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Biomass round bales infield aggregation logistics scenarios

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ABSTRACT

Biomass bales often need to be aggregated (collected into groups and transported) to a field-edge stack or a temporary storage before utilization. Several logistics scenarios for aggregation involving equipment and aggregation strategies were modeled and evaluated. Cumulative Euclidean distance criteria evaluated the various aggregation scenarios. Application of a single-bale loader that aggregated bales individually was considered as the "control" scenario with which others were compared. A computer simulation program developed determined bale coordinates in ideal and random layouts that evaluated aggregation scenarios. Simulation results exhibited a "diamond pattern" of bales on ideal layout and a "random pattern" emerged when ≥10% variation was introduced. Statistical analysis revealed that the effect of field shape, swath width, biomass yield, and randomness on bale layout did not affect aggregation logistics, while area and number of bales handled had significant effects. Number of bales handled in the direct method significantly influenced the efficiency. Self-loading bale picker with minimum distance path (MDP, 80%) and parallel transport of loader and truck with MDP (78%) were ranked the highest, and single-bale central grouping the lowest (29%) among 19 methods studied. The MDP was found significantly more efficient (4%–16%) than the baler path. Simplistic methods, namely a direct triple-bale loader with MDP (64%–66%), or a loader and truck handling six bales running parallel with MDP (75%–82%) were highly efficient. Great savings on cumulative distances that directly influence time, fuel, and cost were realized when the number of bales handled was increased or additional equipment was utilized.

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1. Introduction

The common adage "Field to Factory" used in connection with biomass logistics sounds like a simple point-to-point transportation of well-packaged biomass. But a closer look at the biomass distribution for collection reveals a different situation. Although, a "factory" can be considered as a point destination, the biomass on the field, even after consolidation into bales, is a dispersed source. These bales need to be aggregated (collected and transported) to a field-edge stack or field storage to be considered a point source of biomass.

As such, baling is an important postharvest operation because baling of biomass material helps in collection and preservation of biomass as well as clearing the field for subsequent cropping operations. Round bales can be made, left on field, and transported later, uncoupling the harvest and infield transportation operations, which offers a significant advantage [1]. In the field, however, the bales are dispersed (Fig. 1) and hinder future agricultural operations and potential crop regrowth, if not aggregated in a timely manner. Bales left on field too long will damage the plants under them, while the bales themselves lose their integrity, become difficult to handle, and lose significant dry matter [2,3]. Usually, the bales will be moved to a field-edge stack before being transported to a secured storage location or transported to other facilities or to a feedlot for local consumption. Thus an efficient aggregation of bales with the least total distance involved is a goal of producers and bale handlers.

Most of the biomass logistics analyses have concentrated on transporting biomass from the field to proposed processing facilities, considering "field" as a point source of biomass with biomass made into several forms (e.g., pellets, briquettes, bales). Elaborate logistics models of biomass supply to biorefinery have been developed and implemented [4–8]. As these models address biomass supply to a processing facility as a whole, detailed infield bale aggregation was beyond their scope or simplistic methods were assumed for this minor subcomponent. Some of the biomass logistics analyses have been location specific, for instance, biomass transport model to a power plant in India [9], and rice straw biomass for power generation in Thailand [10]. However, literature exclusively on infield biomass logistics is very limited.

Grisso et al. [11] developed a MATLAB interface and program to calculate a logistical pattern of removing round hay bales from a field to storage as a "students' tool" to train students on the timing, distance and pattern of moving, handling and storing round bales. The students developed a loading pattern for a self-loading bale wagon. This system was used to deliver round bales from satellite storage locations to a proposed biorefinery plant [12]. In their study, the bales were assumed randomly placed, collected in batches, and cumulative distances involved were calculated geometrically.

The major component activities of infield bale aggregation are collection of bales into sub-groups and transportation to a field-edge stack or storage using various bale handling equipment. Several scenarios emerge for the various possibilities of aggregation (sub-grouping before field-edge stack transport), loading, and transport involving different equipment (e.g., bale loaders, bale wagons, bale pickers), strategies (e.g., direct transport by loaders, grouping bales and transport, parallel run of baler and truck, bale pickers), and collection paths (e.g., baler and minimum distance). Other factors that influence the aggregation logistics are the crop species handled, area and shape of field, biomass yield, mass of bale, swath width, random variation between the distances of the bales, as well as the economics involved in all the scenarios.

The cumulative transport distance in aggregating bales in a given area directly quantifies the effort involved in this operation. This total distance also serves as an indicator of the time involved and the fuel consumed (energy), hence influences equipment selection and overall economics of the operation. The point of interest in this research is determining the total bale transport distances for various possible scenarios.

The present paper proposes to mathematically simulate the action of a baler to generate the layout of bales on the field, and statistically evaluate and rank the various bale aggregation scenarios. The total distance involved is calculated as the sum of Euclidean distance between the bale and a field-stack or between bales using the analytical distance formula for all bales in the field based on the selected scenario.

Thus the objectives of this research are: To simulate the action of the baler and determine the ideal and random layout of bales; model bale aggregation scenarios and determine the total aggregation distances; statistically determine the effects of field size, number of bales handled, field shape, biomass yield, swath width, bale layout, and collection path on bale aggregation; and rank the considered bale aggregation methods.

Fig. 1 – Biomass bales dispersed on a field after baling. Inset: Bales brought to field-edge stack.

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