EFFECT OF FOLIAR APPLICATION OF METHANOL ON EFFICIENCY, PRODUCTION AND YIELD OF PLANTS - A REVIEW

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ABSTRACT

Many cultivated area are situated in arid zone, where crop photosynthesis and productivity is limited by drought. Thus any treatment, such as methanol, that improves plant water relation and reduces stress impacts, could be of benefit. This paper investigated the effects of methanol application on some physiological and growth properties of plants. Recent reports indicate that vegetative growth and yield of C3 crops were enhanced by foliar methanol application and that overall crop water use was reduced by methanol sprays. It has been suggested that methanol may act as a C source for the plant and a photorespiration inhibitor. However foliar application of methanol solutions on crops would improve their accelerate ripening, reduce impacts of drought and decline crop water requirements. Methanol also appeared to improve the efficiency of water use in C3 plants, especially under water stress situations. On the other hand, methanol leads to increase of plants resistance to drought stress because these compounds play primarily a role in preventing increasing photorespiration induced in stressed plants.

Key words: Methanol, Foliar application, Plant yield.

Definition Biofuel

The word “biofuel” designates liquids and gases derived from organic materials that can be used as fuel in combustion engines. At present, biodiesel and bioethanol along with biogas are the most common biofuels. However, other forms of alcohols and esters which could be used in combustion engines are currently being researched. In addition, other technologies are being developed which would make it possible for combustion engines to be run with pure vegetable oils (Bruckman and Habermann, 2008).

That the prefix “bio” is used to indicate that the source material is derived from renewable feedstocks is considered to be misleading by many experts and environmental organizations. In this research, we evaluate one of most important biofuels (e.g. methanol).

What is methanol?

Methanol is an alternative fuel that can be produced from domestic resources, both fossil and renewable (Ma and Hanna, 1999). Methanol or “wood alcohol” is a colorless, toxic liquid (Ma and Hanna, 1999). In the United States, it is most commonly used as chemical feedstock, extractant, or solvent, and as a feedstock for producing methyl tertiary butyl ether (MTBE), an octane-enhancing gasoline additive.

Methanol can also be used in near (100%) from as a gasoline substitute or in a blend with gasoline, most commonly as M85 (85% methanol, 15% gasoline).
The resources of generation

Methanol was generated from three resources (Bruckman and Habermann, 2008):

1. Natural gas: Natural gas resources in the United States are estimated to be from 300 to 500 trillion cubic feet (Tcf). Current U.S. consumption of natural gas is about 20 Tcf/yr. The technology for making methanol from natural gas is already in place and requires only efficiency improvement and scale-up to make methanol an economically viable alternative transportation fuel.

2. Coal: Coal reserves in the United States (known and undiscovered) are estimated to be about 4 trillion tones. A coal-to-methanol fuel industry producing 1 million b/d would require about 150 to 200 million tones of coal per year. Recent concerns about sulfur oxide emissions from coal combustion can be mitigated because, in coal-to-methanol gasification, sulfur is removed as a routine part of the process.

3. Biomass: Biomass resources can be used to produce methanol and ethanol, another alcohol fuel (Demirbas, 2005). Estimates of biomass resources available for use in the production of alcohol fuels range from 1 million to 4.7 million dry tons per day (one ton equaling 100 gallons of methanol when biomass is also used to fuel the processing plant). Biomass resources include crop residues, forage (grass) crops, wood resources (forest residues and short-rotation wood energy crops), and the cellulosic components of municipal solid waste. As a renewable resource, biomass represents a potentially inexhaustible supply of feedstock for methanol production (Demirbas, 2005).

Comparison with fossil fuels

Agrofuels certainly have the potential of generating more profit for agricultural land use, creating jobs in rural areas, reducing CO₂ emissions and diminishing dependency on petroleum. In the context of the EU, agrofuels could boost agricultural commerce with additional sources of revenue while stimulating economic and political stability (Bruckman and Habermann, 2008).

Agrofuels compete with fossil fuels, especially gasoline and diesel products derived from petroleum. Recent developments have made it clear that the days of cheap and seemingly unlimited petroleum are over. Currently, approximately ten million tons of petroleum are consumed every day, an amount which is continually rising due to increasing energy needs in the newly industrializing countries. Only recently, Fatih Birol, the chief economist of the International Energy Agency (IEA), warned of an oil shortage within the coming years and of its economic consequences. Even now there are concrete signs that peak oil production has already occurred or will occur shortly, although this opinion is not universally shared, especially in petroleum industry circles. They claim, on the contrary, that there is still an enormous potential in difficult to exploit resources such as tar sand or deep-sea deposits and that these resources could provide enough fossil fuels for the foreseeable future in spite of the extremely high investment costs which would be necessary to exploit them.

Viewed from the perspective of oil consuming countries, however, this situation is even more problematic because the countries with the largest deposits of oil also tend to have an unstable political situation. For this reason, the future supply of crude oil is not only a question of remaining deposits but also of political developments.

If one compares agrofuels to fossil fuels with regards to emissions released during combustion, agrofuels do much better in several respects. For example they contain less sulfur, not to mention that with agrodiesel, soot particles and particle matter emission is reduced.

However, if one compares the volumetric energy density of fossil and agrofuels, it is clear that agrofuels tend to have a lower value, depending on the blend ratio with fossil fuels, resulting in an increase in consumption for the same power output.
But in order to establish the most comprehensive basis of comparison with fossil fuels, it is also necessary to take the by-products into consideration. Considered this on the level of international trade, Austria exports about 500,000 tons of grains and imports 600,000 tons of soy pulp. If one would process the annual export of grains into ethanol, 160,000 tons of DDGS (Dried Distillers Grains with Solubles) would be produced, which would in part be able to take the place of the imported soy pulp. With vegetable oil production for agrodiesel, the advantage is even more pronounced: After the process of pressing, about 1/3 of the total weight can be recovered in the form of vegetable oil and about 2/3 in the form of pressed solid matter (pomace), the so-called “press cake”, which could in part take the place of the soy pulp (Bruckman and Habermann, 2008).

Considering these circumstances, the advantages of agrofuels are more pronounced in regional economies, especially in rural areas, which would be less dependent on animal feed imports especially from the USA. The current price advantage of agrofuels in comparison to fossil fuels can be explained by a significantly lower level of taxation. The production of conventional fuels tends at present to still be less expensive, which is without a doubt also a result of the large-scale production facilities already in operation around the world. If agrofuels were taxed to the same extent, they would tend to be more expensive than fossil fuels. In Germany, biofuel taxation has come to be held in part responsible for creating the situation that more and more oil mills are threatened with bankruptcy (Bruckman and Habermann, 2008).

If the market share of agrofuels increases, it will no doubt go hand in hand with an increase in taxation because otherwise the state would lose one of its most important sources of revenue.

**Utilization of methanol in agriculture-Land Use**

According to the European Environment Agency (EEA) report, almost 13 million hectares of land will become usable in the EU-22 by 2010 (EEA, 2006). A large portion of this will come from using formerly uncultivated land, which constitutes approximately 10% of the cultivable land. The European commission has made the assumption that by 2020 there will be enough land available to blend 10% agrofuels with conventional fuels without limiting the production of food. According to the agricultural spokesman for the Green Party, Wolfgang Pirkhuber (2006), the goal of 10% agrofuel will only be achievable with an increase of 18 million hectares of additional land. But the use of hitherto uncultivated land will only make a further 7 million hectares available. Rudy Rabbinge (2008), head of the Science Council of the Consultative Group on International Agricultural Research (CGIAR) has confirmed the impending land conflict between energy and food production. Especially the poorer countries will be the hardest hit by the current developments.

Meat consumption is increasing in newly industrializing countries such as India and China but also in other developing countries, which is leading to an increased demand for feed. The United Nations estimates that by 2030, the third world nations will increase their net imports of food by a factor of five. This will result in nations which are currently export-oriented becoming import oriented. Rabbinge (2008) has calculated that a diet based on meat requires about ten times more land than a vegetarian diet.

Sten Nilsson (2009) from the International Institute for Applied Systems Analysis (IIASA) has estimated that by 2030, the worldwide demand for available farmland will have increased by between 250 to 300 million hectares. Alone the demands made by increased food and feed production will account for about 200 million hectares. As a result, it is expected that there will be an increase on a global level in competition for the use of agricultural area between food, feed and energy production.
EFFECT OF METHANOL ON PLANTS

Effect of methanol on physiological processes

The metabolism of short-chain alcohols in plants and their mechanism of action as plant growth regulators have not been studied in detail and thus are not well understood. Most of the research on this topic has been conducted on methanol. In the proposed methanol pathway in plants, this alcohol undergoes linear oxidation to CO₂ via formaldehyde formation, or cyclic assimilation into carbohydrates, organic acids and amino acids, especially serine and methionine. A similar pathway is thought to occur for ethanol (Cossins, 1964; McGiffen and Manthey, 1996).

No growth simulation due to methanol or ethanol treatment has been reported in C₄ plants such as sugarcane (Saccharum officinarum) or Maize (Zea mays) (Devlin, 1994), whereas alcohol application to Kentucky bluegrass (Poa pratensis) were phytotoxic (Crowe et al., 1994). Nonomura and Benson (1992a, 1992b) attributed the different response of C₃ and C₄ plants to treatment with these alcohols to decreased photorespiration rates, stimulation of serine biosynthesis, increased CO₂ availability inside the leaf, and presumed transient modifications in the carbon assimilation processes in C₃ plants.

Effect of methanol on plant resistance to drought stress

In general, drought is one of the most important limiting factors of crop yields in arid zones. The reduction of photosynthesis under drought stress is appeared to be associated with disturbance in biochemical reactions (Desclaux et al., 2000). Photosystem II (PSII) is highly sensitive to environmental inhibiting factors and water stress will damage its reaction centers severely. The chemical reaction of PSII is also affected strictly by water stress (Hanson and Roje, 2001). When stomata are closed due to drought or high temperature, the available CO₂ in intercellular space (Ci) would be reduced, leading to reduced electron transport capacity and restricted assimilation potential (Heins, 1980). On the other hand, stomata closure will result in evaluated temperatures of leaf and plant, limiting light reaction of photosynthesis (Andres et al., 1990).

More recently, scientists are seeking to find compounds to be used in field, to raise plant internal CO₂ concentration and to stabilize their yield. Many Researches have done in recent years on using some compounds such as methanol, ethanol, bothanol, propanol and some amino acids like as glycine, aspartate and glutamate, to improve yields of, especially, C₃ crops (Kesselmeier and Staudt, 1999). In general, these compounds play primarily a role in preventing increasing photorespiration induced in stressed plants (Moran et al, 1994). It is important, because 25% of total plant carbon gain is using in photorespiration (Daneshian and Zare, 2005).

It was first reported at the early 90s that foliar application of methanol solutions on crops will improve their yields, accelerate ripening, reduce impacts of drought and decline crop water requirements (Kesselmeier and Staudt, 1999; Madhaiyan, et al 2006).

Applying a 20% volumetric solution of methanol on peanut (Arachis hypogaea) plants increased LAI, CGR, RUE, protein content and grain yield (McGiffen and Manthey, 1996). This increased yield has resulted from a reduced photorespiration along with an increased cell turgor of plant’s tissues and from an enhanced photosynthesis capacity during reproductive stage due to an increased Ci (Kesselmeier and Staudt, 1999). Methanol application also can enhance plant photosynthetic capacity by delaying leaves senescence and therefore extending photosynthesis active course (Feibert et al, 1995) and by increasing activity of FBPase, an important enzyme controlling photosynthesis (Nonomura and Benson, 1997).

It seems methanol can act as an alternative source of carbon especially for C₃ plants, causing a substantial increase in their CO₂ fixation, growth and yield (McGiffen and Manthey, 1996), primarily due to inhibiting their photorespiration. The reason for this is rapid uptake of methanol by plants and its
quick metabolizing to CO$_2$ in plant tissues (Daneshian and Jonobi, 2001), as a result of smaller size of methanol molecules compared to CO$_2$. The main source of methanol generation in plants is demethylation of their cellular pectin. This volatile compound escapes through leaf stomata (Daneshian and Jonobi, 2001) and it may certainly be stated that plant tissues metabolize methanol. The 14C labeled methanol rapidly enters tissues after foliar application and, after influencing plant carbon metabolism, can be found in serine structure (Daneshian and Jonobi, 2001). Increased methanol concentration in plant tissues has a positive effect on carbon conversion efficiency (Feibert et al., 1995; Makhdum et al., 2005) and can increase leaves expansion by stimulating genes encoding for pectin methyl esterase, which enhance plant’s access to Ca in order to increasing leaf area (Makhdum et al., 2005). Furthermore, there are some symbiotic bacteria, called methylotrophic bacterium, living on leaves of most plant. These bacterium catch escaped methanol from leaves and as a trade-off, supply plants with substrate to form some phytohormons such as auxins and cytokines. In addition, these bacteria may involve in nitrogen metabolism in plants, by releasing bacteria urea, enhancing N assimilation in methanol sprayed plants (Makhdum et al., 2002). According to Nonomura, treated plants appeared to require less water both during the growing period and near harvest because the plants matured sooner (Nonomura and Benson, 1992c; Mauney, 1993). The potential for water conservation is important in drought-stricken areas, such as central Oregon. Water use for irrigation is increasingly debated throughout the West. If methanol does in fact reduce water requirements, then this may be a partial solution to increasing the water-use efficiency of crops.

Effect of methanol on plants yield

Many researchers tend to use growth regulators to improve crop growth and production. The first step to achieve high yield per unit area is high production of dry matter because almost 90% of plant dry weight is resulted from CO$_2$ assimilation during photosynthesis. Methanol spray is a method which increases crop CO$_2$ fixation in unit area. Recent investigation showed that C$_3$ crops yield and growth increased via methanol spray and methanol may act as C source for these crops (Ali and Mazumdar, 1991; Hemming, 1995; Hanson and Roje, 2001; Makhdum et al., 2002; Nonomuraa and Benson, 1992; Zbiec and Karczmarczyk, 1997; Zbiec et al., 2003). Generally, the major roll of this substance is to prevent negative effects of stresses on crops via reduction of photorespiration (Lawlor, 1987; Robinson and Jones, 1986). Application of methanol, ethanol, propanol, botanol and amino acids such as glycine, glutamate and spartat materials
is an approach for increasing CO₂ concentration in plants (Nonomura and Benson, 1997; Kishitani et al., 2000; Safarzade Vishgahi et al., 2005). The major source of methanol production in plant is cellular pectin demethylation. Such volatile organic compound, i.e., methanol exists leaves via stomata (Fall and Benson, 1996) and it is obvious that plant tissues metabolize methanol (Galbally and Kirstine, 2002; Nemecek-Marshall et al., 1995). Methanol sprayed on plants, enters their tissues rapidly and can be found in serine structure following influence on plant carbon metabolism (Gout et al., 2000). Increase of methanol concentration in plant tissues positively affects carbon fixation efficiency and cause to leaf enlargement via up regulation of pectin methyl esterase gene (Gout et al., 2000; Ramirez et al., 2006; Safarzade Vishgahi et al., 2005). Symbiotic bacteria named Methiob trophic bacteria live on most of plant leaves (Nonomura and Benson, 1997; Ivanova et al., 2001; Ivanova et al., 2000). These bacteria receive methanol extruded from plant leaves and in return donate precursor of some hormones such as auxin and cytokinin, which involve in leaves growth and development. Also, these bacteria are associated with nitrogen metabolism in plants through production of bacterial urea (Fall and Benson, 1996; Ivanova et al., 2001; Joshi, 1996). Thus nitrogen metabolism is higher in plants sprayed with ethanol (Andres et al., 1990; Heins, 1980). (Robinson and Jones, 1986) declared that glycine has effective role in drought tolerance. Glycine protective role is not limited just to its osmosis protection roll but is involved other stress induced physiological response (Kishitani et al., 2000). Some investigation related to effect of methanol spray on crop growth and yield indicated that spry of ethanol on water deficit exposed crops increases their biomass but decreases biomass of control plants (Nonomura and Benson, 1992; Ramberg et al., 2002; Theodoridou et al., 2002; Safarzade Vishgahi et al., 2005). It shows that methanol can affect crop CO₂ assimilation (38) Photo respiration can be minimized with methanol spry, since 25% of carbon wastes during photorespiration (Desclaux et al., 2000; Lawlor, 1987; Safarzade Vishgahi et al., 2005). That is because methanol is absorbed in plant and rapidly metabolized to CO₂ in plant tissue (Gout et al., 2000) due to smaller size of methanol rather than CO₂. Spray of methanol on drought encountering plants prevents loose of their biomass (Benson and Nonomura, 1992; Downie et al., 2004; Gout et al., 2000). Safarzade Vishgahi et al. (2005) reported that 20% (v/v) methanol spray increases leaf area index, crop growth rate, pod growth rate, radiation use efficiency, pod and grain yield, 100 grain weight, number of ripened pod and grain protein of peanut.

Nonamura and Benson (1992) reported that foliar-applied methanol increased crop production of C₃ plants. In tomato (Lycopersicon esculentum), foliar sprays up to 20% ethanol significantly increased shoot fresh and dry weight (Rowe et al., 1994). Submersion of bell pepper (Capsicum annuum) seedling in aqueous ethanol solutions resulted in increased plant biomass (Morales-Payan and Santos, 1997). Nonomura and Benson (1992a, 1992b) reported that methanol treatment resulted in biomass increase of 36% in watermelon (Citrus lanatus), 40% in rose (Rosa spp.), 50% in Savoy cabbage (Brassica oleracea Capitita group), tomato and cotton (Gossypium hirsutum), 60% in strawberry (Fragaria x ananas) and eggplant (Solanum melongena), 70% in palm (Washingtonia robusta), and 100% in wheat (Triticum aestivum). Enhanced yields also been reported for methanol-treated soybeans (Glycine max) (Li et al., 1995), radish (Raphanus sativus) and peas (Pisum sativum) (Devlin, 1994). However according to other reports, methanol has failed to stimulate crop productivity in cotton (Mauney and Geric, 1994; Madhaiyan et al., 2006), sour orange (Citrus aurantium) (ldso et al., 1995; Madhaiyan et al., 2006) carrots (Daucus carota), lemon (Citrus limon) (McGiffen et al., 1995), melon (Cucumis melo) (Hartz et al., 1994) and wheat (Albrecht et al., 1994).
In lettuce, McGiffen et al. (1995) reported that treatment with 30% methanol was toxic, and that increasing alcohol rates were correlated with increasing plant injury when the crop was grown under desert conditions. Morales-Payan (1997) found no effects of methanol or ethanol at rates up to 20% in ‘Black Seeded Simpson’ loose leaf lettuce. In the case of lettuce and other C₃ plants, the differences in reported results are apparently due to variations in experimental procedures, alcohol rates, environmental conditions and/or genotype responsiveness.

According to Benson and Nonomura (1992), 10-50% (v/v) methanol spray increase plant growth and yield due to reduction of photorespiration rate and increase in cell turgescence as well. Also methanol spray delay leaf senescence via effect on ethylene which can prolong photosynthetic active period (Heins, 1980). It is necessary to dark for a few hours following methanol spray in order to better absorption. Also, methanol spray increases soybean yield by 16-22% as a result of increase in photosynthetical capacity of plant at reproductive stage due to increase in amount of CO₂ (Yuncong et al., 1995). According to Andres et al. (1990), methanol spray increases activity of FBPase which is one of the important enzymes controlling photosynthesis. In addition, Hemmingle and Criddle (1995) reported that methanol spray increases carbon assimilation efficiency. Yield of C₄ plants less affected by methanol spray because of different leaf internal structure and CO₂ enrichment in mesophyll cells (Nemecek-Marshall et al., 1995; Feibert et al., 1995). Consider increase in growth of wheat, radish, pea, peanut and tomato as a result of methanol spray has reported too (Ramberg et al., 2002; Ramirez et al., 2006; Safarzade Vishgahi et al., 2005). It should be considered that time and method of methanol application in field is very important (Nemecek-Marshall et al., 1995; Ramberg et al., 2002; Ramirez et al., 2006).

CONCLUSION

Methanol is an alternative fuel that can be produced from domestic resources, both fossil and renewable. Methanol or “wood alcohol” is a colorless, toxic liquid. The researches so much have done in relation to effect of methanol on plants. These researches indicated that foliar-applied methanol lead to enhance growth and yield for C₃ crop plants. It has been suggested that methanol may act as a C source for the plant and a photorespiration inhibitor. However foliar application of methanol solutions on crops will improve their accelerate ripening, reduce impacts of drought and decline crop water requirements. This was probably the result of the efficiency of the methanol in increasing plant growth or yield under these conditions.

REFERENCE


