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# Effect of the application of a biofertilizer on the yield of forage oats (*Avena sativa* L.) in the southern Durango, Mexico

## Efecto de la aplicación de biofertilizante sobre el rendimiento de avena forrajera (*Avena sativa* L.) en el sur de Durango, México

## Efeito da aplicação de biofertilizantes no rendimento de aveia forrageira (*Avena sativa* L.) no sul de Durango, México

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**Crop production**

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## Abstract

It is a priority to identify more efficient ways to fertilize crops without harming the soils. Biofertilizers obtained from the anaerobic digestion of manure can emerge as an ecological alternative in crop production. This study aimed to evaluate the yield and nutritional characteristics of oats (*Avena sativa* L.) fertilized with different doses of biofertilizer (Biol) through foliar application. In southern Durango, Mexico, four doses of Biol were applied: 0, 220, 440, 660 and 880 $L.ha^{-1}$, corresponding to treatments T1, T2, T3, T4, and T5, respectively, using a completely randomized block design. The crude protein (CP) content was similar among treatments ($p>0.05$); meanwhile, neutral detergent fiber (NDF), acid detergent fiber (ADF), and phosphorus (P) decreased with the maximum doses of Biol ($p<0.05$). Regarding *in vitro* dry matter digestibility (IVDMD) differences were found ($p<0.05$). Fresh weight (FW) and dry weight (DW) yields increased with the higher doses of Biol, achieving higher values of 25.50 and 7.05 $t.ha^{-1}$, respectively. Additionally, the application of the biofertilizer Biol increased oat yield and improved some nutritional values of the forage. These results suggest that Biol is a viable alternative to the use of chemical fertilizers, promoting sustainable agriculture and contributing to the mitigation of the negative environmental impact generated by chemical fertilizers.

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## Resumen

Es prioritario identificar formas más eficientes de fertilizar los cultivos sin ser perjudiciales para los suelos. Los biofertilizantes obtenidos a partir de la digestión anaerobia del estiércol pueden surgir como una alternativa ecológica en la producción de cultivos. Este estudio tuvo como objetivo evaluar el rendimiento y las características nutricionales de avena (*Avena sativa* L.) fertilizada con diferentes dosis de biofertilizante (Biol) mediante aplicación foliar. En el sur de Durango, México, se evaluó la aplicación de cuatro dosis de Biol: 0, 220, 440, 660 y 880 $L.ha^{-1}$ correspondientes a los tratamientos T1, T2, T3, T4 y T5, respectivamente, utilizando un diseño de bloques completamente al azar. Los contenidos de proteína cruda (PC) fueron similares entre tratamientos (p>0,05); mientras que, la fibra detergente neutra (FDN), la fibra detergente ácida (FDA) y el fósforo (P) disminuyeron con las dosis máximas de Biol (p<0,05). En cuanto a la digestibilidad *in vitro* de la materia seca (DIVMS) se encontraron diferencias (p<0,05). Los rendimientos en peso fresco (PF) y peso seco (PS) se incrementaron con las dosis más altas de Biol; alcanzándose valores más elevados con 25.50 y 7.05 $t.ha^{-1}$, respectivamente. Además, la aplicación de biofertilizante Biol incrementó el rendimiento de avena y mejoró algunos valores nutricionales del forraje. Estos resultados sugieren que el Biol es una alternativa viable al uso de fertilizantes químicos, promoviendo una agricultura sostenible y contribuyendo a la mitigación del impacto ambiental negativo generado por los fertilizantes químicos.


**Palabras clave**: Biol, estiércol bovino, producción, fermentación, composición química, digestibilidad.


## Resumo

É uma prioridade identificar formas mais eficientes de fertilizar culturas sem prejudicar os solos. Biofertilizantes obtidos da digestão anaeróbica de esterco podem surgir como uma alternativa ecológica na produção agrícola. Este estudo teve como objetivo avaliar o rendimento e as características nutricionais da aveia (*Avena sativa* L.) fertilizada com diferentes doses de biofertilizante (Biol) por meio da aplicação foliar. No sul de Durango, México, foram aplicadas quatro doses de Biol: 0, 220, 440, 660 e 880 $L.ha^{-1}$, correspondendo aos tratamentos T1, T2, T3, T4 e T5, respectivamente, utilizando um delineamento de blocos completamente randomizados. O teor de proteína bruta (PB) foi semelhante entre os tratamentos (p>0,05). Enquanto isso, a fibra em detergente neutro (FDN), a fibra em detergente ácido (FDA) e o fósforo (P) diminuíram com as doses máximas de Biol (p<0,05). Em relação à digestibilidade da matéria seca *in vitro* (DMSIV), foram encontradas diferenças (p<0,05). Os rendimentos de peso fresco (PF) e peso seco (PS) aumentaram com as doses mais altas de Biol, alcançando valores mais altos de 25,50 e 7,05 $t.ha^{-1}$, respectivamente. Adicionalmente, a aplicação do biofertilizante Biol aumentou o rendimento da aveia e melhorou alguns valores nutricionais da forragem. Esses resultados sugerem que Biol é uma alternativa viável ao uso de fertilizantes químicos, promovendo a agricultura sustentável e contribuindo para a mitigação do impacto ambiental negativo gerado pelos fertilizantes químicos.


**Palabras-chave**: Biol, estrume de bovinos, produção, fermentação, composição química, digestibilidade.

## Introduction

The production of livestock is a significant contributor to the global economy. Its primary function is to provide animal protein for human consumption. Forage production is a vital component in meeting the nutritional requirements of the livestock sector. In Mexico alone, over 108 million hectares are dedicated to the cultivation of productive ruminants (Enríquez Quiroz *et al.*, 2021). Livestock farming is developed in extensive systems and produces about 70 % of forage for use in animal feed (SIAP, 2013). However, soils used for pasture production have been coming through several affectations and degradation due to overexploitation, which leads to critical reduction in forage production and availability (Duan *et al.*, 2024). Therefore, irrigated crops have become a significant source of forage for animal feed (Souza *et al.*, 2019). However, the demand for irrigated soils to produce more forage is high, as it is necessary to supply more productive animals to feed a growing population.

The global population has grown at an alarming rate, accompanied by a corresponding increase in demands. It is projected that the global population will reach 9.5 billion people by 2050. Therefore, the demand for food supplies has reached a critical point. Thus, a constant increase in livestock demands greater high-quality forage production (González-Salas *et al.*, 2018). To achieve high yields, it is necessary to satisfy the nutritional needs of plants, which are not always supplied by the air, water, and soil. Therefore, it is essential to provide plants with the requisite macronutrients and micronutrients for optimal growth (FAO and IFA, 2002). The majority of farmers utilize chemical fertilizers in their cultivation practices. It would appear that cultivars result in an immediate increase in production. However, the environmental cost of this approach is higher. The accumulation of selective chemical elements in the soils is a significant concern, particularly in the case of phosphorated fertilizers (Mukhtar *et al.*, 2017; Elbasiouny *et al.*, 2020). Additionally, numerous researchers have documented detrimental impacts on soil quality following the application of chemical fertilizers. These practices have been linked to a decline in soil fertility and the disruption of the native soil microbiota (Torres-Moya *et al.*, 2016; Vásquez and Maraví, 2017). As a result, sustainable agricultural practices and the use of organic products have gained greater prominence.

Biol is a liquid biofertilizer produced through the anaerobic digestion of one or more substrates, including animal manure, agricultural residues, and organic matter (Peñafiel Rodríguez and Ticona, 2019). The product contains microelements that are not typically present in chemical fertilizers. Propagation may be achieved through direct irrigation or foliar application (Linares-Gabriel *et al.*, 2016). Furthermore, Biol may provide essential macronutrients including nitrogen, phosphorus and potassium. As a result, it is regarded as a complex phytostimulant that promotes root growth and increases photosynthesis, thereby enhancing plant production and quality (Cabos Sánchez *et al.*, 2019).

Conversely, oats (*Avena sativa* L.) are frequently utilized as a forage source in the feeding of cattle and other ruminants. Given that oats are a seasonal crop, they may be able to adapt to changes in environmental conditions. However, Alejo Rivera *et al.* (2020) reported a negative correlation between reductions in water supply and production. Additionally, Arias *et al.* (2021) proposed that oats can be cultivated in a range of loamy to sandy loamy soils with a pH slightly acidic to neutral (5 – 7). In addition, they noted that the production may fluctuate contingent on soil and irrigation conditions. Accordingly, the objective of this study was to assess the yield and nutritional attributes of oats treated with different doses of biol through foliar application.

## Materials and Methods

**Experimental location**

The experiment was conducted from January to April 2023 in a crop area in Paura, municipality of El Mezquital, Durango (23°36'43.3" N, 104°21'44.5" W). The mean annual temperature is 19.2 °C, with an annual precipitation of 650 mm (SMN, 2024). The crop is irrigated via an irrigation channel that draws water from the San Pedro Mezquital River.

**Soil analysis**

Four soil samples were extracted using a zigzag sampling pattern at a depth of 30 cm from the surface of the entire crop field. The soil samples were allowed to dry at room temperature in a ventilated shaded area for a period of five days. After drying, the samples were sieved at 2 mm. Subsequently, soil parameters were analyzed, including pH, electrical conductivity (EC), organic matter (OM), texture, total Kjeldahl nitrogen (TKN), phosphorus (P), potassium (K), sodium ($Na^+$), calcium ($Ca^+$), magnesium ($Mg^+$), chlorides ($Cl^-$) and bicarbonates ($HCO_3^-$). The soil parameters are presented in Table 1. All analyses and sampling methods were conducted in accordance with the standards set forth in NOM-021-SEMARNAT-2000 (SEMARNAT-2000).

**Table 1. Soil parameter analysis.**

| Parameter | Soil | Reference | Observation |
|---|---|---|---|
| pH | 8.2±02 | 7.4-8.5 | Slightly alkaline |
| EC ($mS.cm^{-2}$) | 7.01±0.038 | 4.1-8.0 | Saline |
| OM (%) | 1.5±0.30 | 0.6-1.5 | Low |
| Texture | Sandy loam | | |
| TKN (%) | 0.19±0.0188 | 0.05 %-0.10% | Low |
| P ($mg.kg^{-1}$) | 6.72±0.33 | 5.5-11<br>>11 | Medium<br>High |
| K sol ($Cmol.L^{-1}$) | 0.11±0.001 | <0.2 | Very Low |
| $Ca^+$ ($Cmol.L^{-1}$) | 0.091±0.008 | <2 | Very Low |
| $Mg^+$ ($Cmol.L^{-1}$) | 0.1±0.03 | <0.5 | Very Low |
| $HCO_3^-$ (%) | 0.3±.015 | <0.5% | Very Low |
| $Cl^-$ ($mg.kg^{-1}$) | 142±12.8 | <4000 | Low |
| $Na^+$ sol ($mg.kg^{-1}$) | 50±0.29 | <4000 | Low |

Note: Observations are following NOM-021-SEMARNAT-2000

The pH, EC, and OM are within the ranges specified in reference data proposed by NOM-021-SEMARNAT-2000. However, the pH value is deemed to be slightly alkaline, while the EC value is classified as saline. In contrast, the organic matter value is relatively low. Nonetheless, the texture obtained (sandy loam) permits the cultivation of oats, as evidenced by prior research conducted by Arias *et al.* (2021).

Additionally, the total nitrogen (TKN), chloride (Cl), and sodium (Na) values are deemed to be low, while the mineral concentrations of potassium (K), calcium (Ca), magnesium (Mg), and bicarbonate ($HCO_3$) are considered very low. These results suggest that soil conditions are mainly characterized as poor soil or degraded soil (Mosier *et al.*, 2021). These conditions may affect or limit the growth of crops; maximum yield may be diminished, and the cost of production of every unit of dry matter will be higher. Moreover, at these pH values, phosphorus and nitrogen become less accessible to plants, while calcium, magnesium, and potassium become more accessible (Osman, 2013). Otherwise, phosphorous levels are considered as medium. However, as indicated earlier, this may not be available for plant growth due to pH values (Bouray *et al.*, 2021).

## Biofertilizer

Biol is produced locally through the anaerobic digestion of bovine manure (Cabos Sánchez *et al.*, 2019). The Biol was analyzed for parameters including pH, electrical conductivity (EC), total Kjeldahl nitrogen (TKN), phosphorus (P), potassium (K), sodium ($Na^+$), calcium ($Ca^+$), magnesium ($Mg^+$), chlorides ($Cl^-$) and bicarbonates ($HCO_3^-$), all in accordance with the standard set forth NOM-021-SEMARNAT-2000 (SEMARNAT, 2000).

**Treatments and crop field**

The oats were sown in a 2000 m² field using the turning technique. The foliar fertilization doses are detailed in Table 2. Fertilization was applied using battery backpack sprinklers in two applications, each consisting of 50% of the total dose, at 30 and 60 days after sowing. The experiment included three repetitions for each treatment. The oats were allowed to grow for 90 days post-sowing.

**Table 2. Treatments evaluated.**

| Treatment | T1 | T2 | T3 | T4 | T5 |
|---|---|---|---|---|---|
| Dose $L.ha^{-1}$ | 0 | 220 | 440 | 660 | 880 |

**Biomass production and chemical composition analysis**

Following a period of 90 days, the whole plants of oat forage was harvested for the purpose of evaluating its production in terms of dry weight (DW) and fresh weight (FW), the total of plants harvested were selected in accordance with the square meter methodology described by Ferro-Díaz (2015). Subsequently, the chemical composition of the samples was analyzed. The dry matter (DM), and crude protein (CP) were analyzed according to the AOAC (2005) methodology, while the phosphorus content was determined according to the Galyean (2010) approach. The neutral detergent fiber (NDF) and acid detergent fiber (ADF) were evaluated according to the Van Soest *et al.* (1991) protocol. Finally, *in vitro* dry matter digestibility (IVDMD) was analyzed using the methodology and equipment provided by ANKOM Technology (ANKOM-Technology, 2008).

**Statistical analysis**

Chemical composition and biomass production were evaluated using a completely randomized block design, analyzed through the GLM procedure in SAS (2003). The observed differences among means were subjected to a Tukey test with a significance level of $p<0.05$.

## Results and discussion

The parameters in the biol are presented in Table 3. The foliar application of fertilizers presents significant advantages for agricultural production, providing essential nutrients during instances when soil conditions hinder root absorption and achieving enhanced application efficiency , thus potentially supplying a portion of the nutrients required to support vegetative growth (Otálora *et al*., 2018) Analysis of soil indicated that N availability is low; thus, a N direct foliar application will conduct to higher yields as reported previously (Henrichsen *et al*., 2022; Peter *et al*., 2024). Otherwise, the concentration of K in Biol is high; higher concentrations of K may lead to an increase in growth and salinity tolerance as reported by other studies (Hasanuzzaman *et al*., 2018). In fact, exogenous application of K improves organic osmolyte synthesis which indicates that recovery from osmotic stress will be faster. Likewise, similar concentrations of K have been reported by Gutierrez Arce *et al*. (2020) which also increased alfalfa yield. However, higher concentrations of Na and Cl are not recommended since they promote salinity in plants and may decrease growth (Hasanuzzaman *et al*., 2018). Calcium serves a pivotal structural function within the middle lamella, where it binds to the carboxyl groups of pectins, effectively acting as an adhesive between neighboring cell walls; it also facilitates cellular elongation in shoot apexes and root tips. Magnesium is indispensable for chlorophyll synthesis, ATP biosynthesis, and enzyme activation, with foliar applications offering rapid alleviation of deficiency symptoms compared to soil treatments. Chloride is readily absorbed by plants and functions as a crucial cofactor in various enzymatic processes, enhances tissue hydration, regulates osmotic pressure, and contributes to stomatal movement and ion balance (Micro-Macro Publishing, 2014). The concentration of macronutrients observed in the biol are similar to those reported by Gil Ramírez *et al*. (2023); these authors reported 290 $mg.L^{-1}$ of N in the digestate. Contrarily, minerals such as Na, Ca, Mg, and Cl reported in this study was different from those reported by Mortola *et al*. (2019).

**Table 3. Chemical composition of Biol.**

| Parameter | Biol |
|---|---|
| pH | 8.34±0.05 |
| EC ($\mu S.cm^{-2}$) | 3331±19.23 |
| TKN ($mg.L^{-1}$) | 171.58±5.08 |
| P ($mg.L^{-1}$) | 16.49±0.36 |
| K (sol $mg.L^{-1}$) | 3148±18.17 |
| $Na^{+}$ (sol $mg.L^{-1}$) | 17164±99 |
| $Ca^{+}$ ($mg.L^{-1}$) | 113.4±5.6 |
| $Mg^{+}$ ($mg.L^{-1}$) | 63.96±2.04 |
| $HCO_3^{-}$ ($mg.L^{-1}$) | 1110±9.9 |
| $Cl^{-}$ ($mg.L^{-1}$) | 532.5±3.2 |

Table 4 presents the results of the chemical composition and yield of the harvested oats. It is observed that the application of Biol did not affect the total N and protein contents ($p>0.05$). These results indicate that N contained in biol was not used to increase protein content in plants. Instead, the N administered to crop fields is used for plant growth and could be perceived in the yield of crops. In accordance with the aforementioned findings, a study conducted by Marty *et al.* (2019), indicated that N-fertilization did not exert a notable influence on foliar N concentrations in blueberries. This observation may be attributed to a dilution effect resulting from the enhanced aboveground biomass production associated with N-fertilization. However, the protein content observed in this study is consistent with protein contents reported for this type of forage (Mamani Paredes and Catacallapa Gutiérrez, 2018).

Conversely, the contents of ADF and NDF exhibited differences among treatments ($p>0.05$). A reduction in NDF and ADF in forage is evident when higher concentrations of biol are administered ($p<0.05$); except for T4 which shows similar results to T1 ($p>0.05$). In a similar study, Coblentz *et al.* (2017) applied nitrogen as a chemical fertilizer in the form of urea on oats cultivars and observed a linear increase in NDF, ADF, lignin, and ash when increased doses of urea. In contrast, the concentrations of non-fibrous carbohydrates (NFC) and water-soluble carbohydrates (WSC) exhibited a linear decline when increased urea doses. These changes were attributed to the application of nitrogen or urea fertilizers. Nevertheless, these effects are not observed in the present study. These results may be explained by discrepancies in the application of fertilizer. In the present study biol was applied via foliar spraying, whereas in the study evaluated by Coblentz *et al.* (2017) the fertilizer was applied through irrigation in a flooded furrow. In the context of irrigation, the direct application of nutrients to soil, such as nitrogen (N), can be a viable approach. Conversely, foliar fertilization allows a direct nutrient absorption by plants, thereby mitigating the negative impacts of chemical fertilizers on soil health (Niu *et al.*, 2021). Therefore, this type of fertilization may reduce the adverse effects of chemical fertilizer on roots and soils, which can be positively associated with improvements in soil quality.

On the other hand, the results presented in this study indicated that there are not changes in IVDMD ($p>0.05$); except for the value obtained in T4 which presented a reduction in IVDMD ($p<0.05$). As a matter of fact, these changes are in accordance with those obtained in the concentration of structural carbohydrates as NDF, ADF and lignin; T4 showed the highest concentrations of these cell-wall carbohydrates and led to a reduction in the IVDMD. Furthermore, it is well established that the digestibility of ruminant animals is reduced when forage presents higher proportions of structural carbohydrates (Van Saun, 2015).

Finally, foliar fertilization of biol resulted in increased yields in fresh weight (FW) and dry weight (DW) ($p<0.05$). Similarly, Montaño-Carrasco *et al.* (2017) observed comparable results with organic fertilizers, reporting yields up to 15 $t.ha^{-1}$ of DW with a combination of compost and inorganic fertilization. In another study, Lama-Calvente *et al.* (2024) applied macroalgae digestate as a biofertilizer and they reported a 76% augmentation in FW fo *Avena strogosa* (black oats) grown in a greenhouse; in the same study, authors applied inorganic fertilization and reported an 25% increase in FW when compared to control.

As previously noted, the nitrogen content of biol did not impact on the crude protein (CP) content of oats. However, the release of nitrogen enhances rapid foliage growth, which makes more efficient the energy absorption through the photosynthesis pathway and promoting the carbon fixation. Nitrogen application can yield improved growth parameters, such as elevated seed and straw yields (Mondal *et al.*, 2024). While foliar spraying may be less effective than soil fertilization due to nutrient limitations, nutrients can be absorbed through leaves and transported to roots, enhancing root activity and delaying plant senescence. This synergy between foliar fertilization and soil nutrient absorption is a significant agricultural practice (Niu *et al.*, 2021).

**Table 4. Chemical composition and oat production (*Avena sativa* L.).**

| Variable | T1 | T2 | T3 | T4 | T5 |
|---|---|---|---|---|---|
| CP (%) | 7.07±0.167$^{a}$ | 7.01±0.200$^{a}$ | 7.10±0.100$^{a}$ | 7.38±0.060$^{a}$ | 7.22±0.149$^{a}$ |
| P (g.kg$^{-1}$) | 3.07±0.037$^{ab}$ | 2.91±0.133$^{ab}$ | 3.59±0.075$^{a}$ | 2.87±0.055$^{ab}$ | 2.56±0.026$^{b}$ |
| N (g.kg$^{-1}$) | 11.5±0.416$^{a}$ | 11.8±0.164$^{a}$ | 11.3±0.275$^{a}$ | 11.2±0.554$^{a}$ | 11.3±0.462$^{a}$ |
| N/P ratio | 3.7±0.165$^{ab}$ | 4.0±0.213$^{ab}$ | 3.1±0.142$^{b}$ | 3.9±0.208$^{ab}$ | 4.42±0.154$^{a}$ |
| NDF (%) | 69.52±0.179$^{a}$ | 64.54±0.423$^{ab}$ | 63.21±0.194$^{ab}$ | 68.65±0.288$^{a}$ | 60.53±0.036$^{b}$ |
| ADF (%) | 45.44±0.255$^{a}$ | 43.17±0.407$^{a}$ | 41.11±0.164$^{ab}$ | 44.17±0.598$^{a}$ | 38.46±0.123$^{b}$ |
| IVDMD (%) | 55.66±0.975$^{a}$ | 57.18±0.94$^{a}$ | 55.03±0.568$^{ab}$ | 51.41±0.912$^{b}$ | 53.87±0.554$^{ab}$ |
| Yield (t.ha$^{-1}$; FW) | 16.25±1.299$^{ab}$ | 16.16±1.922$^{b}$ | 24.33±1.878$^{ab}$ | 25.83±2.420$^{a}$ | 25.50±2.598$^{ab}$ |
| Yield (t.ha$^{-1}$; DW) | 4.92±0.072$^{ab}$ | 4.65±0.947$^{b}$ | 5.83±0.457$^{ab}$ | 5.89±0.026$^{ab}$ | 7.05±0.258$^{a}$ |

WM= Note: Different superscript letters in the row indicate significant differences ($p<0.05$).

## Conclusions

The application of biol via foliar fertilization resulted in a notable enhancement in the yield and quality of oats in the study area. As observed, foliar administration of biol did not affect protein content in oats. However, it did increase the yield in fresh and dry weight. Specifically, 880 L.ha$^{-1}$ of biol increased the yield by 58 % and 43 % in FW and DW, respectively. Although biol application affected DIVMS, it did not make it poor forage, which is highly desirable when oats are utilized as animal feed. The application of biol has been demonstrated to enhance the yield potential of crops. These findings indicate that biol may serve as a viable alternative to chemical fertilizers, thereby promoting sustainable agricultural practices and reducing environmental impact. Further research is recommended to optimize the administration rates of biol and to assess its long-term effects on soil health and crop productivity.

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