A Case Study Sequel: Sustainable Remediation Using Succession Crops for PAH Impacted Soil

Linda C. Yang, Matt Catlin, and Michael Jordan

Abstract A site in northern Illinois was impacted with polycyclic aromatic hydrocarbons (PAHs) in soil from historical foundry operations. Three PAHs—benzo(a)pyrene, benzo(b)fluoranthene, and dibenzo(a,h)anthracene were identified with concentrations exceeding their site remedial objectives in the upper three feet of soil. The remedial remedy was complicated due to the large volume of impacted soil, project funding limitations, and the site's location within a flood plain, preventing the importation of fill to create an engineered barrier. To address these challenges a sustainable design relying on phytoremediation was employed. In an effort to accommodate a short remedial timeframe, a unique approach was selected that was predicated on employing unique phytoremediation agents. The chosen planting regime allowed for maximum root production using rapidly maturing crops where multiple succession crops could be grown during the traditional growing season. The growing season was extended by using cold hardly winter crop, which allowed nearly year-round plant activity. The design and initial implementation was presented in Geo-Chicago 2016: Sustainability, Energy, and Geoenvironment in 2016. This paper summarizes the phytoremediation's operation and monitoring, follow up planting, and soil sampling results.

Keywords Phytoremediation · Sustainability · PAH impacted soil remediation

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1 Introduction

This paper discusses the continuation and site closure strategy of phytoremediation at a site where historical foundry operations generated a significant volume of foundry sands impacted with PAHs.

Since the late 1990s phytoremediation of soils impacted with PAHs has increased in popularity. The appeal of phytoremediation lies in its inexpensive, relatively non-invasive implementation and waste reduction. Of particular interest with regard to remedy evaluation criteria, phytoremediation scores high as a green and sustainable remedy as well as providing multiple secondary benefits not realized through excavation, thermal destruction, in-situ oxidization, or other applicable PAH remedies.

The phytoremediation design incorporates a new approach selected to address the difficult site conditions by incorporating readily available agricultural implements, conventional planting methods, and cold hardy cover crops to extend the growing seasons. The approach combines successional conventional tillage to take advantage of green manure plowdown to build organic matter, increase soil tilth, water retention field capacity, and increase the diversity of soil fauna bacteria fungi facultative groups.

Remedy evaluation and design were conducted at the subject site in 2014, and the initial growth cycle included planting of buckwheat in June, July and August of 2015 and winter rye in September 2015. Repeated planting of successional crops took place annually from 2016 to 2018 where two stands of buckwheat were followed by winter rye. Each crop was disced followed by immediate replanting. Soil sampling and analyses of PAHs has been performed since 2016 and the results show significant reduction of PAHs concentrations in soil.

1.1 Background

The Corner Parcel Site (Site) is located at the northeast corner of Gardner Street (IL-75) and Blackhawk Boulevard (IL-2) in South Beloit, Illinois. The Site is approximately 4.94 acres and is currently unoccupied and vacant. It is fenced with access on both Gardner Street and Blackhawk Boulevard.

The Site was operated as Beloit Foundry/Prime cast Foundry producing ductile, gray iron, and stainless steel castings from 1852 through 2003. From at least 1939 and until late 1960s or early 1970s, the site was also occupied by two gasoline service stations. The City of South Beloit acquired the Site in 2002 and the onsite buildings were demolished in 2003. The Site has been vacant since that time.

1.2 Site Setting

The Site is at a major intersection near the Illinois/Wisconsin border and is close to Turtle Creek and Rock River. South Beloit has developed a draft Comprehensive Plan including well-maintained parks and open spaces centered on and showcasing the Rock River, Turtle Creek, and City Parks. The City desires to develop the Site into a public green space in a safe and environmentally sustainable way, while not exceeding the limited funding available.

1.3 Site Investigation and Cleanup Objectives

A series of environmental assessments and subsurface investigations were conducted; and the Site was entered into the Illinois Environmental Protection Agency's (IEPA) voluntary cleanup program, Site Remediation Program (SRP). Initial investigations identified volatile organic compounds, semi-volatile organic compounds, pesticides, polychlorinated biphenyls, and metals at concentrations above the IEPA's Tier I cleanup objectives. The main challenge or driver to the closure of the site was the widespread PAH concentrations.

In accordance with the IEPA SRP regulations, a 95% upper confidence limit (95UCL) was established for the individual PAH concentrations at the site. The site-wide 95UCLs were then compared to the remedial objectives. Three PAHs exhibited 95UCLs in the upper three feet of soil at concentrations exceeding their respective site specific remedial objectives. Table 1 illustrates the IEPA approved remedial objectives and maximum concentrations of the PAHs detected at the Site before phytoremediation. The site investigation results indicated that six areas of the Site contain three PAHs concentrations over the remedial objectives. The contaminant distribution does not exhibit a pattern, which is likely due to the historical industrial operations and nonpoint source contamination nature of the Site.

Figures 1 and 2 illustrate the site general location and the areas with PAHs exceedances.

Table 1 PAHs concentration and remedial objectives

Parameters	Remedial objectives (mg/kg)	Maximum concentrations (mg/kg)
Benzo(a)pyrene	2.1	130
Benzo(b)fluoranthene	8	190
Dibenzo(a,h)anthracene	0.8	40

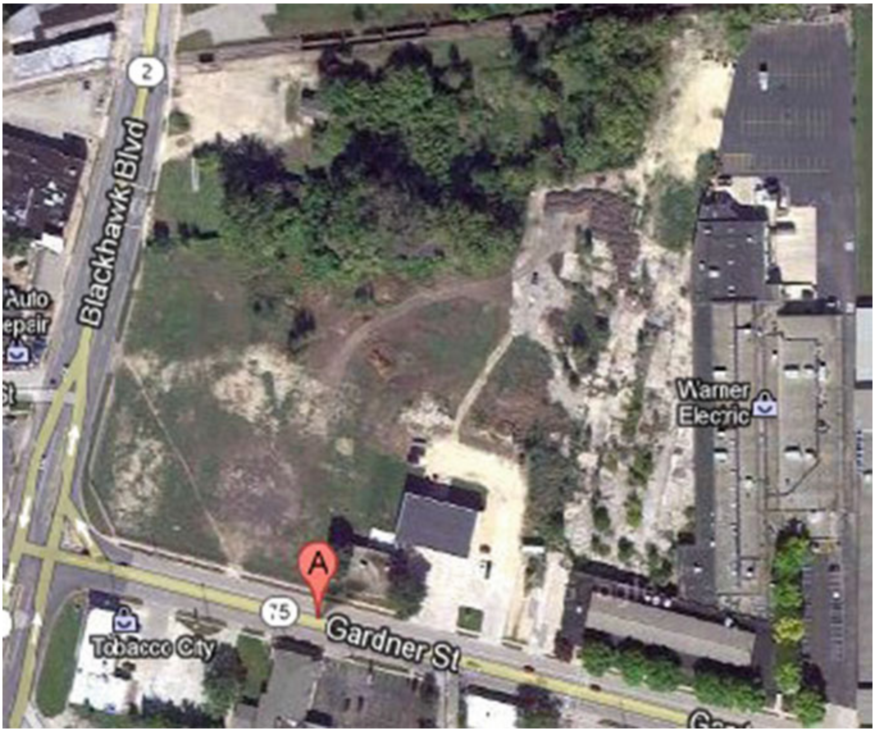

Fig. 1 The corner parcel site, South Beloit, Illinois

2 Remedy Design

Phytoremediation was selected to remediate PAH impacts in soil. Of the potential remedies evaluated, phytoremediation was selected based on the sustainability goal, Site end use, and budget allocation [1].

A comprehensive review of available literature was conducted in an attempt to identify low maintenance plant species with demonstrated abilities to degrade PAHs; and ideally, degrade them in soil and climate conditions similar to the Site. Installation of multiple plant species offers a greater chance for success than planting of a monoculture [2]. Several plants including rye grass [3], black willows [4], and prairie grasses [5] have established track records of success with PAHs. While effective, grasses are limited by a shallow rooting depth and trees and prairie grasses are hampered by slow development.

To overcome this challenge, an innovative solution of succession crops (buckwheat and cereal rye grain) was selected [6]. The successive approach (two rounds of buckwheat planting in the summer and early fall, followed with winter rye planting in late fall) takes advantage of the specific natures of the plants and the seasons. Given

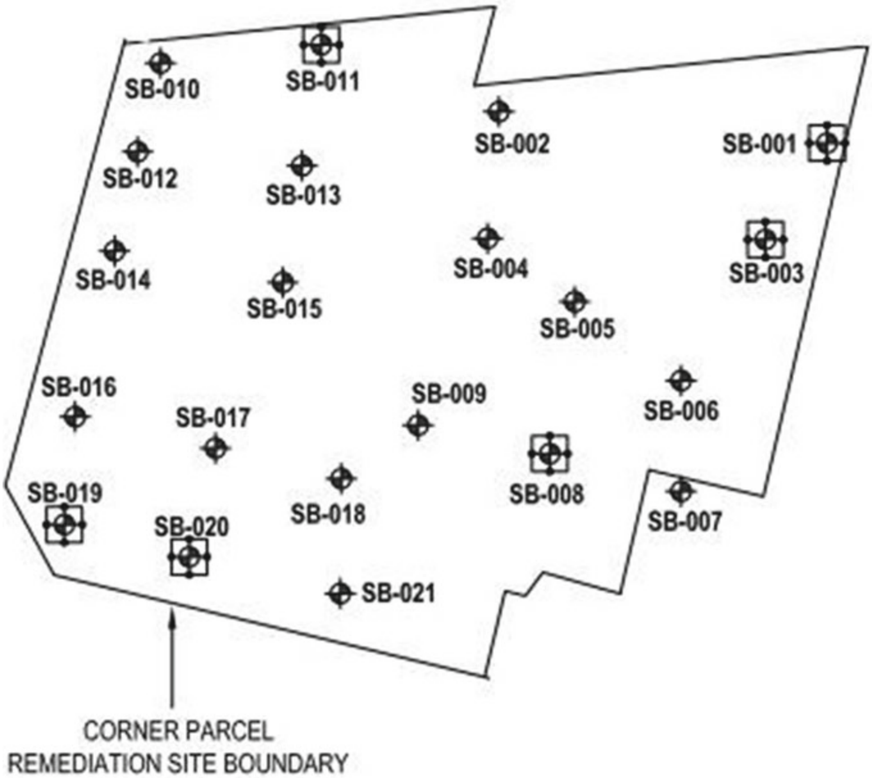

Fig. 2 Site Plan (PAH exceedance around SB-001, SB-003, SB-008, SB-011, SB-019, and SB-020)

the less than ideal soil conditions at the site, a succession planting regimen offers the additional benefit of rapidly improving soil [1].

Buckwheat rapidly matures; and once soil conditions reach approximately 80 degrees F, it can produce substantial biomass and a dense root system within approximately 35 days. The rapid growth of buckwheat allows multiple crops to be sown and tilled in a single season. Buckwheat also readily grows on poor soils and is drought resistant. It is so vigorous, organic farmers often utilize it as a smother crop during fallow periods as it will rapidly outcompete most weed species. The buckwheat crop's substantial root and biomass production is conventionally tilled in using a large double gang disc harrow with aggressive disc angles pulled by a farm tractor. The incorporation of the green plants into the soil rapidly builds soil tilth, increases organic matter and begins to break down hardpan while increasing the diversity and population of soil fauna.

Buckwheat is a plant that is cultivated for its grains and is commonly used as a cover crop. It has a branching root system, with one primary root reaching deeply in the moist soil, causing a better adaption to its environment than other cereal crops

[7]. The life cycle of buckwheat is shorter than others, approximately 6–12 weeks. It is considered that the buckwheat's adaptation to the northern Illinois environment, short life cycle, and dense root system will enhance the biomass in the shallow soil, biodegradation of the PAHs, and maximize the relatively short growing season length in northern Illinois.

Buckwheat in this regimen is followed by cereal rye. Cereal rye extends the growing season as it will germinate and grow when temperatures are above 33 degrees F. Cereal rye produces an extremely large network of root mass in the soil, providing one of the largest root surface areas per acre of readily available plants. Cereal rye also provides a deep root system capable of encompassing the depth of impact identified at the site.

Winter rye is an excellent winter cover crop because it rapidly produces a ground cover that holds soil in place against the forces of wind and water. The extensive root system of rye helps prevent compaction in annually tilled fields. Winter rye also has a positive effect on soil tilth. Compared to other cereal grains, rye grows faster in the fall and produces more dry matter the following spring. Rye is the most winter-hardy of all cereal grains, tolerating temperatures as low as −30 °F once it is well established. It can germinate and grow at temperatures as low as 33 °F [8]. The deep root of winter rye has a significantly greater root surface compared to other plants. This allows the plant to extend to deeper areas below the surface, access the vertical extent of contamination, and increase drought existence,therefore, reducing the operation and maintenance costs.

It is considered that the buckwheat and winter rye's adaptation to the northern Illinois environment, reduced maintenance including no irrigation requirements, and their extensive root systems will enhance the biomass in the shallow soil and biodegradation of the PAHs.

3 Succession Crops Installation and Monitoring

The site was prepared for planting by mowing the existing vegetation and tilling the surface using a double gang disc harrow pulled by a tractor. The disc harrow exposed the soil and generated an appropriate seed bed for planting. A conventional grain drill was used to drill the buckwheat into the soil at a typical rate of 60 lb per acre. Cereal rye grain was drilled using the same methodology after discing in the second buckwheat crop.

The first planting of buckwheat took place in the first week of June 2015. Site visits were conducted on a weekly basis to observe the site conditions. Buckwheat was observed to germinate approximately 1.5 weeks after the planting. Plants were observed to be fully blossoming one month after the planting. The second round of planting occurred in the seventh week after the first panting. It was observed that the buckwheat height ranged from approximately 51 inches in most of the site to 3 inches in the area that was poorly drained. Some plants were removed from the ground and the roots were observed to be dense and approximately 4 inches in length (Photos 1 and 2).

In late September 2015, winter rye was planted after the second round of buckwheat was terminated. In about three weeks, the plant grew to approximately 2–4 inches. The plant was observed to germinate slower than buckwheat and continued to grow in colder temperatures in October and November. In about five weeks, winter

Photo 1 Preparation for first planting

Photo 2 Buckwheat blossoming (5 weeks after planting)

Photo 3 Winter Rye

rye grew to approximately 3 inches (in the poorly drained area) to 9 inches tall. By May 2016, winter rye grew to approximately 36 inches in height in the good growth area (Photo 3).

It is well known that winter rye has a very intense root system and can improve soil significantly. It was reported anecdotally that winter rye roots could grow to 45 inches in north-central Indiana in May. During the project monitoring, particular attention was paid to the roots system. The observation showed that winter rye had very dense root system. In May 2016, the plant was removed from the ground using a hand auger. The measurement showed that the width of one plant root ball was approximately 9 inches wide and the root was approximately 11 inches long. The dense root system attached a lot of soil to it (Photo 4).

4 Soil Sampling and Analyses

After one cycle of the buckwheat and winter rye crop, soil sampling was conducted from (0–3) feet below grade interval at the original sampling locations (Fig. 1) to evaluate remedial progress and obtain another set of entire site condition of PAHs of concerns.

Analytical results showed that soil samples at three locations (SB-004, SB-010, and SB-012) exceeded site specific remedial objectives for benzo(a)pyrene, benzo(b)fluoranthene, and dibenzo(a,h)anthracene. 95UCL of the three PAHs of concern were calculated using the USEPA statistical tool. Benzo(a)pyrene exceedance in sampling location SB-010 was eliminated by the statistical evaluation.

Photo 4 Winter Rye Root System (May 2016)

In June 2017, after two cycles of succession crops treatment at the site, lateral delineation samples were collected from sampling locations SB-004 and SB-012. Four soil samples were collected in the four cardinal directions approximately 10 to 15-foot distance from the 2016 sampling locations, and the samples were analyzed for PAHs of concern. The objectives of the 2017 sampling were to (1) assess the remedial progress near the sampling locations that exceeded site specific remedial objectives in 2016; and (2) identify the areas of exceedance that potential soil removal might be necessary in order to achieve the objectives more quickly. The statistical evaluation using 95UCL was performed on the entire data set. The 95UCL statistical calculations eliminated the sampling area of SB-004.

In summer 2018, after three cycles of the succession crops planting, one soil sample was collected from SB-012 N location, the only remaining location with benzo(a)pyrene and dibenzo(a,h)anthracene concentrations exceeding the site specific remedial objectives. The 2018 sampling results illustrated that the PAHs concentrations decreased significantly from 2017, and the 95UCL calculations indicated that the entire data set met site specific remedial objectives for PAHs of concern.

Soil analytical results and 95UCL calculation demonstrated that phytoremediation achieved the site specific remedial goals of PAHs of concern (Tables 2 and 3).

Table 2 Remediation progress soil sampling analytical results

Polynuclear Aromatic Hydrocarbon (PAHs) Parameters			Benzo(a) pyrene	Benzo(b) fluoranthene	Dibenzo(a,h) anthracene
			(mg/kg)	(mg/kg)	(mg/kg)
IEPA Approved Site-Specific Remedial Objectives Site Specific Soil Remedial Objectives			2.1	8	0.8
Sample Identification	Sample Date	Units			
SB-001	10/10/2016	mg/kg	0.75	1	0.31
SB-002	10/10/2016	mg/kg	1.4	1.7	0.55
SB-003	10/10/2016	mg/kg	0.26	0.34	0.11
SB-004	10/10/2016	mg/kg	6	8.9	2.3
SB-004	10/26/2017	mg/kg	0.05	NA	7.4
SB-004N	6/20/2017	mg/kg	0.26	0.28	0.089
SB-004E	6/20/2017	mg/kg	0.32	0.37	0.11
SB-004S	6/20/2017	mg/kg	0.044	<0.034	<0.034
SB-004W	6/20/2017	mg/kg	0.8	1	0.25
SB-005	10/10/2016	mg/kg	0.31	0.42	0.13
SB-006	10/10/2016	mg/kg	0.74	0.9	0.31
SB-008	10/10/2016	mg/kg	0.1	0.14	< 0.046
SB-009	10/10/2016	mg/kg	1.6	2.1	0.61
SB-010	10/10/2016	mg/kg	2.7	2.8	0.72
SB-011	10/10/2016	mg/kg	0.52	0.68	0.21
SB-012	10/10/2016	mg/kg	6.2	6.7	1.8
SB-012	10/26/2017	mg/kg	<0.045	NA	2.3
SB-012N	6/20/2017	mg/kg	19	24	28
SB-012N	7/6/2018	mg/kg	3.2	NA	0.95
SB-012N1	6/20/2017	mg/kg	2	2.3	0.48
SB-012E	6/20/2017	mg/kg	0.57	0.65	0.17
SB-012S	6/20/2017	mg/kg	0.88	1	0.28
SB-012W	6/20/2017	mg/kg	6.4	7.7	2.3
SB-013	10/10/2016	mg/kg	0.043	0.048	< 0.036
SB-014	10/10/2016	mg/kg	< 0.042	< 0.042	< 0.042
SB-015	10/10/2016	mg/kg	< 0.034	< 0.034	< 0.034
SB-016	10/10/2016	mg/kg	< 0.037	< 0.037	< 0.037
SB-017	10/10/2016	mg/kg	1	1	0.34
SB-018	10/10/2016	mg/kg	0.074	0.096	< 0.043
SB-019	10/10/2016	mg/kg	0.36	0.64	0.25
SB-020	10/10/2016	mg/kg	0.75	1	0.23
SB-021	10/10/2016	mg/kg	0.099	0.13	0.045

Notes
1. Site Specific Remedial Objectives were approved by the IEPA in the April 16, 2012 Remedial Action Plan
2. Cells highlighted in yellow indicate exceedances of IEPA approved remedial objectives
3. NA = Not Analyzed
4. Soil samples were collected from (0–3) foot interval below ground

Table 3 PAHs Remedial objectives and 95UCL results

Parameters	Remedial objectives (mg/kg)	95UCL (mg/kg)
Benzo(a)pyrene	2.1	1.79
Benzo(b)fluoranthene	8	6.08
Dibenzo(a,h)anthracene	0.8	0.59

5 Conclusions

A phytoremediation approach including succession crops of buckwheat and winter rye was successfully employed to reduce PAHs in soils resulted from historical foundry operations to site specific cleanup objectives in a sustainable and cost effective way.

Additional benefit of phytoremediation was aesthetical. The desirable appeal of blossoming buckwheat in summer and fall, and ground covering plant of winter rye in winter and spring improves the negative perception from the dilapidated vacant brownfields site prior to phytoremediation.

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