diameter that yielded a straight line. This suggests that total seeds head^{-1} increases with the increase of dead diameter and ~80% of the variation in total seeds head^{-1} was defined by variation in head diameter.

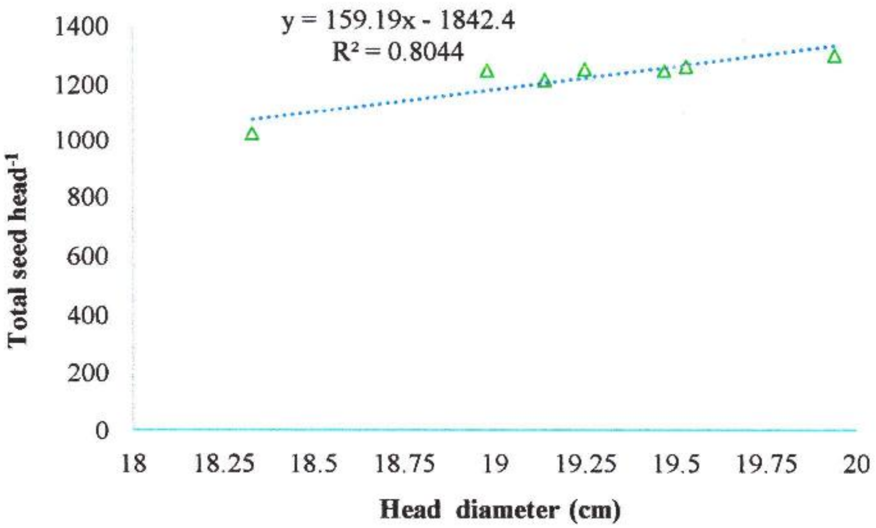

Figure 12: Functional relationship between head diameter and total seed head^{-1}

With the application of optimum potassium head diameter was increased as potassium ions stimulate cell expansion. In this experiment, head of sunflowers showed maximum diameter (19.94 cm) at 60 kg potassium application for per ha. Consequently, the highest number of seeds (1297.7) was found from application of 60 kg ha^{-1} as this treatment provided larger head diameter. As consequence the lowest number of seeds (1024.0) was found from the head which was lowest in diameter (18.33) except for K_6 (140 kg ha^{-1}). This functional relationship between head diameter and total number of seed head^{-1} is supported by Ullah et al. (2018). They revealed that the maximum number of seed head^{-1} was due to maximum head diameter. Number of seed head^{-1} was totally dependent on disc area as larger will be the disc more number of seeds will be grown (Hassan et al., 2007). Both the head diameter and total seed head^{-1} were found at the application of 60 kg K ha^{-1}. As a consequence, filled seed head^{-1}, 1000-seed weight, seed weight head^{-1} were found highest at the application of 60 kg K and lowest from control treatment as expected.

4.5.2 Functional relationship between 1000-seed weight (g) and seed yield (t ha^{-1})

There is a linear relationship between 1000-seed weight (g) and seed yield (t ha^{-1}). Usually with the increase of 1000-seed weight, the rate of seed yield is also increased. This relationship was also found in the present study. The maximum seed yield (3.32 t ha^{-1}) was found from the treatment (60 kg ha^{-1}) where the 1000 seed weight (72.33 g) was also maximum. As expected the minimum seed yield (2.49 t ha^{-1}) was found from the treatment (control) where the 1000-seed weight (64.67 g) was also minimum. Seed yield was plotted against 1000-seed weight that yielded a straight line. This suggests that seed yield of sunflower was dependent on 1000-seed weight and ~94% of the variation in seed yield was defined by variation in 1000-seed weight.

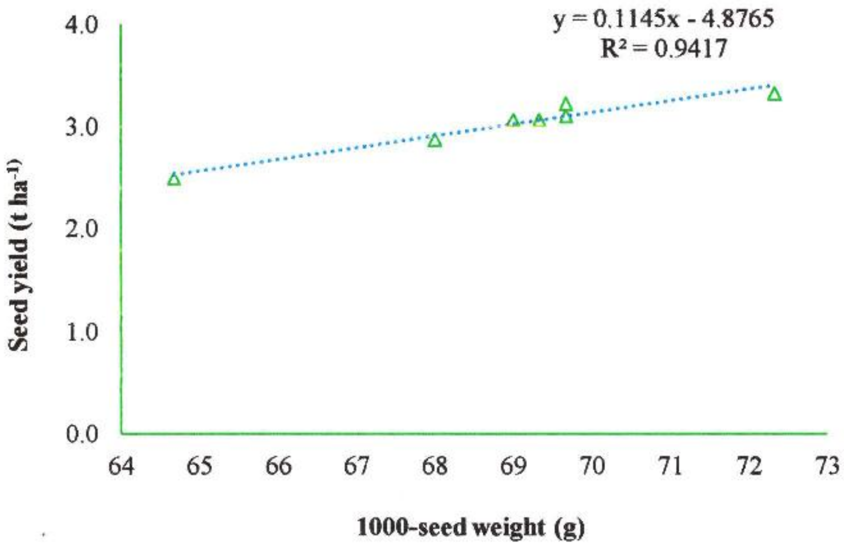

Figure 13: Functional relationship between 1000-seed weight (g) and seed yield (t/ha)

4.6 DISCUSSION

Potassium is known for its interaction, both antagonistic and synergistic with essential, macro and micronutrients. In saline soil potassium reduces the uptake of Na^+. Addition of potassium reduced the toxic effect of sodium in plants and increased the K^+/Na^+ ratio in soil. But in case of experimental field, it was found from soil analysis report that the soil was enriched with high amount of potassium (0.35 meq/100 g soil). That is why significant difference was not found in case of most of the parameters. But it was found that if optimum rate of potassium (60 kg K ha^{-1}) was applied it would provide the maximum results over control and other doses (control, 40 kg ha^{-1}, 80 kg ha^{-1}, 100 kg ha^{-1}, 120 kg ha^{-1} and 140 kg ha^{-1}). The findings also indicate that application of potassium over 60 kg ha^{-1} caused declination of results of different parameters which might be happened because of potassium toxicity (due to over doses) in soil which was already high in soil.

Growth parameters

As the soil of experimented field was high in potassium, application of different doses of potassium had no significant effect on the growth parameters like plant height, plant diameter, number of leaves and plant biomass. Though there was no significant variation was found among the rates of potassium but the recorded growth parameters were increased with the application of potassium up to 60 kg ha^{-1} over control and then declined. With increasing of optimum potassium amount, CO_2 fixation because of better conductivity of stomata would improve, and this subject increase carbohydrate production in plant and finally led to plant height increase (Marschner, 2013). Potassium also enhances meristematic activity (Verma and Verma, 2007) resultantly increases chances of more leaves production. Again, Potassium helps in water economy, energy metabolism and enzymes activity (Mengel and Kirby, 1980), which have positive effect on flower weight. But the suitable rate of potassium found from this experiment was lower than that of findings of other authors. These contradictions might be due to variation in fertility status of the soil. It had been already found from nutrient analysis of experimental soil that the soil was highly rich in potassium (0.35 meq/100 g soil). So application of 60 kg ha^{-1} potassium was sufficient to get maximum results from growth parameters.

Phenological parameters

The effect of potassium on first heading and first flowering of sunflower was non-significant. But it was found that the application of maximum rates of potassium (140 kg ha^{-1}) promoted numerically early heading and flowering. The result in this experiment showed that no potassium added plot first heading and flowering was delayed and the gradually minimize the duration with the increase of K rates. Potassium is required to increases carbon exchange and enhances carbohydrate movement and stimulates early growth and decreases the translocation of photosynthates into storage organs (Larik at al., 1999) and consequently these photosynthates may be used in the early initiation of flowers. Protacio (2000) also noted that potassium have a more direct role in floral initiation such as in mangoes. That is why plants of plots treated with higher amount of potassium (140 kg ha^{-1}) took comparatively fewer days for flowering.

Yield contributing parameters

From the findings of the study it was found that potassium had no significant effect on different yield contributing characters like head diameter, head circumference, total seed $head^{-1}$, filled seeds $head^{-1,}$ unfilled seeds $head^{-1}$, 1000-seed weight, stover yield, oil content etc. But significant difference was recorded when fertilized with different levels of potassium application was reported elsewhere (Ahmed, 1989, Taher et al., 2013 and Zaidi et al., 2012. These contradictory results might be due to variation in fertility status of the soil. Probably the experiments conducted by the mentioned authors were completed in soil of deficient potassium and shown significant effects as expected. This incidence was not happened in case of experimented field at Pankhali which was rich in potassium (0.35 meq/100 g soil).

The results of stover yield were also found non-significant which was in good agreement with Zaidi et al. (2012). The result of the experiment revealed that application of K did not have significant effect on stover yield, although it gradually increased with the increase in K application (Table 3). These results are in conformity with those reported by Ahmad (2009) that K application did not increase stover yield. Usually, potassium application significantly affected the stover yield according to Taher et al. (2013). It is possible due to the role of fertilization for increasing photosynthesis and translocation of photosynthetic from source to sink. But the friction among the result of researches might be due to abundance of potassium in coastal region.

Another probable reason might be variation of genetic makeup among different hybrid. For example, S-278 produced the highest stover yield when crop was fertilized @ 100 Kg K_2O ha^{-1}, which was statistically at par with many other treatments. On the other hand, Hysun-33 produced the lowest stover yield when crop was fertilized without any K application, which was statistically similar with many other treatments. These results are in accordance with the findings of Richards (2006) that sunflower hybrids differ in their genetic make up for response to stover yield.

The results of seed yield, seed weight $head^{-1}$, harvest index and oil yield were found significant at different level of potassium which were similar to the findings of Ullah et al. (2018). The increase in seed yield might be due to optimum uptake of potassium (60 kg ha^{-1} from this experiment) from the salt affected soil where potassium fertilizer was applied that counteracted the toxic effect of unwanted ions like Na^+.

The probable reason for significant increase in harvest index might be due to increase in seed yield. It might be due to more assimilates partitioning with the application of optimum level of potassium which resulted greater seed yield in sunflower. Harvest index is directly associated with the plant dry matter and seed weight. As the maximum dry matter and seed yield were found @ 60 kg ha^{-1}, harvest index was as expected found maximum @ 60 kg ha^{-1}.

Oil content as found maximum in 60 kg K but the results for different application of K was non-significant. This result are conflicting with the results revealed by Ayub (1999) and Mollashahi et al. (2013) who found significant effect of potassium on oil content. But the similarity with our study is that up to a certain level oil content increased with potassium then reduced. The results might be due to the fact that K is used as a tool to activate enzymes for photosynthesis, starch formation and protein synthesis and to improve oil concentration and quality, but when potassium exceeds from a certain limit it may break enzymes and reduce the oil concentration.

Potassium had no significant difference on growth, yield and yield attributes of sunflower except few parameters i.e. the sunflower meet up their major potassium requirement from the soil as the potassium levels in the soil of experimental plot was high. In no potassium added plot seed yield was much lower compared to other rates of potassium added plot.

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

An experiment was carried out at Pankhali, Dacope, Khulna during the period from December, 2018 to April, 2019 (*Rabi* season) to find out the effect of potassium on yield of sunflower in southwestern coastal Bangladesh. The treatments of K @ 0, 40, 60, 80, 100 and 120 kg ha^{-1} were applied from muriate of potash. Data were collected on plant height (cm), number of leaves $plant^{-1}$, plant diameter (cm), plant biomass (g), first heading and first flowering, relative water content (%), head diameter (cm), head circumference (cm), number of seeds $head^{-1}$, number of filled seeds $head^{-1}$, number of unfilled seeds $head^{-1}$, weight of hundred seeds (g), seed weight $plant^{-1}$ (g), seed yield (t ha^{-1}), stover yield (kg ha^{-1}), harvest index (%) and oil yield (kg ha^{-1}). Seeds were analyzed for the determination of oil content (%), free fatty acid (%) and seed moisture content (%).

The potassium levels in the soil of the experimental site were relatively high (0.35 meq/100 g soil). Potassium levels had significant difference only on seed weight $head^{-1}$ (g), seed yield (t ha^{-1}), harvest index (%) and oil yield (kg ha^{-1}) and rest of the parameters had no significant effect. But difference was found between the potassium treated plots and control plot where treated plots shown better performance than control plot.

Potassium applied @ 60 kg ha^{-1} produced the highest plant height (125.23 cm), leaf number (28.57) and stem diameter (8.34 cm) at harvest while the lowest plant height (120.40 cm), leaf number $plant^{-1}$ (25.13) and stem diameter (7.33 cm) was recorded from control treatment (no potassium added).

The highest value of plant biomass (5 weeks after sowing) (3.76 g plant^{-1}), plant biomass at flowering (71.00 g plant^{-1}) and total dry matter (7.97 t ha^{-1}) were found where plots were treated with K of 60 kg ha^{-1}, 140 kg ha^{-1} and 60 kg ha^{-1}, respectively where the lowest value of plant biomass at seedling (3.11 g plant^{-1}), plant biomass at flowering (62.50 g plant^{-1}) and total dry matter (7.13 t ha^{-1}) were found where K was not applied.

Plot treated with 140 kg K ha^{-1} took minimum days for both first heading (52 days) and first flowering (70 days) and plot treated with no potassium took maximum days for both first heading (54 days) and first flowering (72.33 days). Relative water content was found maximum (76.73%) @ application of 60 kg ha^{-1} K where the minimum (73.66%) was from control plot.

The maximum results of head circumference (54.83 cm), head diameter (19.94 cm), filled seed head^{-1} (1171.0), total seed head^{-1} (1297.7), 1000 seed weight (72.33 g), seed weight head^{-1} (77.43 g) and stover yield (4.75 t ha^{-1}) were obtained by application of 60 kg K whereas the control plot provided the minimum results of head circumference (49.84 cm), head diameter (18.33 cm) filled seed head^{-1} (910.7), total seed head^{-1} (1024.0), 1000 seed weight (64.67 g), seed weight head^{-1} (58.33 g) and stover yield (4.46 t ha^{-1}). But the maximum unfilled seed (148.05) was found from 120 kg K ha^{-1} and minimum (113.28) was found from control plot.

On the other hand, the highest oil content (39.89%), seed moisture content (5.14%) and free fatty acid (1.79%) were found from the application of potassium @ 60 kg ha^{-1} , 40 kg ha^{-1} ,40 kg ha^{-1}, respectively while the lowest oil content (37.12%), seed moisture content (5.05%) and free fatty acid (1.67%) were found from the application of potassium @ 80 kg ha^{-1}, 140 kg ha^{-1}, and 120 kg ha^{-1}, respectively.

Seed harvest index (41.70%), seed yield (3.32 t ha^{-1}) and oil yield (1326.0 kg ha^{-1}) were statistically higher in application of 60 kg K ha^{-1} and harvest index (34.97%), seed yield (2.49 t ha^{-1}) and oil yield (943.2 kg ha^{-1}) were statistically lower in control treatment.

Conclusion

From the results of the experiment it is revealed that potassium had little response on growth, yield and yield attributes of sunflower. The soil in the coastal region is high in potassium content. Yet the response of potassium on sunflower is little but performance of sunflower was better in 60 kg K ha^{-1} in case of most of the parameters which was more or less similar to others rates of K over no K added treatment (K_0). As there is no K rate recommended in the coastal soil of southwestern Bangladesh. From the findings of this experiment it could be suggested that application of 60 kg K ha^{-1} to be a promising practice for sunflower cultivation in southwestern coastal Bangladesh.

Recommendation

However, to reach a specific conclusion it is recommended that-

- ✓ The experiment should be repeated at least one more year for better understanding and conformity of the findings.
- ✓ The experiment should be trialed in other location of the southwestern coastal region of Bangladesh to observe the response of K on growth and yield of sunflower.

CHAPTER VI

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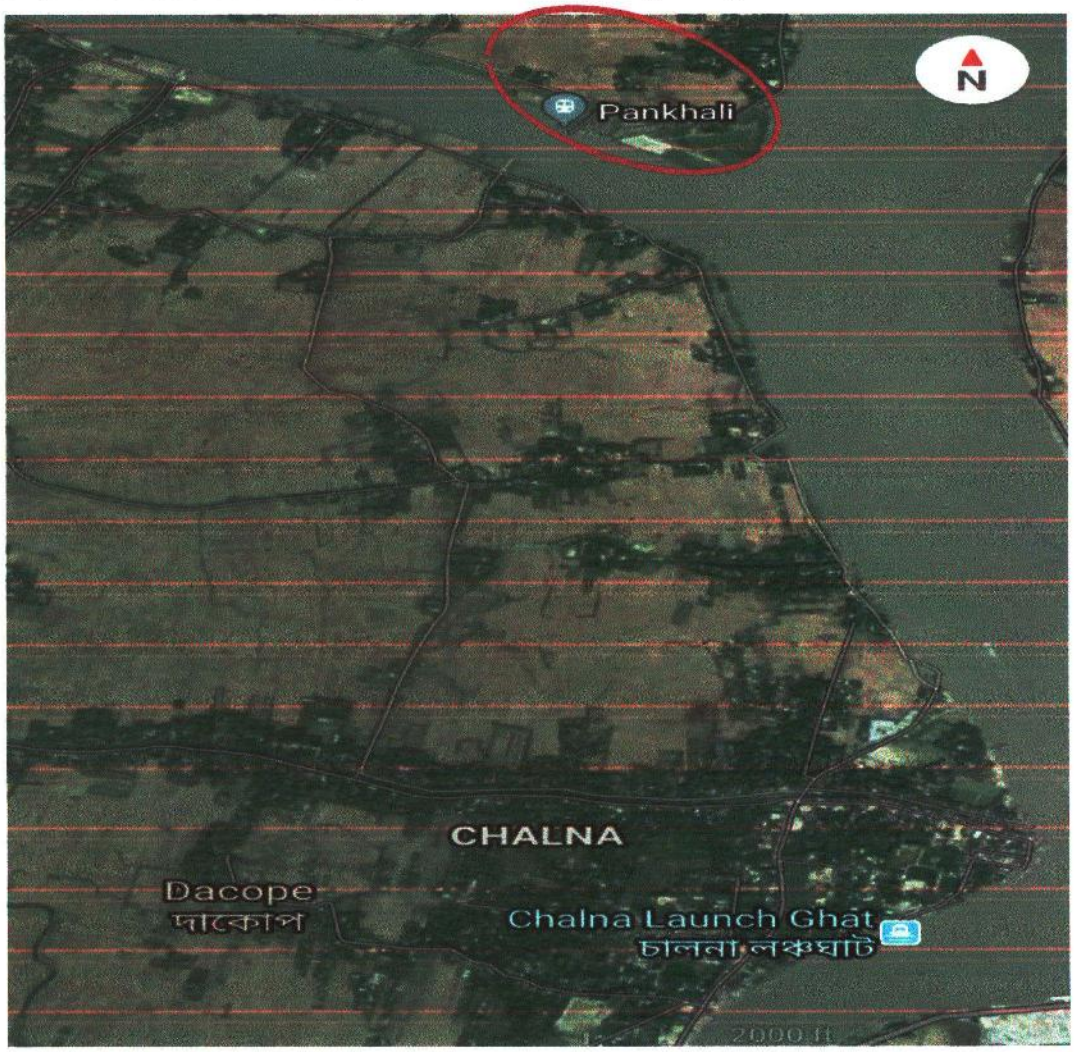
APENDICES

Appendix I: Nutrient rate and plot wise fertilizers calculation

K level	**Nutrient** (kg ha^{-1})	**Fertilizer** (kg ha^{-1}) (Urea-TSP-MoP-Gypsum-ZnSo4-Borax)	**Fertilizer** (g plot^{-1}) (12 m^2) (Urea-TSP-MoP-Gypsum-ZnSo4-Borax)
K_0	N_{120}-P_{50}-K_0-S_{30}-Zn_4-B_2	265-250-0-170-12-12	318-300-0-204-14.4-14.4
K_1	N_{120}-P_{50}-K_{40}-S_{30}-Zn_4-B_2	265-250-80-170-12-12	318-300-96-204-14.4-14.4
K_2	N_{120}-P_{50}-K_{60}-S_{30}-Zn_4-B_2	265-250-120-170-12-12	318-300-144-204-14.4-14.4
K_3	N_{120}-P_{50}-K_{80}-S_{30}-Zn_4-B_2	265-250-160-170-12-12	318-300-192-204-14.4-14.4
K_4	N_{120}-P_{50}-K_{100}-S_{30}-Zn_4-B_2	265-250-200-170-12-12	318-300-240-204-14.4-14.4
K_5	N_{120}-P_{50}-K_{120}-S_{30}-Zn_4-B_2	265-250-240-170-12-12	318-300-288-204-14.4-14.4
K_6	N_{120}-P_{50}-K_{140}-S_{30}-Zn_4-B_2	265-250-280-170-12-12	318-300-336-204-14.4-14.4

Appendix II: Location of the experimental site in Google map



Appendix III: Pictorial view of the experimental plot at different stages and operation of crop growth

Plate 1: Layout of the field

Plate 2: Irrigation

Plate 3: Drainage

Plate 4: Measurement of RWC

Plate 5: Sun drying of plant and seed sample