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Allelopathic Effects of Sorghum and Sudan Grass on Some Following Winter Field Crops

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Authors' contributions

Author SEAT designed the study, wrote the protocol, facilitated the implementation of this study and overcome any problems, provided the scientific and technical support to carry out these trials, and reviewed the final manuscript. Author MML carried out the field experiments, follow up the growth, development and harvest of all tested field crops, prepared samples of the experimental soil from the rhizosphere of the tested field crops for chemical and microbial analyses, and recorded the data of all the tested field crops. Authors TIAW and SIAW follow up the chemical and microbial analyses of the experimental soil to obtain the data, performed the statistical analysis, managed the analyses of the study, wrote the results, managed the literature searches, discussed the results, and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Allelopathic compounds are secreted into the environment by living plants or released from dead plant tissues. The basic release routes of allelopathic substances by donor plants are secretion from the roots, washing out of compounds by water, emission of volatile substances and destruction of tissues during the decomposition of plant material. These observations led to the principles of crop sequence. A two-year study was carried out at Sids Agric. Exp. & Res. St., ARC, Beni – Sweif governorate, Egypt, during 2011/2012 and 2012/2013 seasons to study the allelopathic effects of sorghum and Sudan grass on berseem, faba bean, fodder beet, onion, sugar beet and wheat crops. This experiment included 18 treatments which were the combinations of fallow, sorghum and Sudan grass as preceding crops and six winter field crops (berseem *'Trifolium alexandrinum*', faba bean *'Vicia faba'*, fodder beet *'Beta vulgaris*', onion *'Allium cepa*',

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sugar beet *'Beta vulgaris*' and wheat *'Triticum aestivum'*) as following crops. A split plot distribution in randomized complete block design replicated thrice was used. The results indicated that roots of sorghum or Sudan grass secreted biologically active chemical compounds which have a positive effect on the growth and development of berseem, faba bean and onion which led to increase in their yields as compared with the fallow treatment. The preceding crops tested appear to be promising for berseem, faba bean and onion production, some benefits included releasing compounds that activate growth of *Rhizobia sp.* in berseem field, accelerate growth of *Bacillus sp.* that inhibit *Orobanche* plant emergence in faba bean field, produce nematicidal compounds that reduce nematodes in onion field. On the contrary, fodder beet, sugar beet and wheat yields were depressed when the crops are grown after sorghum or Sudan grass as compared with the fallow treatment.

Keywords: Allelopathy; Sorghum; Sudan grass; Microorganisms; Crop sequence.

1. INTRODUCTION

Forage sorghum (*Sorghum vulgare*) and Sudan grass (*Sorghum vulgare* var*. sudanense* Hitchc) growing very fast and producing as much biomass as any cover crop can in just a few months, at least in temperate regions in Egypt. In the summer season, these plants offer a solution to produce forage dry matter when an emergency occurs in Egypt. Sorghum or Sudan grass is capable of producing large amounts of dry matter where nitrogen content is low (in the range of 1 to 2 percent of dry matter). Although the total amount of nitrogen accumulated in plant residues may be considerable, because of the high C:N ratio, very little or none of the nitrogen is available to subsequent crops [1]. Irrigated forages contribute about 18% of the value of field crops and are grown on the average of about 1,323,529 per ha annually [2]. Forage crops, mainly fresh berseem during winter and as hay during summer, represents about 70% of available local feed. Summer forage crops such as Darawa, millet, sorghum, cowpea, Sudan grass and corn silage represent about 5% of the available local feed. Alfalfa which provides feed all the year around represents about 3% of the available local feed. So, the feed shortage peak is during summer [3,4]. Sorghum and Sudan grass, called cyanogenetic plants, produce cyanogenetic glucosides during their growing stage. Glucosides are compounds that break down or decompose into glucose sugars by hydrolysis-addition of water. In cyanogenetic plants, this decomposition process frees the cyanide from its chemical bond, and it becomes toxic hydrocyanic acid, frequently called prussic acid and abbreviated HCN. The intact, still-bonded cyanide and glucosides are not themselves poisonous, but when certain enzymes are present, they are highly toxic to both man and animal.

Allelopathy is the effect(s) of one plant on other plants through the release of chemical compounds in the environment [5]. This definition is largely accepted and includes both positive (growth promoting) and negative (growth inhibiting) effects. The term allelopathy, originated from the Greek word `allelon' meaning `each other' and `pathos' meaning `feeling', or `sensitive' and could therefore be used to describe both positive (sympathetic) and negative (pathetic) interactions [6]. The negative influence of the allelopathy of some plants on others has been described mainly in crops [7]. On the contrary, selection of allelopathic plants is a good and commonly used approach for identification of plants with biologically active natural products [8], where, allelochemicals suppressing weed growth [9].

Allelopathic potential of sorghum has been reported in many studies [10]. It is related to stresses of environment including soil nutrients deficiency. Allelopathic interference may operate simultaneously, sequentially and/or in combination with other mechanisms of interference such as nutrient deficiency. Organic molecules released from some plants may influence the mineralization, mycorrhizae and nutrient dynamics [11]. Soil has a complex and unique environment, in which the biological activity is mostly controlled by microorganisms. Soil microorganisms play a critical role in nitrogen, sulphur and phosphorus cycles as well as ecosystem functioning by changing soil structure formation, organic matter decomposition, nitrogen fixation and toxin removal. Consequently, allelopathy is considered as a phenomenon that occurs between donor and target organisms by which plants, algae, bacteria and fungi can release chemical substances (allelochemicals) into the environment, influencing the growth and development of biological systems [12]. The extent of soil microbial diversity is important for maintaining good quality of agricultural soil [13].

The release of soil non-exchangeable potassium (K) is related to the concentration of organic acids in soil in Southern China [14]. The application of vanillin and *p*-hydroxybenzoic acid to *C. lanceolatea* and *Schima superba* (Gardn. et Champ.) woodland soils decreased the available nitrogen and potassium in soils but increased the available phosphorus [15]. Plant secondary metabolites inhibits the soil microorganisms and influence the nitrogen (N) cycle due to their effects on soil nitrifiers and immobilization of nitrogen in organic forms [16]. The role of allelopathy in plant-soil-plant interactions in agriculture are controversial, because evidence for direct allelopathic effects and ecological relevance is often difficult to prove. So, the purpose of this study was to evaluate the allelopathic effects of sorghum and Sudan grass on berseem, faba bean, fodder beet, onion, sugar beet and wheat crops.

2. MATERIALS AND METHODS

A two-year study was carried out at Sids Agricultural Experiments and Research Station, A.R.C., Beni – Sweif governorate (Lat. 29º 12' N, Long. 31º 01' E, 32 m a.s.l.), Egypt, during 2011/2012 and 2012/2013 seasons to study the allelopathic effects of sorghum and Sudan grass on berseem, faba bean, fodder beet, onion, sugar beet and wheat crops. Table 1 shows chemical analysis of the experimental soil field after harvest sorghum and Sudan grass. Table 2 shows total count of *Rhizobia sp*., *Bacillus sp.* and *Nematode sp*. after 45 days from growing berseem, faba bean and onion. These analyses were performed in General Organization for Agricultural Equalization Fund, Agricultural Research Center, Giza, Egypt and Cairo University Research Park, Faculty of Agriculture, Cairo University, Giza, Egypt.

This experiment included eighteen treatments which were the combinations of fallow, sorghum (*Sorghum vulgare*) and Sudan grass (*Sorghum vulgare* var. *sudanense* Hitchc) as preceding crops in the summer and six winter field crops (berseem '*Trifolium alexandrinum*', faba bean '*Vicia faba*', fodder beet '*Beta vulgaris*', onion '*Allium cepa*', sugar beet '*Beta vulgaris*' and wheat '*Triticum aestivum*') as following crops in the winter. Sorghum variety (BAN8) and Sudan grass variety (FF9) were used. Also, the used varieties of berseem, faba bean, fodder beet, onion, sugar beet and wheat were Giza 6, Misr 1, Voroshenger, Giza 6 improved, Misribal and Beni – Sweif 1, respectively. Sorghum and Sudan grass grains were sown on June 14 and 4th at 2011 and 2012 summer seasons, respectively, while, all the winter field crops were sown on November 6th and October 29th at 2011 and 2012 winter seasons, respectively.

Table 1. Chemical analysis of experimental field soils (0-20 cm soil depth)

Properties	Fallow	Sorghum	Sudan grass
pH	8.0	8.2	8.3
E.C. (mmohs/cm)	2.20	0.35	0.30
$CaCO_3$ (%)	5.4	1.5	1.9
Ca^{+2} (ml/litre)	7.0	2.2	1.2
Mg^{+2} (ml/litre)	5.4	0.6	0.4
Na^{+} (ml/litre)	9.7	0.9	0.9
K^{+} (ml/litre)	0.06	0.12	0.14
CO_3^{-2} (ml/litre)	---	---	---
HCO_3^{-} (ml/litre)	0.8	1.0	1.2
Cl^{-} (ml/litre)	7.0	1.0	1.0
N (ppm)	25.0	10.0	10.0
P (ppm)	14.0	21.0	20.0
K (ppm)	224.0	254.0	264.0
Fe (ppm)	8.6	8.0	7.0
Cu (ppm)	1.8	1.4	1.3
Zn (ppm)	1.9	0.9	1.4
Mn (ppm)	25.0	25.6	25.4
Hydrocyanic 'HCN' (g/100 g)	0.003	0.070	0.050

Table 2. Total count of *Rhizobia sp*., *Bacillus sp.* and *Nematode sp*. after 45 days from growing berseem, faba bean and onion in the experimental field

Microorganism	Crop	Fallow	Sorghum	Sudan grass
Bacteria *'Rhizobia sp.'* (CFU/g soil)	Berseem	6.9×10^3	8.2×10^3	8.4×10^3
	Faba bean	6.4×10^3	7.9×10^3	8.0×10^3
Bacteria *'Bacillus sp*.' (CFU/g soil)	Faba bean	11×10^5	3×10^6	5×10^6
	Onion	11×10^5	4×10^6	4×10^6
nematode (CFU/kg soil)	Onion	500	104	64

In the two summer seasons, sorghum and Sudan grass grains were grown in two sides of the ridge (70 cm) and were distributed to two plants per hill at 10 cm between hills. After harvest of the cyanogenetic plants, sorghum or Sudan grass roots was plowing in the soil during soil preparation for planting the following winter crops.

In the two winter seasons, wheat grains and berseem seeds were drilled at the rate of 166.6 and 59.5 kg per ha, respectively. Sugar beet and fodder beet seeds were grown in one side of the ridge (70 cm) and were distributed to one plant per hill at 20 cm between hills. Faba bean seeds were grown in two sides of the ridge (70 cm) and were distributed to two plants per hill at 25 cm between hills. Onion transplants were grown in three rows of the ridge (70 cm) and were distributed to one plant per hill at 10 cm between hills. Normal practices for growing all crops were used as recommended in the area.

Calcium super phosphate (15.5% P_2O_5) at rate of 357 kg/ha and potassium sulfate (48% K_2O) at rate of 119 kg/ha were applied during soil preparation for planting sorghum and Sudan grass in the summer season. In the winter season, the previous rates of calcium super phosphate and potassium sulfate were also applied during soil preparation for planting the winter crops. Also, potassium sulfate (48% K_2O) at rate of 357 kg/ha was added during different growth stages of fodder beet. Nitrogen fertilizer rate was applied during different growth stages of all the tested crops as follows: 202.3 kg N/ha for sorghum, 202.3 kg N/ha for Sudan grass, 35.7 kg N/ha for berseem, 35.7 kg N/ha for faba bean, 166.6 kg N/ha for sugar beet, 243.5 kg N/ha for fodder beet, 285.6 kg N/ha for onion and 178.5 kg N/ha for wheat.

A split plot distribution in randomized complete block design replicated thrice was used. The sorghum, Sudan grass and fallow treatments were randomly assigned to the main plots, while the following winter field crops were allotted in subplots. Each plot contained five ridges, each ridge was 3.0 m in length, 0.7 m in width and the plot area was 10.5 m^2.

At harvest, the following traits were measured on ten guarded plants from each plot, while, yields per ha (ton) were recorded on the basis of experimental plot area by harvesting all plants of each plot.

2.1 Berseem Yield and Its Attributes

Plant height (cm), number of leaves per plant, plant fresh weight (g) and forage yield per ha (ton).

2.2 Faba Bean Yield and Its Attributes

Plant height (cm), number of branches per plant, number of pods per plant, number of seeds per plant, 100 – seed weight (g), seed yield per plant (g) and seed yield per ha (ton).

2.3 Fodder Beet Yield and Its Attributes

Root length (cm), root diameter (cm), shoot length (cm), root weight per plant (kg) and root yield per ha (ton).

2.4 Onion Yield and Its Attributes

Bulb height (cm), bulb diameter (cm), bulb weight per plant (g), bulb yield per ha (ton) and weed biomass per m^2 (g).

2.5 Sugar Beet Yield and Its Attributes

Root length (cm), root diameter (cm), root weight per plant (kg), root yield per ha (ton), total soluble solids (%) and sucrose content (%). Total soluble solids and sucrose content were analyzed by Sugar Crops Research Institute, Agricultural Research Center, Giza, Egypt.

2.6 Wheat Yield and Its Attributes

Plant height (cm), number of spikes per m^2, number of grains per spike, grain weight per spike (g), 1000 – grain weight (g) and grain yield per ha (ton).

Analysis of variance of the obtained results of each season was performed. The measured variables were analyzed by ANOVA using MSTATC statistical package [17]. Mean comparisons were done using least significant differences (L.S.D) method at 5 % levels of probability to compare differences between the means [18].

3. RESULTS AND DISCUSSION

3.1 Berseem

3.1.1 Yield and its attributes

Sorghum or Sudan grass – berseem sequence affected significantly plant fresh weight and forage yield per ha, whereas, plant height and number of leaves per plant were not affected in comparison with growing berseem after fallow in the two growing seasons (Table 3). Growing berseem after sorghum or Sudan grass caused significant increase in plant fresh weight and forage yield per ha in comparison with growing berseem after fallow in the two growing seasons.

Sorghum and Sudan grass increased significantly *(P=.05)* forage yield per ha by 3.11 and 3.83% in the first season and 1.73 and 2.07% in the second season, respectively, in comparison with the fallow treatment (Table 3).

Table 3. Effect of sorghum, Sudan grass and fallow treatments on berseem yield and its attributes in 2011/2012 and 2012/2013 growing seasons

Traits	Plant height (cm)	Number of leaves/plant	Plant fresh weight (g)	Forage yield (ton/ha)
2011/2012 season				
Sorghum	64.46	7.56	12.83	66.64
Sudan grass	64.66	7.67	13.43	67.11
Fallow	62.20	6.72	11.91	64.63
F calculated	5.75	3.53	12.51	10.98
LSD .05	2.85	1.38	1.08	1.98
2012/2013 season				
Sorghum	78.38	8.75	15.83	70.96
Sudan grass	79.18	8.90	16.08	71.20
Fallow	77.25	8.26	14.92	69.75
F calculated	4.59	2.66	11.21	12.24
LSD .05	2.26	1.01	0.91	1.10

Obviously, potential yield of berseem as legume crop was increased by the preceded crops in comparison with growing berseem after fallow and played a major role in the economic yield per unit area. These results are in agreement with those seasonal fresh forage yield that had the highest positive direct effect on seasonal protein yield (0.84) followed by mean dry matter percentage (0.46) [19]. These results reveal that sorghum or Sudan grass – berseem sequence promoted growth and development of berseem plant in comparison with growing berseem after fallow. These results are in harmony with those of sorghum-Sudan grass that suppressed alfalfa root growth significantly in a Virginia greenhouse study [20], but no effect was observed on alfalfa germination when alfalfa was no-till planted into killed or living sorghum-Sudan grass. Also, berseem grown in winter season followed by sorghum Sudan during summer season in small plots (8m x 5m) with 4 replications each under recommended level of inputs [21]. The data showed that average production (q/ha) of green fodder and dry matter was 1040 and 139, respectively.

3.1.2 Allelopathic effects

It is clear that sorghum or Sudan grass – berseem sequence had positive effect (growth promoting) on forage yield per ha in comparison with growing berseem after fallow. The positive effect of this crop sequence could be due to nitrogen soil deficiency, availability of potassium soil and turn off hydrocyanic acid 'HCN' toxicity.

3.1.2.1 Nitrogen soil deficiency

Several plant nutrients are unavailable at very strongly acidic or very strongly alkaline soil. This is due to the various reactions in the soil that fix the nutrients and convert them to the form that is unavailable to the plants [22]. The results indicate that there were reduction in nitrogen soil (Table 1) that exhausted by the cyanogenetic plants from the experimental soil, but the reverse was true for total count of *Rhizobia sp* after 45 days from growing berseem after sorghum or Sudan grass (Table 2) in comparison with growing berseem after fallow. Obviously, bacteria that actually fix the atmospheric nitrogen became more active after harvest sorghum or Sudan grass than the fallow treatment. It is clear that *Rhizobia sp.* had important role during the early growth stages of berseem as preceded by sorghum or Sudan grass than the fallow treatment and reflected on the economic yield per unit area (Table 3). The results reveal that growing berseem after sorghum or Sudan grass resulted in counterbalance the reduction in nitrogen soil that caused by the cyanogenetic plants. Legumes contain symbiotic bacteria called *Rhizobia* within nodules in their root systems, producing nitrogen compounds that help the plant to grow and compete with other plants. When the plant dies, the fixed nitrogen is released, making it available to other plants and this helps to fertilize the soil [23].

These results are in harmony with the incorporation of non-legume (high C:N ratio) residues (e.g., corn) led to depression of N availability greater than that for surface residues. N availability was in this order for crop residues: alfalfa > peanut > soybean > oat > sorghum > wheat > corn [24]. Also, when commercial nitrogen fertilizer is added to legumes, whether straight seeded or in a blend, the bacteria that actually fix the nitrogen can become lazy and nitrogen fixing declines [25]. Moreover, mineral nitrogen fertilization is a crucial factor in oil seeded legume production [26]. Finally, the application of reduced amount of nitrogen as starter fertilizer could improve nodulation and biological nitrogen fixation capabilities [27].

3.1.2.2 Availability of potassium soil

Availability of potassium soil was increased by growing sorghum or Sudan grass in the experimental soil as compared to the fallow treatment (Table 1). Potassium plays a vital role where promotes photosynthesis process and consequently more dry matter accumulation in the plant [28]. Obviously, growing berseem after fallow couldn't improve a vital role of potassium in photosynthesis process within berseem leaves as compared with growing berseem after sorghum or Sudan grass. These results are in harmony with the conclusion that berseem showed better performance in terms of the maximum forage yield under 60 kg phosphorus ha^{-1} x 30 kg potassium ha^{-1} levels [29]. Therefore, 60 kg phosphorus ha^{-1} x 30 kg potassium ha^{-1} levels is recommended for higher forage yield from berseem. Moreover, seed yield of berseem and the test weight of the seeds increased with each successive increase in the potassium level in all three years but the number of seeds /head were not influenced by the levels of potassium in the first year [30].

3.1.2.3 Turn off hydrocyanic acid 'HCN' toxicity

It is clear that there was an interaction that occurred between berseem and residues of cyanogenetic plants roots through sorghum or Sudan grass – berseem sequence. Berseem roots could be use HCN which secreted from sorghum or Sudan grass roots (Table 1) and synthesize plant growth – promoting substances by symbiotic nitrogen fixers (Table 2). This positive effect of sorghum or Sudan grass on dry weight per plant reflected to the highest forage yield of berseem per unit area in comparison with growing berseem after fallow (Table 3). These results are in harmony with those of *Rhizobia sp*. synthesize plant – growth promoting substances from HCN [31,32,33].

3.2 Faba Bean

3.2.1 Yield and its attributes

Sorghum or Sudan grass – faba bean sequence affected significantly number of seeds per plant, seed yields per plant and per ha, while, plant height, numbers of branches and pods per plant, as well as, 100 – seed weight were not affected in comparison with growing faba bean after fallow in the two growing seasons (Table 4). This crop sequence caused significant increase in number of seeds per plant, seed yields per plant and per ha in comparison with growing berseem after fallow in the two growing seasons.

The preceding Sorghum and Sudan grass crops increased significantly *(P = .05)* seed yield of faba bean per ha by 4.70 and 4.95 % in the first season and 3.26 and 3.49 % in the second season, respectively, in comparison with the fallow treatment (Table 4). It is important to mention that number of seeds per plant and seed yield per plant have important role in seed yield per ha. These results are in agreement with the significant and positive correlation between plant seed yield and number of seed per pod [34]. Also, it was found that seed yield per ha had significant positive relationship with number of seeds per pod [35].

Table 4. Effect of sorghum, Sudan grass and fallow treatments on faba bean yield and its attributes in 2011/2012 and 2012/2013 growing seasons

Traits	Plant height (cm)	No. of branches /plant	No. of pods /plant	No. of seeds /plant	100-seed weight (g)	Seed yield /plant (g)	Seed yield (ton/ha)
2011/2012 season							
Sorghum	119.00	5.23	17.50	48.13	78.10	41.70	8.45
Sudan grass	119.50	5.26	17.60	48.63	77.70	42.03	8.47
Fallow	116.66	5.03	16.53	45.56	78.73	36.36	8.07
F calculated	6.17	1.53	3.00	13.07	0.63	76.47	89.43
LSD .05	3.04	0.50	1.69	2.27	3.27	1.81	0.11
2012/2013 season							
Sorghum	120.66	5.40	20.50	49.93	86.10	45.33	9.17
Sudan grass	121.33	5.60	21.23	50.33	86.20	45.90	9.19
Fallow	119.00	5.26	20.23	47.76	87.93	39.76	8.88
F calculated	2.00	2.71	2.01	31.30	4.05	46.05	56.43
LSD .05	4.24	0.50	1.82	1.23	2.55	2.49	0.11

3.2.2 Allelopathic effects

Sorghum or Sudan grass – faba bean sequence had a positive effect (growth promoting) on seed yield of faba bean per ha in comparison with growing faba bean after fallow and could be due to some allelopathic effects (growth promoting) which included nitrogen soil deficiency, turn off hydrocyanic 'HCN' toxicity, availability of potassium soil and acceleration growth *Bacillus sp*.

3.2.2.1 Nitrogen soil deficiency

Sorghum or Sudan grass – faba bean sequence which affected positively number of seeds per plant, seed yields per plant and per ha led to reduction in nitrogen soil (Table 1) that exhausted by the cyanogenetic plants from the experimental soil and consequently promoted bacteria growth that actually fix the nitrogen where it become more active (Table 2) in comparison with growing faba bean after fallow. It is clear that sorghum or Sudan grass – faba bean sequence promoted *Rhizobia sp.* during the early growth stages of faba bean in comparison with growing faba bean after fallow and reflected on the economic yield per unit area (Table 4). The results reveal that growing faba bean after sorghum or Sudan grass resulted in counterbalance the reduction in nitrogen soil that caused by the cyanogenetic plants. These results are in harmony with that nutrients such as nitrogen, sulfur and phosphorus are important factors in increasing yield of faba bean [36]. In addition, it was noticed that when commercial nitrogen fertilizer is added to legumes, whether straight seeded or in a blend, the bacteria that actually fix the nitrogen can become lazy and nitrogen fixing declines [25]. Moreover, faba bean produce 3/4 of their nitrogen requirement through nitrogen fixation [37]. In another study, grain yield and shoot dry weight of faba bean indicated significant quadratic relation with the increasing nitrogen rates between 0 and 200 kg/ha [38]. Also, nitrogen uptake was found to be more with advancement of growth period of faba bean especially between 70 and 140 days, grain yield was correlated with nitrogen uptake [39].

3.2.2.2 Turn off hydrocyanic acid 'HCN' toxicity

The positive effect of sorghum or Sudan grass on number of seeds per plant, seed yields per plant and per ha could be due to synthesize plant growth – promoting substances from HCN, which secreted from roots of sorghum or Sudan grass, by symbiotic nitrogen fixers (Tables 1 and 2) and resulted in the highest seed yields per plant and per ha in comparison with growing faba bean after fallow (Table 4). These results are in harmony with those of that *Rhizobia sp*. synthesize plant – growth promoting substances from HCN [31], [32] and [33].

3.2.2.3 Availability of potassium soil

Sorghum or Sudan grass – faba bean sequence led to increase in potassium soil in comparison with growing faba bean after fallow (Table 1). Obviously, growing faba bean after the cyanogenetic plants led to counterbalance the reduction in availability of nitrogen soil that caused by the cyanogenetic plants and consequently positive effect on availability of potassium soil in the experimental soil. It is clear that this crop sequence affected positively photosynthesis process and consequently more dry matter accumulation in faba bean yield per plant in comparison with growing faba bean after fallow (Table 4). Since most chloroplast protein in green leaves is present as RuBP carboxylase, the CO_2 fixing enzyme in C3 plants, which requires potassium for activation, a lack of potassium inhibits photosynthesis and hence the ability for dry matter accumulation [28]. These results suggest that sorghum or

Sudan grass – faba bean sequence could be increase the efficiency of the photosynthesis process and finally high faba bean yield per plant as compared with growing faba bean after fallow (Table 4). These results are in harmony with those found that potassium uptake more with advancement of growth period of faba bean especially between 70 and 140 days, grain yield was correlated with potassium uptake [39].

3.2.2.4 Acceleration growth of Bacillus sp.

Cyanogenetic plants roots secreted certain chemical compounds which could be accelerate growth of *Bacillus sp*. (Table 1) and led to inhibit *Orobanche* emergence that occurred in faba bean fields and consequently the positive effect on the following faba bean yield per plant in comparison with growing faba bean after fallow (Table 4). These results are in agreement with those members of the grass family (rye, sorghum, oats, corn and Sudan grass) used as green manure increased bacterial populations, predominantly *Bacillus spp*. and Fluorescent *Pseudomonas spp* [40]. In addition, it was demonstrated that faba bean inoculated with the combination between bacterial strains TAL 1399 plus A. brasilense, TAL 1399 plus *Bacllius megathirium var phosphaticum* alone or in combination with *mycorrhiza* fungi were completely inhibited *Orobanche* plant emergence [41]. Time at which highest rate of *Orobanche* emergence occurred on faba bean was significantly delayed with *mycorrhiza* fungi incorporated with each of the bacterial strains. The highest increment of faba bean shoot was obtained when arbuscular *mycorrhiza* fungi was incorporated with bacteria *Bacllius megathirium var phosphaticum* as compared to infested control. It increased plant height by 33%. Also, they added that all treatments increased faba bean dry matter as compared to the infested control.

3.3 Fodder Beet

3.3.1 Yield and its attributes

Sorghum or Sudan grass – fodder beet sequence affected significantly root yields per plant and per ha, while, root length and diameter, shoot length were not affected in comparison with growing fodder beet after fallow in the two growing seasons (Table 5).

In regard to the preceding crops, the negative effect of sorghum on root yields per plant and per ha was similar to Sudan grass effect (Table 5). Growing fodder beet after sorghum and Sudan grass decreased *(P = .05)* root yields per ha by 4.19 and 2.99 % in the 1st season and 3.73 and 3.37 % in the 2nd season, respectively, in comparison with growing fodder beet after fallow (Table 5). These data show that sorghum or Sudan grass – fodder beet sequence had adverse effects on the growth and development of fodder beet in comparison with growing fodder beet after fallow.

3.3.2 Allelopathic effects

Sorghum or Sudan grass – fodder beet sequence resulted in a negative effect on root yields per plant and per ha and could be due to certain allelopathic effects (growth inhibiting) which included nitrogen soil deficiency, availability of potassium soil and secretion hydrocyanic acid 'HCN'.

Table 5. Effect of sorghum, Sudan grass and fallow treatments on fodder beet yield and its attributes in 2011/2012 and 2012/2013 growing seasons

Traits	Root length (cm)	Root diameter (cm)	Shoot length (cm)	Root yield /plant (kg)	Root yield (ton/ha)
2011/2012 season					
Sorghum	28.00	17.48	45.15	1.64	102.90
Sudan grass	29.33	17.99	45.68	1.65	104.19
Fallow	33.33	18.14	46.25	1.69	107.41
F calculated	6.40	6.48	2.38	25.20	14.26
LSD .05	5.48	0.67	1.78	0.02	3.07
2012/2013 season					
Sorghum	30.66	17.89	45.53	1.66	103.91
Sudan grass	30.66	18.05	46.18	1.67	104.30
Fallow	33.33	18.26	46.51	1.70	107.94
F calculated	6.40	1.40	5.90	21.50	71.06
LSD .05	3.04	0.79	1.03	0.02	1.31

3.3.2.1 Nitrogen soil deficiency

Sorghum or Sudan grass – fodder beet sequence affected negatively root yields per plant and per ha of fodder beet; these results could be due to the reduction in availability of nitrogen soil (Table 1) that exhausted by the cyanogenetic plants from the experimental soil and consequently low yield potential of fodder beet in comparison with growing fodder beet after fallow (Table 5). These results are parallel with those showed that high C:N ratio and biomass production of Sudan grass may immobilize nitrogen and reduce nitrogen availability to the next cash crop [42]. However, it was found that fodder beets have extremely high yield potential when grown on high fertility soils [43]. Other study, [44] indicated that the fodder beets require large amounts of nitrogen. Nitrogen fertilizers are one of the major costs for production of these crops. Also, nitrogen rates affected significantly most of the yield components determined in fodder beet [45]. Nitrogen applications increased length, diameter and yield of root. Moreover, nitrogen fertilization resulted in leaves of fodder beet exceeded tubers in crude protein [46], crude fiber and ash highly significantly while tubers were superior over leaves in dry matter and nitrogen free extract.

3.3.2.2 Availability of potassium soil

Sorghum or Sudan grass – fodder beet sequence led to increase in potassium soil in comparison with growing fodder beet after fallow (Table 1). Obviously, growing fodder beet after the cyanogenetic plants led to imbalance in availability of nitrogen soil that caused by the cyanogenetic plants and consequently negative effect on availability of potassium soil in the experimental soil. Obviously, the study suggests that nitrogen soil deficiency which caused by sorghum or Sudan grass could be inhibit potassium uptake in fodder beet tissues despite the availability of potassium in the soil. Similar results [47] revealed that high nitrogen rates can promote potassium uptake and increase potassium depletion if clippings are removed as on greens.

3.3.2.3 Secretion hydrocyanic acid 'HCN'

The negative effect of sorghum or Sudan grass on root yields per plant and per ha could be due to HCN in the experimental soil (Table 1) which affected negatively the following fodder beet yield per unit area (Table 5). Another compound found in sorghum genotypes is dhurrin, a cianogenic glycoside that degrades to para-hydroxybenzaldeide, HCN, and glucose [48]. It is clear that sorghum or Sudan grass – fodder beet sequence could be responsible for growth and development inhibition of fodder beet. These results are parallel with that of sorghum Sudan grass is characterized by its allelopathic potential [49]. Growing sorghum Sudan grass exudes sorgoleone, a photosystem II inhibitor which had negative effect on the following crop.

3.4 Onion

3.4.1 Yield and its attributes

Sorghum or Sudan grass – onion sequence affected significantly bulb height and diameter, bulb weight per plant, bulb yield per ha and weed biomass per m^2 in comparison with growing onion after fallow in the two growing seasons (Table 6). Growing onion after sorghum or Sudan grass caused significant increase in bulb height and diameter, bulb weight per plant and bulb yield per ha, whereas, it had negative effect on weed biomass per m^2 in comparison with growing onion after fallow in the two growing seasons.

Obviously, sorghum or Sudan grass – onion sequence had a positive effect on the growth and development of the acceptor plant (onion); this crop sequence increased significantly *(P = .05)* bulb yield per ha by 6.25 and 6.67 % in the first season and 6.43 and 7.06 % in the second season, respectively, in comparison with growing onion after fallow (Table 6). Similar results were demonstrated [50] that sorghum Sudan grass improved onion stand. Also, the fresh bulb weight of onion was significantly affected by the application of varying levels of potassium [51], nitrogen and weed interference in both seasons and the combined analysis. At harvest, the highest mean fresh bulb weights of 36.90 t/ha were produced with the application of 150 kg/ha nitrogen and 250 kg/ha potassium in 2006.

Table 6. Effect of sorghum, Sudan grass and fallow on onion yield and its attributes in 2011/2012 and 2012/2013 growing seasons

Traits	Bulb height (cm)	Bulb diameter (cm)	Bulb weight /plant (g)	Bulb yield (ton/ha)	Weed biomass/m^2 (g)
2011/2012 season					
Sorghum	37.56	5.51	95.23	40.01	1.62
Sudan grass	38.10	5.63	96.00	40.27	1.43
Fallow	34.06	5.22	92.46	37.75	2.24
F calculated	18.31	19.22	27.15	10.28	11.65
LSD .05	2.55	0.24	1.78	2.15	0.62
2012/2013 season					
Sorghum	39.03	6.16	96.46	40.83	2.02
Sudan grass	39.43	6.19	97.30	41.10	1.87
Fallow	34.70	5.87	93.73	38.39	2.73
F calculated	161.77	17.19	53.10	9.39	62.80
LSD .05	1.03	0.21	1.28	2.43	0.29

Moreover, it was suggested that brassica and sorghum Sudan grass cover crops could provide multiple benefits if incorporated into short-term onion rotations under Michigan growing conditions [52]. They added that Brown mustard, yellow mustard and sorghum Sudan grass also increased bulb number, but the increased bulb number did not translate into significant increases in total weight.

3.4.2 Allelopathic effects

The positive effect of sorghum or Sudan grass – onion sequence on bulb yield per ha could be due to weed suppression, turn off hydrocyanic acid 'HCN' toxicity, availability of potassium soil and acceleration growth of *Bacillus sp*.

3.4.2.1 Weed suppression

The results in Table (6) indicate that the preceding sorghum or Sudan grass decreased weed biomass per m^2 into onion fields in comparison with growing onion after fallow in the two growing seasons. This could be due to sorghum or Sudan grass roots secreted certain allelopathic compounds that suppressed the weeds into onion fields. It is clear that sorghum or Sudan grass – onion sequence inhibited growth and development of weeds into onion fields and reduced competition between onion and weed for basic growth resources which reflected on the positive impact for bulb yield per ha in comparison with growing onion after fallow (Table 6). These results are in harmony with those revealed that sorghum-Sudan grass hybrids make an effective smother crop [53]. Their seedlings, shoots, leaves, and roots secrete allelopathic compounds that suppress many weeds. The main root exudate, sorgoleone, is strongly active at extremely low concentrations, comparable to those of some synthetic herbicides. Also, sorghum Sudan grass reduced weed density significantly into onion fields [52]. The fresh bulb weight of onion was increased significantly by 6 WAT in comparison with unweeded treatment [51].

3.4.2.2 Nitrogen soil deficiency

The positive effect of sorghum or Sudan grass on onion growth and development could be due to inhibit nematode growth by increasing concentration of glucosinolates compound which secreted from onion plants. Nitrogen soil deficiency could increase concentration of this compound. These results are parallel with those demonstrated that total glucosinolates increased with high sulfur supply and low nitrogen rates [54].

3.4.2.3 Turn off hydrocyanic acid 'HCN' toxicity

Bulb height and diameter, bulb weight per plant, bulb yield per ha were increased significantly by the preceding sorghum or Sudan grass in comparison with growing onion after fallow in the two growing seasons. This could be due to roots of sorghum or Sudan grass secreted HCN which is used as nematicidal compound to inhibit growth of nematode larvae in onion (Tables 1 and 2) and led to increase in bulb yield per ha (Table 6). Also, HCN may be interacted with sulfur compounds to increase isothiocyanates concentration for control soil pests and weeds (Table 6) because this compound is a product resulted from the bioactive hydrolysis of onion [55]. In the same trend, the cyanogenetic plants secreted certain chemical compounds that accelerated growth of *Bacillus sp*. which led to increase in availability of sulfate soil and consequently increase in isothiocyanates concentration that inhibit growth of nematode larvae (Table 2). These results are in agreement with that allelochemicals are plant-produced compounds (other than food compounds) that affect the behavior of other organisms [56] in the plants environment. Sudan grass or sorghum contains a chemical, dhurrin, that degrades into hydrogen cyanide, which is a powerful nematicide. Also, plants can impact soil-dwelling species [57]. Oats, barley and sorghum-Sudan grass have been shown to reduce nematodes—a pest that can reduce carrot quality and affect other vegetable crops such as onions and potatoes. He added that leaves of these plants produce a nematicidal compound. Furthermore, plant availability of S in a given soil is dependent on the S speciation in soils, influenced by pedogenetic processes and physicochemical factors, that is, water logging [58]. The oxidation of S to SO_4^{-2} in soil is a biological process and is carried out by several kinds of microorganisms, that is, *Thiobacillus thiooxidans, T. ferrooxidans*, *T. thioparus*, *T. denitrificans*, and *T. novellus*. The rate at which this conversion takes place is determined by three main factors, that is, microbiological population in the soil, physical properties of the S source, and environmental conditions. Most agricultural soils contain some microorganisms that are able to oxidize S. However, the most important organisms in S oxidization are a group of bacteria (SoxB) belonging to the genus *Thiobacillus*.

There is variability in the levels of resistance to root-knot nematodes in sorghum cultivars [59]; [60]; [61]; [62] and [63]. Also, rice root-knot nematode, *Meloidogyne graminicola,* infects all commercially grown onion cultivars in rice-onion cropping systems in the Philippines, but its economic importance has not been established [64]. That the author added that growth and yield decreased with increased nematode levels. Bulb weight was reduced by 7 to 82% and diameter by 10 to 62% when plants were inoculated with 50 to 10,000 second-stage juveniles. Onion bulbs from the field were reduced by 16, 32, and 35% in weight and by 6, 17, and 18% in diameter when the percentage of roots galled was 10, 50, and 100%, respectively.

3.4.2.4 Acceleration growth of Bacillus sp.

Bulb height and diameter, bulb weight per plant, bulb yield per ha were increased significantly by the preceding sorghum or Sudan grass in comparison with growing onion after fallow in the two growing seasons. This could be due to certain chemical compounds were secreted by growing the preceding sorghum or Sudan grass which accelerated growth of *Bacillus sp.* (Table 2). These bacteria decreased nematode eggs in the soil and consequently positive effect on onion growth and development which reflected on the economic yield (Table 6). These results were previously showed that members of the grass family (rye, sorghum, oats, corn and Sudan grass) used as green manure increased bacterial populations, predominantly *Bacillus spp*. and Fluorescent *Pseudomonas spp* [40]. Also, bacterial antibiotics and other toxic compound present in metabolites as well as direct interaction might be responsible for the J2 immobility, production of metabolites by *rehizosphere* bacteria causes lysis of nematode eggs and affects vitally of root-knot nematode J2 stage [65], [66] and [67]. Also, *Bacillus subtilis* significant reduced eggs hatching of *M*. *javanica* in vitro [68]. Moreover, it was observed that the bacterial treatment [69] shows the most effective to reduced nematode populations next to nematicidevydate 10 Gas compared with fresh leaf extract of neem, garlic and marigold. Finally, soil application of both *Pseudomonas fluorescens* and *Bacillus subtilis* alone [70] or in combination was able to reduce the nematode population and improve the onion growth parameters in terms of shoot length, root length, shoot fresh and dry weight, root fresh weight.

3.5 Sugar Beet

3.5.1 Yield and its attributes

Sorghum or Sudan grass – sugar beet sequence affected significantly root weight per plant, root yield per ha, T.S.S. and sucrose percentages, whereas, root length and diameter were not affected in comparison with growing sugar beet after fallow in the two growing seasons (Table 7). Sorghum or Sudan grass – sugar beet decreased *(P = .05)* root weight per plant and root yield per ha in comparison with growing sugar beet after fallow in the two growing seasons. On the contrary, T.S.S. and sucrose percentages were increased significantly *(P = .05)* after sorghum or Sudan grass as compared with the fallow treatment in the two growing seasons. In regard to the preceding crops, the negative effect of sorghum on root weight per plant and root yield per ha was similar to Sudan grass effect.

Table 7. Effect of sorghum, Sudan grass and fallow treatments on sugar beet yield and its attributes in 2011/2012 and 2012/2013 growing seasons

Traits	Root length (cm)	Root diameter (cm)	Root weight/plant (kg)	Root yield (ton/ha)	T.S.S. (%)	Sucrose (%)
2011/2012 season						
Sorghum	30.85	11.35	1.04	72.66	21.75	17.90
Sudan grass	29.68	11.21	1.09	73.85	21.16	17.80
Fallow	31.66	11.48	1.21	78.22	20.14	15.51
F calculated	1.17	0.58	13.52	31.57	22.18	34.77
LSD .05	4.58	0.86	0.11	2.60	0.86	1.14
2012/2013 season						
Sorghum	29.26	10.08	1.09	75.20	22.28	18.41
Sudan grass	30.93	12.53	1.11	75.87	21.62	17.68
Fallow	32.58	12.69	1.23	79.88	19.56	16.31
F calculated	1.24	5.79	10.26	11.57	30.67	35.86
LSD .05	7.42	3.03	0.11	3.71	1.28	0.89

Also, T.S.S. and Sucrose percentages were not differed significantly between the preceding sorghum and Sudan grass (Table 7). Sorghum and Sudan grass decreased significantly root yield per ha by 7.10 and 5.58% in the first season and 5.85 and 5.02% in the second season, respectively, in comparison with the fallow treatment (Table 7). These results indicate that sugar beet preceded by shallow – rooted crops as such as sorghum or Sudan grass had lower root weight per plant and root yield per ha as compared the fallow treatment in the two growing seasons.

3.5.2 Allelopathic effects

The negative effect of sorghum or Sudan grass – sugar beet sequence on root weight per plant and root yield per ha could be due to nitrogen soil deficiency, availability of potassium soil and secretion hydrocyanic acid 'HCN'.

3.5.2.1 Nitrogen soil deficiency

Sorghum or Sudan grass – sugar beet affected negatively root weight per plant and root yield per ha of sugar beet; these results could be due to the reduction in availability of nitrogen soil (Table 1) that exhausted by the cyanogenetic plants from the experimental soil and consequently low yield potential of sugar beet in comparison with growing sugar beet after fallow (Table 7). These results are parallel with those obtained on fallow treatment that resulted in high residual NO_3 – N which led to high root yields, whereas growing wheat, sorghum and alfalfa resulted in less residual nitrogen and lower sugar beet root yields [71].

3.5.2.2 Availability of potassium

Sorghum or Sudan grass – sugar beet sequence led to increase in potassium soil in comparison with growing sugar beet after fallow (Table 1). Obviously, growing sugar beet after the cyanogenetic plants led to imbalance in availability of nitrogen soil that caused by the cyanogenetic plants and consequently negative effect on availability of potassium soil in the experimental soil. Obviously, the study suggests that nitrogen soil deficiency which caused by sorghum or Sudan grass could be inhibit potassium uptake in sugar beet tissues despite the availability of potassium in the soil. Similar results are in agreement with those indicated that nitrogen content influenced from presence and ratio mineral elements in the soil [72]. From all metabolic elements which plants use from soil, nitrogen needs in the largest amounts.

3.5.2.3 Secretion hydrocyanic acid 'HCN'

The depressive effect of sorghum or Sudan grass on root weight per plant and root yield per ha could be due to HCN in the soil (Table 1) which affected negatively the following sugar beet yield (Table 7). Sorghum Sudan grass secreting other organic acids that have been demonstrated to inhibit seed germination and seedling growth of the following plant [73]. Toxic compounds, which include several phenolic acids; cyanogenic glycosides; and a hydroquionone, sorgoleone, occur in both the roots and the shoots of sorghum [74]. Obviously, growing sugar beet after sorghum or Sudan grass led to inhibition of sugar beet growth and development in comparison with growing sugar beet after fallow. These results are to those obtained that sorghum Sudan grass is also characterized by its allelopathic potential [49]. Growing sorghum Sudan grass exudes sorgoleone, a photosystem II inhibitor which had negative effect on the following crop.

3.6 Wheat

3.6.1 Yield and its attributes

Sorghum or Sudan grass – wheat sequence affected significantly number and weight of grains per spike, as well as, grain yield per ha, whereas, plant height, number of spikes per m^2 and 1000 – grain weight were not affected in comparison with growing wheat after fallow (Table 8). Sorghum or Sudan grass – wheat sequence decreased *(P = .05)* number and weight of grains per spike and grain yield per ha in comparison with growing wheat after fallow in the two growing seasons. Fallow – wheat sequence recorded the highest values for number and weight of grains per spike, as well as, grain yield per ha in comparison with growing wheat after the cyanogenetic plants (Table 8). It is clear that number and weight of grains per spike played a major role in the grain yield per unit area by affecting directly genetic yield potential. It seems that number and weight of grains per spike may be correlated positively with the economic yield of wheat. Grain weight per spike is very important yield components, which directly influence to harvest index and yield and depends on grain number and grain chemical composition [75].

Sorghum and Sudan grass decreased significantly grain yield per ha by 5.44 and 2.35% in the first season and 5.03 and 3.16% in the second season, respectively, in comparison with the fallow treatment (Table 8). These results indicate that wheat preceded by sorghum or Sudan grass had lower number and weight of grain per spike and grain yield per ha as compared the fallow treatment in the two growing seasons.

Table 8. Effect of sorghum, Sudan grass and fallow on wheat yield and its attributes in 2011/2012 and 2012/2013 growing seasons

Traits	Plant height (cm)	No. of spikes /m^2	No. of grains /spike	Grains weight /spike (g)	1000-grain weight (g)	Grain yield (ton/ha)
2011/2012 season						
Sorghum	116.33	457.50	45.72	1.91	43.00	6.43
Sudan grass	118.00	462.76	49.90	2.13	44.83	6.64
Fallow	119.33	462.76	54.33	2.40	46.86	6.84
F calculated	1.52	4.89	54.86	55.08	3.58	28.75
LSD .05	6.08	6.87	2.90	0.16	5.10	0.19
2012/2013 season						
Sorghum	115.66	461.16	48.56	2.21	45.23	6.59
Sudan grass	122.83	464.30	53.16	2.45	46.13	6.73
Fallow	120.66	466.13	57.20	2.61	48.03	6.95
F calculated	1.83	2.19	165.73	94.75	3.57	42.63
LSD .05	13.56	8.48	1.67	0.10	3.77	0.13

With respect to the preceding crops, Sudan grass recorded higher values for number and weight of grains per spike, as well as, grain yield per ha than sorghum which may be due to Sudan grass restores carbon in the soil which increases crop vigor and reduces disease on the following crop, in comparison with the sorghum treatment. These data show that Sudan grass had lower adverse effects on wheat growth and development than the sorghum treatment. These results are in agreement with those found that Sudan grass restore carbon to low-quality muck soil [76] which increases crop vigor and reduces disease on the following crop, in comparison with the sorghum treatment. In the same trend, the preceding Sudan grass had the highest influence on the concentration of the total amino acids in wheat rhizosphere soil solution which lead to the highest grain yield of wheat [77].

3.6.2 Allelopathic effects

The negative effect of sorghum or Sudan grass – wheat sequence on number and weight of grains per spike and grain yield per ha could be due to certain allelopathic effects (growth inhibiting) which included nitrogen soil deficiency, availability of potassium soil and secretion hydrocyanic acid 'HCN'.

3.6.2.1 Nitrogen soil deficiency

Sorghum or Sudan grass – wheat affected negatively number and weight of grains per spike and grain yield per ha of wheat; these results could be due to the reduction in availability of nitrogen soil (Table 1) that exhausted by the cyanogenetic plants from the experimental soil and consequently low yield potential of wheat in comparison with growing wheat after fallow (Table 8). Nitrogen soil plays main role in wheat nutrition because of its importance in protein and nucleic acid synthesis as well plant species and cultivars to suboptimal supplies of mineral element, including N, are different [78]. These results are in harmony with those found that wheat yield was [79] affected negatively by the preceding sorghum in comparison with the other preceding crops where wheat yield after sorghum recorded the lowest yield (23.5 bu/a), whereas wheat yield recorded 31.5, 38.5 and 54.8 bu/a after soybean, corn and wheat, respectively. The authors added that protein was slightly lower in wheat following sorghum than following the other crops. Also, it was found that high C:N ratio and biomass production of Sudan grass may immobilize nitrogen and reduce nitrogen availability to the next cash crop [42]. Moreover, there was an indication that soybean as preceding crop recorded the highest seed yield of wheat, whereas, the yield of wheat following sorghum was the lowest [80]. In another study, [81] crop sequence significantly influenced wheat yield. In their 4 – year experiment, wheat following soybean or maize produced greater yield than wheat following grain sorghum. Their work indicated that lower wheat yield and a greater fertilizer N requirement for wheat planted after grain sorghum as compared with wheat planted after soybean or corn and attributed those results to greater immobilization of both soil and fertilizer N after grain sorghum. Also, the allelopathic effect of sorghum residue on wheat is unaffected by whether the crop failed or yielded normally [82]. The wheat will need extra N to overcome this effect and produce normal yields. They added that it will still be a good idea to apply the recommended extra 30 lbs/acre of N to wheat being planted into failed sorghum. Is possible that residual nitrogen remains in the soil and a profile soil test will provide valuable information. That extra N should be added to the topdressing done this winter or early spring, as long as the wheat crop seems to have at least average yield potential. Finally, wheat grain protein following wheat, canola, and corn was greater than that of wheat following grain sorghum, soybeans, and sunflowers [83].

3.6.2.2 Availability of potassium

Sorghum or Sudan grass – wheat sequence led to increase in potassium soil in comparison with growing wheat after fallow (Table 1). Obviously, growing wheat after the cyanogenetic plants led to imbalance in availability of nitrogen soil that caused by the cyanogenetic plants and consequently negative effect on availability of potassium soil in the experimental soil. Obviously, the study suggests that nitrogen soil deficiency which caused by sorghum or Sudan grass could be inhibit potassium uptake in wheat tissues despite the availability of potassium in the soil. Similar results [47] revealed that high nitrogen rates can promote potassium uptake and increase potassium depletion if clippings are removed as on greens.

3.6.2.3 Secretion hydrocyanic acid 'HCN'

Roots of sorghum and Sudan grass secreted certain toxic compounds, *i.e.* hydrocyanic acid 'HCN' (Table 1) which inhibited emergence and growth of the following wheat plants and finally decrease in the final yield per unit area (Table 8). These results are in harmony with that wheat (*Triticum aestivum* L.) yield is depressed when the crop is grown after sorghum [84]. Also, the sorghum species, including Sudan grass, are capable of building up high levels of Prussic acid, also known as HCN or hydrocyanic acid in the leaves [25]. This occurs when environmental conditions are unfavorable for growth. Cultivars differ in their Sudan grass is California’s most important summer annual hay crop. Prussic acid causes death by interfering with the ability of red corpuscles in the blood to transfer oxygen. Since prussic acid deteriorates over time, hay or silage that contained HCN at harvest is usually safe after storage for three or more weeks. Nitrate poisoning is also a hazard of Sudan grass production, as well as the other summer annual grasses. Nitrate accumulation can occur with any species (particularly grasses), but Sudan grass is a famous nitrate accumulator. Moreover, some sorghum genotypes produce the phytotoxic compounds which have inhibitory effects on wheat, so probably a fallow period would be the best choice after sorghum [85]. Finally, the extract of different tissues of sorghum plant has severe deterrent effect on wheat seeds germination of Alvand cultivars [86]. The results showed that four extracts of leaf, seed, root, and stem have more deterrent effects on wheat seed germination. Some of different tissues extracts of sorghum plants has an effect stimulated on longitudinal growth and wet weight of wheat radicle, coleoptile and seedling of Alvand cultivar, and also the most effect stimulated is related to the root extract, and the leaf extract has a deterrent effect on wet weight of seedling, radicle and coleoptile.

4. CONCLUSION

The results concluded that *Sorghum sp*. (cyanogenetic plants) promoted growth plants of *Fabaceae* and *Lillaceae* families under this study and appear to be promising for berseem, faba bean and onion production. Sorghum or Sudan grass roots secreted biologically active chemical compounds which have a positive effect on the growth and development of acceptor plants (berseem, faba bean and onion). On the contrary, growth plants of *Poaceae* and *Chenopodiaceae* families were affected negatively by the cyanogenetic plants as preceded crops.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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