Quantification of Wheel Traffic and its Effect in Lucerne Hay Production

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1. Introduction

Lucerne hay is a significant rural industry in Australia, producing approximately one million tonnes of hay valued at around $300 million per year (ABS, 1996). It is usually grown on irrigated land and farmers often take 6-8 cuts each year. Unlike other field crops, lucerne is not sown each year and thus there is no opportunity to loosen the soil every season or year. As a result of repeated wheel traffic cut after cut and year after year, the compaction effects accumulate on lucerne fields and result in reduction of hay yield (Douglas, 1994). Grimes et al. (1978) reported that up to 70% of crop area may be covered by wheel traffic during each lucerne harvest. The annual traffic loading on lucerne fields is likely to be many times more than that on fields where grain crops are grown. Annual traffic loading in lucerne hay production depends upon the type of haymaking machinery system. For example, unconditioned haymaking systems use lighter cutting equipment (mower) and require more trips to the field for raking operation due to prolonged drying. On the other hand, mechanically conditioned haymaking systems use heavier cutting equipment (mower-conditioner) and require fewer trips to the field for raking operation because of enhanced field drying process. The objectives of this paper are:

(i) To describe the method of quantifying wheel traffic in lucerne hay production;
(ii) To compare the wheel traffic loading for unconditioned and conditioned haymaking systems;
(iii) To compare the wheel traffic loading of lucerne hay production system with grain crop production system; and
(iv) To review the effect of wheel traffic on lucerne hay production and suggest various methods for minimising wheel traffic.

2. Analysis of Quantification of Wheel Traffic

Numerous criteria have been used to quantify wheel traffic in crop production. They range from a simple single parameter such as rut length per hectare (Frese, 1969) to a very complex mathematical model predicting crop yield loss due to wheel traffic (Arvidsson and Hakansson, 1991). Kuipers and Van de Zande (1994) have comprehensively reviewed these criteria and suggested that the Field Load Index is the most appropriate criterion for assessing the compaction risk from wheel traffic on a field scale. Thus, this criterion will be used for quantification and comparison of wheel traffic intensity under different lucerne haymaking systems.

The Field Load Index is defined as the product of load and loading time per unit area. Mathematically, it can be expressed as follows:

$$FLI = (m_t + m_i) \times T$$

where

FLI = Field Load Index (t h ha^{-1})
m_t = Mass of tractor (t)
m_i = Mass of implement (t)
T = Field time (h ha^{-1})

A typical haymaking system involves four field operations in a sequence: cutting, raking, baling and carting. Field time for these operations can be determined as follows:

Cutting/Raking

$$T = \frac{10}{width\,(m) \times Speed\,(km\ h^{-1})} \tag{2}$$

Baling/Carting

$$T = \frac{Yield\,(t\ ha^{-1})}{Capacity\,(t\ h^{-1})} \tag{3}$$

3. Comparison of Wheel Traffic for Two Haymaking Systems

To compare the wheel traffic intensity in lucerne hay production, the two most common haymaking systems were considered: (i) unconditioned haymaking system and (ii) mechanically conditioned haymaking system. Specifications of machines and implements used in each system are given in Table 1. Reasonable estimates of the mass of machines and implements, and their operating speeds were derived from TMA (1997) and Anon. (1998).

All operations other than raking are single pass operations ie. they are carried out only once in a harvest. However, number of rakings carried out in any cut could vary depending upon whether the crop is conditioned or not. As the field drying time is different for summer and winter periods (Akkharath *et al.*, 1996), the number of rakings could also vary whether the crop is cut during summer or winter periods. The number of rakings used for these situations is given in Table 1.

Estimates of Field Load Index (FLI) for different haymaking operations were carried out using Eqns (1) to (3). Table 2 presents Field Load Index for unconditioned and conditioned haymaking systems under summer and winter weather conditions. The FLI for a single cut during winter periods is approximately 18% more than that during summer periods primarily because of greater number of rakings carried out during the field drying process.
Most farmers will have eight cuts per year - usually five in summer and three in winter. Table 3 presents the annual traffic load on a typical farm using either unconditioned or conditioned haymaking system. The annual traffic load for unconditioned haymaking system is 160 t h ha^{-1} and raking contributes nearly 60% of wheel traffic. The annual traffic load for conditioned haymaking system is only 96 t h ha^{-1}, which is 40% less than that of the unconditioned haymaking system. The annual load due to raking in conditioned system is only 40% of that of unconditioned system.

Table 1: Specifications of machines and implements for unconditioned and conditioned haymaking systems.

Unconditioned Haymaking System	
Operation	Equipment
Mowing x 1	35 kW tractor, 1.6 m disc mower
Raking x 3 (summer) Raking x 4 (winter)	35 kW tractor, 2.5 m oblique reel rake
Baling x 1	35 kW tractor, 8 t h^{-1} rectangular baler
Carting x 1	35 kW tractor, , 8 t h^{-1} pull-type bale wagon
Conditioned Haymaking System	
Operation	Equipment
Mowing x 1	35 kW tractor, 2.8 m mower-conditioner
Raking x 2 (summer) Raking x 4 (winter)	35 kW tractor, 2.5 m oblique reel rake
Baling x 1	35 kW tractor, 8 t h^{-1} rectangular baler
Carting x 1	35 kW tractor, 8 t h^{-1} pull-type bale wagon

Table 2: Field load index for a single harvest during summer and winter weather conditions.

Operation	Summer Periods				Winter Periods			
	Unconditioned System		Conditioned System		Unconditioned System		Conditioned System	
	t h ha^{-1}	%	t h ha^{-1}	%	t h ha^{-1}	%	t h ha^{-1}	%
Cutting	3.4	18.2	2.4	21.4	3.4	15.3	2.4	18.2
Raking	10.5	56.1	4.0	35.7	14.0	63.1	6.0	45.5
Baling	2.1	11.2	2.1	18.8	2.1	9.4	2.1	15.9
Carting	2.7	14.5	2.7	24.1	2.7	12.2	2.7	20.4
Total	18.7	100.0	11.2	100.0	22.2	100.0	13.2	100.0

Table 3: Annual traffic load in lucerne hay production.

Operation	Annual Traffic Load			
	Unconditioned Haymaking System		Conditioned Haymaking System	
	t h ha^{-1} year^{-1}	%	t h ha^{-1} year^{-1}	%
Cutting	27.2	17.0	19.2	20.1
Raking	94.5	59.0	38.0	39.7
Baling	16.8	10.5	16.8	17.6
Carting	21.6	13.5	21.6	22.6
Total	160.1	100.0	95.6	100.0

4. Comparison of Wheel Traffic Intensity in Lucerne Hay Production and Grain Crop Production Systems

Field load indices for various operations under wheat production system were calculated using a method similar to the one explained in Section 2. Specifications of machines and implements commonly used in wheat production are given in Table 4. The annual traffic load in wheat production is estimated to be 15.6 t h ha^{-1}, out of which approximately 65% is exerted during tillage, 19% during planting, 3% during spraying and 13% at harvest. Annual traffic load in wheat production is 6-10 times less than that of lucerne hay production.

Table 4: Specifications of machines and implements for wheat production system.

Operation	Equipment
Ploughing x 2	100 kW tractor, 5 m chisel plough
Cultivation x 1	100 kW tractor, 6 m scarifier
Planting x 1	100 kW tractor, 6 m scarifier/planter
Spraying x 1	35 kW tractor, 18 m boom sprayer
Harvesting x 1	Self propelled grain harvester with 6 m cutterbar

Table 5: Annual traffic load in wheat production system.

Operation	Annual Traffic Load	
	t h ha^{-1} year^{-1}	%
Ploughing	7.2	46.1
Cultivation	2.9	18.6
Planting	3.0	19.2
Spraying	0.4	2.6
Harvesting	2.1	13.5
Total	15.6	100.0

5. Effect of Wheel Traffic on Lucerne Hay Production

Studies conducted overseas (Meek *et al.*, 1988; Meek *et al.*, 1989; Rachel *et al.*, 1987; Rachel *et al.*, 1990; Rachel *et al.*, 1991; Sheesley *et al.*, 1974) and in Australia (Neale and Tullberg, 1996) have indicated a significant reduction (10-26%) in hay yields due to soil compaction. The reduction in yield is mainly attributed to:

- Increased soil strength
- Increased bulk density
- Decreased hydraulic conductivity
- Decreased root density
- Decreased water use efficiency
- Mechanical damage to regrowth

6. Methods of Minimising Wheel Traffic in Lucerne Hay Production

Eliminating the wheel traffic damage in lucerne will save $60 million per year to lucerne growers in Australia. Complete elimination of wheel traffic may be practically difficult in lucerne hay production due to various sizes of machines used. However, substantial reduction in soil compaction can be achieved by following methods.

Controlled Traffic

Sheesley (1978) in USA and Neale and Tullberg (1996) in Australia have demonstrated that by slightly modifying the existing haymaking equipment, traffic lanes can be created to reduce traffic coverage from 70% to 20% of the field area. Establishing permanent uncropped wheel tracks is unlikely to be beneficial, as 20% increase in yield will be offset by the reduction in similar yield loss due to decrease in 20% of uncropped area.

Low Ground Contact Pressure Systems

Low ground contact pressure systems are those harvesting systems in which machines and implements are fitted with larger-than-standard tyres with low inflation pressures (Douglas, 1994). These systems have the potential to reduce soil compaction by reducing tyre/soil contact pressure. Douglas *et al.* (1992) found comparable dry matter yields of grass in zero-traffic and low ground contact pressure silage harvesting systems. Compared to conventional traffic, these systems resulted in 16% increase in dry matter yields. There is a scope to use such systems in lucerne hay production but presently information is scanty and research in this area would be useful.

Superconditioning of Hay

Superconditioning (hay maceration) is a new technology which has the potential to further improve the drying rate, allow baling within one day of mowing and minimise the number of rakings. Preliminary studies conducted in the USA (Koegel *et al.*, 1988) and Canada (Savoie and Beauregard, 1991) have shown that macerated hay can be dried to a baling moisture content within 5 to 8 hours during sunny weather. Adoption of such technology by Australian farmers will not only reduce wheel traffic substantially but also result in reduction of production costs.

Use of Double Rakes

Wheel traffic can also be reduced by using double rakes which can rake two adjacent swaths together. As raking contributes more than 50% of wheel traffic, such machines should reduce the annual traffic load by 25%.

7. Conclusions

(i) Annual traffic load in mechanically conditioned haymaking system is 40% less than that of unconditioned haymaking system.
(ii) Raking induces majority of soil compaction during haymaking - 40% in conditioned haymaking system compared to 60% in unconditioned haymaking system.
(iii) Annual traffic load in lucerne hay production is 6-10 times more than that of the traffic load in wheat production system.
(iv) Significant increases in hay yields are possible by minimising soil compaction in lucerne fields. Further research in the following areas would be useful:
  - Assessment of benefits of low pressure machinery systems in hay production
  - Development/modifications of machinery systems for adoption of controlled traffic
  - Development of methods/machines to enhance the drying rate of hay to reduce number of rakings during the field drying process.

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