Infield optimized location of biomass bales stack for efficient collection logistics

Subhashree N Srinivasagan and Dr. C. Igathinathane, NDSU Agricultural and Biosystems Engineering

Fig 1. Formed bales on the field ready to be aggregated into bale stacks and transported to outlet

Agricultural biomass is one of the most abundant renewable energy resources. The importance and demand of biomass are ever increasing due to its versatility, as biomass is used to generate different forms of energy such as electricity, heat, and biofuels for the transportation vehicles. Biofuel production at large scale faces a lot of issues and challenges associated with collection logistics, schedule of delivery and inconsistent feedstock supply. Transport of biomass from the point of origin to the point of consumption was conceptually considered as a single logistics operation. However, a careful examination can reveal that the infield biomass logistics is a time-consuming operation involving several components. Studies focus only on developing models for optimizing the logistics outside the field, and often infield logistics is over-looked. Infield logistics of collecting and moving biomass to a location suitable for further use represents a substantial field operation.

Biomass after harvest is usually made in a compacted form, such as bales and are initially left on the field (Fig.1). Producers often aggregate bales into several stacks in the field before transporting the bales to an outlet location in their field. Motivations for the bale stacks formation that will lead to efficient logistics include (i) clearing the field for next crop, (ii) smoother mechanical crop management operations without bales hindrance, (iii) short window between harvest and next planting schedule, and (iv) field conditions may not allow for driving equipment. Furthermore, the desire for forming bale stacks in the field is to utilize efficient multiple bale-hauling equipment from the stack to the outlet.

Thus, given the advantageous role of bale stacks in the infield logistics, it will be pertinent to investigate “where” to locate the bale stack so that the logistics will be efficient. Therefore, this study focuses on determining the strategic location of the bale stacks, so that the bale aggregation and subsequent transport distances will be minimized, and improve the infield logistics efficiency. Various mathematical grouping methods selected for this study were field midpoint, middle data range, centroid, geometric median, and medoid (Fig. 2). Direct aggregation of bales to the field outlet was also considered as one

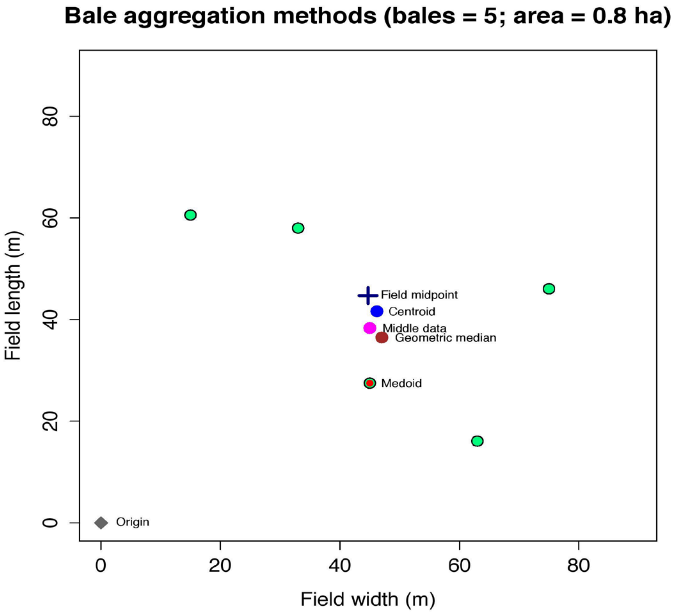

Fig. 2. Bale aggregation methods are illustrated with a small field area (0.8 ha) with a limited number of bales (n=5).

of the methods called ‘origin’. Considering bales as points on a 2D plane, mathematical grouping methods were employed to simulate the aggregation of the bales into stacks. These methods of locating bale stack lead to different locations in the field, based on their algorithm. Using these methods, the optimum bale stack location was determined that gave the least aggregation (collecting the bales to the stack) or total (aggregation + transport, (hauling bales from stacks to outlet)) distances, and the methods were ranked based on these distances.

Analysis showed that the origin method had the highest aggregation distance among all methods and areas, whereas the other methods’ logistic distances were different and they did not vary much from one another because of convergence of locations (Fig. 3). Among the other methods, the geometric median was the most efficient with the lowest aggregation distance for all areas. Similarly, the least efficient (2.02 - 259 ha) was the medoid with the largest aggregation distance. Field middle method closely followed the best geometric median method, while the middle data range and centroid methods also had a similar trend with no clear best. Statistical analysis reveals that several areas (≤11.8%) produced significant differences among the methods. For areas ≥2.02 ha, the difference of the total logistics distance of field middle ranged only from -0.34% to 0.18% with reference to the best method in each area.

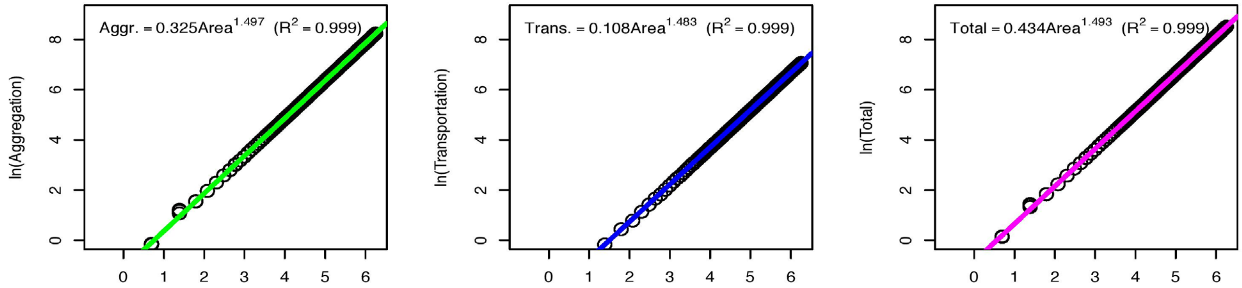

Fig 4. Fitted power models for logistics distances for the selected field middle method

Therefore, for practical use and simplicity, the field middle method was selected as the efficient bale stack location for further correlation analysis and regression model development. The following power models of logistics distances of the field middle method had excellent fits ($R^2 > 0{:}99$) (Fig.4):

$$\text{Aggregation (km)} = 0.325 \times \text{Area (ha)}^{1.497}$$

$$\text{Transport (km)} = 0.108 \times \text{Area (ha)}^{1.483}$$

$$\text{Total (km)} = 0.434 \times \text{Area (ha)}^{1.493}$$

These simple logistics models can be used to predict the aggregation, transport, and total distances directly from the field area of interest (0.5–520 ha).

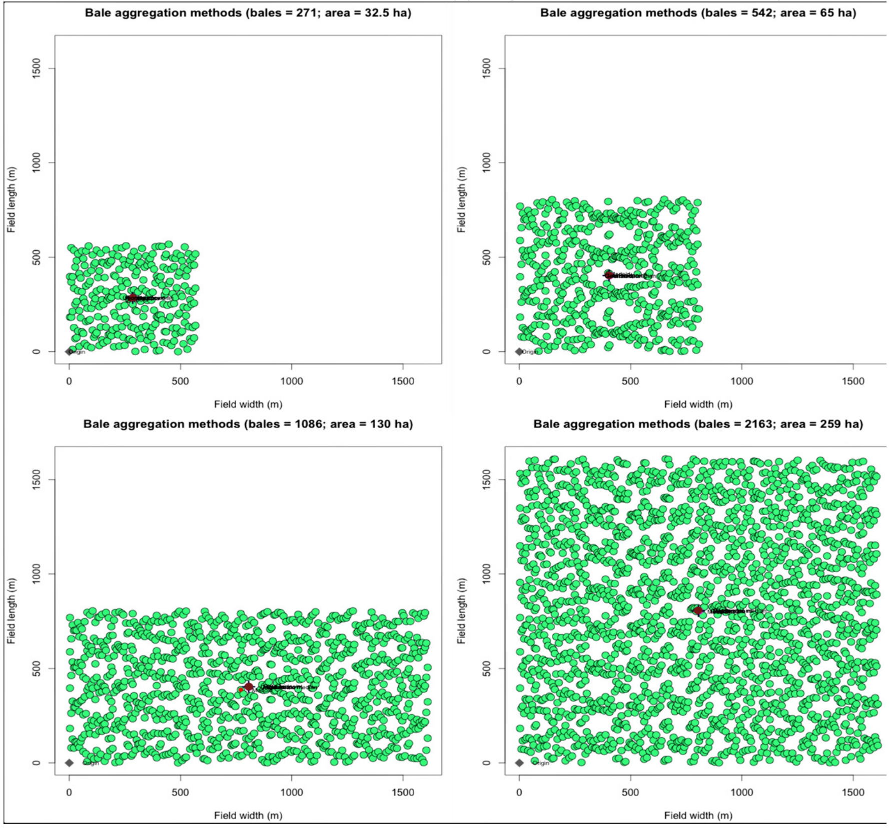

Fig 3. Bales layout and bale aggregation methods location for different field areas overlaid in a section area of land. Simulation data: biomass yield/ha = 5 Mg; bale mass = 600 kg; harvester swath = 6 m; aspect ratio = 1.0 and 0.5; biomass yield variation = 10%

Further reading: Subhashree, Srinivasagan N., C. Igathinathane, Ganesh C. Bora, David Ripplinger, and Leslie Backer. “Optimized location of biomass bales stack for efficient logistics” Biomass and Bioenergy 96 : 130-141. http://www.sciencedirect.com/science/article/pii/S0961953416303580

Igathi Cannayen 701.667.3011 igathinathane.cannayen@ndsu.edu