Locating bale field stacks and outlets for efficient infield logistics

C. Igathinathane, J.S. Tumuluru, D. Keshwani, NDSU; M. Schmer; D. Archer, M. Liebig, J. Halvorson, J. Hendrickson, S. Kronberg, ARS

Baling of harvested material infield is a traditionally followed practice for efficient handling of loose hay and biomass. The bales formed that lay in the field need to be transported to the outlet for livestock consumption or further dispatched to a potential biorefinery. To better manage the bale collection, producers often aggregate bales within a field into stacks before transporting to an outlet location for consumption or transport off-site for final use (Fig. 1). Here the underlying motivation for forming subfield stacks is to aggregate bales into groups sized for bale-hauling equipment that can haul multiple bales in one step to a field outlet, making the logistics efficient.

Figure 1. Biomass bales remain distributed on (A) field, (B) subfield stacks made after aggregation (arial view), and (C) field outlet where subfield stacks bales were transported for livestock consumption or dispatched to biorefinary.

The specific objectives of this research effort were to: develop simulation of biomass baler for layout of bales on the field; delineate subfields and form bale stacks in desired layouts; perform bale logistics operations involving aggregation of bales to stacks and bales transportation to the field outlet for various bale stack and field outlet locations; and determine the effects of field size, field shape, harvester swath, biomass yield, bale mass, biomass windrow variation as well as number of subfield stacks and number of bales transported per trip on the collection logistics distances.

Materials and Methods

Overall simulation strategy for bales infield logistics

The overall strategy of the mathematical simulation can be summarized as to: (1) form the bales based on the bale pickup length along windrow, (2) divide the field into subfields for bale aggregation, 3) aggregate the bales into subfield stacks, and (4) transport bales from the subfield stacks to the field outlet. Simulation also includes studying the effect of number of subfield stacks, their distribution layout with respect to the outlet, location of outlet with respect to the field, and various field variables that affect the bale formation and eventually the collection logistics. Coordinates of formed bales and subfields were simulated for evaluating the logistics. Simulation of bales layout on field in this study follows our reported methodology. The yield variation existing in the field was simulated through a factor that will affect the windrow pickup length and alters the bale layout spacing.

Stack bale aggregation and field outlet transportation

In this study, all bale movements (aggregation or transportation) were considered to be along a straight line path. Thus, the sum of linear (Euclidean) distances of all subfield bales to the subfield stack represents the total aggregation distance, and that from subfield stacks to field outlet represents the total transportation distance. Only these direct (one-way) distances were used in the analysis, but were sufficient to provide the data required for scenarios comparison. However, to obtain the actual working distances these working distances need to be multiplied by two to account for the to-and-fro movement of the equipment.

Results and Discussion

Stack locations effect along specified paths

The simulated field was 569 m wide and 1138 m long having its centroid coincided with the middle of the field (284.5, 569 m). Total aggregation distances of the bales (total 1295) along these selected linear paths at 50 locations were studied (Fig.2). In general, a symmetrical parabola-shaped variation was obtained when the paths were along the field boundary (0 to W or 0 to L) and along the diagonal (0 to W, L). The variations were not completely symmetrical when the stack location paths were from the origin to the mid-length (0 to W, L/2) or mid-width (0 to W/2, L), because these paths did not divide the field symmetrically or run completely along the edges.

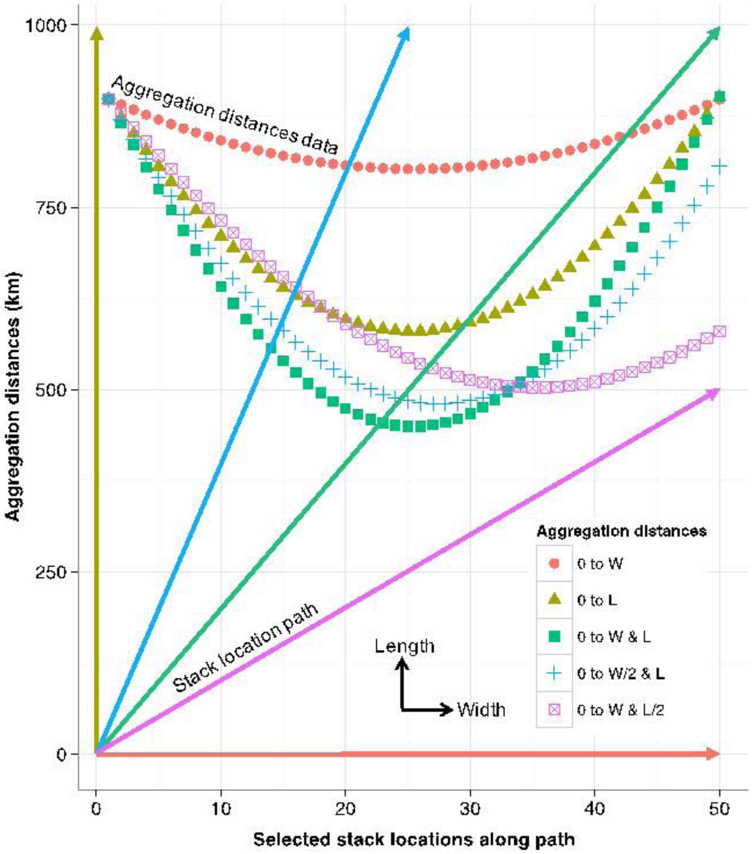

Figure 2. Bale aggregation distances (data points) to subfield stacks as affected by stack locations along specified paths (colored arrows). Simulation parameters used: area = 64.75 ha (1 quarter section, field dimensions (L = 1138 m, W = 569 m) not shown), L/W = 2, swath width = 6 m, biomass yield = 12 Mg ha−1, bale mass = 0.6 Mg, windrow variation = 10%, number of subfields = 1, and number of bales = 1295.

From these results (Fig.2), it can be concluded that the best locations for the subfield stack or field outlet are: (1) field center, (2) near the field center, (3) mid-length, (4) mid-width, and (5) field corners. For square fields or subfields, the mid-length and mid-width aggregation results coincide.

Stack and outlet locations effect on logistics

Following the collection path aggregation results (Fig. 2), the possible significant layouts of subfield stacks and outlets were considered for logistics evaluation (Fig.3). Collection logistics distances of the various scenarios (Fig.3a–d) evaluated for a square (L/W = 1) and rectangular (L/W = 2) fields are presented in Figure 4.

Total aggregation distances reduced from the diagonal corner (D) to the field middle (M), as were ranked earlier (Fig.2). The mid-width (W) and mid-length (L) showing similar aggregation values for square field but continuous reduction with rectangular field (Fig.4). Because of the assumption of single bale handling during aggregation, all aggregation curves representing different bales/trip coincided. Overall, compared to the reference method applied to corner outlet (O:D; shown as dotted line in Fig. 4), the aggregation distances were <30%. Rectangular fields require increased logistics distances as the collective distances of the bales from any point is greater than that of square field.

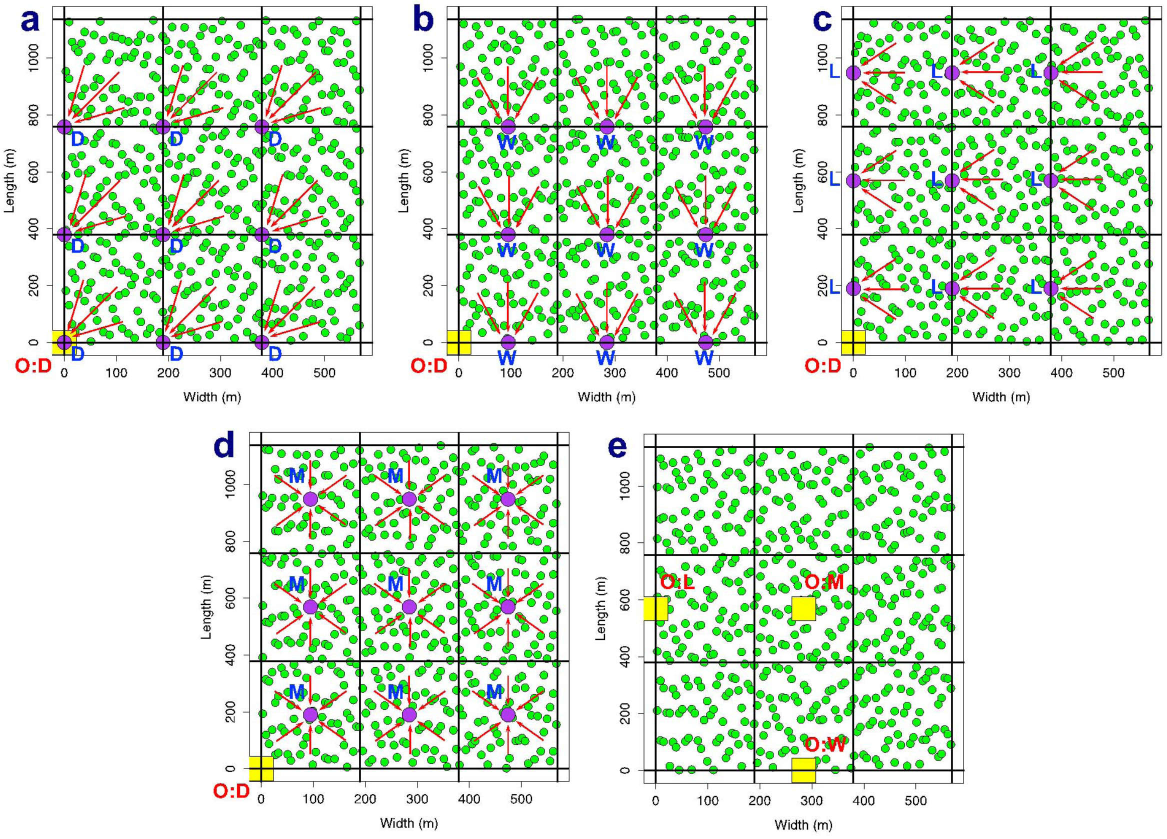

Figure 3. Subfield stacks and field outlets location layouts studied for infield bale logistics. Green circles = bales, black grids = subfield boundaries, purple circles = subfield stacks, yellow squares = field outlets, and red arrows = bale aggregation direction. Letters represent subfield/field location such as O = outlet, D = diagonal corner, W = mid-edge width, L = mid-edge length, and M = middle. The first four subfigures illustrate layouts with corner field outlet (O:D) with subfield stacks at: (a) corner (D), (b) mid-edge width (W), (c) mid-edge length, and (d) field middle (M). The fifth subfigure (e) illustrates the other possible outlet combinations with the above subfield stack locations.

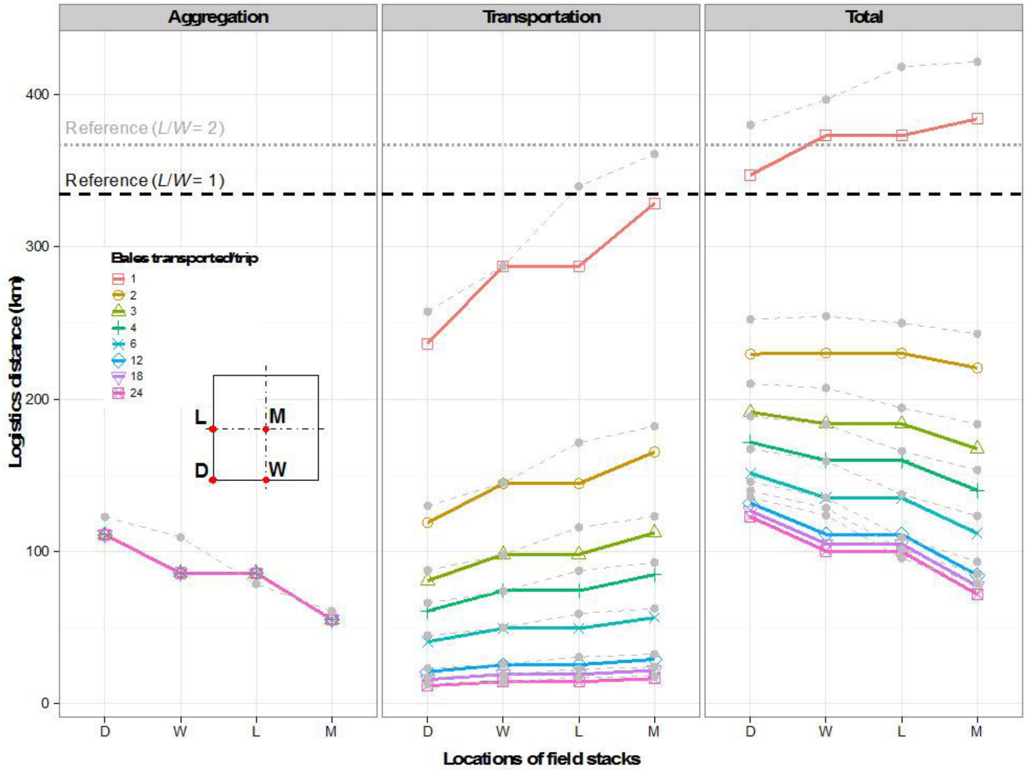

Figure 4. Effect of subfield stack and field outlet locations on logistics for the bales layout illustrated in Fig.3 with fixed corner field outlet (O:D) for two field shapes (L/W = 1 - colored symbols and lines, and L/W = 2 gray circles and lines) and various number of transported bales/trip.

Compared to aggregation, an opposite increasing trend with transportation and a clear reduction with increased number of bales/trip were observed with respect to the subfield stack locations (Fig. 4). The reduction effect on the transportation distances was substantial at first from one to two bales/trip, then the rate of reduction decreased, and not appreciable after 12 bales/trip. Bales total transportation distances from the subfield middle (M) to the corner outlet in all cases were higher than that from the other subfield locations (D, W, and L). It is interesting to note that the advantage of making the subfield stacks can be realized starting from two bales/trip onwards in transportation for both shapes of the field. This hauling of multiple bales (≥2), especially 2 to 6 bales using trailers is highly practicable in the present modern farm operations.

Effect of number of stacks and transported bales/trip on logistics

Results indicate an overall trend of total logistics distance reduction with both number of subfield stacks (Fig. 5a) and bales/trip in transportation (Fig. 5b) for a square field with different field outlets. Aggregation by principle is not affected by the outlet location, hence all field outlet trends coincided. Transportation showed a gradual increase after 16 stacks, but reduced drastically with bales/trip initially, and the reduction was less after 6 bales/trip for all the three outlets.

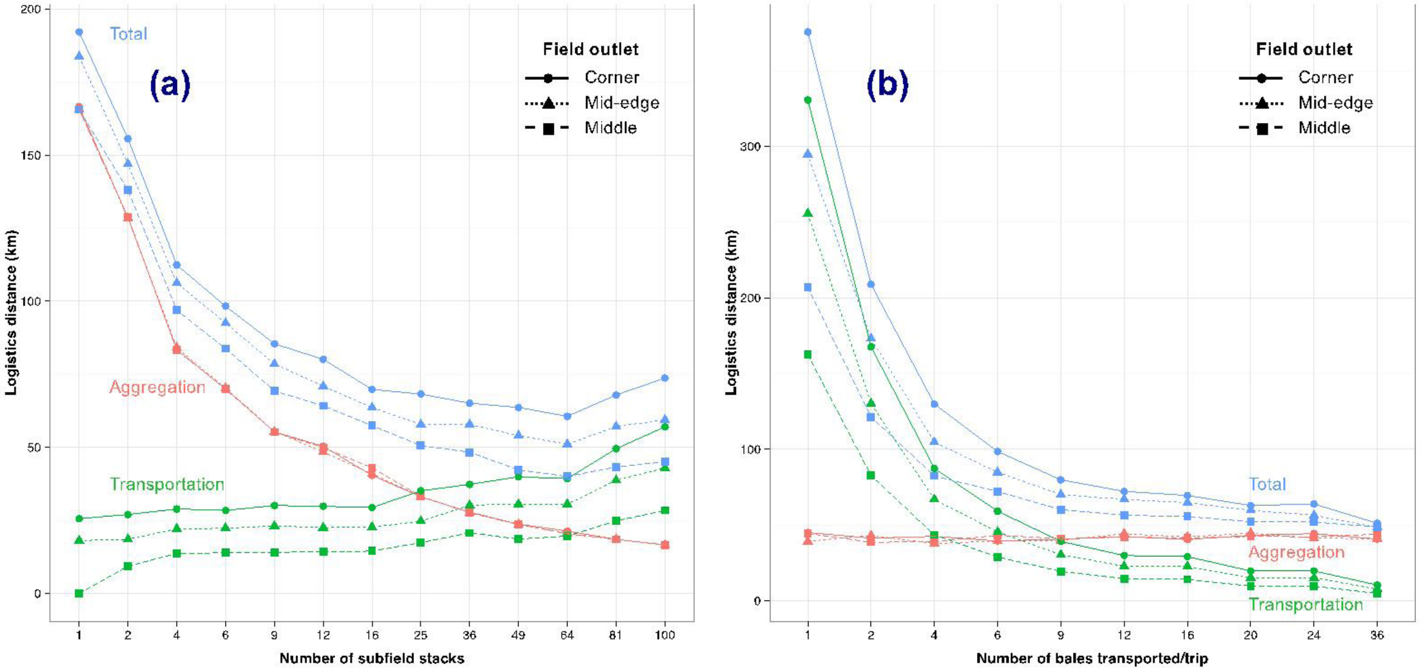

Figure 5. Effect of (a) number of subfield stacks (6 bales/trip assumed) and (b) bales/trip (4 × 4 = 16 subfields assumed) used in transportation on logistics distances for different outlets.

All logistic distance trends followed the order of middle, mid-edge, and corner outlets in terms of reduced logistics distances. Therefore, considering the practical operations using smaller equipment, a middle subfield stack location with 6 bales/trip and 16 subfields for a 64.75 ha (quarter section) field appears to be an efficient combination, keeping in mind that increased number of stacks and bales/trip will also be efficient provided the operations allow for such expansions (Fig.5).

Field outlet location and recommendations

Bale collection logistics analysis indicates that the field middle (centroid) is the best location for the field outlet. If this option is not available then other locations in the field closer to centroid will be the next choice, followed by mid-edges on the boundary (length first then width), and finally field corners. Therefore, for collection logistics involving formation of subfield stacks it is recommended that a central outlet combined with appropriate large number of stacks formed in the middle of each subfield represent the most efficient arrangement for collecting the bales for livestock consumption or to a biorefinery.

Conclusions

Formation of subfield stacks allows for decoupling of aggregation and transportation components leading to more efficient infield logistics. Increased number of subfield stacks and number of transported bales/trip reduced the total logistics distance. Logistically square shaped subfields are more efficient than rectangular. Best bale stack location on subfields as well as outlet for the whole field followed this order: middle (e.g., −50% from corner), near middle, mid-edge along length — longer dimension (−36%), mid-edge along width — shorter dimension (−11%), and corners (0%). Field variables, such as field size, field shape, biomass yield, and bale mass, except the harvester swath and windrow variation had significant influence on the logistics distances (aggregation, transportation, and total) among different values as well as number of subfield stacks. Total logistics distance was significantly ($p < .001$) influenced by location of stacks and outlet, number of stacks, and bales/trip. Fixing the field outlet at or near the center of the field and establishing a transportation road/pathway, if not present, along with appropriate number of square subfields with stacks at the middle will lead to the most efficient bale collection logistics in terms of reduced distances and time expended. When increased number of bales/trip (e.g., ≥ 6) were used in transportation, the variation among the field outlet locations gets minimized; and outlets can be located based on existing facilities and ease of operation.

Igathinathane Cannayen, 701-667-3011; Igathinathane.Cannayen@ndsu.edu