Effects of Eucalyptus species plantations and crop land on selected soil properties

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ABSTRACT
The physical and chemical properties of soil are strongly influenced by type of land use system implemented. Eucalyptus is a group of tree species, which is native to Australia but widely grown throughout the world. In Ethiopia also due to its fast-growing nature of eucalyptus combined with its extensively recognized socio-economic benefits, this introduced species has been widely planted. Even if the economic contributions there are a lot of controversies are raised from different parts of the world. Therefore, this study is planned to evaluate the effects of Eucalyptus species plantations and crop land on selected soil properties around Bale. In the case, moisture content, except for Goro district, for the other districts (Agarfa, Dello Menna, Goba, Robe) the amount of moisture content is higher in the soil under Eucalyptus plantation land uses than crop land. When we see the overall mean wise comparison of the whole land uses, as the depth increases the overall mean potential of soil chemical properties in PH, OC%, OM%, and available P decreases. But in the case of EC as the depth increases the concentration slightly increases. When we see the general overview of the land uses, no significant differences were observed between Eucalyptus plantation land uses and crop land use. Even in most of the parameter especially in soil organic carbon and soil organic matter the highest value were recorded in Eucalyptus plantation land uses than crop land use. This is due to the recycling of nutrient through decomposition of different tree parts. In terms of crop land due to cereal crop-intensive agricultural system, most the soil nutrient is depleted. Therefore, this finding concluding that eucalyptus could positively impact soil physical and chemical properties through decayed litter than intensively cultivated crop.

Introduction
Eucalyptus is a group of tree species, which is native to Australia but widely grown throughout the world. It is one of the dominant and potential tree species which belongs to the Myrtaceae family with three genera such as Eucalyptus, Corymbia and Angophora. It is one of the most planted woody species in the world next to Pinus and Cunninghamia (Food and Agriculture Organization [FAO], 2006; Oballa et al., 2010). There are about 900 Eucalyptus species globally grown in the world (Boland et al., 2006). From those species more than 700 known Eucalyptus species are native to Australia (GOA, 2008). Outside its natural eco-region, Eucalyptus is expanding from 0.7 million ha in 1955 to more than 20 million ha Table 1 in 2009, distributed to over 100 countries (Iglesias & Wilstermann, 2008, Shi et al., 2012). Eucalyptus can grow in tropics, sub tropics and some temperate regions and covers 0.5% of the global surface forest area (Grupo, 2009).

Due to high population pressure and unwise utilization, the forest resources of Ethiopia are severely declined and the land is converted in to agricultural land and fast-growing trees plantation. In Ethiopia Eucalyptus is the widely grown tree species in different parts of the country. Due to its potential and its fast-growing nature of the species it supports the livelihood of most of rural as well as the urban society of the country. This species used to fill the construction and fuel wood demand of the country. In Ethiopia Eucalyptus plantation is covering about 506,000 ha from the total land (FAO, 2009). From the total planted area 58% were planted between 1978 and 1989 as community plantation (Yitebitu, 2010).

In the area of Eucalyptus plantation, there are a lot of controversies are raised from different parts of the world and also many concerns have been reported about the negative ecological effects of Eucalyptus species. Different studies have reported that Eucalyptus spp. plantations have devastating effects on the soil physico-chemical properties, depleting soil organic matter content, and negatively impacts soil hydrology (Kindu et al., 2006a; Terefer et al., 2014). Lane et al. (2004) in China found that the expansion of Eucalyptus spp. plantation lowers water tables and reduces water availability due to its deep and dense root network. According to Wen et al. (2009) and Zhu et al. (2009) indicated, Eucalyptus spp. plantation adversely affects the soil physical and chemical properties and plant community biodiversity in China. In Argentina, it affects the nutrient cycling capacity,
ecological, and economic implications of *Eucalyptus* spp. in terms of sustainable forestry (Goya et al., 2008).

The negative effects of *Eucalyptus* on neighboring food crops due to the competition of soil moisture and nutrients, and shade effect were reported in Amhara regional state of Ethiopia (Alebachew et al., 2015). According to different studies, there are a lot of impacts of Eucalyptus tree species are studied in different scholars. The major impact of *Eucalyptus* tree species is impacts on water resources, soil nutrient resources, allelopathic effect on other species, and impacts on agro biodiversity and human nutrition security (Aklilu et al., 2019).

In reverse to this studies from the recent studies suggested that if Eucalyptus is properly planted and managed it supports and improves soil nutrients. Eucalyptus species has potential positive impacts on soilphysico-chemical properties. Recent evidence from the literature suggests that eucalyptus may not always have negative effects on topsoil retention and soil nutrient availability. If Eucalyptus species are planted properly, it can be used as a shelterbelts for crops (Beinart, 2003; Oballa et al., 2010). Also in dry areas, it is used to protect the soil from wind erosion through its lateral roots by holding the top soil from erosion (Oballa et al., 2010).

The effects of *Eucalyptus* spp. plantations on soil properties and depleation of the soil essential nutrients still remain unclear (Bernhard-Reversat & Schwartz, 1997; El-Amin et al., 2001) and conventional scientific reports are scanty (Oballa et al., 2010). Also in Eucalyptus plantation there are a lot of controversies were observed from different parts of the world. A lot issues are raised on the impacts of Eucalyptus plantation on the soil physico chemical properties. According to different studies such types of issues are disproved by different scholars. Due to this, effects of *Eucalyptus* spp. plantations on soil properties and depletion of the soil essential nutrients still remain unclear. These similar issues are also raised in our country as well as in our district. Due to this information gap, additional documentation on the specific effects of *Eucalyptus* spp. plantations in relation to soil physical and chemical properties as well as contribution of the litterfall to soil nutrients enrichment is required. Therefore, this study is planned with the aim of evaluating the effects of *Eucalyptus* spp. plantations and cropland on selected soil properties and to compare the impacts of different species of eucalyptus plantation and cropland uses on soil physical and chemical property around Bale.

**Materials and methods**

**Study area description**

The study was conducted in Bale districts of Oromia regional state of Ethiopia. The area is located in South-eastern part of Ethiopia. Specifically, the study was conducted in Agarfa, Dello Menna, Goba, Goro, and Robe districts of Bale. The study area is located in from highland up to midland agroecology areas of Bale with the bimodal rainfall pattern. The area was located from 1285 to 2732 m.a.s.l. altitudinal range (Figure 1). The major farming system of the study area is crop production with cereal dominant crop farming system.

![Figure 1. Map of Agarfa, Goba, Sinana, Dello Menna and Goro districts of Bale zone, Southeast Ethiopia.](image-url)
Climatic condition

The study was conducted in Agarfa, Dello Menna, Goba, Goro and Robe districts of Bale. When we the overall mean temperature of the study area ranges from 13.1–22.5°C. The rainfall pattern of the area is grouped as bimodal rainfall pattern which the annual totally of rainfall of the area is ranges between 806.9 and 1066.7 ppm (Figure 2–4).

Sampling techniques, data collection and analysis

During this study, the site was selected purposely based on land use type, type of planted species and age categories. From all locations, two land uses those are Eucalyptus plantation and Crop land-use system was selected. From the Eucalyptus land use, four types of Eucalyptus species those are Eucalyptus globulus, Eucalyptus camaldulensis, Eucalyptus saligna and Eucalyptus citrodora was selected based on age categories. The soil sample was collected based on systematic sampling approach. From each land uses the soil sample was collected from five points. During soil sampling from each land uses the sample was collected from three depth (0–15 cm, 15–30 cm, and 30–45 cm) of the soil for each systems. To get the accurate result and to minimize the error, the data collection was carried during the dry season at the month of January to February 2019. According to our context, the selected month is the typical dry season of the district. This is used to get the exact moisture content of the soil.

Data analysis

The samples were air-dried in the laboratory, ground with wooden mortar and passed through 2 mm nylon sieve, finally packed in the polythene bags and labeled for conducting analysis as per standard.

The soil sample was analyzed based on the following procedure.

(1) Soil particle size distribution (texture): was analyzed using Bouyoucos hydrometer method following the procedure described by Bouyoucos (1962).

(2) Soil pH: was measured potentiometrically using a pH meter with combined glass electrode in 1: 2.5 soil to water ratio:

(3) Soil electrical conductivity (EC): was measured in 1:5 (soil to water ratio) (Ryan et al., 2001).

(4) Soil organic carbon content: was determine using Walkley and Black (1934) wet digestion method.

(5) Percent soil OM: was obtained by multiplying percent soil organic carbon by a factor of 1.724.

(6) Available P: was carried out by the Olsen method using sodium bicarbonate as extracting solution (Olsen et al., 1954).

Statistical analysis

Soil parameter for all land uses was analyzed by using one way ANOVA. Mean comparison of the four systems interims of soil depth and land uses were tested by least significant difference (LSD) test at P < 0.05 by using SAS statistical software version 9.1.

Result

Soil physical properties in Eucalyptus species plantation and crop land use systems

The results of the laboratory showed that a high percentage of clay was observed in all soils across
all locations. From all textural class over 50% clay concentrations were recorded in between 0–45 cm soil depths. The soil texture was classified as Clay both for the Eucalyptus and crop land uses (Table 1).

Soil chemical properties under different depths in different land use

Discussion

According to different studies monoculture, plantation forestry may affect soil physical and chemical properties in two different ways. That through direct depletion from the soil into the tree component, and changes in the chemical status of the soil surface as the litter layer is dominated by leaf fall derived from one species. In the case of Moisture content, even if the statistically difference for most of the location, except for Goro district, for the other districts (Agarfa, Dello Menna, Goba, Robe) the amount of moisture content is higher in the soil under Eucalyptus plantation land uses than crop land (Table 2).

When we see the overall mean depth-wise comparison of the whole land uses (Agarfa crop land use system, Agarfa Eucalyptus globules plantation-1, Agarfa Eucalyptus globules plantation-2, Dello Menna crop land use system, Dello Menna Eucalyptus camaldulensis plantation, Dello Menna Eucalyptus citrodora plantation, Dello Menna Eucalyptus saligna plantation, Goro crop land use system, Goro Eucalyptus camaldulensis plantation, Robe crop land use system, Robe Eucalyptus camaldulensis plantation, Goba crop land use system and Goba Eucalyptus globules plantation) as the depth increases the overall mean potential of soil physiochemical properties in PH, OC%, OM%, and available P is decreases. But in the case Electronic conductivity (EC) as the depth increased the concentration slightly increased (Figure 3).

In Agarfa district, when we compare the Eucalyptus land use with the crop land, the overall PH mean value is statistically different. In this district, the PH level of the whole land uses is varied from 6.08 to 6.41. This
shows that the soil of the area is categorized under slightly acidic soil type in nature. Even if there is statically difference between the land uses, the highest PH value (6.41) is recorded in crop land than Eucalyptus land which is more nearest to neutral. For EC there is no statistical difference between the land uses. The overall mean EC of the district 0.04 ds/m which grouped under non-saline soil type. In terms of %OC and %OC there statistical difference among the land uses and the highest value is observed in the soil under Eucalyptus plantation than crop land. For OM the value of the district is ranged from 5.53 to 9.14% which is rating under high-level concentration. For available phosphorus (P) there is no difference between the land uses and the observed available P potential of the whole land uses are grouped under very low class (Table 3a).

In Dello Menna district, there is statistical difference for PH and the highest value was recorded in Eucalyptus saligna (7.05) and Eucalyptus citrodora (7.11) which is based in nature. When we categorize the PH level of the whole land uses, they are grouped under neutral PH level. In terms of EC, the soil around the area is categorized under non-saline soil type and the highest EC value was recorded in the sol under Eucalyptus citrodora plantations (0.07 ds/m). But there is no statistical difference among the other land uses. In the OM and OC%, the high concentration level is observed in the soil under Eucalyptus plantation land uses than crop land. In the case of available P level, even though there is statistical difference, the area is grouped under a very low concentration level. For OC and OM, the highest percent is observed in the soil under Eucalyptus citrodora plantation. Generally, overall OM% and OC% potential of the district are grouped under high concentration level. When we see the available P, they have very low in terms of the concentration level and the highest value is in the crop land uses (2.15 mg/Kg) (Table 3b).

In Goba district there is no statistical difference in PH, OM%, and OC% among the land uses. The PH level shows that the soil is grouped under slightly acidic type. For EC they are grouped under non-saline soil type. In terms of OM and OC% even though there is statistical difference between the land uses as
Table 1. Soil moisture content under eucalyptus plantation and crop land systems.

**(a) Agarfa**

| Land use          | Moisture Content % |
|-------------------|--------------------|
| Eucalyptus globules-1 | 29.83 (± 4.76)*    |
| Eucalyptus globules-2 | 26.30 (± 3.52)*    |
| Crop land         | 28.79 (± 7.50)*    |
| Mean              | 28.30 (± 5.59)     |
| P-value           | < .0001            |
| CV                | 9.71               |

**(b) Dello Menna**

| Land use          | Moisture Content % |
|-------------------|--------------------|
| Eucalyptus salicina | 21.16 (± 3.24)*    |
| Eucalyptus citrodora | 21.01 (± 1.65)*    |
| Eucalyptus camaldulensis | 23.23 (± 3.87)*   |
| Crop land         | 18.04 (± 4.47)*    |
| Mean              | 20.86 (± 3.86)     |
| P-value           | < .0001            |
| CV                | 12.39              |

**(c) Goba**

| Land use          | Moisture Content % |
|-------------------|--------------------|
| Eucalyptus globules | 23.05 (± 2.76)*    |
| Crop land         | 12.96 (± 16.56)*   |
| Mean              | 18.00 (± 12.74)    |
| P-value           | 0.0005             |
| CV                | 7.74               |

**(d) Goro**

| Land use          | Moisture Content % |
|-------------------|--------------------|
| Eucalyptus camaldulensis | 30.57 (± 15.88)*   |
| Crop land         | 36.48 (± 37.02)*   |
| Mean              | 33.52 (± 28.15)    |
| P-value           | 0.2371             |
| CV                | 9.63               |

**(e) Robe**

| Land use          | Moisture Content % |
|-------------------|--------------------|
| Eucalyptus camaldulensis | 28.78 (± 3.74)*    |
| Crop land         | 20.74 (± 6.56)*    |
| Mean              | 24.76 (± 6.65)     |
| P-value           | < .0001            |
| CV                | 10.09              |

the other district the highest concentration is recorded in the eucalyptus land uses than crop lands. In the case of OM and OC percent as the other location of Bale district they have high potential in organic matter and organic carbon percent. For EC and P, the largest value is recorded in crop land uses than in the soil under Eucalyptus plantation land uses. Generally the available P of the district is grouped under a very low level (Table 3c).

In Goro district, there is no statistical difference in PH, OC, and OM soil chemical characteristics. The PH level of the area is grouped under neutral soil class level. In terms of EC there is statistical difference between the land uses and they are grouped in non-saline soil class. For EC the highest value is in the soil under Eucalyptus camaldulensis than crop land uses 0.25 ds/m. For OM% and OC% even if there is no statistical difference between the land uses, the highest percent of concentration is estimated from the soil under eucalyptus plantation than crop land uses. The overall OM and OC percent the soil type of the area is categorized in higher level. In the case of available P there is statistical difference between the land uses and the concentration level is grouped under very low-class level. Due to several factors the largest values are recorded in crop land uses (4.75 mg/Kg) than the other system (Table 3d).

In Robe district there is no statistical difference among the land uses in all soil chemical properties. Except for available P for the remaining parameter (PH, EC, OC, OM) there is no statistical difference between the land uses. The PH level of the district is categorized under slightly acidic soil level. For EC the soil is categorized in the non-saline soil type. For OC% and OM% even if there is no difference between the land uses the amount of OM% in the Eucalyptus plantation is categorized in the high concentration level. For OM and OC percent the concentration is ranged from moderate up to high potential. But for available P even if there is a difference between them both land uses are grouped in a very low level (Table 3e).

**Conclusion and recommendation**

When we see the overall mean wise comparison of the whole land uses as the depth increases the overall mean potential of soil chemical properties in PH, OC %, OM% and available P is decreases. But in the case Electronic conductivity (EC) as the depth increased the concentration slightly increased. In the case of moisture content, except for Goro district, for the other districts (Agarfa, Dello Menna, Goba, Robe) the amount of moisture content is higher in the soil under Eucalyptus plantation land uses than crop land. This may be due to deep-rooted and huge amounts of lateral root nature of the species which contributed to the strong moisture attraction capacity of the species.

When we see the general overview of the land uses, there is no significant differences are observed between Eucalyptus plantation land uses and agricultural land use. Even in most of the parameter especially in soil organic carbon and soil organic matter the highest values were recorded in Eucalyptus plantation land uses than agricultural land use. This is due to the recycling of nutrient through decomposition of different tree parts. In terms of agricultural land due to cereal crop intensive agriculture, most the soil nutrient is depleted.

When we see the nature of Eucalyptus tree species, they have the capacity of extracting large amounts of soil nutrient and moisture from the soil. At the same time, they have the potential of building large amounts of biomass than any other tree species. But if the rotation age of the tree is not properly managed the rate of biomass construction is reduced and they loss huge amount of soil nutrient and moisture. In addition to this due to its large amounts soil nutrient and
Table 2. Chemical properties of soil under eucalyptus plantation and crop land systems.

(a) Agarfa

| Land use                  | PH(±SD)    | EC(±SD)    | OC(±SD)    | OM(±SD)    | P(±SD)    |
|---------------------------|------------|------------|------------|------------|-----------|
| Eucalyptus globules-1     | 6.25(±0.04)* | 0.4(±0.03)*  | 5.3(±0.71)*  | 9.14(±1.23)* | 2.86(±0.62)* |
| Eucalyptus globules-2     | 6.08(±0.06)* | 0.31(±0.04)* | 5.09(±0.77)* | 8.77(±1.33)* | 1.93(±0.35)* |
| Crop land                 | 6.41(±0.04)* | 0.04(±0.01)* | 3.02(±0.29)* | 5.33(±0.50)* | 2.80(±0.63)* |
| Overall Mean              | 6.24(±0.03)  | 0.04(±0.002)  | 4.53(±0.38)  | 7.81(±0.66)  | 2.53(±0.32)  |
| P- Value                  | < .0001     | 0.0501      | < .0001     | < .0001     | 0.2793     |

(b) Dello Menna

| Land use                  | PH(±SD)    | EC(±SD)    | OC(±SD)    | OM(±SD)    | P(±SD)    |
|---------------------------|------------|------------|------------|------------|-----------|
| Eucalyptus saligna        | 7.05(±0.14)* | 0.04(±0.01)* | 2.92(±0.56)* | 5.03(±0.97)* | 1.94(±0.07)* |
| Eucalyptus citradora      | 7.11(±0.06)* | 0.07(±0.01)* | 4.84(±0.79)* | 8.34(±1.36)* | 2.09(±0.07)* |
| Eucalyptus camaldulensis  | 6.47(±0.06)* | 0.03(±0.01)* | 3.71(±0.58)* | 6.39(±0.99)* | 2.03(±0.07)* |
| Crop land                 | 6.56(±0.04)* | 0.02(±0.00)* | 1.68(±0.22)* | 2.89(±0.38)* | 2.15(±0.07)* |
| Overall Mean              | 6.80(±0.06)  | 0.04(±0.00)   | 3.28(±0.32)  | 5.66(±0.50)  | 2.05(±0.04)  |
| P- Value                  | < .0001     | 0.0003      | < .0001     | < .0001     | 0.0001     |

(c) Goba

| Land use                  | PH(±SD)    | EC(±SD)    | OC(±SD)    | OM(±SD)    | P(±SD)    |
|---------------------------|------------|------------|------------|------------|-----------|
| Eucalyptus globules       | 6.04(±0.07)* | 0.03(±0.00)* | 5.16(±0.75)* | 8.00(±1.29)* | 2.21(±0.72)* |
| Crop land                 | 6.23(±0.08)* | 0.04(±0.00)* | 4.56(±0.69)* | 7.85(±1.19)* | 7.42(±3.28)* |
| Overall Mean              | 6.14(±0.05)  | 0.04(±0.00)   | 4.86(±0.50)  | 8.37(±0.87)  | 4.82(±1.72)  |
| P- Value                  | 0.7253      | 0.0284      | < .0001     | < .0001     | 0.4188     |

(d) Goro

| Land use                  | PH(±SD)    | EC(±SD)    | OC(±SD)    | OM(±SD)    | P(±SD)    |
|---------------------------|------------|------------|------------|------------|-----------|
| Eucalyptus camaldulensis  | 7.19(±0.18)* | 0.25(±0.06)* | 5.01(±0.62)* | 8.63(±1.08)* | 0.91(±0.36)* |
| Crop land                 | 7.35(±0.11)* | 0.05(±0.00)* | 4.83(±0.21)* | 8.32(±0.37)* | 4.75(±2.01)* |
| Overall mean              | 7.27(±0.10)  | 0.15(±0.03)   | 4.92(±0.32)  | 8.47(±0.56)  | 2.83(±1.07)  |
| P- Value                  | 0.7097      | 0.0106      | < .0001     | < .0001     | 0.2264     |

(e) Robe

| Land use                  | PH(±SD)    | EC(±SD)    | OC(±SD)    | OM(±SD)    | P(±SD)    |
|---------------------------|------------|------------|------------|------------|-----------|
| Eucalyptus camaldulensis  | 6.29(±0.06)* | 0.04(±0.00)* | 3.9(±0.55)*  | 6.85(±0.95)* | 2.15(±0.04)* |
| Crop land                 | 6.31(±0.05)* | 0.03(±0.00)* | 2.86(±0.39)* | 4.94(±0.67)* | 1.62(±0.45)* |
| Overall mean              | 6.30(±0.04)  | 0.04(±0.00)   | 3.42(±0.35)  | 5.89(±0.60)  | 1.89(±0.23)  |
| P- Value                  | 0.1048      | 0.2604      | 0.0036      | 0.0036      | 0.3037     |

Table 3. Particle size distribution (%) in the different land use systems and depths, 0–15 and 15–30, 30–45 (n = 5).

| Land use                  | Soil Depth (cm) | Fine Sand % | Clay % | Silt % | Textural Class |
|---------------------------|-----------------|-------------|--------|--------|----------------|
| Dello Menna Eucalyptus saligna plantation | 0–45             | 3           | 78     | 19     | Clay           |
| Dello Menna Eucalyptus citradora plantation | 0–45             | 15          | 58     | 27     | Clay           |
| Dello Menna Eucalyptus camaldulensis plantation | 0–45             | 5           | 74     | 21     | Clay           |
| Dello Menna Crop land use system | 0–45             | 3           | 88     | 9      | Clay           |
| Robe Eucalyptus camaldulensis plantation | 0–45             | 5           | 74     | 21     | Clay           |
| Robe Crop land use system | 0–45             | 5           | 68     | 27     | Clay           |
| Goro Eucalyptus camaldulensis plantation | 0–45             | 9           | 64     | 27     | Clay           |
| Goro Crop land use system | 0–45             | 13          | 52     | 35     | Clay           |
| Agarfa Eucalyptus globules plantation –1 | 0–45             | 11          | 68     | 21     | Clay           |
| Agarfa Eucalyptus globules plantation –2 | 0–45             | 13          | 54     | 33     | Clay           |
| Agarfa Crop land use system | 0–45             | 5           | 76     | 19     | Clay           |
| Goba Eucalyptus globules plantation | 0–45             | 9           | 52     | 39     | Clay           |
| Goba Crop land use system | 0–45             | 23          | 44     | 33     | Clay           |

moisture attraction capacity of Eucalyptus tree species the place where the tree was planted also taken in to consideration and it must be far from the crop field.

Generally due to its large computation capacity of the Eucalyptus species, even if it is based on the agro ecology it is not recommended for intercropping, adjacent to crop field and it must be far from river banks. Therefore when we conclude this study, if we are planting Eucalyptus tree species in appropriate place, and if we manage properly (silvicultural practices and timely cutting), Eucalyptus plantation has positive impacts on soil physical and chemical property through decayed litter than intensively cultivated crop land.

Acknowledgments

Thanks to Oromia Agricultural Research Institute for their funding. And special thanks to Sinana Agricultural Research Center Soil Fertility Improvement Research case team for the soil analysis. Also we thank Mr. Asefa Amede (Bale Oromia Forest and Wild life Enterprise, Forest Expert) for their field assistance.
Figure 5. Physico-chemical properties of under different depth of Eucalyptus plantation and crop land. (a) Agarfa crop land use system. (b) Agarfa *Eucalyptus globules* plantation −1. (c) Agarfa *Eucalyptus globules* plantation −2. (d) Dello Menna crop land use system. (e) Dello Menna *Eucalyptus camaldulensis* plantation. (f) Dello Menna *Eucalyptus citrodora* plantation.
Disclosure statement

No potential conflict of interest was reported by the authors.

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