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# The Effects of Biosolid Application on Water-Use Efficiency and the Growth Behavior of Sesbaniasesban (L.) Merr in Arid Mediterranean Environments

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## Abstract

Improving water-use efficiency (WUE) of cultivated crops serves as a key solution for maintaining high crop production levels under limited water resources. The main objective of this study is to investigate the potential use of municipal biosolids as soil amendments for the improvement of the production and WUE of *Sesbaniasesban* (L.) Merr. Different levels of fermented dewatered biosolid were applied and mixed with the soil surface at the rates of 0.0 (control), 2.0, 4.0, 6.0, 8.0, and 10.0 ton/ha. Experimental treatments were arranged in a randomized complete block design with three replicates. The biological yield and water-use efficiency were significantly affected by biosolid applications. The highest increase in the biological yield (49.83 ton/ha) and water-use efficiency at the biological yield harvest stage (5.46) were obtained at the highest rate of biosolid application (10 ton/ha). Lower levels of biosolid applications (2, 4ton/ha) did not affect the biological yield. Moreover, grain yield, water-use efficiency at grain yield stage, Harvest Index, and average stem diameter were not significantly affected by biosolid applications. The biological yield and water-use efficiency showed a high increase (29 %) in their outputs compared to the control treatment.

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**Keywords:** Sesbania species, sewage sludge, grain and biological yield, forages, Mediterranean basin.

## 1. Introduction

The estimated agriculture production in 2050 must increase by 60 % globally to satisfy the food needs of the growing populations, particularly (up to 100 %) in developing countries (UN, 2015). The increasing demand for water in agriculture has increased the pressure on fresh water resources (Molden et al., 2010). The potential livestock production possibly will be negatively affected because of the continuous need for water for agricultural crops. Several researches were done in this regard to investigate the potential improvement in water-use efficiency aiming to increase the agricultural production at low water contents, especially for fodder production (Mendoza-Grimón, et al., 2015).

Water-Use Efficiency (WUE) is defined as the ratio of total biomass produced to the water supply used, and is considered an efficient tool in detecting the conservative plant properties. WUE is a measure of specific crop capacity to convert absorbed water into plant biomass, including other plant metabolic activities (Molden and Oweis, 2007), and therefore, it is considered a key factor in securing environmental sustainability of food production in dry areas. The improvement in plant biomass and crop yield is possible by increasing the percentage of WUE by plants, while maintaining the production levels at economically feasible levels (Aggarwal, 2000; Wang et al., 2011).

Municipal wastewater treatment plants transform sewage biosolids into a uniform waste type referred to as biosolids. The biosolids, which are treated and managed appropriately complying with the national and international standards, can be used to support plant nutrition (Albaladejo et al., 2008). Biosolids are rich in several macronutrients such as N, P, K, Ca, Mg , S and micronutrients, such as Ca, Cu, Zn, Fe, Mg, Mn, B and Mo (Usman et al., 2012). For this study, biosolids were brought from the Municipal Water Treatment Plant (MWTP) of Ramtha in Northern Jordan. They were dewatered using an Infrared radiation (IRD) process, where moisture is removed, and pathogens in sewage sludge were destroyed, to confirm their compliance with the standards and regulations, set by the Jordanian national authorities to regulate the environmental and health issues (JOB, 2006).

The moisture content was measured and found to be (<10 %), with non-traceable pathogens. After grinding, the biosolids were distributed manually over the plots, based on the treatment specified for each plot. The biosolids were mixed and incorporated into the soil, using a rotovator to a depth of 20 cm, and then covered with black plastic mulch before sowing Sesbania seeds. The area of each plot was 6 $m^2$ (2×3 m).

(L.) Merr is a fast growing shrub belonging to the Fabaceae family. It is a short-lived tree with a high foliage percentage, and is characterized by its deep-root system with a single or multiple stems reaching a height of 6 m (Hang

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et al., 2011; Mani et al., 2011) and a diameter of 20 cm. It is a nitrogen-fixing species with a high nitrogen content (Dinendra and Azad-ud-doula, 2001; Gupta et al., 2011; Pandhare et al., 2011) that could be used as an effective source of protein to support the low-protein roughages for livestock feeds (Patra et al., 2006). The rapid Sesbania growth and its high nutritive value, make it a very promising nutritive source of cut-and-carry forages (Gupta et al., 2011; Manaye et al., 2009; Naik et al., 2011; Pandhare et al., 2011; Sabra et al., 2010).

S. sesban can be grown in a variety of soil characteristics and can tolerate salinity especially at a maturity stage. The production of S. sesban under low soil-moisture content possibly can be improved using soils with a high-nutrient content, such as those treated with fermented biosolids. The efficiency of such protocols can by assessed using biological and grain yields and harvest indices (Bolinder et al., 2007; Bondeau et al., 2007). These indices are considered ideal measurement to estimate the effect of certain treatments used to improve the crop progression rate and production, and to show variability in the harvested components of interest to compare the effects of different treatment application rates. Several plant parameters were used to evaluate the effect of biosolid application on Sesbania growth and the potential benefits that might be attained.

The objective of this research is to assess the effect of applying different levels of municipal biosolids on the biological yield and the WUE of the forage crop S. sesbanat at the stages of grain yield, and to measure other parameters of plant growth such as the harvest index (HI), and the average stem diameter (ASD).

## 2. Materials And Methods

The current study was executed at Deir-Alla agriculture station in Jordan Valley-the Northern Ghorat 32°11'36.3"N 35°37'16.7"E. Deir-Alla is considered a subtropical steppe of a low-latitude and a semi-arid hot climate. The annual average temperature is 23.6 °C with an average annual precipitation of 280 mm. According to the National Soil Map Project (NSM and LUP, 1993), the soil is fine and loamy.

The experiment was set up based on randomized complete block design (RCBD) with three replicates and six treatment levels. The biosolids were applied at different levels: 0, 2, 4, 6, 8, 10 ton/ha. This study did not cover the biosolid chemical or nutrient analysis, since several other studies have already reported the beneficial use of biosolid application on plant production due to the appropriate content of plant-required nutrients. Such studies reported that the digested and dewatered biosolids contain 3-6 % N, 1-4 % P, 0.2-1 % K and 50-60 % organic matter.

Sesbania seeds were planted for two seasons on the 5th of June, 2014 and 2015 and were harvested after ninety-nine days on the 14th of September, 2014 and 2015. The planting spaces were 40 cm within lines and 60 cm between lines. Seedlings were irrigated using an inline drip irrigation system with emitters (4 L/h), with a spacing of 0.4 m and 0.6 m between laterals. The amount of irrigation water was based on the potential evapotranspiration that was calculated based on Penman-Monteith equation, and crop coefficient was obtained from FAO 56 hand book. The meteorological data were obtained from the meteorological climatic station in Deir-Alla. Supplemental irrigation was added after the rainfall to reach the crop evapotranspiration point based on 100 % ET. The total accumulated amounts of added water during the growing seasons were 613 and 650 mm for 2014 and 2015, respectively.

Water-Use Efficiency (ton/$m^3$) was measured by dividing the biological or grain yield (ton/ha) over the total amount of water added ($m^3$). The rate of dry matter increase was the best measure to evaluate plant performance and its success in any environment (Vasudevan et al., 2005). BY, GY, HI, and the average stem diameter (ASD) were measured in both growing seasons. For BY, leaves from the selected plants were taken and oven-dried at 68 C° for twenty-four hours for dry weight estimation. The total biomass or biological yield was calculated by adding the woody biomass weight and the dry leafy biomass weight. The GY was estimated by the recurrent harvest of random plants in different rows, while HI was used to quantify the yield of Sesbania species versus the total amount of biomass that has been produced. HI was measured using grain yield in weight base (ton/ha) of the harvested product divided by the total mass of the aboveground plant as a percentage. The stem diameters (SD) were measured as an average value of the stem diameters taken at the knee height (DKH) above the average ground level at 50 cm height, outside bark and at the breast height (DBH).

The data for the two years were merged and averaged (data were normally distributed) because the analysis output showed similar results between years. The collected data were analyzed using Statistical Analysis Software (SAS Institute, 2011). Treatments were considered statistically significant, when the model statement showed α value (< 0.05). LSD (Least Significance Difference) was used to separate means whenever the significant variability was detected.

## 3. Results and Discussion

The statistical analysis shows that there were significant differences in BY (Table 1), and WUE at the biological yield stage ($WUE_{BY}$), as represented in table 2, with the different biosolid application rates. The same was seen in WUE at the grain yield stage ($WUE_{GY,}$ Table 2). There was an increase by about 39 % in BY (Tables 1 and 2), as well as $WUE_{BY}$ (Tables2). The analysis of variance shows no significant effects at different biosolid application rates on GY.

**Table 1**. Sesbania BY and GY significance distribution using different rates of biosolid.

| Treatment | Mean for Biol. | Std Err Mean | Mean for Grain. | Std Err Mean |
|---|---|---|---|---|
| T1-0 | 38.42c | 1.12 | 2.69c | 0.85 |
| T1-10 | 49.83a | 1.22 | 3.9a | 0.44 |
| T1-2 | 39.06c | 0.64 | 2.76c | 0.52 |
| T1-4 | 39.16c | 0.97 | 2.83bc | 0.49 |
| T1-6 | 42.98bc | 0.51 | 3.15b | 0.55 |
| T1-8 | 43.73b | 1.01 | 3.73a | 0.20 |

Values in a column followed by the same letter are not significantly different according to the Newman-keuls test at $p < 0.05$.

**Table 2**. Sesbania WUE Biol. and WUE grain significancy

| Treatment | Mean for WUE boil | Std Err Mean | Mean WUE grain. | Std Err Mean |
|---|---|---|---|---|
| T1-0 | 4.21c | 0.12 | 0.29c | 0.09 |
| T1-10 | 5.46a | 0.13 | 0.43a | 0.05 |
| T1-2 | 4.28c | 0.07 | 0.30c | 0.06 |
| T1-4 | 4.29c | 0.11 | 0.31c | 0.05 |
| T1-6 | 4.71b | 0.06 | 0.35b | 0.06 |
| T1-8 | 4.7b | 0.11 | 0.41a | 0.02 |

Values in a column followed by the same letter are not significantly different according to the Newman-keuls test at $p < 0.05$.

The applied biosolids underwent what is called Vector attraction reduction (EPA, 2000), which is referred to as the processing of biosolids to make them less attractive to vectors or organisms, such as rodents and insects (EPA, 2002), which, at the end, reduced the potential for transmitting diseases. Microbial analysis indicated the absence of harmful pathogens, and the biosolids were found to be safe.

The results obtained underwent statistical analysis for significancy of the data obtained, and were represented in tables and figures, as well as linear regression analysis. None documented analysis of Pearson correlations indicates that there was a high correlation between the biosolid application rate and BY (0.872), whereas BY increased as the biosolid rate increased. This was approved when measuring the R- square, in which less than 76.1 % of variability in the biosolid application rate can be accounted for the quantity of the biosolid applied. Also, the adjusted R- square (0.75) of variability and the difference between the R- square and the adjusted R- square becomes smaller as the sample size becomes larger, since the standard deviation was positive.

A biosolid application rate of (10 ton/ha) showed the highest biological yield value (Table 1). The biological yield tended to increase with the increase of the biosolid application rates, which was represented also in mean plots diagram. The line of fit in the fitting curve histogram (Figure 1) was suspended away from the horizontal by the points through confidence curve. This figure shows that the biological yield is statistically significant. Grain yield exhibits the same trend (Figure 2), in which it was statistically significant, while the intercept value (Figure 3) shows how much the grain yield can increase with the increase of the biosolid rate; it goes down as the biosolid application rate gets down.

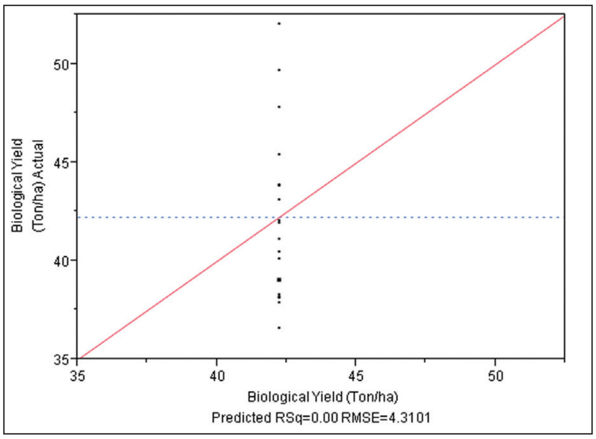


**Figure 1.** Actual predicted plot of the whole model response of biological yield (ton/ha) in Sesbania

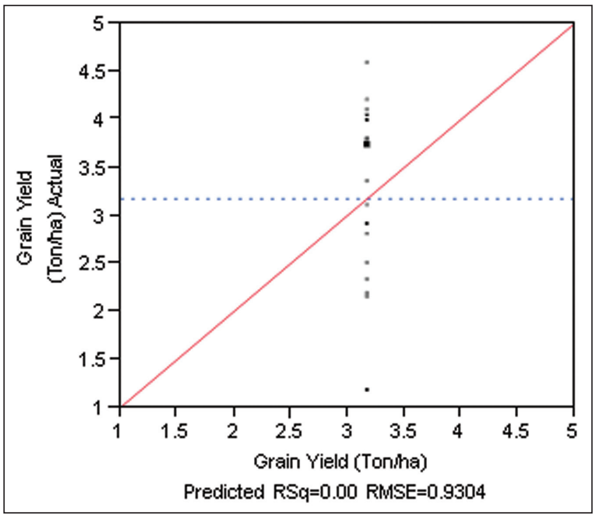


**Figure 2.** Actual predicted plot of the whole model response of Grain yield (ton/ha) in Sesbania

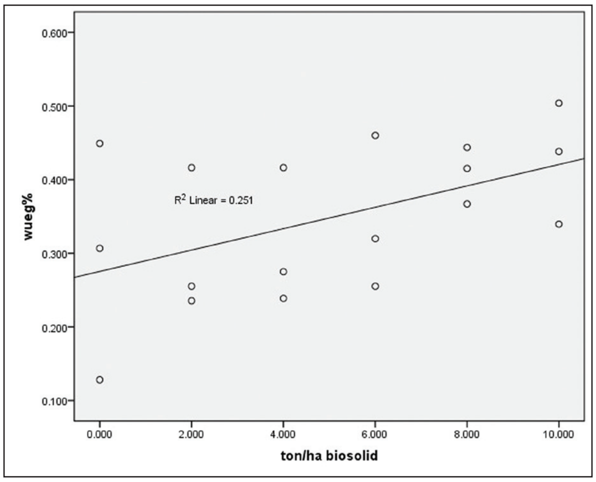


**Figure 3.** Scattered plot distribution of WUE at grain yield in Sesbania

The improvements obtained with the increase of biosolid application rate was consistent with the results of Garcia et al. (2000), where they reported an increase in the biomass production of some herbaceous plants in response to biosolid application. This is probably because the biosolid application improved plant growth rates and conditions, as a positive effect (Fernández-Luqueño et al., 2010; McLaughlin et al., 2007).

The responses of Sesbania to the addition of biosolids were also noticed through its effects on the WUE (Table 2). There were significant differences of the WUE for the biological yield of Sesbania under the different levels of biosolid applications (Table 2).

The same trend of improvement was obtained in the WUE for the biological yield level by the same amount of increment (23 %), at the rate of 10.0 ton/ha of biosolids when compared to the control treatment rate. Results obtained shows that there was a relationship between the amount of the biological yield obtained, and the improvement in WUE, in which a significance difference occurs clearly at 10.0 ton/ha of the biosolid application rate in comparison to the lower biosolid application rates (8.0 ton/ha). These results show an increase in both parameters of about 12 %, while measuring the change in these parameters when compared to the differences between the lower biosolid application rates, at 8.0 ton/ha and 6.0 ton/ha, or much lower rates, the results show an increase in just about 2 % of them. These results support the findings of other researchers (Rostagno, 1998; Moffet, 1997; Harris-Pierce et al., 1995; Aguilar et al., 1994), who stated that using biosolids can increase soil water availability. At the same time, it can said that the biosolid application rate may act as any other organic form of fertilizer, in which the N conversion to plant state– available inorganic forms increase, especially in the case of legumes, and to a certain limit much higher than non nodulated crops were steady – being not reached yet.

Although the statistical analysis shows no significant differences among the grain yield, and WUE at the grain stage (Table 2) with respect to the different biosolid application rates, the amount of increment produced in grain yield was (33 %) at 10.0 ton/ha, when compared to the control treatment rate. The responses of the harvest index and average stem diameter parameters to different biosolid application rates were not significant, and show the same trend, but in a lower percentage, in which the increase in their values was up to (10 %), when compared to the control.

Davis et al. (2014) reported similar results, where they noticed that the vegetative growth of Irish potato due to the inorganic fertilizers addition was higher than that for the tuber formation. The results of this research emphasize the current obtained results which show that the outcome of using biosolids to improve the biological yield and the water-use efficiency of Sesbania plant was achieved.

The (S. Sesbania) crop is expected to serve as a source for animal feeds especially in arid regions where water is in a very limited supply. It might be necessary, later on, to run further studies to study the presence of biosolid residues in the soil after harvesting crops at higher levels of application rates (>10 ton/ha). Although Garrido et al. (2005) did not find a significant increase in organic matter and the total nitrogen in the soil, which is possibly due to the use of low biosolid rate (4.5 ton/ ha), as well as the short-term nature of biosolids application, and the relatively low concentrations of trace elements in the biosolids.

It can be concluded that the effect of biosolid application on the plant biological yield and WUE is detectable with a possible minimal effect on the grain yield and grain related indices. This conclusion encourages farmers to look after such crops for the sake of thier herds, and their production sustainability, especially under arid and semi-arid conditions.

## 4. Acknowledgment

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