agronomy

Editorial

Bioenergy Crops: Current Status and Future Prospects

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Biomass always played a crucial role as an energy source during the evolution of humankind and our technical development. During the last decades, beginning with the industrial revolution, starting in the second half of the 18th century, a rapid economic growth occurred after 1870. Since then the world's population has grown exponentially, with a simultaneous increase in energy demand—but without an implemented long-term sustainable resource strategy to meet that demand.

In todays' energy mix, biomass in the form of, for example, wood and bioenergy crops plays an important role to meet the energy demands for heating, cooking in private households, and electricity generation, among others. Particularly in rural areas with insufficient energy infrastructure and access to the national grid, "decentralized bioenergy production is a major driver for increasing access to modern, clean, and affordable energy" [1]. In addition, the use of biomass for energy generation also has the potential to contribute to climate change mitigation, i.e., the urgent need to reduce fossil-born CO_2 in the atmosphere. Particularly the latter makes bioenergy crops an important potential contribution to an almost CO_2-neutral energy and raw material supply. However, depending on the biomass, the associated land use changes (LUC) or indirect land use changes (ILUC) may fundamentally affect sustainable resource use and biodiversity, and can result in the release of large amounts of CO_2—which all needs careful consideration not to counteract the benefits of bioenergy crops.

The imperative change from a petroleum-based economy to a more sustainable and bio-based economy also requires the increased use of plant biomass as a source of alternative raw materials—all without compromising food security. Bioenergy and bioenergy crops have therefore attracted growing scientific interest and socio-economic importance during recent decades, particularly in terms of sustainability and climate change. The publication of research articles on topics such as "bioenergy" and "bioenergy crops" increased rapidly during the last two decades, with a majority of contributions related to energy fuels and agronomy. The content of our *Agronomy* Special Issue, appropriately entitled *"Bioenergy Crops: Current Status and Future Prospects"*—comprising nine original research articles, three reviews, and one opinion paper—contributes notably to this huge and even growing puzzle in the given topic.

The tasks ahead, the adaptation of agronomic approaches to produce plant biomass in sustainable and profitable ways while answering social-ecological demands, are part of this article collection. The development of novel research strategies is also reflected in the contributions to this *Agronomy* Special Issue.

Optimization of biomass yield–crops, soils and input: A major topic in current plant biomass production is, by necessity, the optimization of cropping systems towards their overall sustainability and towards the achievement of the sustainable development goals. Conventional agricultural approaches in terms of soil cultivation, fertilization strategies and crops are still being applied and are of relevance for achieving adequate yields, particularly to meet the target of production on marginal soils. However, the values of further social-ecological aspects are becoming more and more recognized. Wever et al. thus call for third-generation of biomass crops with flexible use as either food, energy, or raw materials [2]. Such crops should further enrich farm diversity and flexibility while providing numerous

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other ecosystem services than the provision of raw materials, such as carbon sequestration, erosion mitigation, or habitat functions for pollinators. Growing climate threats such as drought events or adverse precipitation patterns, a decrease in biodiversity, and a loss of fertile soils are major challenges to cope with. These challenges however, also offer great opportunities for the de novo domestication of new multipurpose crops derived from wild plant species, "dominated by the sustainable traits of perennial plants" [2]. Plant biomass could also increasingly be used for material applications and bio-based products. In terms of a growing bioeconomy, this may lead to an increased demand for biomass, resulting also in an increased demand of suitable land for its cultivation. Von Cossel et al. approached this topic in terms of a social-ecologically more sustainable biomass production, considering the use of marginal soils not competing with food production, rural development under ecological premises, and climate resilient crops and landscape aesthetic aspects [1].

Alternative perennial second generation energy crops such as Virginia mallow (*Sida hermaphrodita* L. Rusby), cup plant (*Silphium perfoliatum* L.), and giant miscanthus (*Miscanthus x giganteus*) that do not directly compete with food or feed have received considerable research attention in recent years and continue to be investigated, as is also shown in this special issue [3–5]. Among the use of such crops solely as energy carriers, higher value, and in return energy savings, could be achieved by emphasizing more the use of its biomasses for material applications. A prominent example is *Miscanthus* as a renewable feedstock in materials production, aiming also for climate mitigation by a permanent CO_2 fixation within building materials [6]. Wood and straw for example have been used for construction and insulation purposes over centuries. The question of how far *S. hermaphrodita* and *S. perfoliatum* biomass could also serve for sustainable materials production as an alternative for energy applications may open promising research avenues. Generally, we could state that an overall goal should not just be the supplementation of the increasing energy demand by energy crops or in general by biogenic sources, but to decrease the overall energy consumption by employing smart solutions and complementing high energy-demanding applications with sustainably-produced biomass feedstocks.

Next to maize (*Zea mays* L.) as a prominent worldwide cash crop for food, feed, and energy applications, two first generation bioenergy crops adapted to the North-Eastern European climate are oilseed rape (*Brassica napus*) and triticale (×*Triticosecale*, in this *Agronomy* Special Issue *Triticosecale* Witt.). In a field study, two morphotypes of hybrid cultivars of winter oilseed rape were investigated, showing in both cases the demand for high-input production technologies, which increased the seed yield significantly, outweighing the rise in production costs in return [7]. Triticale as a feedstock for bioethanol production showed the best ratio of energy efficiency in conventional agricultural conditions at traditional tillage and a nitrogen fertilization dosage of 40–80 kg per hectare [8]. With regard to climate change mitigation strategies in bioenergy cropping systems, first-generation energy crops are being controversially discussed. In a growing bioeconomy however, crops such as oilseed rape and triticale may play an important role in feedstock supply for special applications or goods of higher value compared to its use as a pure energy source, particularly when addressing the reclamation of marginal soils and nutrient recycling.

Intercropping-increasing yield and biodiversity: To increase biomass production and soil nutrient retention, as well as to mitigate soil erosion, intercropping systems are promising approaches. Even though intercropping has a long agronomic tradition in maintaining soil health and improving crop health and performance, the technique should further be employed for a sustainable biomass production allowing, for example, the reduction of nitrogen fertilizers when employing nitrogen-fixing legumes. Intercropping maize and sorghum (*Sorghum bicolor* L.) with legumes reduced the adverse effects of drought stress and phosphorous deficiency, as demonstrated in an outdoor pot trial by Eichler-Löbermann et al. [9]. Under suboptimal conditions of water and phosphorous shortage a higher yield stability of the crop mixtures was demonstrated, which makes them a suitable agronomic alternative to sole cropped maize or sorghum. Similar positive results for intercropping the perennial energy crop *S. hermaphrodita* with perennial legume species was also demonstrated in earlier studies, and was highlighted in the review-article on this crop by Cumplido-Marin et al. [3].

In accordance with the steep increase in scientific publications on the topics "bioenergy" and "bioenergy crops" from 2008 onwards, this trend is mirrored by the search topics "energy crops" and "biodiversity". The influence of numerous perennial energy crops on weed biodiversity compared with annual agricultural crops under conventional and organic farming systems was studied and presented in this special issue by Feledyn-Szewczyk et al., demonstrating a generally higher diversity and abundance of weed flora in perennial cropping systems [10]. While the necessity to control the spread of non-native or invasive weed species may become relevant, the observations presented might also offer the chance for directed increase of biodiversity in perennial cropping systems.

With regard to the more social-ecologically sound bioenergy cropping systems, *Miscanthus* was found to be suitable for maize intercropping, with maize compensating for *Miscanthus* yield losses in the year of plant establishment [5]. However, how far legume-intercropping could be applied to other (perennial) energy crops in a multi-purpose approach to sustain natural nitrogen supply for the target-crop, additional biomass, and soil stability, needs further investigation under realistic field conditions. Among these beneficial aspects of legume-intercropping, it can be strongly assumed that intercropping can help to maintain or increase (agro-) biodiversity and yield stability in the long term.

Assuming an amelioration of marginal soils via perennial energy crop cultivation due to an accumulation of organic carbon via roots, litter, and plant detritus in general, first-generation energy crops serving also as food or feed may play an important role again in intercropping approaches.

Trends and future prospects: The transition from first generation energy crops (e.g., maize) with a well-established infrastructure for harvesting, processing, and further valorization through biorefinery, including all associated disputes, highly depends on the need and willingness of consumers, producers, and politicians to change running systems. Sugarcane dominates Brazilian agriculture, accounting for 10 million hectares, of which 6.7 million hectares are used to grow sugarcane for ethanol production—replacing 48% of the Brazilian gasoline needs by sugarcane ethanol, as reported by The Brazilian Sugarcane Industry Association (UNICA). The perennial nature of sugarcane and its flexible application opportunities depending on the market demands still make it a promising cash crop, despite its monoculture and intensive cultivation on arable land. An alternative use of innovative high-yielding energy cane breeds for biogas production was investigated by Hoffstadt et al., concluding that biogas production from energy cane may result in higher energy yields compared with ethanol production [11]. Such application opportunities widen its potential use and application as an energy crop. In the case of sugarcane as a biogas-feedstock, the resulting digestate as a by-product can also further be used as a fertilizer and soil conditioner. Alternative fertilization strategies need to be investigated and implemented, not only to replace or substitute fossil energy carriers by energy crops, but also to overall reduce CO_2-emissions to mitigate climate change. One promising but also logical approach is to close nutrient loops in various sectors, such as residues or wastes as they occur in agriculture (e.g., manure, crop residues, etc.) and the associated energy sector (e.g., biogas digestates). Organic nutrient-rich residues may combine both plant fertilization and biomass yield increase and the amelioration of marginal soils, as well as carbon sequestration in the soil. The use of biogenic residues such as maize-silage based digestates originating from biogas facilities as well as biochar was investigated in this special issue by Robles-Aguilar et al. and Dietrich et al. under greenhouse conditions [12,13]. Both studies clearly identified beneficial effects of the biogenic residues on plant performance in the given experimental time in maize. Such positive effects of digestate application in sand and other soils were also described in earlier greenhouse and outdoor studies using the perennial plant *S. hermaphrodita* as a promising bioenergy carrier, as described and summarized in the review-article by Cumplido-Marin et al. [3]. Overall, in terms of declining mineral phosphorus resources and to reduce the high energy demand for nitrogen and mineral fertilizers in general, nutrient recycling becomes an important issue particularly for bio-energy crop production. Recovery processes of essential plant nutrients from digestates or other waste streams (e.g., phosphorous and nitrogen recovery from waste-water via struvite, etc.), and their use in plant biomass production, would benefit from expanded research under real field conditions. The amelioration of marginal soils, considering biodiversity increases and intercropping approaches, should be implemented to meet the growing demand for plant biomass, thus paving the way to a social-ecologically more sustainable biomass production.

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