EFFECT OF ALTITUDE ON CEREAL, BRASSICA AND GRASS GROWTH IN OTAGO

G.G. COSSENS

Invermay Agricultural Research Centre, Ministry of Agriculture and Fisheries, Mosgiel

ABSTRACT

Dry matter yields of greenfeed oats, ryecorn and Tama ryegrass; of the brassicas turnips and kale; and of pasture were compared over an altitude range from 30 to 1050 m.

All crops, except Tama, showed a linear decrease in yield with increasing altitude, the magnitude of this decline being greatest for kale followed by pasture, oats, turnips and ryecorn.

Crop yield decrease directly related to the temperature lapse rate of 0.46°C/100m of altitude was strongly influenced by lack of days warmer than 10°C as elevation increased.

Amuri and Winter Grey oats, although highest yielding of the greenfeeds, were subject to severe winter damage by frost or snow from 450 m altitude, as was Ruanui ryegrass at 750 and 1050 m. Tama ryegrass yield was unaffected by altitude but was lower than that of Rahu ryecorn. Both survived vigorous winter conditions at 1050 m, ryecorn being the more winter hardy.

The other major pasture components, Apanui cocksfoot and Huia white clover were frosted during the winter above 450 m but recovered well. Medium-stemmed marrowstem kale overwintered satisfactorily at all altitudes but York Globe turnips did not above 750 m.

The nitrogen and phosphorus responses of these crops cultivated directly from unimproved tussock grassland or developed pasture are also discussed.

Additional Key Words: Altitude, pasture, brassicas, autumn greenfeeds, winter damage.

INTRODUCTION

Traditionally brassicas, autumn greenfeeds and hay provided winter forage in Otago, particularly on the lowland downlands below 300 m altitude. Since 1950, the area conserved for hay increased by 120% but the brassica area decreased by 38%, a decline accelerated during the past twelve years by the widespread adoption of controlled-grazing all-grass farming systems. Nevertheless the brassicas, kale and turnips, and to a lesser extent swedes, have an important role in the development of the upland and high country tussock grasslands of the Otago Plateau.

The plateau of some 450,000 ha at 300 to 1200 metres altitude lies south and east of the Central Otago intermontane basins and is the largest undeveloped arable agricultural resource in Otago. Partially improved by oversowing and topdressing it has been further developed up to 600 m by ploughing of the tussock, sowing to a brassica crop, then to permanent pasture. Autumn greenfeeds are also sown but meadow hay still remains the main winter-feed reserve, a necessity in a region prone to heavy snow falls.

Because of the extent and agricultural importance of the Otago plateau, a series of trials were commenced in 1968 to observe the performance and yield of various crops as altitude increased. The crops were turnips and kale, the cereal greenfeeds oats and ryecorn; the greenfeed ryegrass Tama; and the pasture. These trials were conducted at 400 to 1100 metres altitude and included two rates of nitrogen and two of phosphorus. In order to provide a more complete sequence and a datum for yield comparisons, additional material from similar already existing lowland trials up to 300 m elevation has also been included. The collated results thus cover an altitudinal sequence whose mean heights were 30, 100, 450, 750 and 1050 metres.

Prior to 1970 there was little published information on brassica, greenfeed or pasture yields in Otago. Scott (1971) and Scott and Barry (1972), the first to publish trial results from the Otago Plateau, also noted the paucity of data on brassica trials. The situation improved subsequently when Stephen (1974, 1975, 1976), McDonald and Stephen (1979) and McDonald and Wilson (1980) conducted sequential growth and quality trials with brassicas and autumn greenfeeds, all however on a lowland soil at one site and so of limited regional applicability. Forage crop yields summarised by Douglas (1980) for New Zealand included all available information from lowland trials in Otago, but again no upland data.

Pasture yields have been reported from four of the altitudes studied: 30 and 100 m (Round-Turner *et al.*, 1976), 450 m (Cossens and Radcliffe, 1978) and 1050 m (Cossens and Brash, 1981). Douglas and Kinder (1975) working in tussock grassland from 850 to 1300 m, concluded that oversown clover growth was limited by low temperatures at higher altitudes.

The responses of brassica and greenfeed crops to nitrogen and phosphorus were assessed by Stephen and Kelson (1974) and by McDonald *et al.* (1977) and pasture phosphorus rates by Scott (1968).

TABLE 1: Soil Classification, altitude and chemial analyses.

Soil set	Soil classification	Altitude (m)	pH	P	%C	%N	C/N
Wingatui	Recent soils associated with YG/YBE intergrades	30	6.3	Low	4.1	0.41	10
Warepa	YG/YBE intergrade	100	5.9	Low-med	4.4	0.31	14.2
Wehenga	Upland YBE	450	5.6	Low	4.9	0.23	21.4
Lammerlaw	Upland YBE	750	5.3	Low	8.5	0.36	23.6
Teviot	High Country YBE	1050	5.2	Low-med	5.3	0.31	17.1

METHODS

Location:

The trials formed a soil and climosequence northwest from the coast near Dunedin to 90 km inland. The mean latitude of the sequence was 45°45'S with a range of ± 20' for site replicates; each altitude studied having at least two trial locations. Sites were flat, or gentle slopes of less than 2° and of similar exposure, with the two lower altitudes being the more sheltered.

Soils:

The soils were silt loams recent and lowland yellow-grey/yellow-brown earth integrades at 30 and 100 metres through upland yellow-brown earths at 450 and 750 metres, to high country yellow-brown earths at 1050 metres. The altitudes were the mean for the soils studied, the 450, 750 and 1050 m sites being in the Otago Plateau. Selected soil chemical properties are presented in Table 1; more detail on the plateau soils can be found in McIntosh and Backholm (1981).

TABLE 2: Mean daily and absolute-minimum air temperature (°C), rainfall (mm) and growing degree days (GDD) greater than 5°C at four altitudes.

Altitude (m)	Spring Mean	Spring Abs.	Spring GDD	Spring Rain	Summer Mean	Summer Abs.	Summer GDD	Summer Rain
30	10.2	-2.9	495	147	14.2	0.3	824	192
450	8.1	-7.2	303	147	12.5	-3.0	632	173
750	6.4	-5.4	130	245	10.0	-5.0	447	288
1050	3.9	-12.0	45	116	9.5	-7.0	403	145

Altitude (m)	Autumn Mean	Autumn Abs.	Autumn GDD	Autumn Rain	Winter Mean	Winter Abs.	Winter GDD	Winter Rain
30	10.4	-5.1	504	195	5.6	-6.2	122	128
450	8.9	-5.2	318	176	3.9	-9.0	51	145
750	7.7	-10.8	277	263	3.4	-8.6	0	280
1050	6.4	-10.8	200	161	0.2	-11.6	0	119

Altitude (m)	Year Mean	Year GDD	Year Rain
30	10.1	1945	662
450	8.3	1304	641
750	6.9	854	1076
1050	5.0	648	541

*Spring — September, October, November.

Climate:

Climatic data (Table 2) available for a minimum of six years at all altitudes were obtained from official New Zealand Meteorological Stations at Invermay (30 m) and at Hindon (450 m). Additional stations were placed on site at Castle Dent (750 m) and at Ranui (1050 m). Although the 100 m altitude had no climatic station, temperatures can be predicted from the Invermay station (Chiew, 1976). Accumulated heat units or growing degree days (GDD) >5°C and >10°C were calculated from mean daily temperatures at each station.

Experimental:

Although many trials were laid down or considered for this study, all were generally of a randomised-block split-plot design. The brassica and greenfeed were single harvest trials which included two rates of N (0 and 50 kg/ha) broadcast shortly after sowing as nitrolime and two rates of P (18 and 36 kg/ha) as borated reverted superphosphate drilled with the seed. In a few cases there were three or four rates of P and N (Tables 6 and 7). Yields were assessed by harvesting 3 x 0.6 m of 20 metre long plots.

Herbage dry matter yields of ryegrass, cocksfoot, clover pastures were measured under grazing by a moving cage technique (Lynch 1960) usually with two rates of P or N, except on the nitrogen and phosphate trial at 1050 m where ungrazed 4 x 1 m plots were mown. The cages were mown at two (30 and 100 m) or three weekly intervals. Pasture maintenance superphosphate was applied annually: 30 kg P/ha at 30 m; both 10 kg P/ha and 30 kg P/ha rates were used at 100 and 450 m; and 20 kg P/ha and 40 kg P/ha at 750 and 1050 m. The pasture nitrogen rate was 150 kg N/ha/year as a split application of 50 kg N as nitrolime in September, December and March. Molybdenum (150 g/ha) was a basal dressing on all pasture trials.

The mean annual yield for each crop was analysed by linear regression against altitude (Table 3).

Cultivation:

The tussock soils of the Otago Plateau have a thick turf mat and high organic matter levels (Table 1). Experience in developing these had shown that a two-winter fallow after ploughing was essential for good brassica and pasture establishment. Accordingly the following procedures were adopted for all plateau sites: Month 1 (usually March), plough and fallow; month 10, topdress 5 t/ha lime; month 12, disc and fallow: month 21, disc,

TABLE 3: Linear regression of yield (Y) DM kg/ha with altitude (x) in metres for pasture, brassica and greenfeed crops.

Crop	Regression		Slope SE
Kale	Yk = 11357 - 9.85x	r = 0.93**	2.23
Pasture	Yp = 10219 - 7.05x	r = 0.99***	0.67
Swedes (bulbs)	Ys = 7876 - 5.18x	r = 0.82	2.55
Turnips (bulbs)	Yt = 5557 - 1.40x	r = 0.63*	1.01
Oats	Yo = 4876 - 1.87x	r = 0.98***	0.24
Ryecorn	Yr = 4012 - 1.11x	r = 0.60*	0.85
Tama	Yta = 2427 + 0.08x	r = 0.06 NS	0.84

harrow, sow, roll. The lowland sites, if from pasture, were cultivated and directly sown to the trial but if from tussock, they were managed as for the plateau soils.

Sowing and Harvesting:

The cultivars, seeding rates, sowing and harvest dates are given in Table 4. Kale sowing rate at 30 m was 3 kg/ha and 1.5 kg in other trials. Although not strictly in this series, swedes are occasionally quoted and agronomically were treated the same as turnips.

RESULTS

The improved lowland sites (30 and 100 m) had been in pasture for 50 or more years, the upland (450 and 750 m) and high country (1050 m) sites for 10 years or less. The soil pH (Table 1) partly reflects the stage of improvement of the soils as indicated by the time out of the native vegetation. At the 1050 m site for example, the pH rose from 5.0 to 5.8 in the six years after cultivation and liming. Nevertheless the pH in Table 1 is a representative mean for sites and years.

The majority of yields were obtained between 1969 and 1976 with some pasture data extended to 1981 at 750 and 1050 m. At each altitude studied (Table 1) there were six observation years for pasture yield, other crops had five or six years. The exceptions were turnips and kale at 450 m with three; oats and Tama with two and four respectively at 450 m. The greenfeeds at 100 m were omitted from the regression analysis as no satisfactory data were available. Bulb yields only were used for turnips; kale yields included the leaf and stem (Tables 3, 5, 6, 7).

Climatic conditions prevailing during the main yield record period from 1969 to 1981 would be representative of the long term average. Notable departures from the normal were the very cold winter of 1972 which was 1 to 2 °C below normal, the drought conditions of 1972/73 and 1975/76 and the mild moist seasons from 1977 to 1980. Absolute minimum air temperatures are given (Table 2) as oats suffered winter damage at 450 m and higher, and Ruanui ryegrass from 750 m. Air frosts, possible on any night of the year, except in summer at 30 m, could be extremely severe in spring and autumn at 750 and 1050 m. The trial locations were apparently subject to an ameliorating coastal influence as air temperatures as low as -18.6 °C have been recorded at 750 m (New Zealand Meteorological Service, 1973), 30 km further inland than the 1050 m station where the lowest air temperature was - 12.0 °C. Minimum ground temperatures were on average 2 °C lower than the absolute minimum air temperatures.

Dry matter yields were negatively correlated with altitude (Table 3): highly significant for pasture, kale and oats; significantly for turnips and ryecorn; but positively and non significantly for Tama. The regression for a limited number of swede trials recorded during the study was also significant.

Pasture growth was recorded for the whole year; the spring, summer and autumn production accounting for over 90% of the annual total. Data from trials (MAF unpubl.) at 30 and 100 m indicated a 12% increase in annual yield when mowing period was three weeks rather than the two used at these heights. If all pasture yields had been adjusted to 3 weeks, the 30 and 100 m sites would be slightly higher yielding but not enough to significantly change the slope of the regression.

As the sowing and harvest dates (Table 4) for the brassicas were similar, their yield over all sites was directly comparable and determined on an approximate 250 day growth period whose GDD >5 °C varied according to altitude. However, the greenfeeds were to be autumn-sown to provide vegetative forage during the winter. This was satisfactory up to 450 m but at higher elevations autumn

TABLE 4: Cultivar, seeding rates, sowing and harvest dates.

	Cultivar	Sowing rate kg/ha	Sowing date 30-450 m	Sowing date 750-1050 m	Harvest date 30-450 m	Harvest date 750-1050m
Oats :	Amuri or Winter Grey	134	Mid Mar.	Early Dec.	Late July-Aug.	Late May-June
Ryegrass :	Tama	34	Mid Mar.	Early Dec.	Late July-Aug.	Late May-June
Ryecorn :	Rahu	134	Mid Mar.	Early Dec.	Late July-Aug.	Late May-June
Turnips :	York Globe	0.6	Early Dec.	Early Dec.	Late July-Aug.	Late May-June
Kale :	Medium stemmed	1.5-3.0	Early Dec.	Early Dec.	Late July-Aug.	Late May-June
Pasture :	Ryegrass: Ruanui	15-20				
	Cocksfoot: Apanui	5				
	White Clover: Huia	3-5				

sowing was unsatisfactory as temperatures were too low for establishment and growth (Table 2). The greenfeed sowing date was therefore brought forward to late November or early December at 750 and 1050 m. Yields were then compared on a variable growth period of 150 to 200 days depending on altitude but limited to 650 GDD >5 °C accumulated from time of sowing to harvest at the cessation of growth, or in late July-early August, whichever was first.

The main effect of the nitrogen and phosphorus yield response is given in Tables 5 and 6. The N x P interaction for turnips (Table 7) showed a similar but not always as large, response pattern in the other crops sown into ground newly cultivated out of tussock.

TABLE 5: Mean crop and pasture yield response (kg DM/kg N) to applied nitrogen for Lowland, Upland and High Country sites.

Crop	N Rate (kg/ha/yr)	Lowlands 30 m:100 m	Uplands 450 m:750 m	High Country 1050 m
Oats, Tama, Ryecorn: Ex tussock	50	—	15.6	23.1
Turnips:				
Ex Pasture	50	8.6	2.8	—
Ex Tussock	50	22.7	17.9	50.4
Kale:				
Ex Pasture	50	14.6	27.4	—
Ex Tussock	50	—	28.6	50.6
Pasture	150	10.8	15.6	6.1

TABLE 6: Mean crop and pasture yield response to applied P. Percent response for given increments.

Crop	Rate/Yr P (kg/ha)	Lowlands	Uplands	High Country
Greenfeeds				
Ex Tussock	0 - 18	—	62	-6
	18 - 36	—	66	23
Brassicas				
Ex Pasture	0 - 36	3	-7	—
Ex Tussock	0 - 18	172	40	—
	18 - 36	6	4	7
Pasture				
Ex Pasture	10 - 30	12	12	—
Ex Tussock	20 - 40	—	60	39

TABLE 7: Yield response (kg DM/ha) and interaction of York Globe Turnips to N and P. Ex Tussock 450 m.

kg/ha

N \ P	0	9	18	36	Mean
0	2120	3520	4000	4430	3520 C
25	2840	3860	5600	5430	4430 C
50	2320	4240	5510	5890	4490 C
75	2480	5190	6500	7230	5350 A
Mean	2440C	4220B	5400B	5750A	4450

Main effects L.S.D. 1% = 350
CV = 14.9%
Interaction P x N sign 1%

DISCUSSION

Tama ryegrass yield was not affected by altitude but for the other crops there was a linear decrease in yield with increase in altitude, a decline which was greatest in those crops which were highest producing at the lowest altitude (Table 3). Plant growth in the sequence depended, not only on agronomic practices as plant density, insect and weed control and soil fertility, but also on environmental conditions as solar radiation, soil moisture, wind velocity and air temperature. The agronomic deficiencies were corrected as far as possible at sowing and any effect of altitude on yield would be due to a change in climatic conditions. Neither solar radiation nor soil moisture would contribute to yield decline. Solar radiation increased with altitude and distance inland (New Zealand Meteorological Service, 1970-1980; Bliss and Mark, 1974) and at all sites was non-limiting for photosynthesis. Similarly, soil moisture stress decreased with altitude, the mean annual deficit for a soil with a moisture holding capacity of 75 mm was, 220 mm at 30 m, and 37 mm at 1050 m.

The causal nature of wind velocity on plant growth is more difficult to assess as transpiration depends on relative humidity and air temperature, there being no linear relationship between wind velocity and transpiration (Sturrock, 1973). Wind velocity in Otago increased with altitude (Dawber and Edwards, 1978). Certainly plant yields would be depressed too situations by the strong hot dry northwest winds which frequently sweep the plateau and by the chill factor induced by cold southerly winds.

There was a linear decline of air temperature which was highly correlated with increased altitude (r = 0.99 ***), and the mean lapse rate of 0.46 °C/100 m of elevation was similar to trends recorded by Mark (1965) in Central Otago. As crop growth, except for Tama, was also negatively correlated with altitude, yield decline was directly proportional to lapse rate.

The yield lapse rate in kg DM/ha/ °C = 217 x Crop slope coefficient of Table 3. Kale yields thus fall by 2140 kg DM/ha/ °C, pasture by 1530 and ryecorn by 240. Two yield decline classes can be recognised: those whose rate is less than 200 kg DM/ha/100 m (turnips, oats, ryecorn, Tama) and those over 500 kg DM/ha/100 m (pasture, kale, swedes). The greenfeed yields were limited to a period of 650 GDD >5 °C on all sites. Nevertheless a yield decrease was still present with oats and ryecorn suggesting that their potential growth and that of Tama is strongly influenced by the number of days warmer than 10 °C rather than 5 °C; for between 30 and 1050 m with 5 ° GDD held constant there was a 55% reduction in GDD >10 °C. Data presented by Douglas (1980) indicated that Tama yields are higher under warm more northerly New Zealand conditions than in the cooler south.

Douglas and Kinder (1975) and Cossens and Brash (1981) concluded also that clover growth in oversown or cultivated pasture was limited by temperatures lower than 10 °C. Since clover was not only the nitrogen source for the grasses but also contributed 50% or more of the annual pasture yield (Op. cit.) air temperatures above 10 °C influence the magnitude of the total yield. Ryegrass and cocksfoot growth occurred mainly in the spring and autumn provided temperatures were above the 5 °C threshold temperature for plant growth. Air temperatures in these seasons (Table 2) were close to 5 °C from 750 m so the period of grass growth was shortened and total yield further reduced.

The short cool growing season at higher altitudes had a more marked effect on kale and swedes than turnips, again indicating that temperatures above 10 °C are important in maintaining production of the higher yielding brassicas.

Winter damage, a hazard with oats from 450 m and with Ruanui ryegrass from 750 m, occurred when the air temperatures were lower than -9 °C particularly when followed by frequent freeze and thaw conditions, with periods of snow burial an additional factor. Oats did not survive the winters above 750 m and Ruanui ryegrass was killed out one year in ten at 750 m and one year in four at 1050 m. Clover, cocksfoot, kale and swedes, Tama and ryecorn survived in winter at all altitudes and of the last two, ryecorn was the more winter hardy. Turnips rotted and did not survive winter at 1050 m. Snow mould (*Fusarium nivale, Typhula idahoensis*) and ice sheet damage were probably responsible for much of the winter injury observed. At 1050 m in particular, the ground surface was flat and thick ice sheets which formed on poorly drained areas would damage the plant crowns.

Yield responses to nitrogen and phosphorus (Tables 5, 6, 7) in the brassicas and greenfeeds were generally greatest from 450 m altitude or when sown out of unimproved tussock. After a period of fertility build up when sown into lea out of improved pastures these responses were considerably reduced or even negative in the case of P. There were few trials available with more than two rates of P or N however, when all the information was amalgamated, it was apparent that near maximum yield occurred with 36 kg P/ha. In improved soils out of pasture, kale was more responsive to P than turnips.

Pasture maintenance P response was consistent, 375 kg/ha superphosphate giving 12% more yield than 125 kg/ha for lowland and upland sites. P maintenance requirements were not reliably defined for the 1050 m site where the soils were of low phosphate status and medium to high phosphate retention.

Except for pasture, the crops generally received a single application of 50 kg N/ha so it is possible they could continue to respond to higher rates of nitrogen as indicated by Table 7. It is also probable that pasture would respond to rates above 150 kg N/ha annually. Although yield responses to N were greatest when applied to crops sown out of tussock, it must be emphasised that the use of nitrogen does not eliminate the need for a two winter fallow. Farmer experience has shown that a short fallow with nitrogen produced inferior crops to a long fallow without nitrogen.

More work is required on pasture and crop P maintenance and N topdressing rates. These trials only gave a preliminary assessment of the fertility situation particularly as it applied to the Otago Plateau soils. The study showed that crop and pasture adequately topdressed with P provided useful yields which could be increased further by the use of nitrogen however the practicality will depend largely on fertiliser application prices. In this respect, the study provides base crop yield data on which economics of higher altitude undeveloped areas can be assessed.

CONCLUSIONS

1. Crop yields, except for Tama ryegrass, were negatively correlated with increased altitude. Tama yield as an autumn greenfeed was not affected by altitude.
2. Temperature less than 10 °C was the main factor causing yield decline with increasing altitude.
3. Oats, turnips and Ruanui ryegrass were subject to winter damage by frost and snow particularly from 750 m altitude. In this respect further work is required on the winter hardiness of perennial ryegrasses. Clover, cocksfoot, kale, ryecorn and Tama all had good winter keeping qualities.
4. Potential yield estimates for various crops can be made for any altitude up to 1050 m provided crop yield or temperature data are available for two altitudes.
5. Further work is required on crop response to sequential cutting and to higher rates of P and N than those used in this study.

ACKNOWLEDGEMENTS

To those farmers on whose properties the trials were conducted, the field technicians; J. Cherry, J. Thorley and R.J. Clare and the herbage laboratory staff at Invermay Research Centre.

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