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Reed canarygrass (*Phalaris arundinacea*) outperforms *Miscanthus* or willow on marginal soils, brownfield and non-agricultural sites for local, sustainable energy crop production

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ABSTRACT

Growing biomass on non-agricultural land could potentially deliver renewable energy services without displacing land from food production, avoiding the social and environmental conflicts associated with bioenergy. A variety of derelict underutilized and neglected land types are possible candidates, sharing a number of challenges for agronomy, including contaminants in soils, potential uptake and dispersion through energy use. Most previous field trials have grown woody biomass species during phytoremediation. Five one-hectare brownfield sites in NE England, were each amended with c.500 t ha^{-1} of green-waste compost, planted with short-rotation coppice willow, *Miscanthus*, reed canarygrass and switchgrass,[1] and then harvested for 3–5 years.

Critical issues for the economic and environmental viability of energy production on brownfield land were investigated: The yields achieved on non-agricultural land; the potential for fuel contamination; the suitability for use and potential markets for any biomass produced. RCG appears best suited to the challenging soil conditions found on non-agricultural land, outperforming other species in ease of establishment, cost, time to maturity, yield and contamination levels. Invasive spreading and low melting ash compositions were not observed. Annual yields of 4–7 odt ha^{-1} from the second growth season were found consistently across a range of previously-developed, capped or former landfill sites, with a gross annual energy yield of 97 GJ ha^{-1} at contamination levels acceptable for domestic pellets. The analogy with marginal agricultural land suggests that this species and approach could help boost biomass production while avoiding the natural capital "nexus" related to global food-fuel-land-water limits.

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[1] Hereafter abbreviated as SRC, MC, RCG, SG respectively.

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1. Introduction

Biomass is the commonest form of renewable energy [1] and combustion of ligno-cellulosic energy crops as a renewable heat source presents an available technology and a cost effective means of reducing greenhouse gas emissions, addressing climate change and meeting renewable energy targets: As an example, in the UK the Renewable Energy Review [2] found biomass boilers to offer the lowest minimum abatement cost (-£150/t CO_2 in 2020) among a range of low carbon heat technologies. However, the widespread utilization of biomass for heat or power generation in the UK and elsewhere has been tempered by concerns over the sustainability of biomass and biofuels in general [3]. Discussion of the economic, social and environmental impacts of biofuel production and use has centred on three aspects [4,5]: Firstly, the net carbon reduction benefit of using bioenergy when the whole life-cycle energy balance, fossil fuel use and greenhouse gas emissions of production and transport are considered [6,7]; secondly, the additional demand from direct utilization of food crops for liquid biofuels manufacture, or the potential for purpose-grown "energy crops" to compete indirectly with food production on agricultural land, together impacting on global food supplies or price [8], water and land availability - the so-called "land-fuel-water" nexus [9]; thirdly, negative impacts on the environment through land use change or deforestation from biofuels production, or indirect land use changes from displaced agriculture [7,10,11]. Using locally available non-agricultural land for energy crop production [12,13] could potentially circumvent each of these concerns, while offering a sustainable reuse option for brownfield sites, with improved habitat and amenity value at many sites [14–17].

To date, the existing field-scale demonstrations of biomass production on brownfields, contaminated land or landfills have mainly involved growing woody biomass as short rotation coppice or forestry [14,18–23], more rarely oil seed crops or perennial grasses [24–26]. Paradoxically, the majority of contaminated sites, whether brownfield or greenfield, are affected by heavy metals or mineral oils [27], which together with other prevailing site conditions might compromise economic viability by reducing yields [20,22]. Biomass production may be a secondary consideration to pollutant control [28], accompanying various forms of phytoremediation [29] or "gentle" remediation of contaminated sites [30]. The processing and utilization of recycled organic wastes may be used to add value to the biomass operation [14], which can be part of the long-term management of damaged land [31]. However, a real or perceived consequence of growing biomass in contaminated soils is the potential for it to become contaminated, which could reduce the value or suitability for use of the woody biomass [32,33]. This might occur directly by contaminant uptake (i.e. phyto-extraction [29]), or indirectly, by cross-contamination from adhering soil dust during growth or forage harvesting [15]. This would detract from the economic viability and environmental validity of the approach [31], unless an adequately productive energy crop can be identified with an acceptably low level of contamination to allow both its safe cultivation on these challenging sites and subsequent suitable use, ideally in an existing market.

This paper uses the results of five full scale multi-season field trials in NE England to assess the potential of RCG as an energy crop grown on brownfield land, comparing the actual yields achievable on non-agricultural sites, quantifying the potential uptake of toxic elements from contaminated soils and investigating the resultant biomass fuel quality and uses.

2. Materials and methods

Five 1 ha brownfield trials were established in 2007 as part of an EU Life Programme demonstration project "Biomass, Remediation, re-Generation (BioReGen): Reusing Brownfield sites for Renewable Energy Crops" [34] in order to directly compare the suitability of SRC, MC, RCG and SG for growth on non-agricultural land. The five field trial sites were selected on the basis of adequate size, absence of scrub and apparent suitability for cultivation, using desk studies of historic maps to establish their previous use (Table 1). During walkover surveys three or more non-systematic surface soil samples were collected over a depth interval of 0–0.1 m to determine potential contamination, baseline nutrient status and physiochemical properties in the surface soil available for cultivation (Table 2).

2.1. Site preparation & planting

Sites were prepared using the results of smaller scale single species or hand-cultivated trials planted between 2004 and 2006 [15,35,36]. From these a generalized approach was developed for *in situ* cultivation of non-agricultural sites, requiring surface incorporation of c.500 t ha^{-1} (fresh mass at 20–30 % H_2O) of green waste compost produced to BSI PAS100 specification [37,38] and supplied from stock from a single composting site (Premier Waste Management Ltd, Joint Stocks, Coxhoe, County Durham). To do this any standing vegetation was first mown and sprayed with glyphosate. Ploughing and disking was used to break open the soil. Compost was applied using a back-end spreader, then incorporated by further disking to a maximum depth of c.0.1 m. All crops were planted in spring 2007 using standard agricultural equipment and conventional UK planting methods for energy crops: For SRC 0.2 m cuttings were step-planted (Coppice Resources Ltd) at a rate of 15,000 ha^{-1} using a conventional double-row layout (alternate 0.75 m and 1.5 m machine aisles, along row spacing 0.59 m) using single commercial hybrid clones (*S. schwerinii x S . viminalis*), either Tora (SW910007) or Torhild (SW930725) [39]; MC rhizomes (*Miscanthus x giganteous*) were planted at a rate of c. 20,000 ha^{-1} using a modified potato planter (Bical Ltd). Both SG (Ernst Seeds, variety Shawnee, 10 kg ha^{-1}) and RCG (uncertified seed, Advanta, 20 kg ha^{-1}) were sown from seed by broadcast spreading, followed by firming with a Cambridge (multi-segmented, rib-edged) roller. Finally, the sites were protected from rabbits (*Oryctolagus cuniculus*) and deer (*Cervus elaphus*) by erecting an enclosing wire mesh fence with a buried lower edge. Thus planting mimicked current UK deployment methods for commercial energy crops at agricultural sites.