White clover or nitrogen fertiliser for dairying?

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Abstract

Annual production in New Zealand dairy pastures is limited by nitrogen supply and therefore requires nitrogen fertiliser to increase annual pasture production. This paper summarises the advantages and disadvantages of clover nitrogen and fertiliser nitrogen including the effects of both nitrogen sources on feed quantity and quality, factors limiting nitrogen fixation and nitrogen fertiliser response, defoliation effects on white clover (*Trifolium repens* L.), animal health problems associated with clover and nitrogen fertiliser, and environmental effects. UDDER, a dairy farm simulation model, is used to predict the nitrogen fertiliser rate and white clover content in pasture necessary for optimum pasture production and feed quality. Maximum gross margins per ha and a high level of milksolids production per ha and per cow can be best achieved by combining nitrogen inputs from white clover and nitrogen fertiliser. The model predicts best results would be achieved with clover contents of 30–40% and nitrogen fertiliser rates of 100–200kgN/ha/yr.

Keywords: dairying, feed quality, nitrogen fertiliser, nitrogen fixation, *Trifolium repens*

Introduction

In an analysis of the role of legumes in the nitrogen (N) cycle of temperate pastures Thomas (1992) estimated legume contents of 20–45% could provide the N requirements of a sustainable and productive pasture. This compares well with the 20–30% legume DM content estimated as optimum for animal production (Simpson & Stobbs 1981) and with the range of 30–50% legume thought to result in maximum DM and protein yield in temperate-clover based systems (Martin 1960). New Zealand dairy farms, however, have average white clover contents less than 20% (Ettema & Ledgard 1992). At such low clover contents N inputs from N fixation are too low to support the full production potential of ryegrass-white clover pastures. To correct this N deficiency (Ball & Field 1982) it has become necessary to apply N fertiliser.

White clover-based systems have lower costs since there is no N fertiliser requirement. Systems based on N fertiliser, despite being more costly, are usually a more reliable means of providing increased pasture at critical periods within the dairy season. There are, however, a number of factors which may affect the level of N inputs from both systems, and both systems have advantages and disadvantages. This paper also examines these and identifies optimum systems for combined use of clover and N fertiliser.

Feed quantity

White clover monocultures can grow 11.8 and 10.2 t DM/ha with and without irrigation respectively (Spedding & Diekmahns 1972; Reid 1983). However, these yields are insufficient to provide the energy requirements of milksolids production on an intensive NZ dairy system. Greater yields are obtained from mixed ryegrass/white clover swards but even these pastures fail to provide enough energy at critical times.

The primary advantage of using N fertiliser is increased dry matter production per ha compared with production from a clover based system. A trial comparing 0, 200 and 400 kgN/ha/yr under two stocking rates at the Dairying Research Corporation (DRC) showed substantial increases in pasture and milksolids production (Table 1). This trial confirmed the high and

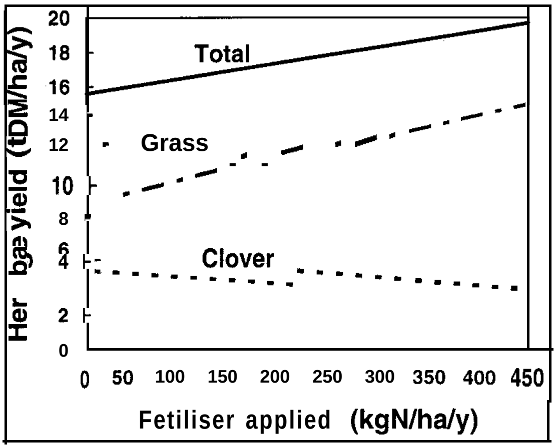
Table 1: Seasonal pasture and milksolids production on DRC farmlets during 1993/94 and 1994/95 (Harris et al. 1994, Penno pers. comm.). Farmlets received 0, 200 or 400 kgN/ha/yr and were stocked at either 3.2 (L) or 4.5 (H) Friesian cows/ha.

Treatment	L0	L200	L400	H0	H200	H400
1993/94						
Pasture production (kgDM/ha)	14346	16964	18827	14892	18710	18463
Extra (kgDM/ha)		*2618*	*4481*		*3818*	*3571*
Milksolids (kg/ha)	1321	1335	1357	1692	1765	1778
Extra (kgMS/ha)		*14*	*36*		*73*	*86*
1994/95						
Pasture production (kgDM/ha)	16444	20591	23501	17830	21405	22146
Extra (kgDM/ha		*4147*	*7057*		*3575*	*4316*
Milksolids (kg/ha)	1276	1320	1354	1742	1849	1858
Extra (kgMS/ha)		*44*	*78*		*107*	*116*

predictable responses to N fertiliser recorded in spring from many other trials (O'Connor 1982).

Although application of N fertiliser increased total herbage production, numerous studies have shown a continuous decline in clover content with increasing amounts of N fertiliser (Ball & Field 1982; Harris & Clark 1996; O'Connor 1982). Figure 1 shows there can be a decline in the absolute amount of clover in mixed swards with increasing amounts of fertiliser N. At rates of 420 kgN/ha/yr distinct regional differences were found by O'Connor and Cumberland (1973). Swards in northern North Island trials retained clover contents above 20% while in South Island trials clover was reduced from 20% to less than 5%. O'Connor (1982) attributed this to differences in temperature between regions but variation within a region suggests that defoliation frequency and intensity may also be important.

Figure 1: Annual pasture DM yield from continual applications of fertiliser N (from Ball & Field 1989).

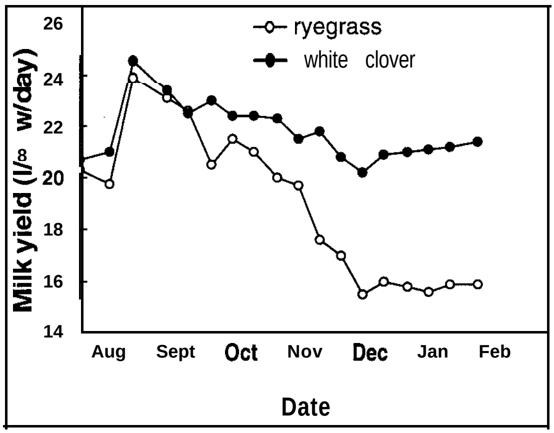


Feed quality

The superiority of white clover over ryegrass for milk production occurs under *ad libitum* and restricted levels of feeding (Figure 2). The response to *ad libitum* feeding is greater because not only does white clover have higher nutritive value per unit DM than ryegrass, but cows grazing clover have a higher intake due to clover's lower bulk density and greater rate of digestion. For example, Rogers et al. (1982) showed intakes of 15.9 and 12.0 kg DM/cow/day on pure clover and pure perennial ryegrass respectively. Milk yields were 16.2 and 13.0 l/cow/day respectively. When pure white clover or pure ryegrass was fed at 60% *ad libitum* intake, milk yield was 12.5 and 11.1 l/cow/day respectively, indicating the efficiency of conversion of herbage to milk was higher for clover than for ryegrass. Only small differences were observed in the concentration and fermentation pattern of rumen volatile fatty acids. It was therefore more likely that the higher protein levels in clover were responsible for increased milk yield.

In the absence of clover, N fertiliser applied to grass swards consistently increases the N content of the herbage. A review of 32 data sets by Wilman and Wright (1983) showed an increase of 0.4% units N (1.97 to 2.37% of DM) in grass receiving 200 kgN/ha/yr compared with unfertilised grass. Nitrate N content increased from 0.019% in unfertilised grass to 0.027% in grass receiving 200 kgN/ha/yr.

Figure 2: Milk yield of cows fed pure white clover or pure perennial ryegrass diets (from Rogers & Robinson 1984).



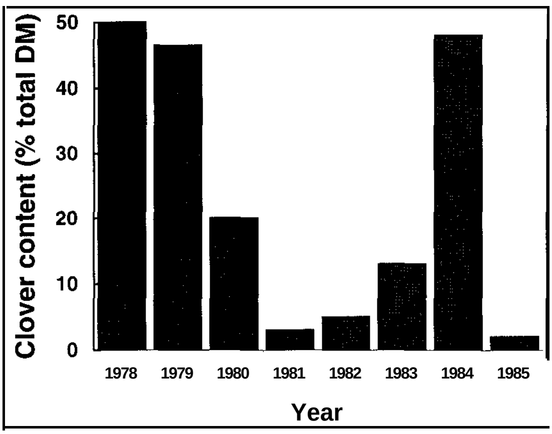
Factors limiting nitrogen fixation

The annual average N fixation input over a range of flat land sites in NZ was 184 kg N/ha (range 107-392 kg N/ha) (Hoglund et al. 1979). Many environmental and management factors may limit the nitrogen input from clover either by decreasing nitrogen fixation activity directly or by reducing clover growth.

In the UK the unpredictable nature of white clover contribution to total herbage yield is often cited as a reason for using N fertiliser (Frame & Newbould 1986). Short-term experiments often fail to identify the cyclic nature of clover contribution, but longer trials (Stewart & Haycock 1984) show large annual variation in clover content (Figure 3). Frame and Newbould (1986) list climate, soil, sward, animal and management factors as contributing to this variation, but there are few examples of manipulative experiments to rank their importance.

Temperature affects clover growth and is particularly important in processes influencing the number and development of leaves and stolons (Brougham 1962). White clover has a lower rate of growth than ryegrass at temperatures below 10°C, but its growth rate continues to increase up to 24°C, whereas that of ryegrass peaks at 15–20°C (Mitchell & Lucanus 1962). High soil temperatures during summer may severely limit clover growth and often cause stolon death. White clover's ability to survive at high temperatures is very dependent on soil moisture levels. Probability of clover survival is reduced as maximum temperature is increased above 20°C for available soil moistures less than 35mm to a soil depth of 600mm. However, clover survival is not affected even at temperatures of 35°C if soil moisture is above 35mm (Archer & Robinson 1989). Low soil temperature plays a major role in limiting N fixation in temperate pastures during spring (Halliday & Pate 1976). These authors showed a broad optimum in nitrogenase response from 13 to 26°C with a sharp decline at either extreme.

Figure 3: Example of variation and "sudden crashes" in white clover content (September data) in a grazed grass/clover sward in the United Kingdom over eight years (from Stewart & Haycock 1984).



Blackman and Black (1959) estimated white clover requires over twice the light intensity of ryegrass for maximum growth due to its less effective photosynthetic area. The most marked response of white clover to light intensity is a reduction in the formation of stolons from axillary buds (Beinhart 1963). The deleterious effect of shading is particularly severe at high temperatures (Mitchell 1956). Both shading and defoliation also reduce number and weight of nodules per plant (Chu & Robertson 1974) as well as limiting photosynthate supply necessary to support nitrogenase activity. This suggests that N fixation is depressed in closely grazed pastures.

Soil nutrient status influences N fixation mainly through white clover growth and demand for N. Fertiliser N interacts directly with N fixation usually decreasing it in proportion to the amount added (Linehan & Lowe 1960).

Numerous pasture pests may also affect clover production and N fixation including slugs, lucerne flea, grass grub, *Porina* and root nematodes. Clover cyst (*Heterodera trifolii*) and root-knot (*Meloidogyne hapla*) nematodes in particular have a large impact on clover growth, N fixation activity and clover's ability to survive drought. Watson et al. (1985) showed using nematicide increased annual clover production 40% and N fixation 57%.

Factors limiting nitrogen fertiliser response

Although a response of 10 kg DM per kg N applied is commonly accepted, such response is not always predictable. Figure 4 (Roberts & Thomson 1989) shows responses are often variable and lower than this, particularly during autumn and winter. O'Connor and Cumberland (1973) in reporting extensive field trials throughout NZ also showed responses to autumn applications were smaller and less reliable than spring responses. The variable nature of the response between and within years is a reflection of the extent to which prevailing climatic conditions affect pasture growth rates and the ability of pasture to respond to N fertiliser (Field & Ball 1978). Unreliable autumn responses are due to variation in mineral N levels in soil following summer droughts and often unpredictable climatic conditions. The probability of achieving a 10:1 response is 0.2 to 0.4 in autumn increasing to 0.8 to 1.0 in spring and early summer (Table 2). Maximum pasture responses occur at a time when pasture surpluses are developing. For example, Roberts and Thomson (1989) showed pasture response to N was positively correlated (r=0.74) to pasture growth rate in the absence of N.

Figure 4: Annual pattern of pasture response to N fertiliser application (3 year average). Shaded area shows SEM (from Roberts &Thomson 1989).

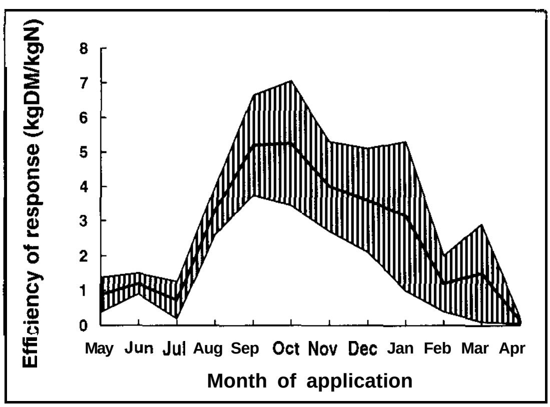


Table 2: Likelihood (% probability) of achieving a 10:1 response to N in different seasons (Roberts & Edmeades 1993).

Season	Probability (%)
autumn	20–40
late winter – early spring	60–80
spring – early summer	80–100

The DRC N fertiliser trial also confirmed the decreased marginal efficiency of pasture production with increasing N input (Harris et al. 1994; Penno *pers. comm*.). Averaged over two years the responses to N fertiliser were 21 and 13 kg DM per kgN for 200 and 400 kgN/ha/yr treatments respectively. These responses are higher but show a similar trend to response rates reported by Holmes (1982) of 10.5 to 7.4 kg DM/kg N for applications of 350 to 440 kgN/ha/yr. The DRC trial showed marginal efficiency declined more rapidly at the higher stocking rate.

Defoliation effects on white clover

At high N rates there is a beneficial effect of close cutting on clover (Frame & Newbould 1986). Close cutting increases the number of clover growing points, promotes photosynthetically efficient leaves and reduces grass competitiveness. However frequent cutting does not offset the adverse effect of applied N by reducing the effects of shading by the grass component. In mixed swards receiving up to 400 kgN/ha/y, white clover production was increased as defoliation intervals increased from 3 to 6 weeks, but the proportion of white clover decreased or remained the same (Frame & Newbould 1984).

The effect of N fertiliser on clover content is indirect with nitrogen-boosted ryegrass outcompeting the clover for light, water and nutrients. This competition effect is minimised if extra pasture resulting from N application is fully utilised either through increasing stocking rate and/or conservation of surplus pasture. For example, in a two year N fertiliser trial at DRC, clover content under 200 kg N/ha/yr was reduced to 10.1% of total DM compared with 16.8% under no N at a stocking rate of 3.2 cows/ha. However, at the higher stocking rate of 4.5 cows/ha clover contents were similar at 15.4% and 14.9% under 0 and 200 kgN/ha/yr respectively. In addition, an increased stocking rate is necessary to make full benefit of N fertiliser in terms of increased milksolids production (Holmes 1981, Harris et al. 1994).

In contrast, grazing has several potential deleterious effects on clover growth. Edmond (1964) rated white clover as more susceptible to treading damage than ryegrass. However, there has been little work done on the effects of soil compaction, reduced soil aeration and lack of water infiltration on the relative growth rates of white clover and ryegrass. Harris (1994) showed on average throughout the year 35% of clover stolon material was buried in dairy pastures. Although there have been no comparisons of stolon burial between cattle grazing and cutting it is possible that such burial could reduce clover content under high stocking rates.

Animal health problems associated with clover

Bloat can develop in any pasture type but is most common in spring pastures with a high white clover content. In NZ, annual dairy cattle deaths from bloat are estimated to exceed 20,000 (Morris et al. 1991). In addition, profits are reduced through loss of production from affected animals and the cost of drenching. N fertiliser may lower clover content so reducing the risk of bloat.

If clover contents in pasture were considerably higher, e.g. above 50%, animal health problems associated with iodine deficiency and possibly cyanide poisoning could occur. At higher clover contents cultivars which persist under NZ conditions would be used and these tend to have high cyanide levels (Crush & Caradus 1995). However, there is potential to use low cyanide level cultivars suitable for dairying in NZ, such as Grasslands Kopu. Nitrate levels in white clover rarely exceed 0.1% (R.A. Carran *pers. comm*.) which is below the level 0.15–0.20% generally considered to cause symptoms of nitrate poisoning in cattle. Therefore pastures containing high levels of white clover should provide safe grazing for lactating cows.

Animal health problems associated with N fertiliser

Following N fertiliser application, N uptake precedes dry matter response. During this time ryegrass accumulates twice the amount of nitrate as white clover (Murphy & Ball 1985). Toxic levels of nitrate can be reached in ryegrass especially during rapid phases of growth when warm overcast weather follows a dry spell leading to nitrate poisoning in dairy cattle. Heavy dressings of N fertiliser will exacerbate this problem.

Outbreaks of hypomagnesaemia occurring in lactating cows during changeable cold weather are often associated with pastures high in nitrogen, potassium and organic acids. Since legumes contain more magnesium than grasses, the decrease in clover content with N application will increase the risk of hypomagnesaemia.

Environmental effects

A model of N balance in intensive dairy farms (Field & Ball 1982) suggests they are in negative N balance (N losses greater than N inputs). However, losses from leaching, denitrification and volatilisation would be lower under a system reliant solely on N fixation from white clover than under a ryegrass-white clover system receiving N fertiliser.

For every kg of N output in dairy products, a further 5 kg of N is lost from the system (Field & Ball 1982). About 80% of these losses result from the aggregation of excess dietary N into excreta, with highest losses from urine patches. In a clover system N losses to non-pasture areas are 32 kg /ha/yr and losses of urine N are 140 kg/ha/yr. However, in a system receiving 100 kgN/ha/yr an extra 18 kg/ha/yr is lost through these pathways. The major reason for lower N losses from clover-based systems is their lower total pasture growth rates leading to lower total animal consumption. Consequently, less N is cycled through the animal and urinary losses are lower. Systems receiving N fertiliser grow more pasture, may have a higher stocking rate, increased total animal consumption and consequently greater losses.

Preliminary data from the first year of a trial at DRC using high N fertiliser rates indicated leaching losses of 74, 101 and 204 kgN/ha/yr under fertiliser rates of 0, 200 and 400 kgN/ha/yr respectively (Ledgard et al. 1996). Nitrogen balance estimates do not indicate net N losses from the clover-based system receiving zero N. Ledgard et al. (1994) stressed the need to continue measurements for a number of years to obtain an accurate estimate of N losses from areas receiving different N fertiliser inputs. Addition of N fertiliser also leads to extra losses not associated with a clover N fixation system. Ledgard et al. (1996) showed 15 and 63 kgN/ha/yr was volatilised at fertiliser inputs of 0 and 400 kgN/ha/yr respectively. Environmental effects of N fertiliser use are covered in much greater detail by Carran and Clough (1996).

Model predictions of optimum N fertiliser rate

In examining the effect of N rate on the economics of dairy farm systems we need to consider the following factors: costs associated with N fertiliser, milksolids price, N response, effect of N on clover content, effect of clover on intake potential and diet digestibility, and stocking rate. To investigate these complex interactions we used a dairy farm simulation model called UDDER (Larcombe 1995). Assumptions made were: $600 per tonne urea, $3.40 per kg milksolids, a variable N response starting at 14 kgDM/kgN for 100 kg N/ha/yr and decreasing to 8 kgDM/kgN at 400 kgN/ha/y, clover content assumed to be 20% at 0 kgN/ha/yr with a linear decline to 0% at 400 kgN/ha/y, a 3.25% increase in intake with each 10% increase in clover content, a 0.5% increase in diet digestibility with each 10% increase in clover content. Stocking rates were optimised for gross margin per ha at each N level. The model was run using initial values and management representative of an intensive Waikato dairy farm. Under these conditions the model showed 100 kgN/ha/yr gave the highest gross margin/ha (Figure 5). However, there was little change in gross margin/ha from 0 to 200 kgN/ha/yr. Associated changes in stocking rate, per cow and per ha performance are shown in Table 3.

Figure 5: UDDER prediction of the effect of N fertiliser rate on gross margin/ha.

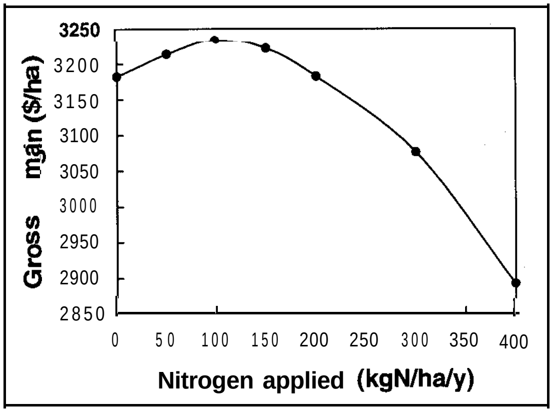


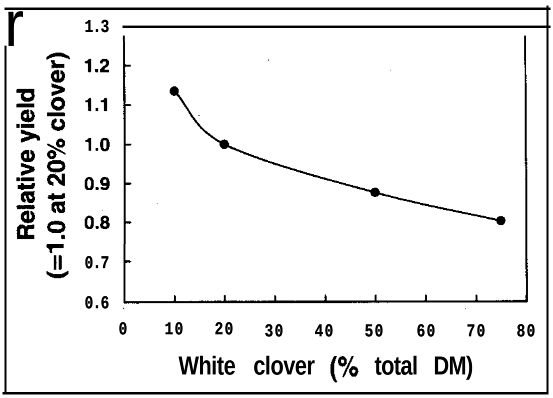
Table 3: The effect of N fertiliser rate, at optimum stocking rate, on production parameters as predicted by UDDER.

N rate (kgN/ha/yr)	Gross Margin ($/ha)	Stocking rate (cows/ha)	Pasture yield (kgDM/ha)	--- Milksolids --- (kg/ha)	(kg/cow)
0	3180	3.7	16.2	1295	349
100	3230	4.2	17.7	1395	334
200	3180	4.3	18.4	1430	330
300	3080	4.6	19.1	1470	317
400	2890	4.6	19.1	1450	313

Model predictions of optimum white clover content

The model was used to find the break even pasture yield for a given gross margin/ha at different clover contents. A yield of 16.2 t DM/ha at 20% white clover was assumed and given a relative yield of 1.0 (Figure 6). To produce an equivalent gross margin a 50% clover pasture needs to reach a relative yield of 0.9 (14.2 t DM/ha), and a 75% clover pasture 0.8 (13.0 t DM/ha). Although total pasture production decreases with increasing clover content, improved pasture quality means milksolids production is not reduced to the same extent. Conversely, where N decreases clover content to 10%, relative pasture yield must increase to 1.15 (18.4 t DM/ha) to give the equivalent gross margin. A critical factor in achieving equivalent gross margins at higher clover contents is the decreased stocking rate. For example, at 20% clover a stocking rate of 3.7 cows/ha gives 1295 kg MS/ha while at 50% a stocking rate of 2.9 cows/ha gives 1213 kg MS/ha. The lower cow costs associated with the lower stocking rate compensate for the slight decrease in milksolids production.

Figure 6: UDDER prediction of relative pasture yield required to give equal gross margin/ha at different clover contents.



What is the optimum system?

The above shows the benefits of using N for increased DM production but also the advantages of clover in terms of per cow performance. An ideal system would capture the benefits of both N and clover while minimising problems associated with excessively high N rates or clover levels. Although presence of white clover may decrease the response to N fertiliser, total pasture production under a given rate of N is generally greater on a mixed ryegrass/clover sward than on pure swards. Reid (1983) demonstrated ryegrass/white clover swards produced more total herbage during a three year cutting trial than either tyegrass or clover alone applying up to 750 kgN/ha/yr. The work of Harris and Clark (1996) shows that when applying up to 200 kgN/ha/yr to dairy pastures, clover contents can be maintained by ensuring additional pasture is fully utilised particularly in spring.

Although dairy trials have shown it is possible to combine inputs from N and clover (Holmes 1981; Harris et al. 1994), this work was done at low clover contents. White clover should make up at least 30% total DM to have any significant contribution to the pasture's N economy and feed quality (Stewart 1984). Little progress has been made in developing practical, long-term methods to increase clover content without compromising potential benefits of N fertiliser use. Management factors which may result in increased clover contents include irrigation and adequate drainage, application of P, K and S fertilisers to ensure optimal nutrient ratios, grazing regimes to ensure there is minimal removal or burial of clover growing points, use of companion grass species compatible with clover growth, periodic cropping to reduce soil N levels and therefore promote clover growth, use of herbicides to suppress ryegrass and combining pure clover and N-boosted grass swards within a single farm system.

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