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# Evaluation of self-heating in *Miscanthus* x *giganteus* energy crop clamps and the implications for harvesting time

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ABSTRACT

*Miscanthus* x *giganteus* energy crop grown in Ireland was harvested on 21st of February and 28th of March 2012 to examine the effects of harvesting time on self-heating during storage of *Miscanthus* chips in clamps (98 $m^3$) under weather sheltered conditions. There was a relatively large difference in moisture content, of 21.4%, between *Miscanthus* crop harvested in February and March (41.6 and 20.2%, respectively). Temperature evolution over a storage period of up to 125 days was monitored at different heights and distances from the centre within the clamps. Maximum temperature in the February constructed clamp reached 69 °C compared to 28 °C in the March constructed clamp. Microbial activity was monitored via carbon dioxide and oxygen gas measurements. The high moisture clamp showed higher microbial activity and a volume yield loss of 4.3% due to decomposition in the top section of the clamp. Quality indices post-storage were also assessed. Calorific values from *Miscanthus* sampled 1 m below the top surface were similar after storage for both February and March constructed clamps, i.e. 18.52 and 18.70 MJ $kg^{-1}$, respectively. A reliable assessment of self-heating in *Miscanthus* chip clamps has important consequences for both self-ignition risk and biomass quality.

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## 1. Introduction

There is a need to increase the use of renewable, carbon neutral forms of energy, such as phototrophic crops which will allow for decreased use of fossil fuels in our energy supply system [1,2]. *Miscanthus* is a high-yielding dedicated energy crop which is suited for growth in central and southern parts of Ireland [3,4]. Co-firing *Miscanthus* directly with peat, and willow wood chip with coal were mooted as the most realistic initial uses of biomass for electricity generation in Ireland due to the relatively low capital investment required [5]. Co-firing of *Miscanthus* with peat in Ireland would be economically advantageous as it would diversify the energy supply making it more secure and its price variation should be more robust than that of imported forms of energy [6]. McGettigan et al. [7] reported that Ireland is falling short of its Kyoto Protocol agreement to keep 2008–2012 greenhouse gases (GHG) emissions at 13% above its 1990 levels; the study reported 25% GHG emissions above 1990 levels in 2004. There is an opportunity to replace a portion of the coal and peat used in power plants in Ireland with renewable biomass [6].

Harvesting of *Miscanthus* has moved from a cut and bale system to a cut and chip system primarily to meet energy market requirements. Wood chips are a uniform fuel and offer advantages such as they can be transported and fed into boilers or other conversion systems because of their flow-like properties and the large surface area to volume ratio allow for them to be burnt more efficiently [8]. In recent years the large scale increases in biomass for energy production has led to more frequent storage of large quantities of biomass and these can be possible fire sources [9]. To meet biomass demands and to avoid space issues associated with the storage of chips it is conceivable that biomass will need to be harvested over a wider harvest window (i.e. Jan–April). This leads to the issue of safely storing moist biomass in piles or clamps. Fires from self-ignition have negative implications for economies and the atmosphere, and are a safety issue. Emissions of carbon dioxide and of toxic gases, such as carbon monoxide through incomplete combustion will increase due to self-ignition of biomass piles [10]. Self-ignition in large open air wood chip piles/clamps is widely reported, however to the best of our knowledge an assessment of the self-heating and self-ignition risks for large *Miscanthus* chip

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piles have not been reported to date [10]. Losses of biomass for bioenergy due to self-ignition cause disruption to the energy supply chain and substitutions for any losses would probably be by fossil fuels [10].

Freshly harvested plant material is highly susceptible to microbial degradation and consequently energy yields will be affected [11]. Storage of wood chip can develop extreme increases in microbial activity and loss in dry matter [12–14] resulting in economic losses [15].

The initial self-heating in newly formed biomass clamps are principally caused by microbial heat production as found by Ferrero et al. [10] and Springer and Hajny [16] while physical and chemical heat sources are much lower. Ferrero et al. [10] developed a mathematical model to assess the likelihood of self-ignition in wood chip clamps and included three heat sources, namely chemical (related to oxidations), physical (related to evaporation/adsorption and condensation/desorption) and microbial. Exothermic reactions such as slow oxidations, physical influences such as coupled effects of condensation and adsorption of water molecules and microbial processes can combine to cause self-ignition [10]. Low heat conductivity of biomass material results in poor dissipation of heat from a biomass pile [10]. Since heat is only dissipated through the surface of the pile, the pile geometry plays an important role in influencing the frequency of occurrence of self-ignition [10]. Hensel et al. [17] reported that an increase of the volume to surface ($V/A$) ratio results in a lower self-ignition temperature ($T_{SI}$). $T_{SI}$ is the highest surrounding temperature at which no ignition occurs [10].

Jirjis [11] reported a sudden rise in temperature inside a willow shoot pile of 3 m in height and that the heat development was rapid as the height of the pile increased. It was reported that the lower regions of the piles had higher temperatures at low ambient temperatures and the top regions had higher temperatures during higher ambient temperatures [11].

The shape of the pile was reported to affect the pile temperature more than pile height as this will influence $V/A$ [11]. Oxygen availability and cooling by convection from the interior of the pile are affected by $V/A$ [18].

In comminuted biomass resulting from the compaction of chips in large piles air movement is reduced and higher internal heat results when compared to uncomminuted biomass [19,20]. A decrease in wood chunk size as well as the presence of fines or small particles reduces air convection which slows cooling and causes an increase in self-heating in piles thus increasing the possibility of self-ignition and dry matter losses [11,18]. The larger surface area in smaller biomass chips can allow for increased microbial activity [11].

Covering biomass piles can protect against rain and snow penetration which will lead to a reduction in the moisture content; however an adequate airflow is necessary to disperse moisture vapour which could cause mould formation and composting [21].

Piles of combustible materials are also affected by penetration of water as liquid or vapour into void spaces in the piles [22,23]. A pile surrounded by high humidity increases the likelihood of self-ignition due to condensation and heat of wetting affects [24]. If the temperature of the material is initially cooler than its surroundings in the storage space moisture evaporates from the material at regions close to the surface and water vapour diffuses into the material pile and condenses on the surfaces of the material. This water vapour along with partly evaporated water and moisture from the surroundings diffuses into the pile via void spaces and the condensation inside the pile leads to heat transfer and the pile heats [24]. Heat of wetting can follow condensation; heat of wetting is heat generated and transferred into the cooler parts of the material as the condensed water is absorbed by the particles and it depends on the specific surface of the material [24]. Heat of wetting increases with lower initial water content of the material; this is due to more free space on the particles [25].

The objective of this study is to assess self-heating in *Miscanthus* chips clamps during storage in weather sheltered conditions. The project monitors temperature and gas evolutions throughout the clamps which were constructed from *Miscanthus* chips harvested at different times and also assesses the quality of the biomass post-storage. Harvesting times were selected to achieve a wide difference in moisture content in the crop. A reliable assessment of the self-heating in *Miscanthus* chip clamps is necessary to prevent costs associated with biomass fire damage, caused by self-ignition, and decomposition, as well as their environmental consequences.

## 2. Materials and methods

### 2.1. Miscanthus growth and harvesting

An 18 year old crop of *Miscanthus* (*Miscanthus* x *giganteus*; sown in 1994) at the Teagasc Crops Research Centre in Carlow, Ireland was used for the self-heating during storage experiments. The crop was harvested on two dates in 2012 (21st February and 28th March) by a New Holland FR9080 forage harvester fitted with a kemper header and set to cut chips to a length of 18 mm.

### 2.2. Clamp construction

Individual clamps for both the February and March *Miscanthus* chip harvests were constructed with dimensions of 3.5 m (height) × 7 m (length) × 4 m (width) (Fig. 1); these will be referred to as the February and March clamps, respectively. The clamps were constructed in a roofed rectangular shaped shed open to the elements at the two ends only. The walls of each clamp were formed by large straw bales on three sides and by the concrete side wall of the shed on the fourth side.

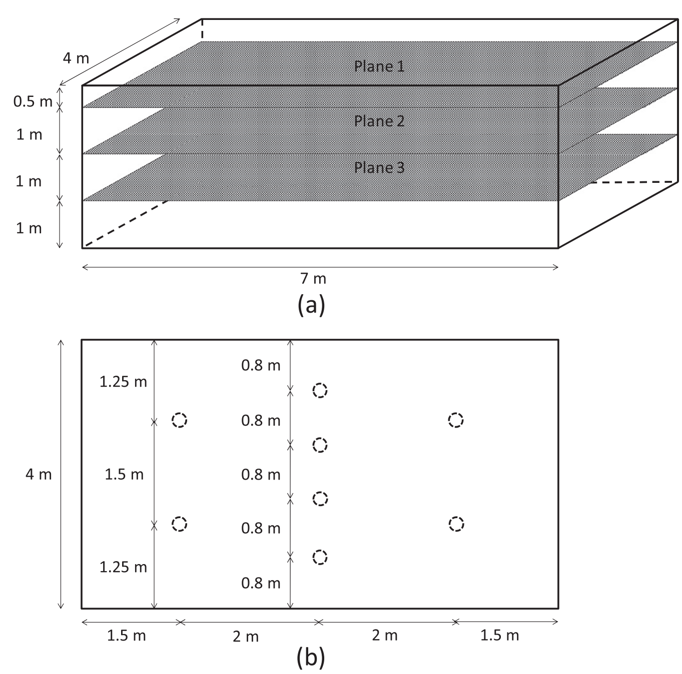


**Fig. 1.** (a) Large *Miscanthus* chip clamp dimensions, showing the planes on which temperature and gas measurements were taken; (b) Positioning of temperature sensors on each of the three planes shown in a.

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