What impact does dairy cow pugging have on clover N_2 fixation and long-term farm production?

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Abstract

The effects of a single, moderate or severe pugging event in early spring on pasture production, clover growth, and N_2 fixation were measured during a 1-year study on dairy pasture in the Waikato. Moderate and severe pugging of the poor-draining Te Kowhai soil resulted in annual pasture production decreases of 21% and 45%, respectively. Clover showed a much greater decrease in production than grass (65% vs. 38%) following severe pugging, and indicates that clover is more susceptible to the negative effects of pugging than grass. Nitrogenase activity showed a rapid decrease (up to 90%) within 3 days of pugging, and reflected the measured decrease in air-filled porosity (from 16% in the non-pugged to an average of 11% for the moderately and severely pugged treatments) and measured loss of root biomass. On an annual basis, the total amount of N fixed decreased from 151 kg N/ha in the control to 109 kg N/ha (-28%) and 45 kg N/ha (-70%) in the moderate and severe treatments, respectively. Longer-term effects of the decrease in clover DM yield from a single moderate or severe pugging event each year were modelled using a dynamic dairying model of N cycling. After 10 years, pugging was predicted to decrease N_2 fixation, soil organic N and grass growth, and result in a loss in milk production of 21% and 54%, respectively. On a whole farm basis, if moderate and severe pugging occurred on 50% and 10% of the farm, respectively, this would represent a decrease in milk production of 16% (e.g., from 1000 to 840 kg milksolids ha/year).

Keywords: dairying, N_2 fixation, pasture production, pugging, ryegrass, white clover

Introduction

In established New Zealand dairy pasture, white clover is capable of N_2 fixation rates as high as 300 kg N/ha/yr (Ledgard *et al.* 1990), and is therefore an important source of nitrogen in these systems. In intensively grazed dairy pastures, such as in the Waikato region, block grazing of dairy herds during winter is a common practice and involves confining the herd to a relatively small area at stocking rates of between 250–300 cows/ha/day. This type of grazing regime may lead to severe treading damage to soils, through trampling or remoulding in drier soils and pugging in wet soils (Scholefield & Hall 1985). Various studies have shown livestock treading (especially during winter and early spring) can cause short-term decreases in pasture production of up to 80% (Ledgard *et al.* 1996) and annual decreases in the range of 0–38% (Brown 1968; Cluzeau *et al.* 1992; Ledgard *et al.* 1996). However, few workers have studied the effect of livestock treading on white clover growth and N_2 fixation, and the consequences of this on nitrogen inputs into dairy systems. Given the relative importance of N_2 fixation in dairy pasture for inputs of fixed nitrogen, any decreases in N_2 fixation owing to intensive winter management of pastures may lead to associated reductions in pasture production. Potentially, clover N_2 fixation could be reduced by pugging, directly, owing to plant tissue damage, or indirectly via soil structural deterioration and effects on soil O_2 status and increased resistance to root growth (Jayasundara *et al.* 1998). This study examined the impact of pugging on clover growth and N_2 fixation in dairy pasture in the Waikato and used modelling to predict impacts on long-term production.

Materials and methods

The experiment was conducted on an established dairy pasture on a Te Kowhai silt loam (Typic Orthic Gley Soil) with impeded subsoil drainage. The pasture was a mixed stand of predominantly ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). Two pre-conditioning harvests (by mowing) were made prior to commencing the study, to improve pasture uniformity and minimise effects from residual excreta patches. Treatments consisted of a single pugging event of three severities (nil, moderate and severe) with eight replicates in a randomised block design. Moderate and severe pugging treatments were pugged by dairy cows in early spring 1999 (at a typical grazing intensity of 4.5 cows/100m^2) for 1.5 and 2.5 hours, respectively, to achieve the desired level of treading damage (Figure 1). Rainfall and irrigation prior to commencing the experiment meant that the soil was near saturation when the pugging treatments were applied. Prior to applying the pugging treatments, the cows were kept in stockyards overnight, to avoid inputs of dung and urine onto the plots during the treading event.

Soil physical properties (bulk density and air-filled porosity; pores > 30 μm) were measured, following the methods of Ball & Hunter (1988) using undisturbed soil cores taken from the topsoil (0–5 cm) 3 days after pugging. The area was fenced to exclude grazing and pasture production was measured over 12 months. Pasture was harvested by mower at 20 – 40 day intervals depending on the growth rate, and dry matter (DM) yield and pasture species composition were determined. Pasture clippings were not returned, but a basal fertiliser containing 15% potassic superphosphate was applied to correct any measured deficiencies of P and K.

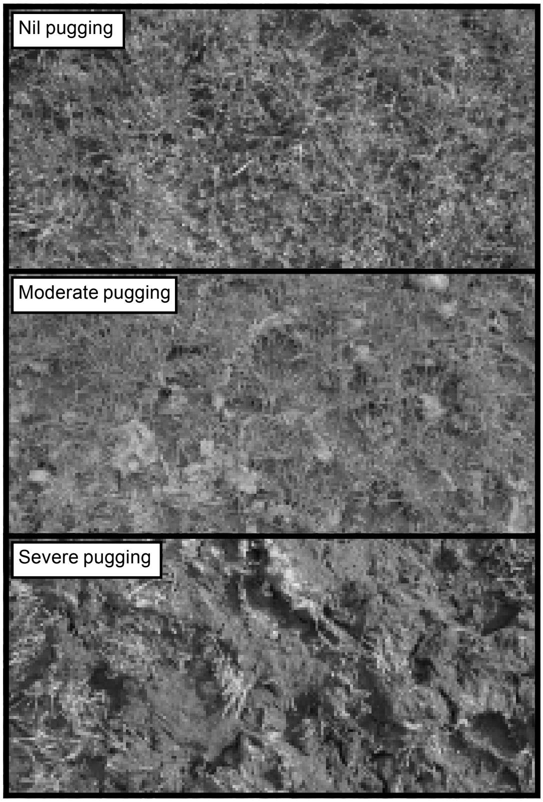
Short-term estimates (days 3, 7, 14, 21 and 27) of N_2 fixation (nitrogenase activity) were performed using the acetylene reduction method (Knowles 1981). Longer-term estimates of the total amount of N_2 fixed were determined using the ^{15}N isotope dilution method (Ledgard & Steele 1992), which include estimates for below cutting-height clover tissue (Jorgensen & Ledgard 1997). A dynamic dairying model of N cycling (DAMN; Ledgard *et al.* unpublished) was used to examine long-term impacts on species composition, soil N, pasture production and milk production. The DAMN model gives an insight into the potential long-term effects of different management practices (e.g., pugging) on legume growth and N cycling, by taking into account the dynamic interaction of grass and clover with changes to soil inorganic and organic N. The model includes a modified version of the dynamic clover/grass model of Schwinning & Parsons (1996) which accounts for seasonality and effects of herbage mass.

Results and discussion

Soil physical measurements

The immediate effect of pugging (within 3 days) on soil physical properties was to significantly ($p<0.05$) decrease air-filled porosity (AFP) from 16% in the non-pugged to an average of 11% for the moderately and severely pugged treatments. This finding supports other work (Scholefield & Hall 1985; Drewry *et al.* 2000) that treading or pugging can have adverse effects on soil structural properties leading to reduced air permeability and restricted water movement in soil. Other studies (Gradwell 1965; Grable 1971) demonstrated that when AFP decreases below a critical level

Figure 1 Photographs of pugging treatments 6 days after treading at 4.5 cows/100m^2 for 1.5 and 2.5 hours for the moderate and severe treatments, respectively.



(often 10%), the oxygen diffusion to plant roots is substantially reduced and has adverse effects on production of some pasture species.

In contrast to AFP, bulk density was not affected ($p>0.05$) by pugging.

Pasture production

Annual pasture production decreased ($p<0.01$) under moderate and severe pugging by 21% and 45%, respectively (Table 1). These decreases in pasture production are higher than values reported in other studies of cattle treading (e.g., Campbell 1966; Cluzeau *et al.* 1992), and probably reflect differences in the severity of treading damage between studies owing to variations in key factors such as soil type, soil moisture, stocking rates and time of year.

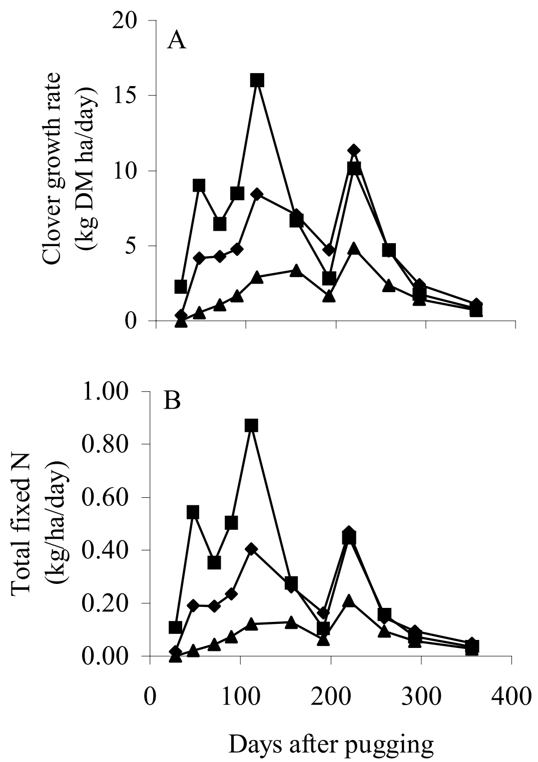
The largest decrease in pasture growth occurred during the first 100 days, where 52% (moderate) and 88% (severe) decreases were observed. Similar decreases in pasture production (up to 80%) were reported by Ledgard *et al.* (1996) in the Waikato following a single treading event on dairy pasture.

Table 1 The effect of pugging on annual pasture production and N_2 fixation. Treatments followed by a different letter for each plant measurement are significantly ($p<0.01$) different.

	---- Pugging Severity ---- Nil	Moderate	Severe	SED
Total pasture yield (kg DM/ha)	8168a	6456b	4526c	366
Clover yield (kg DM/ha)	1887a	1601a	660b	425
Total N fixed (kg N/ha)	151a	109a	45b	22

Annual clover DM production was decreased by 15% and 65% under moderate and severe pugging, respectively. The effect of pugging on clover growth was prolonged and persisted for up to 161 days and 259 days under moderate and severe pugging, respectively (Figure 2a). Interestingly, under severe pugging the annual clover DM yield reduction was much greater than grass (65% vs. 38%). This suggests that clover is more susceptible to severe pugging than ryegrass.

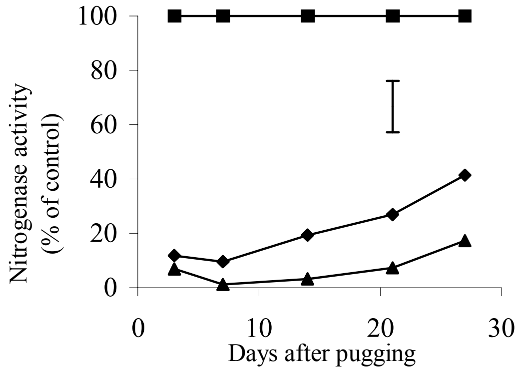
Figure 2 The effect of pugging on (A) clover growth (average SED = 1.8) and (B) N_2 fixation (average SED = 0.037), for nil (■), moderate (◆), and severe (▲) pugging treatments.



N_2 fixation

The moderate and severe pugging treatments markedly decreased (up to 90%) nitrogenase activity within 3 days of pugging (Figure 3). This was probably due, in part, to the measured decrease in air-filled porosity and supports other findings (Shiferaw *et al.* 1992; Pugh *et al.* 1995) that reduced aeration or waterlogging can cause dramatic decreases in nitrogenase activity. However, in addition to decreases in air-filled porosity, measurements of below-ground biomass after 21 days showed that clover root DM yield decreased by 64% and 91% in the moderately and severely pugged treatments, respectively. This indicates that both reduced soil aeration and a decrease in root biomass, probably as a direct result of treading damage, contributed to the reduction in N_2 fixation.

Figure 3 The effect of pugging on nitrogenase activity, for nil (■), moderate (◆), and severe (▲) pugging treatments. Error bar represents standard error of difference between means (SED).



Severe pugging reduced the proportion of total clover N derived from N_2 fixation (%N fixed) by up to 47% ($p<0.05$) over the first three harvests (71 days; data not presented). This decrease in %N fixed was independent of clover yield and suggests that changes in the efficiency of nodule functioning is important in the short-term after a severe pugging event. On an annual basis, the total amount of N fixed in all pugging treatments decreased from 151 kg N/ha in the control to 109 kg N/ha (-28%) and 45 kg N/ha (-70%) in the moderate and severe treatments, respectively (Table 1). The reduction in total amount of N fixed was most pronounced during the first 150 days after pugging (Figure 2b) and coincides with the period of greatest clover yield reduction.

In practice, it has been suggested that moderate and severe pugging damage may affect about 50% and 10% of an entire farm area, respectively (P. Singleton pers comm.). When these values are used with data in Table 1, we estimate that total pasture production would decrease by 15% and annual N_2 fixation by 19% on a whole farm basis.

Nitrogen modelling

The effect of decreased N_2 fixation on N availability and long-term pasture productivity and milk production was estimated using a dynamic model of N cycling under dairying that has an interactive grass/clover component. The evaluation was based on a Waikato dairy farm with no N fertiliser input and producing c. 1000 kg milksolids/ha/year. Using a 10-year scenario with a moderate or severe pugging event annually and annual N_2 fixation reductions of 28% and 70%, the predicted loss in grass yield after 10 years was 21% and 44%, respectively (Table 2).

Table 2 Predicted effects after 10 years of a single annual pugging event (moderate or severe) on annual grass and clover production, N_2 fixation, soil organic-N and milk-N using the DAMN model (Ledgard *et al.* unpublished). The 'default' simulation was a Waikato dairy farm producing 1000 kg milksolids/ha with nil N fertiliser. Clover growth potential inputs for the moderate and severe pugging treatments were varied to simulate the proportional decrease in N_2 fixation measured in the field study.

Modelled Parameter	Default	-- Pugging Severity -- Moderate	Severe
Clover yield (kg DM/ha)	4537	3393	1152
Grass yield (kg DM/ha)	10765	8474	6070
N_2 fixation (kg N/ha)	176	132	50
Soil organic-N (kg N/ha)*	0	-21	-47
Milk-N (kg N/ha)	72	57	35

* decrease relative to default

Soil organic N was predicted to decline because of decreased inputs of N from N_2 fixation. The associated predicted loss in milk production after 10 years (owing to reduced N inputs and less pasture production) was 21% and 54% for the moderate and severe pugging treatments, respectively. On a whole farm basis with moderate and severe pugging on 50% and 10% of the farm, respectively, this would represent a decrease in milk production of 16% (e.g., from 1000 to 840 kg milksolids/ha/year).

Conclusions

This field study and associated modelling showed that pugging has both short-term (≤ 1 year) and long-term impacts (with recurring annual pugging events) on clover growth and N_2 fixation. Short-term effects include a large reduction in N_2 fixation owing to soil physical changes and reduced clover production. Longer-term effects largely occur owing to reduced fixed N inputs which lead to a gradual decline in soil organic N to a lower equilibrium level. This can result in a long-term reduction in total pasture production and milk production and the need for increased N fertiliser use to maintain productivity.

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