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The Character of Composted Bracken (*Pteridium aquilinum* L. Kuhn) and its Potential as a Peat Replacement Medium

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Summary

The preparation of natural bracken (*Pteridium aquilinum* L. Kuhn) from the field to a compost suitable for acid loving plants is described. Key chemical and physical characteristics of the compost were determined by laboratory assessments of particle size, pH, air filled porosity (AFP), water retention characteristics, nitrogen draw down index (NDI) and basic chemistry. The procedure to ensure the breakdown of Ptaquiloside carcinogens is discussed. The material is naturally N poor, K rich with pH < 5.0, at cutting. During composting, particle size declines but pH naturally rises. Options to retain low pH and improve the water holding capacity are discussed. Nitrogen lock-up is similar to peat, but conductivity is lower, making nutrient management of pot plants easy. Water management is the key to successful use in the nursery. This plant is a highly sustainable resource, regaining biomass if cut in alternate years, growing along the western oceanic areas of Europe, particularly on light acid soils, from Norway to Spain and from Ireland eastward beyond Germany.

Key words. pH – air filled porosity – nitrogen draw down – Ptaquiloside – conductivity – water management

Introduction

Bracken (*Pteridium aquilinum* L. Kuhn) is a world-wide plant of the temperate latitudes in both northern and southern hemispheres (Braid 1959; Marrs and Watt 2006), favouring more oceanic locations as its vigour is restricted naturally by exposure to frost, or water-logging. In the UK it grows vigorously over millions of hectares of moor, heath and neglected farm land (Taylor 1986), benefitting from an under-ground rhizome system in which carbohydrates are stored over winter. Recent agricultural practice has been to spray out persistent growth in pasture land, and bracken harvesting has fallen out of use with the development of peat based composts and artificial fertilizers. The historical use of bracken has been documented by Rymer (1976) and past use of the litter in horticulture has been as a surface mulch to suppress weed growth, and in potting mixes for acid loving plants by nurserymen local to heathland. Within the forestry sector it was trialled for tree seedlings of Sitka spruce, pines, ash and silver birch as early as 1945 and 1946 (Benzian 1965), where compost mixes of 3:1 by volume of bracken (rich in phosphate) and hopwaste (rich in nitrogen and phosphorous), were compared against chemical fertilizers.

The hypothesis tested in this paper is that composted bracken can still provide a valuable substrate for horticultural plants, safe to handle with potential as a peat substitute.

Field harvesting restraints

Bracken is most effectively cut as it reaches maximum biomass at the end of July or early August (Pitman 2000). This timing avoids the sporulation period in late August, when air borne spores may pose a health hazard during harvesting activities. However, sporing is very variable year on year, as it is weather dependant (Kendall et al. 1994) and locationally dependant on micro-climate – sporing is less common on northerly and more exposed sites due to late spring frost risk, and cooler summer temperatures. After August the plant becomes more lignified as carbohydrate is translocated underground into the rhizomes for storage, and above ground fronds die back in the frosts of early October. September cut material poses more problem for composting as it becomes lignified, but has low or negligible carcinogenic (Ptaquiloside) content at that time (Potter and Pitman 1995).

The character of the Ptaquiloside compound was established by Evans (1976), and isolated by Niwa et al. (1983) and Fenwick (1988), who showed it to be an unstable glucoside, which breaks down quickly in conditions of low pH, and sustained temperatures over 60 °C – degrading into non-carcinogenic Pterosins (Saito et al.

1989). Concentrations of Ptaquiloside vary throughout frond growth (Williams and Foley 1976; Smith 1990) being at a peak in the crozier stage (May/June in UK), and in spores which may be produced in favourable years in late August/September. Heavy sporing occurs on average once in ten years in southern Britain but less frequently in the north and west.

The source area

Most current bracken cutting is done for conservation purposes, to open up lowland heathland and control bracken spread over habitats special to ground nesting birds. The source of the material in this trial comes from the New Forest in southern UK, where rotational harvesting of ~65 ha annually has been possible over the last decade, from a resource of over 800 ha within the National Park. Heavy duty forage harvesters cut on a four year cycle, obtaining consistent yields of 60 m^3 ha^{-1} volume of chopped wet material (Drake-Brockman 1996). Due to year on year variability of the frond growth and water content, this yields a fresh wet weight of between 7–29 t ha^{-1}. The general recovery of the plant after cutting was documented in the classic studies of Watt (1940), and bracken stands harvested in the New Forest usually regain biomass in the second year of growth. Composting was performed at a central depot on a hard surface under controlled conditions.

This paper aims to provide a full investigation of the physical and chemical properties of bracken cut by this system, with a comparison of its composted properties to those of commercially available peat.

Materials and Methods

Composting

The aims of composting cut bracken were three fold:

a) to produce a chemically and physically homogenous material from a variety of source sites,
b) to ensure the breakdown of the cellulose and lignin fibres of the plant stems and petioles to enhance water holding capacity,
c) to ensure the breakdown of the unstable carcinogenic compounds naturally occurring in the fronds and spores, by controlled use of sustained high temperature and acidity in the composting process (Saito et al. 1989).

Aerobic composting of the cut material was conducted over a period of 16 weeks in 45 m^3 windrows (initial height 1.5 m, width 3.0 m, length 10 m), turned by tractor once every two weeks. This regime is essential to ensure Ptaquiloside break down in summer cut green bracken (Potter and Pitman 1995). Water content of the cut bracken must be at least 70 % to initiate activity, and inside heap temperatures should rise between 60–70 °C (Pitman and Webber 1998). Most September field cut material started with sufficient moisture content, but later cut bracken needed extra wetting before heap construction could be initiated. Temperatures were measured weekly inside the heaps with thermistor probes on long access poles without disturbance to the material. Moisture content was recorded from 3 replicate samples taken from the centre of each heap as tractor turning was in progress – these were weighted wet and after oven drying at 70 °C over three days. In the results,

- 'single' chop material was composted straight from field harvesting by forage harvester.
- 'Double' chop material was chopped a second time at depot before windrowing, in order to increase the proportions of fine material (< 0.6 cm).
- 'Ammended' compost in the results has had an addition of ammonium sulphate at the start of windrow construction to offset the natural pH rise during composting, at a dose rate of approximately 2.0–2.5 kg m^{-3}.
- Commercially available peat (Irish 'Shamrock' Sphagnum) was used for the creation of mixes (e.g. 50:50 % by volume), pre-soaked overnight before mixing by hand.

Particle size, bulk density, and air filled porosity

Particle size was assessed by hand sieving a standard volume (30 × 30 × 30 cm) each time through a nest of sieves between 0.6 and 2.5 cm aperture. Bulk density was completed commercially at NRM, UK, using the British Standards Institution 'Dutch method' (1990), on one litre samples under standard compression tests. The Air Filled Porosity (AFP) of composted bracken and bracken/peat mixtures were tested according to the 'Wolverhampton' method of Bragg and Chambers (1988). The methodology of three soaks and drain cycles was maintained, with 30 minutes for the final drain before any measurements were taken. Irish 'Shamrock' Sphagnum peat from Bord Na Mona was used as standard. Both single and double chopped bracken was tested along with mixes of wetted peat in 25 and 50 % proportions.

Nitrogen drawdown

Nitrogen Drawdown Index was tested using the Australian standard (AS3743) procedure (1989). Compost mixes were charged in 2 litre pots with a solution of potassium nitrate, at 75 mg l^{-1} N concentration, followed by four day incubation at 20 °C in a temperature controlled room. Mixes with peat were included and replicated three times. Nitrate measurements on the leachate at the start and finish were obtained by Dionex ion chromatography at Forest Research. All bracken samples had been cut 18 months previously, composted in the open air, and stored in black sacks until the experiment – the 'double chop' material, with added ammonium sulphate tested

here, was used later in nursery trials (Pitman and Webber 1998).

Water Retention

Water retention characteristics were determined at the Land Research Centre, Cranfield, using a sand suction table and pressure membrane between 4–20 kPa, for single and double chop pure composted bracken. In the second year, with mixes of peat and bracken at 50:50 and 75:25 % proportions were also tested in more detail between 0–10 kPa on a kaolin suction table. A silica flour (HPF5) was used as a standard control. Analyses were completed in triplicate, with water content determined by weight change.

These analyses allowed the calculation of three indices: AWHC (available water holding capacity) as calculated from the definition by Beardsall (in Bragg and Chambers 1988) between a pF of 0 (saturated) and 250 kPa (wilting state): EAW (easily available water, defined by De Boodt and Verdonck (quoted in Bunt 1988) as held over the range of 1–5 kPa tension: and WBC (water buffer capacity) – water available between 5 and 10 kPa tension for the bracken mixes. The water retention characteristics were compared to a standard commercial peat, 'Shamrock' (Bord Na Mona) as quoted in Bunt (1988).

The chemical content of bracken at all stages of growth is well known (Moon and Pal 1950; Braid 1959; Williams and Foley 1976), but for horticultural use, the nature of the leachate released by the medium is more important. Before and after the 16 weeks of composting, leachate derived from centrifugation of the wet material was processed by NRM (Jealotts Hill) and ADAS (Cambridge), adopting the standard Peat leachate analysis techniques used in horticultural assay for assessment of macro-nutrients. Total N and C (Table 5) were then measured from the dried and ground material.

Assay for carcinogens

Chemical analyses for the carcinogen Ptaquiloside were made on composted and fresh samples of bracken using a combination of Mass Spectroscopy and Thermoluminescence (TLC) techniques, as reported in Potter and Pitman (1995), by Menai Organics Ltd. Concentrations of Ptaquiloside and its analogues were determined both at the time of harvest for both summer and autumn cut bracken and then throughout the composting process in order to follow the breakdown of the compound (Potter and Pitman 1995). A summary is presented in Table 5.

Statistical analyses

Statistical analyses were completed in Genstat (Payne et al. 2009) using ANOVA with significance of difference calculated by Duncan's Multiple Range test (at probability of 0.05).

Results

Particle size

The proportion of fines in the material (under 6 mm size) rises from an initial value of 21 % in the fresh material, to 40 % in single chop after composting, and between 34 and 60 % in the double chop bracken (Table 1). After composting, the bulk density (BD) of single chop material increases by one third, but alters little in the double chop material. Single chop summer cut bracken at ~300 kg m^{-3} – reflects the better natural breakdown of the early season material, due to its lower lignin content. All heaps regularly turned, whether originally single or double chop material, finished with significantly higher BD ($P < 0.05$, Table 1) after composting. As a consequence,

Table 1. Physical characteristics of composted bracken (*Pteridium aquilinum*), comparing particle size and bulk density of single and double chopped material at start and completion of the trials.

	Particle size (%)				Bulk density
	< 6 mm	6–12 mm	12–25 mm	> 25 mm	(kg m^3)
Fresh cut material					
single cut start	21	16	21	42	211 ± 19 a
double cut start	34	27	22	17	354 ± 9
Turned heaps at finish (by season of cut)					
Summer	65	23	7	5	340 ± 14*
Autumn-single	40	25	18	17	297 ± 7* b
Autumn-double	60	24	12	4	360 ± 8* b

* Standard error (s. e.) values from 3 Summer and 5 Autumn cut replicates. Indices a, b are significant differences at 95 % CI level

the volume of material reduced by up to one third over the period of experimentation.

Air Filled Porosity

The comparison of results in Table 2 shows that all composted bracken on its own have AFP values higher than the peat standard, which is significantly different ($P < 0.05$) for any mix with a peat component under 50 %. The maximum in the single chop material, composted directly from the forage harvester, is significantly higher ($P < 0.05$) than any other mix. Double chopped bracken is within the recommended APF (Bragg Index 3) suitable for long-term nursery stock and foliage plants, but needing frequent watering.

Water retention characteristics

Available water holding capacity (AWHC) value for the 100 % bracken material (both single and double chopped), is calculated between 25 and 29 % of the wet volume. This compares with 55 % for the standard peat, and places the bracken compost in the range recorded for pine and other hardwood barks. The water retention percentage is marginally increased in mixes with peat (Table 2). After the cessation of drainage, the percent moisture content held by pure bracken, both single and double chopped, is much lower than that of peat (at 95 %), by at least 10 % (Fig. 1). There is fast release from bracken composts between 0–1 kPa tension, as drainage through the open structure under gravity is swift and 50 % or more of the water is available at tensions under 5 kPa. Easily Available Water of the peat used in this trial had a mean value of 28 %, but bracken composts had only 10 % – this value is highest for the finest material (12 %), and lower in both single chop bracken and bracken:peat mixes (~10 %). The Water Buffer Capacity calculated from these results, is 2–3 % of the volume of composted bracken, which slightly exceeds the percentage for peat.

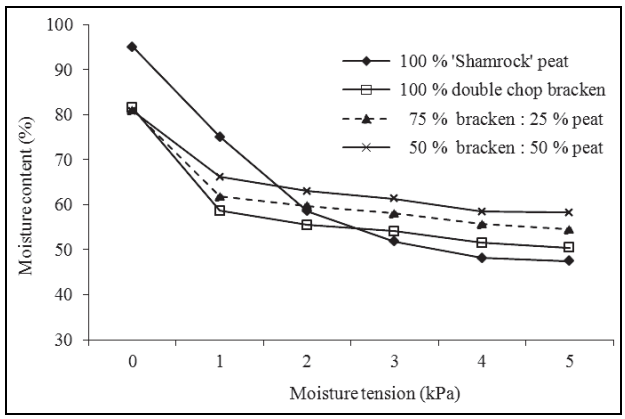


Fig. 1. Composted bracken desorption curves in year 2.

Nitrogen Draw Down Index

Samples of double chopped composted bracken and Irish 'Shamrock' peat were tested to obtain a value of NDI by the Australian Standard® AS3743. Table 3 demonstrates that there is an initial significant difference ($P < 0.05$) between the values of the Index for the 100 % peat and the 100 % composted bracken or the 50:50 % bracken: peat mix, which is maintained through the 4 day incubation period.

Chemical characteristics

Acidity. Fresh harvested bracken cut in mid-summer and early autumn has a pH range of 5.5–5.8, which rises to 6.5 or 7.0 during aerobic composting within a few weeks in the heaps (Table 4). With a higher carbohydrate content, summer cut bracken remains at this level until winter ambient air temperatures in November naturally reduce fungal activity in open windrows. Without additives, pH reduces during storage over 12–18 months, to values of pH 6.0–6.5. Regular turning of both the single and double chop material reduces the pH significantly

Table 2. Air Filled Porosity and water retention characteristics of composted bracken mixes.

	Peat standard 0:100 %	Single 100:0 %	Double 100:0 %	Single + peat 75:25 %	Single + peat 50:50 %	Double + peat 75:25 %	Double + peat 50:50 %
AFP mean (3)	11.31 a	32.93 e	22.24 d	22.86 d	14.82 b	17.19 c	13.18 ab
Standard error (s. e.)	0.13	0.52	1.10	0.36	0.65	0.83	0.23
Bulk density (g cm^{-3})		0.13	0.23			0.22	0.20
Total pore space (%)*	93	94	91	n. a.	n. a.	89	90
Easily available water (%)	28	10	9			7	8

Single = Single chop bracken; Double = Double chop bracken
Indices a, ab, b, c, d and e are significant differences at 95 % CI limit
* data interpolated from Bunt (1988)

Table 3. Nitrogen Drawdown Index (Australian standard method AS3743) of double chopped bracken, peat and bracken: peat mix (Mean of 3 values ± s. e.).

Time from start	Peat standard 100 %	Double 100 %	Double + peat 50:50 %
Day 0 (mg l^{-1} N)	11.75 a ± 0.15	11.99 b ± 0.11	12.13 b ± 0.07
Day 4 (mg l^{-1} N)	10.84 a ± 0.10	11.94 b ± 0.12	11.87 b ± 0.10
NDI (%)	92.2	99.6	98.0

a and b are indices of significant difference in the treatments (95 % CI level) on same day

Table 4. Water leachate chemistry from finished bracken compost, and measured C:N ratio.

Elements	Single & Double		Double + NH_4SO_4	
(mg l^{-1})	Summer cut	Autumn cut	Summer cut	Autumn cut
Chloride	51	54	59.4	24.6
Phosphate P	28.8	8.4	25.2	3.6
Potassium	222	156	90	120
Magnesium	2.4	1.8	0.6	3.0
Calcium	7.8	3.6	4.8	7.8
Sodium	12.6	14.4	9.0	11.4
Sulphate	7.6	< 6.0	9.6	6.0
Boron	0.36	0.24	0.36	0.12
Copper	0.12	0.06	0.06	0.06
Manganese	0.12	0.06	0.12	0.06
Zinc	0.06	< 0.06	0.06	0.60
Iron	1.02	0.36	0.9	1.2
Total N	45.6	36.0	25.2	37.8
C: N ratio	14 : 0	28 : 1	n. a.	n. a.
pH range	n. a.	5.7–6.8 b	6.4	4.6–5.6 a
Conductivity (µS cm^{-1})	n. a.	65–158	20	93–131

Single = Single chop bracken; Double = Double chop bracken
n. a. data not available

(see Pitman and Webber 1998). In heaps with additional ammonium sulphate pH is reduced and stabilised within 6 months to between 4.6 and 5.6, and is maintained in storage in heaps or bags for at least 18 months.

Conductivity. Leachate conductivity draining or centrifuged from freshly harvested bracken never exceeded 300 µS. This value reduced as composting proceeded in every trial, both single and double chop bracken, and even in heaps with added fertiliser (Table 4).

Macronutrients. The results demonstrate the paucity of nutrients available for plant growth from within the material, except for potassium, which leaches out continuously from the material for up to 18 months, and probably accounts for the falling conductivity values during composting. Initial values of P, K, Cl and Na in the leachate are reduced by half in unturned heaps (not presented) within the first three months of composting, but by two thirds in repeatedly turned material (Table 4). Composted bracken 'amended' and more acid, demonstrated the lowest macro-nutrient levels and lowest overall conductivity, whilst the highest N, P and K levels after composting are found in the summer cut bracken.

Ptaquiloside. The results in the summary Table 5 demonstrate that, with the exception of sporing bracken, properly composted material maintained at a temperature of over 60 °C, turned at regular intervals, can be clear of carcinogenic compounds and be safe to handle within twelve

Table 5. Summary table of Ptaquiloside breakdown during composting (main source: Potter and Pitman 1995).

Harvest time	Ptaquiloside and analogues (methyl ptaquiloside)	Pterosins-breakdown products (A, B, L and Z)
Summer cut bracken		
harvested July	present	B
composted 3 weeks	none	B
composted 16 weeks	none	none
Autumn cut bracken		
i) non-sporing cut Sept 93	trace	B and L
composted 12 weeks	none	none
ii) sporing cut Sept 94	present	B and Z
overwinter storage	analogue present	B
composted 16 weeks	none	A
Dead bracken fronds		
harvested November	none	none

weeks of composting. Spores appear to release Ptaquiloside more slowly over a sustained period (Potter, pers. comm.) in comparison to the bruised fronds, and thus need active composting for a longer period (up to 16 weeks).

Discussion

There has been a considerable search to find a low pH potting medium for horticulture to replace peat taken from natural bogs in an unsustainable fashion. Testing of peat alternatives was instigated in the UK in the 1990's by the Horticultural Development Council Report (1993) with the Royal Society For Protection Of Birds (1993) representing conservation interests, and is still the subject of major conference proceedings (see papers by Clarke and Carlisle 2008). The basic advantages of peat over other organic or mixed media is its low pH, high water holding capacity, simple chemistry and overall uniformity of texture, which ensures easy handling and guaranteed return for growers adopting standard management techniques. Novel replacement materials might have higher pH (coir), high heavy metal content and nitrogen (sewage sludge products), very variable composition (domestic green waste) or potential nitrogen lock-up if not thoroughly composted (bark products – Webber and Gee 1996). Bracken is a plant annually producing big biomass in favoured locations of western Europe which dominates a low pH ecosystem by its deep acid litter (Marrs and Watt 2006). It is a highly sustainable resource due to its system of rhizomes storing carbohydrate from one season to the next (Watt 1940).

This study shows that bracken can be cut and composted safely into an almost chemically inert potting medium – an attribute favoured by growers as it allows tailored additions of controlled release fertiliser. The measured value of NDI indicates a medium with very little draw-down of nitrogen, in which good growth should be achieved with a minimum of additional nitrogen for short term crops (Handrek 1992). Simple controlled low additions of standard fertiliser at the start of composting can produce a low pH medium, with very good water drainage characteristics. In terms of desirability for water holding, composted bracken has a low proportion of EAW and Buffer Capacity, but too high pore space, except in mixes with other material.

High AFP values have some advantage in that over-watering risks are reduced, and can be managed through the addition of fine sand, peat or with a water retaining gel of some kind. The AFP index value (Bragg Index 3) measured for the composted double chop material is suitable for long-term nursery stock and foliage plants, for which frequent watering would be required. Selected ornamental plants (Johnson 1968 quoted in Bunt 1988) such as *Azalea*, *Orchidaceae*, *Begonia*, *Daphne*, *Erica*, *Gardenia*, *Rhododendron*, *Podocarpus* and *Antirrhinum*, which require root aeration at 10–20 % porosity in the substrate, would be in this category. The handling of bracken compost will necessitate different watering regimes to those adopted for peat, as moisture stress could become growth limiting for water demanding species in pots on sand beds.

Mixes with composted tree seedlings which would develop compaction in the pot over time, might be suitable (Veijalainen et al. 2008), or composted gorse (*Ulex europaeus* L.) high in nitrogen (Iglesias et al. 2008). The tests completed here indicate that 25 % sphagnum peat admixture to the bracken reduced the AFP by 5 % for double chop and 10 % for single chop bracken. The 50:50 % bracken: peat mix produces an AFP between 13 and 15 % (Bragg Index 2), where such media are suitable for a wide range of bedding plants, nursery stock and smaller herbs for which watering management is less critical.

The variation of natural supply quality was difficult to asses from this study, as all the sites autumn harvested came from an area of less than 25 × 25 km, across a geology dominated by Tertiary plateau gravels. Material cut from sites only 5 km from the sea had a higher chloride (× 6.0), sodium (× 1.5) and potassium content than more distant sites, and this affected the initial conductivity values of the compost. Fresh material nearest the sea started with conductivity at 275 μS, but this declined to 132 μS during normal composting. Soil differences may also determine small changes in the heavy metal content of the compost, derived by translocation from the soil during growth (Davies and Jones 1988). Bracken cut from stagnogley sites has higher iron value (> 7 mg l^{-1}), but higher manganese (~1.0 mg l^{-1}) and zinc values

(< 3 mg l^{-1}) came from plants on podsolic soils. Summer cut bracken tested here growing on a sandy bedrock had higher start content of sodium (× 2.0), chloride (× 4.0–5.0) and potassium (× 8.0) than autumn cut bracken from the New Forest, but these values reduced during composting to be comparable to those in the autumn cut material. Physical and chemical variation of composted bracken is thus minor compared to some other novel composts.

The composting results demonstrate that properly composted material (without spores) maintained at a temperature of over 60 °C, turned at regular intervals, can be clear of carcinogenic compounds and be safe to handle within twelve weeks of composting. As spores appear to release Ptaquiloside more slowly (Potter, pers. comm.), there is a need for a longer period of active composting (up to 16 weeks). If activity within the heaps ceases early, due to falling air temperatures in autumn, a second cycle of composting should be initiated the following spring to ensure complete breakdown. The most suitable harvesting time is therefore at full canopy extension of the plant in late July/early August before any spores begin ripening, or after frost and senescence in October, when there is no Ptaquiloside in the above ground dead fronds. At this time, however, increased lignification and lower carbohydrate resources make proper composting difficult to achieve in one winter.

The chemical and physical analyses summarised here for composted bracken demonstrate that it can be successfully prepared from a highly sustainable resource. It could be considered as a partial peat replacement for more acid loving plants in horticulture, or nursery stock demanding good substrate drainage – its high AFP can be remedied by adaptive water management or by the creation of mixes with materials of high water holding capacity.

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