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PILOT PROJECT BIO-ETHANOL FROM SWEET SORGHUM: DATA CHECKS

Technical note prepared for AidEnvironment and NL Agency

FINAL REPORT

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3. LITERATURE REVIEW

3.1. Land preparation

Project documents provide no data as to carbon contents of the prior vegetation (grass and coconut stumps). Total aboveground biomass in coconut plantations according to IPCC (2006) is estimated at 196 ton/ha. Estimates by Lasco et al. (2002) suggest much larger biomass yields following an ability to annually sequester 4.8 ton of C/ha. A field of coconut trees could thus have, since initiation of the plantation in 1986, accumulated over 100 ton of C. This would include grasses, litter and other organic material plus below-ground material. It is not sure how much material actually has been accumulated. It could well be that in practice less material is found, but no estimations could be found on this in project documents. Whatever the amount of biomass, all existing vegetation will have to be cleared before seeding sweet sorghum.

Data on availability and composition of chicken manure in the project area have not been obtained. Following Tao and Mancl (2008), we assume a daily manure production per layer hen of 0,091 kg per animal per day (33 kg per year). Availability of large amounts of manure for the project is disputable. Over 300 animals would be required to generate 10 tons as presently is applied on one ha.

Depending on nutrient status of the hens, the nutrient contents of 10 tons chicken manure would approximately amount to 145 kg of total nitrogen, 100 kg of phosphate and 60 kg of potassium oxide (Internet source 5).

3.2. Crop cultivation

Sweet sorghum requires some 4.5 to 7.5 kg/ha of seed, to be sown in a warm seedbed - free of weeds (El Bassam, 2010), but lower applications (3-6 kg/ha) have been reported as well (Internet source 2). Recommended plant densities are 70cm between rows and 10-20cm within rows (El Bassam, 2010).

Crop cycle is 120 to 150 days and is co-determined by day length (Grassi, 2004). Accumulated daily temperatures above 10^{o}C ranges between 2600 and 4600 degree-days (idem).

According to a soil map presented by the centre for forestry research, CIFOR (Internet source 2, Figure 1), soils in Mangkutana are characterised as Acrisols (strongly leached acid soils). Such soils are known for low nutrient concentrations, aluminium toxicity and the tendency to absorb available phosphorus (e.g. from fertilizer applications). Acrisols are not very productive, and show similarities to certain types of Ultisols (Internet sources 1, 2)[2]. If soils in the project area would be Acrisols, commercial yield levels could not be realised without high nutrient inputs. Presently, however, available information on soil quality is not sufficient to determine soil type or nutrient availability.

[2] Ultisols are part of the USDA soil taxonomy; Acrisols belong to the FAO soil classification system.

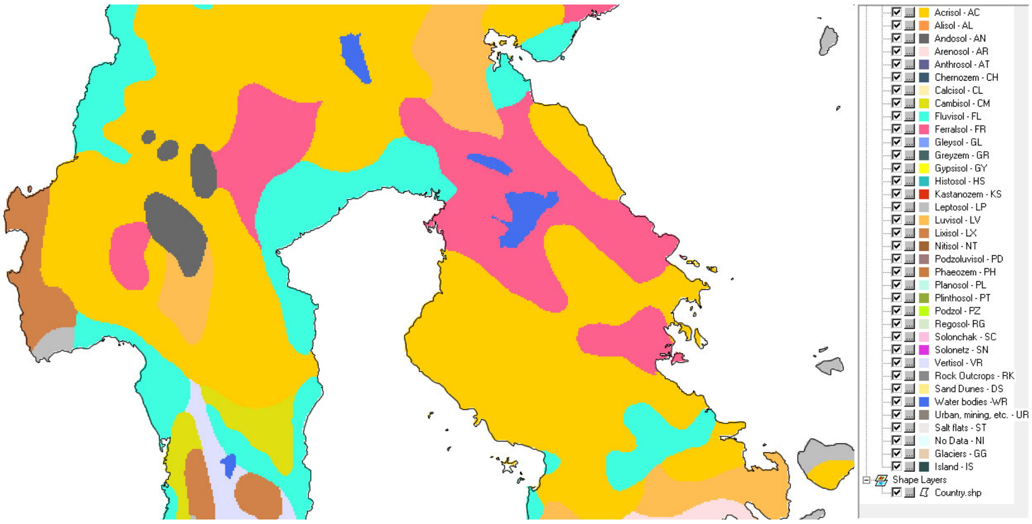

Figure 1. CIFOR soil map of south Sulawesi

Soils in Serang (Java), where sorghum varieties were primarily tested, are mainly Acrisols, Alisols and Plinthisols, all acid soils with a clay horizon and low base saturation (Internet source 3). According to the first Progress Report (dated 31-12-2009), soil conditions in Sulawesi are better than those in Serang (p. 6). Specific information is however lacking.

According to the *Handbook of Energy Crops* (El Bassam, 2010), sweet sorghum can be grown successfully on a wide range of soils including heavy clays, medium loams, calcerous and organic soils. Sorghum is considered to be one of the most drought-resistant agricultural crops, showing the ability to remain dormant during dry periods (El Bassam, 2010). It has a large root system, possibly extending to a distance of 1 meter laterally and depth of 1.9 meter. This systems is showing high activity, e.g. compared to maize, in uptake of water from the soil (El Bassam, 2010).

According to El Bassam (2010), no significant response to nitrogen fertilization has been reported. Potassium requirements, however, are high. A 25 ton/ha crop would remover 617 kg of potassium oxide, which is suggesting a K_2O concentration of 2.5% of fresh biomass (El Bassam, 2010). Figures presented by Grassi (2004), however, suggest much lower concentrations:

- 0.18% N
- 0.04% P_2O_5
- 0.02% K_2O.

These values seem more realistic and it is assumed that El Bassam figure for potassium is too high.

All biomass (grains, stalks) is to be removed from the fields, containing considerable amounts of nutrients. A yield of 50 ton/ha would remove over 91 kg of nitrogen plus 18 kg of phosphate (P_2O_5) and close to 11 kg of potassium oxide (K_2O). An annual stalk yield of 200 ton would thus require application of over 360 kg of nitrogen, 74 kg of phosphate and 33 kg of potassium oxide. It should be noted here that this is not including nutrients in grains which have been reported to contain 1.6% N, 0.5% P_2O_5 and 0.04% K_2O. Five ton of grains would therefore contain an additional amount of 81 kg N, 12 kg P_2O_5 and 2 kg K_2O.

Total nutrient removal by a stalk harvest of 50 ton/ha thus amounts to 172 kg of N, 30 kg of P_2O_5 and 13 kg of K_2O. This is sufficiently covered by fertilizer application during land preparation. A second harvest of another 50 ton plus a total of five tons of grains would require replenishment of a total of 420 kg of N, 72 kg of P_2O_5 and 28 kg of K_2O. This could in principle be covered by land preparation nutrient applications provided (i) chicken manure is of sufficient quality, (ii) nutrient losses through leaching or ammonia volatilization are limited, and (iii) there is no fixation of phosphate by the soil.

Replenishment of nutrients removed by a third crop of 50 ton of stalks plus 2 ton of grains requires additional fertilization. Reported fertiliser application rates (urea, TSP and KCl) are not expected to cover all demand for nitrogen but may be supplying sufficient phosphates and potassium.

Cultivation of sweet sorghum after flooded rice is expected to suffer from specific nutrient problems, referred to as the ´rice-effect´. This is caused by the flooding and consequent drying of the soil. Flooding leads to increased phosphorus availability for the rice crop (P-stocks from the soil dissolving in the water). Following the drying of the soil, dissolved P is locked in insoluble P compounds. This is causing (relative) shortages of phosphorus that may persist for years. Insoluble P will dissolve again only after 30 days of consecutive flooding. Thus, any crop cultivated after paddy rice should be tested for potential extra P fertilization requirements (So and Ringrose-Voase, 1995, Singh et al., 2000).

Total (including rainfall) water demand 200 m^3 per ton of biomass is equivalent to a rainfall need of at least 500 to 600 mm (Grassi, 2004). Irrigation water requirements are low in comparison to those of maize (double the amount of sweet sorghum) and sugar cane (three times sweet sorghum requirements) (El Bassam, 2010).

Ratoon cropping of sorghum requires removal of excess tillers and extra fertilization application. Growing period will be 15-20 days shorter.

3.3. Crop yield

Yields of irrigated crops in southern EU range from 73 to 110 ton fresh biomass/ha in central Greece and 61 to 157 ton/ha in southern Italy (El Bassam, 2010). Figures for the USA suggest much lower yields of 22 to 64 ton/ha total biomass (El Bassam, 2010) although higher yields (50 to 90 tons) also have been reported (Grassi, 2004). Yields for China vary from 49 to 128 ton of stalks per ha plus an additional 1.4 and 6.7 ton of grains, respectively (El Bassam, 2010). For Sub-Sahara Africa, yields amount to only 46 ton/ha (Grassi, 2004).

Stalk yields can attain no more than 150 ton/ha (at plant density of 75,000 stems/ha and 2 kg/stem) (El Bassam, 2010). These yields will require good soils and sufficient nutrient and water availability. It is not clear if these conditions are fulfilled for the project. Under conditions reported or expected it is not realistic to expect *average* yields in the project to reach this level. This also applies to the amount of leaves that will be produced. According to Grassi (2004), sweet sorghum leaves make up 10-15% of total biomass, compared to 75% for stalks. Others (Internet source 2) suggest 75 to 90% in stalks. At reported stalk yield levels of 60 to 130 ton/ha, leave biomass is therefore expected to yield no more than 8-25 ton/ha which is considerably lower than the 22-55 ton that has been reported (2011 Progress Report, p. 10).

Figures presented above all refer sown crops cultivated in the wet season. Attainable (sown) yields during the dry season must be expected to be lower. Dry season yields in Indonesia generally are low (Internet source 5): 1 ton/ha or less for maize, 0.3 to 0.8 ton/ha for soybeans and cowpeas. Yields are especially low when crops follow wet rice, when crop establishment is poor and root growth is hampered by physical constraints resulting from the breakdown of soil structure during wet cultivation (puddling). Yields are further limited by biological constraints, soil acidity and nutritional aspects.

Ratoon yields have been reported to attain only 50 to 60% of a sown crop (Internet sources 7, 8), but other sources are less pessimistic. Ranola et al. (2007) report ratoon yields ranging between 48 and 65 ton/ha plus 4 tons of grains for the Philippines. Again, such yields are only feasible if soils are of sufficient quality. A deep and well-drained clay loam is preferred (Ranola et al., 2007). Insect pressure for ratoon crops will be high (Internet sources 7, 8).

Maize yields for Sulawesi amount to 2.8 ton/ha, with higher yields reported for South Sulawesi (e.g. compared to Central Sulawesi)(Hadijah and Margaretha, 2008).

3.4. Ethanol yield

According to El Bassam (2010), sweet sorghum sugars consist of saccharose (two-thirds) and monosaccharides (one-third). This is confirmed by Grassi (2004) who reports the following sugar contents:

- Saccharose: 7.1%
- Glucose: 1.7%
- Fructose: 1.0%.

Total ethanol yield can be calculated from the following formula (El Bassam, 2010):

sugar content (%) in fresh matter x 6.5 (conversion factor) x 0.85 (process efficiency) x total fresh biomass yield (ton/ha)

Alternative ethanol yield calculations given by Antonopoulou et al. (2007) suggest an ethanol yield of 66 to 127 litre of ethanol per ton of fresh biomass. A manual prepared by the EU Intelligent Europe project 'Sweethanol' (Internet source 6) suggests a conversion efficiency of 0.59 litres of ethanol per kg of sugar.

Ethanol yields reported by El Bassam (2010) amount to 6100 l/ha for the US and China. Average yields of anhydrous (99.5%) ethanol range between 5700 and 6500 l/ha, with yields of irrigated crops locally exceeding to 8000 l/ha (El Bassam, 2010).

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