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Case study of an integrated system for olive mill by-products management in Sfax region in central Tunisia

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Abstract. Olive oil extraction generates annually a huge amount of by-products called olive mill wastewater (OMW) and olive husk in the whole of the producing countries all around the Mediterranean basin. In the particular situation of Sfax (a city in the Center of Tunisia) the major part of the 400 olive mills is located in the urban area. This situation makes olive mil by-products disposal and management hard. This work focused on the agronomical valorisation of these by-products. OMW was directly spread in fields while olive husk was primarily composted with cow manure. The technical and agronomic efficacy of these valorization ways was confirmed through three years field studies. Indeed, OMW spread improved soil cation exchange capacity as well as soil fertility with regards to organic and mineral compounds. The obtained olive husk compost was an organic fertilizer of high quality. The agronomic valorisation of olive mill by-products was technically realisable with important beneficial effects on soil and plants and with very limited impacts on environment. The cost of these techniques is moderate and comparable to the cost of actual disposal methods. This makes the integrated way of management interesting and practically feasible at wide scale. This method involve olive mill by-products transport, temporary storage or composting and spread in the fields.

Keywords. OMW – Olive husk compost – Olive mill by-products – Organic fertilisation.

Étude de cas pour une gestion intégrée des sous-produits des huileries

Résumé. *L'extraction de l'huile d'olive génère d'importantes quantités de sous-produits, l'un liquide appelé eau de végétation ou margines et l'autre solide appelé grignon d'olive. Ces sous-produits représentent un problème environnemental de première importance dans tous les pays producteurs. Leur gestion, différente d'un pays à l'autre, engendre des coûts importants et souvent des effets néfastes sur l'environnement. Dans le cas particulier de Sfax qui est une ville du centre de la Tunisie, ce problème est plus épineux dû au fait de la présence de la majorité des 400 huileries dans le périmètre urbain. Cette situation accentue la difficulté de la gestion de ces sous-produits générant un surcoût dû à la nécessité du transport hors de la ville. La valorisation agronomique de ces sous-produits, par épandage direct pour les margines ou après compostage pour le grignon, peut être une solution faisable et rentable. Après la vérification technique de cette possibilité, une méthode de gestion intégrée des sous-produits a été proposée. Le coût de cette méthode reste modéré et est comparable au coût de la gestion actuelle. De ce fait, cette méthode peut être appliquée à large échelle. La méthode englobe le transport des sous-produits dans les zones d'épandage, le stockage temporaire ou le compostage et l'épandage.*

Mots-clés. *Margines – Compost de grignon d'olive – Sous-produits des huileries – Fertilisation organique.*

I – Introduction

Olive oil is among the main arboricultural products of the Mediterranean Basin. Indeed, 99% of the world olive oil is produced within this area (Loumou and Giuourga, 2003; Ulger *et al.*, 2004). The oil extraction process generates, in addition to oil, two sub-products, olive mill wastewater (OMW) and olive husk. OMW is constituted of vegetable water of the fruit and the water used in oil extraction process. It constitutes the aqueous part of the fruit involving soluble components and suspended materials. It represents a serious environmental problem due to its high organic content [biological oxygen demand (BOD_5) up to 90 x 103 mg/l, and chemical oxygen demand (COD) up to 200 x 103 mg/l], with a dominance of phenolic compounds and various flavonoids (Paredes *et al.*, 1987; Ben Rouina *et al.*, 1999; Gargouri *et al.*, 2007). Hence, the Mediterranean basin is particularly affected by OMW pollution. In addition, this concern is increasing in emerging producer countries such as Argentina, Australia and South Africa (Roig *et al.*, 2006). Olive husk from the three-phase system had a second oil extraction with organic solvents after its drying (Roig *et al.*, 2006). Olive husk is formed by olive stones and flesh. It contains, at lesser degree than OMW, some dangerous compounds and important amount of carbohydrates.

In Tunisia, the average olive production (2007-2011) reached 918,800 (FAOSTAT, 2013). The major part of 1,500 olive mills working in Tunisia is using the continuous three phase process with little classic system. It generates more than 700,000 t/year of OMW and 450,000 t/year of olive husk. According to Tunisian legislation OMW is considered as industrial wastewater. Its disposal is regulated according to the Tunisian Norm NT106-02 which gives the limits of concentration in several parameters for the wastewater to be rejected in the environment or to be used in the treatment plants. Yet, the proposed treatment methods were not supported either by policy or by producers due to several reasons. The main cited reasons are: (i) the low efficiency because of the high contamination level of the OMV i.e. an efficiency of 95% is not enough to allow the use of OMW as treated water (Table 1); (ii) the high cost of the treatment; and (iii) the low capacity of the treatment plants with regards to the huge produced quantity in a short time. Actually, the OMW disposal system is based on collecting and drying it in evaporation ponds located near the producing areas. This practice has harmful effects on the environment, such as the volatilization of certain compounds contained in OMWs (phenols and sulphur dioxide) and their emission into the atmosphere (Rana *et al.*, 2003), strong odours and infiltration risks, which can be a serious pollution risk for superficial and underground waters (Mekki *et al.*, 2006a). Husk from the continuous three-phase process is actually utilised as animal feed or is exported for energy production after residual oil extraction.

Many investigators have searched for better potential solutions including physical, chemical and biological treatments and agronomic and energetic valorisation. The sludge produced after OMW evaporation and olive husk can be valorised as fertilizer after composting or for heat production. The OMW sludge was also proposed to be an additive for the development of construction material (Roig *et al.*, 2006). Physico-chemical treatments through coagulation and flocculation were developed producing water for irrigation and sludge that has been successfully composted with other agricultural by-products (Roig *et al.*, 2006). Biological transformations were used for OMW treatment focusing on phenols degradation and agronomic valorisation of treated OMW. In addition production of biogas by anaerobic digestion was reported as efficient disposal method (Roig *et al.*, 2006). The energy recovery through combustion was also described as valorisation way for olive husk. Other methods such as extraction of valuable products mainly bio pesticides and antioxidants were investigated and valuable results were reported (Roig *et al*., 2006). Finally, composting is an efficient and practical way for olive mill by-products disposal.

In central Tunisia at Sfax region, the major part of olive mills is located in the urban area increasing disposal difficulties. 400 olive mills are located in this area producing about 250,000 m^3 of OMW and 150,000 tons of olive husk. Actually the produced OMW is disposed in evaporation pounds located at 35 km from the most important production area located in the urban area. This situation increases disposal cost since the transport along long distances is necessary. Moreover the disposal area occupies a huge surface reaching 60 ha and present some harmful effects leading to social contestations. The sludge obtained after water evaporation is disposed in a particular area without further transformation. Olive husk is collected for secondary extraction of oil and the produced by product is exported to be used for heating.

Face to this situation our objective was to propose a practical solution for olive mill by-products disposal focusing on agronomic valorisation. Our work was divided in three steps: (i) verifying that OMW spreading and olive husk composting are valuable ways for olive mill by products valorisation; (ii) developing a practical procedure for their application with regards to the location of olive mills in the urban area; and (iii) evaluation of technical and economic efficiency of the applied procedure.

II – Materials and methods

In order to study the effects of OMW spreading and olive husk composting and compost use in agriculture a three years survey was realized in the experimental farm of Olive Institute located in Sfax region (34°55' N; 10°34' E) in centra l Tunisia. The orchard has a sandy soil in lower semi-arid climate with 200 mm of annual rainfall. Four treatments were applied according to full randomized blocks plan. The olive husk was composted with addition of cow manure and use in the same parcel

OMW and olive husk used in this study were obtained from a three phase continuous system oil extraction plant belonging to the farm. Some differences appeared between the OMW according to the year of production (Table 1). However, the OMW composition has mainly the same characteristics with low pH (4.2 to 5.5) high COD, BOD, electrical conductivity (EC) and potassium and phenolic compounds contents. In general the OMW has important amounts of organic and mineral matter allowing it to be considered as liquid fertilizer. The used dose of OMW was 50 m^3/ha. Olive husk was composted with cow manure with a ratio of 2/1 w/w in order to get a starting C/N of 35.

Table 1. Minimum and maximum values of different characteristics of the used OMWs in comparison with the Tunisian norm of reject in the environment or in the treatment plants

Parameter	Unit	OMW		Environment reception limits	Treatment plants reception limits
		Min.	Max.		
Water content	%	87.9	95.4		
pH_w		4.2	5.5	6.5-8.5	6.5-9
EC	dS/m	12.4	18.6		
COD	mg/l	63,790	105,000	90	1000
BOD_5	mg/l	34,900	55,000	30	400
Organic matter	g/l	107.0	32.6		
Sugars	mg/l	14,630	25,300		
Phenols	mg/l	990	5,800	0.002	1
Fat content	mg/l	4,500	3,180	10	30
C	mg/l	1,270	3,740		
Mineral content	g/l	12.1	23.7		
N	mg/l	440	1,400	1	100
PO_4^{2-}	mg/l	186	320	0.05	10
K	mg/l	4,370	7,500	50	50
Mg	mg/l	650	1050	200	300
Na	mg/l	1,150	1,310	500	1000
Ca	mg/l	710	2,300	500	variable
Cl	mg/l	560	1,250	600	700
C/N		2.9	2.7		

Soil samples were collected 3 month after the OMW spreading from different point of each plot.

These samples were collected from one depth horizon: 0-20cm and were air dried, sieved (<2mm) and stored until analysis. Soil analysis interested pH measured on a 1:2.5 soil/water suspension (Pauwels *et al.*, 1996), Organic matter content was measured by Walkley and Black method (Pauwels at al. 1996), total nitrogen was determined by modified Kjelddhal method (Pauwels *et al.*, 1996), available phosphorus content was determined by modified Olsen method (Pauwels *et al.*, 1996) and K an Na amounts were extracted with NH4OAC and measured by emission spectroscopy (Pauwels *et al.*, 1996). Total phenol were extracted by methanol with a ratio soil/methanol 1/5 w/v (Avallone *et al.*, 1997) and the phenol content was by Folin Ciocalteau method and qualitative phenols analysis was realized using HPLC (AOCS, 1990).

The impact of OMW spreading on plant productive behaviors was evaluated throw the measurement of olive yield and oil quality. The olive orchard was rainfed planted at the density of 17 trees/ha. The impact of OMW on olive and olive oil quality was assessed according to standard methods (AOCS,1990).

The main constrain for the application of agronomic valorisation of OMW and olive husk compost was the distance between producing area (urban area) and reception area (rural area) needing transport. The transport has to be as low as possible, for this reason it should be done using big tracks with tanks of 35 m^3 for OMW or dump trailers of 30 tons for olive husk. These devices cannot be used in the field and thus it is mandatory to transfer the product in other equipments adapted for the work. For OMW spreading a tank with high pressure is needed while manure spreader can be used for compost. The raised problem is that these equipments had smaller capacity than transporting equipment. Indeed both of spreading equipments had a capacity of 5 tons. Thus in our work we experimented the use of small buffer pond of a capacity of 400 m^3 and the installation of composting area in the field. The other solution was to build the olive mill in the rural area.

Finally the cost of OMW transport and direct spreading was calculated and compared to actual disposal method cost. In addition the cost of compost fabrication was estimated.

III – Results and discussion

The addition of OMW on soil properties are reported in Table 2. The soil pH was not affected by the OMW spreading This phenomenon may be explained by the buffering capacity of the soil. These results are consistent with those obtained by several other authors (Gargouri *et al.*, 2004; Chartzoulakis *et al.*, 2006). However, contrary results were obtained by Di Giovacchino (2005) and Mechri *et al.*, (2007). The amount of organic matter (OM) in the soil increased after the application of OMW which contain a relatively important amount of organic matter (more than 33 g/l). The amount of OM raised from 0.21% in the control to 0.45%. The more important soil enrichment was observed for the K content. The soil content P showed a small but significant increase caused by the application of OMW. Soil N content was not modified. These results are in accordance with those obtained by several authors (Levi-Minzi *et al.*, 1992; Ben Rouina *et al.*, 1999; Gargouri *et al.*, 2004; Di Giovacchino, 2005; Chartzoulakis *et al.*, 2006; Mechri *et al.*, 2007).

On the other hand, the salinity of the OMW was usually posed as limiting factor. However, the increase in sodium content was not alarming and far under the increase in K content which can counterbalance the negative effect of Na. The phenols content in the soil three months after OMW spreading is the same for the control and for the 50 m^3/ha treatment. These results are in accordance with those obtained by Di Giovacchino (2005) and Chratzoulakis *et al.* (2006). Qualitatively only one phenol compound was detected in treated soil i.e. Tyrosol. This phenomenon indicates the effectiveness of phenol compounds degradation in the soil.

The yield of the olive tree was enhanced by the addition of the OMV. The increase for two consecutive years 2005-2007 was about 83% comparatively to the control while it was 12% for longer period (1995-2007) (Table 3).

Table 2: Soil properties after OMW in field application

	Control	OMW
pH	8.1 + 0.04	8.4 + 0.01
Organic matter (%)	0.21	0.45
Total N (mg/g)	0.42 + 0.01	0.43 + 0.01
P_2O_5 (mg/kg)	59.4	85.4 + 8.8
K_2O (mg/g)	0.2 + 0.003	0.07 + 0
Na (mg/kg)	11 + 1.4	44 + 0.00

Table 3. Impact of OMW spreading on olive yield (kg/ha)

	Yield 2005/2006	Yield 2006/2007	Average (1995-2007)	Effect (1995-2007)
Control	539	75	627.5	-
50 m^3/ha	561	563	705.5	+12%

Di Giovacchino (2005) found that the application of OMW until a dose of 300 m^3/ha increased proportionally the olive production. The contradiction with our results may be due to the aridity of our climate which can slow the organic matter mineralization and reduce the leaching of the eventual excess of some ions. However with a dose of 50 m^3/ha only positive effects were observed.

According to the results obtained during the campaign 2006/2007 (Table 4) the application of OMW has no effect on olive oil major characteristics. This result is in accordance with those obtained by Di Giovacchino (2005), but he found an increase in fruit oil content.

Table 4. Impact of OMW spreading on olive and olive oil quality

Treatment	Control	OMW
Fruit weight (g)	1.17	1.22
Oil / fresh weight (%)	29.02	28.36
Oil / dry weight (%)	55.63	55.21
Free acidity	0.26	0.28
C16:0	20.23	19.61
C16:1	2.45	2.28
C18:0	1.91	2.07
C18:1	57.20	57.82
C18:2	17.14	17.10
C18:3	0.58	0.60
C20:0	0.33	0.33
C20:1	0.13	0.15
K232	1.88	1.87
K270	0.13	0.11
Chlorophylls (ppm)	0.24	0.33
Phenols (ppm)	28.94	23.81
Oxidative stability (hours)	3.03	3.03

The olive husk compost was realised in the experimental farm on a platform avoiding contamination and permitting recycling of lixiviates (Fig. 1). The initial composition of composting material was formed by olive husk from three phase olive mill (66%) and cow manure (34%). This composition was adopted in order to get a starting C/N ratio of 35 and according to the availability and cost of raw material. The humidity of raw materials was maintained at 55% and the aeration was realised by mixing the compost 5 times when the temperature exceeded 55°C. The maturation process took 110 days.

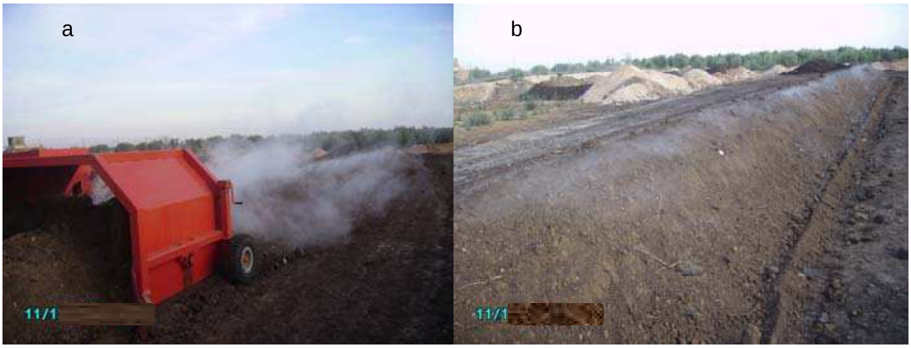

Fig. 1. Composting: a: windrow turning, b: compost platform.

At the end of maturation the obtained compost had a C/N of 12.5, 54% of organic matter and 46% of mineral matter (Table 5). This compost was suitable for agricultural use (Roig *et al.* 2006).

Table 5. Chemical composition of mature compost

Moisture %	pH	EC mS/cm	OM %	MM %	C %	N %	C/N	K g/kg	P g/kg	Na g/kg
16.2	7.8	13.4	54	46	31.2	2.5	12.5	2.6	2	1.4

The obtained compost was spread on the soil of an olive orchard at a rate of 10 tons/ha. The addition of compost improved soil fertility (Table 6). Indeed soil cation exchange capacity (CEC) increased from 0.2 meq/100g dry soil up to 1.2 meq/100g. In addition, organic and mineral content of the soil increased as well as soil electrical conductivity. However soil pH was not affected and was slightly alkaline. These results were consistent with those reported by Roig *et al.* (2006) who claimed that olive mill waste composts are of high purity without recalcitrant toxic substances.

Table 6. Soil physical and chemical characteristics after compost application as compared to control soil

	pH	EC	OM %	CEC meq/100g	N mg/kg	P_2O_5 mg/kg	K_2O mg/kg	Na mg/kg	Cl mg/kg
Control	8.1	0.42	0.34	0.2	290	52.7	136.2	24	92
Treated soil	8.4	0.77	1.57	1.2	560	82.5	325.5	44	116

The positive results obtained after agronomic valorisation of OMW and olive husk compost supports their use at large scale. However, the particularity of olive mills location in the urban area of Sfax makes direct application difficult. For this reason a basin for temporary storage of OMW was build in the field. The basin has a capacity of 400 m^3. It was necessary in order to assure the transport of OMW to use big trucks with tanks of 35 m^3, which is the cheapest way. These trucks are not able to realise the spreading that have to be done by tractors with pressurised tanks of 5 m^3 in the field. The basin plays as a buffer between big and small tanks (Fig. 2). Direct transfer from big to small tanks need much more time than using the buffer basin and thus higher cost. The most important constrain was to avoid environmental bad impact of the temporary storage of OMW. To assure the sealing of the basin, it was coated by a resistant geomembrane. In addition the turnover of the OMW was of 24 hours. Olive husk was transported and compost was made on a platform in the field. The obtained compost was spread using manure spreader of 5 tons.

Fig. 2. a: filling the buffer basin, b: OMW spreading in the field.

The last step of this work was the verification of economical feasibility of the OMW spreading and olive husk composting and use. For this reason the producing cost of compost making and the process of OMW transport and spreading costs were calculated in Tunisia Dinar currency TND (1TND = 0.49 euro).

Two windrow mere installed formed by 80 tons of row materials: 30 tons of cow manure and 50 tons of olive husk. These row materials gave 52 tons of compost with a yield of 65%. The row material cost was: olive husk: 0.012 TND/kg and cow manure: 0.010 TND/kg. Since a 1,000kg of compost needs 1,000kg of olive husk and 600 kg of cow manure the cost of row materials per ton of compost was 18 TND. The fabrication of 1,000 kg of compost needs 0.8 hour of tractor and the cost of one hour of tractor labor is 15 TND. Thus the cost of fabrication of one ton of compost was 12 TND. The platform cost was 31,954 TND and the amortising is calculated on the basis of 30 years. The fabrication of 52 tons of compost needs 110 days for maturation and 10 days for cleaning. Thus during a year, on this platform, it is possible to produce 156 tons (3x52 tons) in three cycles. The cost of amortising per ton of compost was 31.954/30/156=6.8 TND. Finally the global cost of one ton of compost was 18+12+6.8 = 36.8 TND. This cost was high in comparison to other sources of organic fertilisers limiting its valorisation to particular uses needing high quality organic amendments (nursery, gardens...).

The cost of OMW spreading was calculated for olive mills located in the urban area. This means that the costs to be involved are: transport, temporary storage and spreading. The OMW spreading can be made in the area surrounding the storage basin. The quantity to be spread annually is 50000 m^3 in 1000 ha during 120 days. For this reason the quantity to be spread per day is 400 m^3. During 6 hours work a tractor can achieve the operation 6 times corresponding to 30 m^3. Thus 13 tractors are necessary to realise the spreading in a correct way. The cost of the spreading of one cubic meter is 8.100 TND (Table 7).

The actual cost of OMW disposal in evaporation pounds is 8.200 TND financed by olive oil producers. Thus, the application of OMW spreading will not induce additional cost while it will bring valuable beneficial effects.

Table 7. Cost of OMW spreading per m³

	Cost (TND)
OMW price	0.000
Transport cost	5.000
Temporary storage cost	0.100
Spreading cost	3.000
Total	8.100

IV – Conclusions

The agronomic valorisation of olive mill by-products was technically realisable with important beneficial effects on soil and plants and with very limited impacts on environment. The cost of these techniques is moderate and comparable to the cost of actual disposal methods. This make this integrated way of management interesting and practically feasible at wide scale.

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References

AOCS, 1990. *Official methods and recomended practices of the American Oil Chemists Society*. AOCS.

Ben Rouina B., Taamallah H., Ammar E., 1999. Vegetation water used as a fertilizer on young olive plants. In: *Acta Hortic*., 474, p. 353-355.

Chartzoulakis K., Psarras G., Moutsopoulou M. and Stefanudaki E., 2006. Application of olive mill wastewater on olive orchards: effects on soil properties, plant performance and the environment. *Proceedings of the second international seminar Olivebioteq*, p. 37-43

Di Giovacchino L., 2005. Les eaux de végétation des olives : caractéristiques et utilisation rationnelle. In: *Olivea,* n°104, p. 55-63.

Di Giovacchino L., Basti C., Costantini N., Surricchio G., Ferrante M. and Lombardi D., 2002. Effects of spreading olive vegetable water on soil cultivated with maize and grapevine. In: *Olivea,* 91, p. 37-43.

FAOSTAT, 2013. *Production*. ProdSTAT. Crops. At: http://faostat3.fao.org/home/index.html

Gargouri K., Abichou M., Ben Rouina B., Bentaher H., Rhouma A., Ayadi M. and Taamallah H., 2004. La gestion des margines en Tunisie. *The first international symposium on the management of liquid and solid residues (MALISORE).* Mohammadia (Morocco).

Gargouri K., Ben Rouina B., Rhouma A., Ayadi M., Abichou M. and Bentaher H., 2007. Effects of olive mill wastewater spreading on soil quality and vegetative and productive plant behavior. *Proceedings of New Technologies for the Treatment and Valorization of Agro By-Products*, International Conference. ISRIM, Terni (Italy), 3-5 Octobre.

Levi-Minzi R., Saviozzi A., Riffaldi R. and Falzo L., 1992. l'épandage au champ des margines. Effets sur les propriétés du sol. In: *Olivae*, 40, p. 20-25.

Loumou A. and Giourga C., 2003. Olive groves: The life and identity of the Mediterranean. In: *Agr. Hum. Values,* 20, p. 87-95.

Mechri B., Echbili A., Issaoui M., Braham M., Ben Elhadj S. and Hammami M., 2007. Short-term effects in soil microbial community following agronomic application of olive mill wastwaters in a field of olive trees. *Applied Soil Ecology*, 36, p. 216-223.

Mekki A., Dhouib A., Aloui F. and Sayadi S., 2006b. Olive wastewater as an ecological fertilizer. In: *Agron*. *Sustain. Dev.,* 26, p. 61-67.

Mekki A., Dhouib A. and Sayadi S., 2006a. Changes in microbial and soil properties following amendment with treated and untreated olive mill wastewater. In: *Microbiol. Res*., 161, p. 93-101

Paredes M.J., Moreno E., Ramos-Cormenzana A. and Martínez J., 1987. Characteristics of soil after pollution with waste waters from olive oil extraction plants*. Chemosphere,* 16, p. 1557-1564.

Pauwels J.M., van Rust E., Verloo M. and Mvondo Z.E.A., 1992. *Manual of Soil Laboratory, analytical methods of soil and plants.* Agricultural publications, 28th ed. AGCD, Belgium.

Rana G., Rinaldi M. and Introna M., 2003. Volatilisation of substances after spreading olive oil waste water on the soil in a Mediterranean environment. In: *Agric. Ecosys. Environ.,* 96, p. 49-58.

Roig A., Cayuela M.L. and Sánchez-Monedero M.A., 2006. An overview on olive mill wastes and their valorisation methods. In: *Waste Management,* 26, p. 960-969.

Ulger S., Sonmez S., Karkcier M., Ertoy N., Akdesir O. and Aksu M., 2004. Determination of endogenous hormones, sugars and mineral nutrition levels during the induction, initiation and differenciation stage and their effects on flower formation in olive. In: *Plant Growth Regul.,* 42, p. 9-95.