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National Climate Assessment

Agriculture in the Midwest

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MIDWEST TECHNICAL INPUT REPORT

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At the request of the U.S. Global Change Research Program, the Great Lakes Integrated Sciences and Assessments Center (GLISA) and the National Laboratory for Agriculture and the Environment formed a Midwest regional team to provide technical input to the National Climate Assessment (NCA). In March 2012, the team submitted their report to the NCA Development and Advisory Committee. This whitepaper is one chapter from the report, focusing on potential impacts, vulnerabilities, and adaptation options to climate variability and change for the agriculture sector.

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Introduction

Agriculture in the Midwest United States (Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin) represents one of the most intense areas of agriculture in the world. This area is not only critically important for the United States economy but also for world exports of grain and meat. In the 2007 Census of Agriculture these states had a market value of crop and livestock products sold of $76,989,749,000 (USDA Census of Agriculture, 2007). Within the U.S., Illinois, Iowa, and Minnesota ranked 2, 3, and 4 in the value of crops sold and Iowa ranked 3rd in the value of livestock, poultry and their products and Wisconsin ranked 7th in the value of livestock, poultry and their products sold. The economic value of agriculture in the Midwest encompasses corn, soybean, livestock, vegetables, fruits, tree nuts, berries, nursery and greenhouse plants. The economic value of the crop and livestock commodities in these states continues to increase because of the rising prices.

Midwestern states are considered to be the Corn Belt; however, there is a diversity of agricultural production beyond corn and soybean. Area in corn for the Midwest in 2007 was 20,360,396 hectares followed by soybean with 14,277,472 hectares. The diversity of agricultural production is shown in Table 1 for the amount of the commodity produced and the state rank based on the 2007 Census of Agriculture (USDA, 2007).

The impact of climate on agricultural production in the Midwest varies among years particularly in grain, vegetable, and fruit production. Fortunately, there are extensive records of agricultural production across the Midwest which allow for a detailed examination of the variation among years, the relationship to changes in the weather in each growing season, and the changing climate over a long time period in the Midwest. Variation among the years for corn grain can be seen in the records since 1866 for Iowa and Michigan production (Fig. 1), soybean for Illinois and Indiana (Fig. 2), sweet corn in Minnesota and Wisconsin (Fig. 3), and potato in Michigan and Wisconsin (Fig. 4).

Historical Impacts on Production

Climate impacts on production are detectable throughout the history of observations in the United States. There is another trend which is noteworthy in these observations which is related to the rapid and steady increase in annual production for crops beginning after the mid-1940's with the introduction of commercial fertilizers and enhanced genetic materials. However, the introduction of improved agronomic practices has not alleviated the effect from years with large impacts caused by unfavorable weather during the growing season. Soybean production has shown a steady increase since records began for the Midwest in 1924 and there are years with large reductions in yield

Table 1. *Commodities produced and state rank for the Midwest region of the United States.*

Commodity	**Illinois**		**Indiana**		**Iowa**		**Michigan**		**Minnesota**		**Ohio**		**Wisconsin**	
	Amount	**Rank**	**Amount**	**Rank**	**Amount**	**Rank**	**Amount**	**Rank**	**Amount**	**Rank**	**Amount**	**Rank**	**Amount**	**Rank**
Livestock (millions of animals)														
Layers	5.3	18	24.2	3	53.8	1	9.0	14	10.6	11	20.1	2	4.9	19
Hogs and pigs	4.3	4	3.7	5	19.3	1	1.0	14	7.6	3	1.8	10	1.1	
Pullets	0.9	28	6.9	5	11.4	1	2.0	16	3.2	12	6.8	6	1.2	22
Turkeys	0.8	19	6.0	7	4.0	9	2.0	16	18.3	1	2.0	14	3.7	10
Cattle and calves	1.2	26	0.6		3.9	7	1.0	30	1.5		0.8		3.4	9
Broilers	0.3		5.5	23	10.2		4.0		8.6	21	10.0	20	7.1	22
Milk and other dairy products from cows ($100,000)														
	340.3	20	583.2	14	689.7	12	1,285.6	7	1,475.9	6	861.3	11	4,573.3	2
Crop Production (1000 Hectares)														
Corn for grain	5,300.0	2	2,574.9	5	5,614.1	1	951.3	11	3,157.1	4	1,459.4	8	1,315.6	10
Soybean	3,356.5	2	1,936.0	4	3,485.6	1	694.3	12	2,539.0	3	1,714.4	6	551.6	15
Forage	240.1	32	221.3	33	455.5	23	469.6	21	964.7	15	468.0	22	1,132.1	7
Corn for silage	30.4		42.9	17	89.3	8	120.3	7	175.4		74.0	11	296.5	1
Oats for grain	[1]				27.0	7								
Wheat for grain	360.8	12	146.7	19	11.9		211.7	17	691.4	10	296.3	15	113.5	
Sorghum for grain	31.0	11												
Sugarbeets for sugar									196.5	1				
Vegetables													120.3	4

[1] Cells with no values entered represent a very small land area and production of the specific commodity.

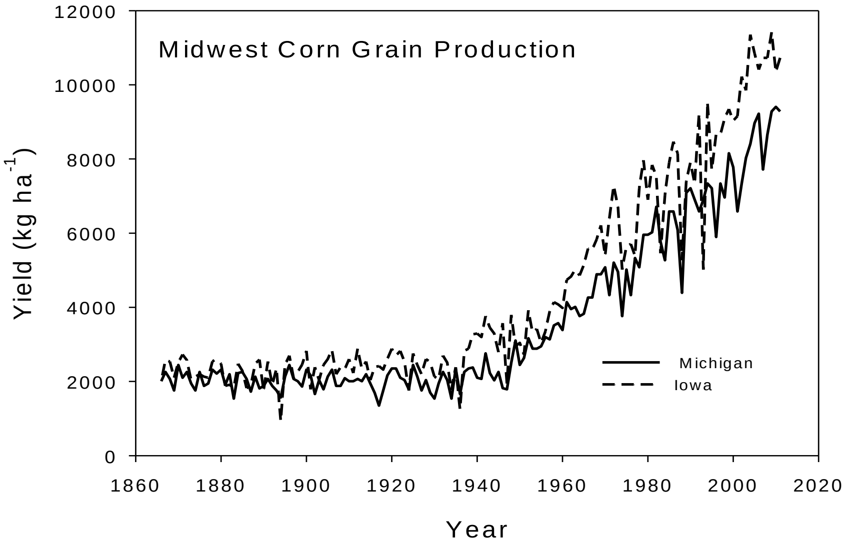

***Figure 1**. Annual corn grain yields for Iowa and Michigan from 1866 through 2011 (Source: USDA-NASS).*

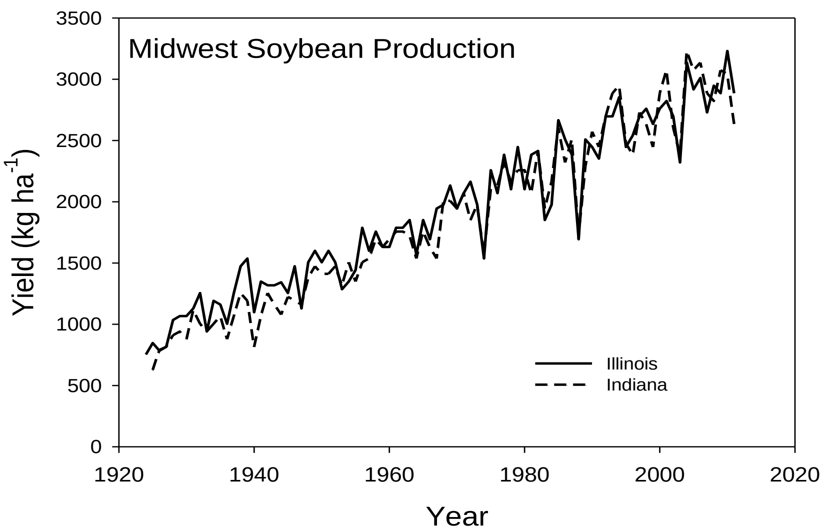

***Figure 2.** Annual soybean grain yields for Illinois and Indiana from 1924 through 2011 (Source: USD A-NASS).*

which are related to extremes due to drought (1988) or flooding (1993). In the grain crops, exposure to extremes, e.g., drought in 1988 created a 30% reduction in yield and the floods of 1993 caused a 44% reduction in the potential sweet corn yield for that year as defined by Hatfield (2010). Water availability is the dominant climatic factor causing yield variation among years. These are significant decreases in crop yield which are observed in all states because of the geographical extent of major climatic events. However, yield decreases in most years average between 15-20% from the potential yield due to short-term exposure to stresses. These stresses can be characterized as periods in which soil water is not available to meet the atmospheric demand or the temperatures are not in the optimal range for growth. It is important to realize that there is only a small fraction of the years in which there is no stress imposed by weather on crop growth or yield.

Sensitivity to Temperature

Temperature effects on plant growth have been extensively studied and future impacts of climate change may be more related to changes in temperature compared to other climatic factors. Each of the crops grown in the Midwest has a specific temperature range characterized by a lower and upper limit at which growth ceases and an optimum temperature at which growth proceeds at a rate for maximum size of the plant. These temperature limits have been recently defined for several species relative to climate change by Hatfield et al. (2011). The effects of temperature as a climate change parameter has been recently evaluated by several different groups in which they suggest that temperature stresses may be extremely significant in terms of affecting crop growth and yield. Lobell et al. (2011) observed that the changes in temperature which have already occurred from 1980 to 2008 have reduced crop productivity. They concluded that corn (*Zea mays* L.) yields already declined 3.8% and wheat (*Triticum aestivum* L.) declined 5.5% compared to the yields without climate trends. An important conclusion from this research was the observation that climate trends have been significant enough effect to offset the yield gains from technology and CO_2 increases. Kucharik and Serbin (2008) reported that projected corn and soybean (*Glycine max* (L.) Merr.) yields for Wisconsin would be significantly impacted because of rising temperatures. Analyses such as these and the results reported by Hatfield (2010) reveal that climate has already affected crop production. The recent study by Schlenker and Roberts (2009) discussed the potential nonlinear effects of warming temperatures on crop yields in the United States and showed there would be large impacts on productivity because of plants being exposed to conditions which are outside the thermal boundaries for optimal growth. A challenge for research is to begin the process of quantifying the temperature response of plants.

One of the changes in the climate which has a negative impact on plant growth and yield is the increase in the nighttime temperatures. The effect of minimum temperatures on plant growth has been observed in the

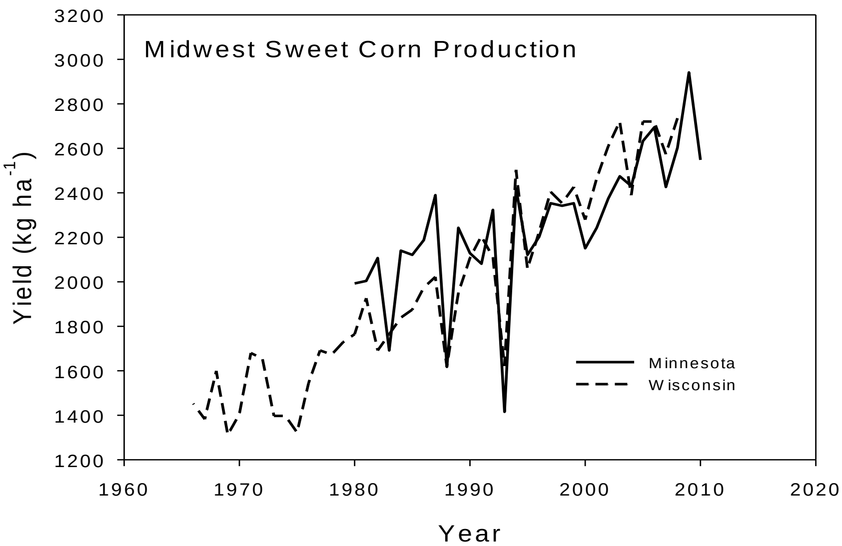

Figure 3*. Annual sweet corn production from 1968 through 2010 for Minnesota and Wisconsin (Source: USDA-NASS).*

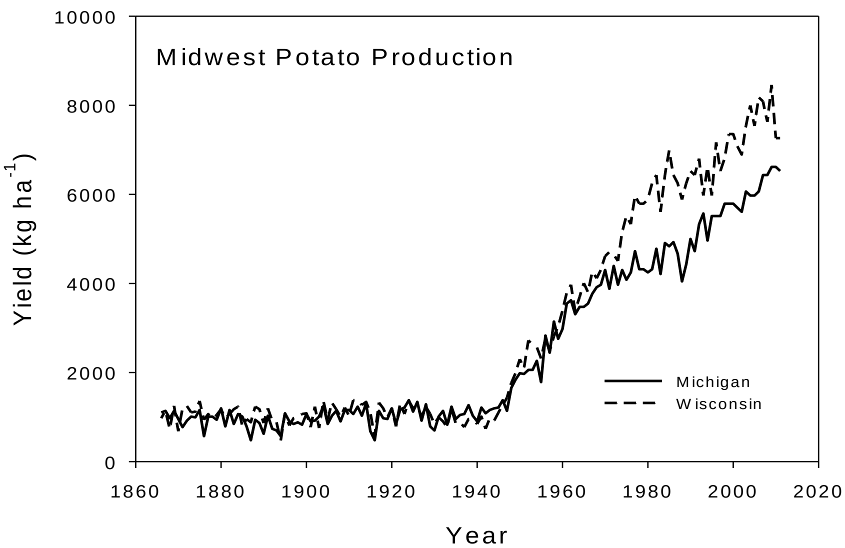

Figure 4*. Annual potato production for Michigan and Wisconsin from 1866 through 2011 (Source: USDA- NASS).*

small grains, e.g., wheat and rice (*Oryza sativa* L.) When temperatures increased above 14°C there was a decreased photosynthesis after 14 days of stress causing wheat grain yields to decrease linearly with increasing nighttime temperatures from 14 to 23°C which in turn leads to lower harvest indices (Prasad et al., 2008). In their studies, when nighttime temperatures increased above 20°C there was a decrease in spikelet fertility, grains per spike, and grain size. Temperature effects on pollination and kernel set in corn may be one of the critical responses related to climate change. Pollen viability decreases when plants are exposed to temperatures above 35°C (Herrero and Johnson, 1980; Schoper et al., 1987; Dupuis and Dumas, 1990). Pollen viability (prior to silk reception) is a function of pollen moisture content and strongly dependent on vapor pressure deficit (Fonseca and Westgate, 2005). Although there is limited data on sensitivity of kernel set in maize to elevated temperature, there is evidence suggesting the thermal environment during endosperm cell division phase (8 to 10 days post-anthesis) is critical (Jones et al., 1984). Temperatures of 35°C compared to 30°C during the endosperm division phase reduced subsequent kernel growth rate (potential) and final kernel size, even after the plants were returned to 30°C (Jones et al., 1984). When corn plants are exposed to temperatures above 30°C, cell division was affected which reduced the strength of the grain sink and ultimately yield (Commuri and Jones, 2001). Leaf photosynthesis rate has a high temperature optimum of 33 to 38°C with a reduction in photosynthesis rate when corn plants are above 38°C (Crafts-Brandner and Salvucci, 2002). In a controlled environment study on sweet corn (*Zea mays* L. var. *rugosa*), Ben-Asher et al. (2008) found the highest photosynthetic rates occurred at temperatures of 25/20°C while at 40/35°C (light/dark) photosynthetic rates were 50-60% lower. They concluded from these observations that photosynthetic rate declined for each 1°C increase in temperature above 30°C. The expectation is that corn grain plants would show a similar response. In soybean, there is a temperature effect and a comparison of growth at 38/30°C versus 30/22°C (day/night) temperatures, revealed elevated temperatures reduced pollen production by 34%, pollen germination by 56%, and pollen tube elongation by 33% (Salem et al., 2007). Exposure to air temperatures above 23°C caused a progressive reduction in seed size (single seed growth rate) with a reduction in fertility above 30°C leading to a reduced seed harvest index at temperatures above 23°C (Baker et al., 1989).

Potential Future Impacts

The chances for continued impacts for climate change are increasing according to a recent study by Rahmstorf and Coumou (2011) in which they attributed the extreme heat events in Russia during 2010 to climate change and concluded these extremes would not have occurred without climate change. They projected an increase in extremes to occur around the world as a result of climate change. The expectation for a changing climate both in means and extremes will cause impacts on agriculture.

High Temperatures

Increases in high temperatures are not the only effect on crops. Although there has been a warming trend in temperatures, the freeze-free season has only lengthened slightly. As perennial plants produce flower buds earlier in the spring due to warmer temperatures, they could be exposed to relatively normal freezing conditions later in the season that destroy the crop. Fruit and berry crops across the Midwest will be subjected to more extreme conditions and negatively impact growth and production. While there is evidence of changing climate, the overall impacts on perennial crops becomes more uncertain because of the uncertainty in chilling requirements.

CO_2 Concentration and Evapotranspiration

Changes in CO_2, temperature, and precipitation will impact agriculture in the Midwest. For plant types that respond well to CO_2 enrichment, (C_3 plants), CO_2 may exert a positive influence on growth until temperatures warm more significantly. The positive effect on grain yield, however, has not been as large (Hatfield et al., 2011). An analysis by Bernacchi et al. (2007) using soybean grown in a free air carbon dioxide enrichment (FACE) system at 550 compared to 375 μmol mol^{-1} showed a 9 to 16% decrease in evapotranspiration (ET) with the range of differences over the three years caused by seasonal effects among years. There has been evidence that the reduction in ET caused by increasing CO_2 will diminish with increasing temperatures; however, this has not been evaluated in Midwestern crops.

Precipitation

Changes in the seasonal timing of precipitation will be more evident than changes in precipitation totals. There is evidence of an increase in spring precipitation across the Midwest and an increase in the intensity of storm events, though climate model projections for precipitation changes don't exhibit the same degree of confidence compared to the observations across the Midwest. The shifts in precipitation will affect field preparation time in the spring. An analysis of workable field days for April through mid-May in Iowa has shown a decrease from 22.65 days in the period from 1976 through 1994 compared to 19.12 days in 1995 through 2010. This is a major change in the days available during the spring for field work. There is an increased risk for both field work and soil erosion because of these shifts in precipitation. There has been little attention directed toward the workable days in the fall during harvest periods and the potential impact on grain, fruit, or berry quality. Impacts of increased precipitation and intense events are associated with increased erosion and water quality impacts (nutrients and pesticides). It is expected that these impacts will increase with increased spring precipitation because of the lack of ground cover with vegetation.

Water Quality

Water quality impacts relative to a changing climate have not been thoroughly investigated, but many impacts are related to soil water excesses. Shifts in precipitation patterns to more spring precipitation coupled with more intense storms creates the potential for increased water quality (sediment, nitrate-N, and phosphorus). In an analysis of the Raccoon River watershed in Iowa, Lucey and Goolsby (1993) observed nitrate-N concentrations were related to streamflow in the river. Hatfield et al. (2009) showed that annual variations in nitrate-N loads are related to the annual precipitation amounts because the primary path into the stream and river network was leaching through subsurface drains. The Midwest is an extensively subsurface drained area and these drains would carry nitrate-N from the fields and across the Midwest with the current cropping patterns which do not have amount of water use during the early spring (Hatfield et al., 2009). Increased intensity of spring precipitation has the potential for increased surface runoff and erosion in the spring across the Midwest. Potential increases in soil erosion with the increases in rainfall intensity show that runoff and sediment movement from agricultural landscapes will increase (Nearing, 2001). Water movement from the landscape will transport sediment and nutrients into nearby water bodies and further increases in erosion events can be expected to diminish water quality.

Weeds, Pests, and Disease

Indirect impacts from climate change on crop, fruit, vegetable, and berry production will occur because of the climate change impacts on weeds, insects, and diseases. This has not been extensively evaluated across the Midwest and presents a potential risk to production. Significant effects on production may result from weed pressure caused by a positive response of weeds to increasing CO_2 (Ziska, 2000; 2003 a; 2003b; Ziska et al., 1999; Ziska et al., 2005). The effects of CO_2 on increasing weed growth may lead to increased competition in fields without adequate weed management. A void of knowledge is the effect of changing climate on insects and diseases and the extent of a changing risk pattern on agricultural production.

Stresses on Livestock

Climate stresses on livestock in the Midwest are reduced because most of the species are grown in confined production facilities where there is control of the temperature and humidity and the animals are not exposed to the natural environment. In these systems, there may be a greater effort directed toward energy efficiency in these facilities and management to ensure a limited exposure to extreme conditions during transport of animals to

processing facilities. Dairy cattle are often grown in unconfined facilities, but shelter is provided for these animals from severe weather events. Increases in temperature and humidity occurring and projected to continue to occur under climate change will impose a significant impact on production of the different species shown in Table 1. Exposure of livestock species to the combination of temperature and humidity factors will increase stress levels. These effects, however, have not been extensively quantified across the Midwest. The indirect impacts of climate change on livestock will occur because of the potential for a changing climate to affect the occurrence of insects and diseases. There is an increased risk of the exposure of animals to insect and disease pressure as a result of climate change, but these relationships have not been established for the animal species of the Midwest. Another indirect impact of climate change may be through the availability of feedstock derived from crop production. Reductions in grain production would have an impact on the number of animals which could be produced.

Adaptation

Agriculture is a very fluid system and within annual crop production there is continual adaptation to adjust to the changing climate conditions. There are shifts in planting dates dictated by the precipitation amounts that occur each year. In order for producers to make large shifts in agronomic practices, e.g., maturity dates on crops, there would have to be a consistent pattern in the climate trends and events each year. Adaptation strategies for Midwest crop agriculture will have to include practices which protect the soil from erosion events while at the same time increasing the soil organic matter content through carbon sequestration via improved soil management (Hatfield et al., 2012). Adaptation strategies for livestock across the Midwest would be relatively minor because of the majority of the production systems already occurring under confined spaces with controlled environments.

Crop insurance has been used as a process to offset losses to producers due to weather events during the growing season. Given the uncertainty in the climate change it is difficult to evaluate how crop insurance payments will change in the future (Beach et al., 2010). There have been shifts in the perils which have triggered crop insurance payments for the past 20 years with a shift from drought to flooding and excess water being the major cause of insurance claims.

Adaptation of agricultural systems will occur through many different paths. Producers have readily adopted changes which entail changes in planting date and maturity selections. Other changes, such as the changing of cropping systems to increase water availability in the soil via increases in organic matter content or reductions in soil water evaporation, may be more difficult to implement. Adoption of improved nutrient management systems to prevent losses of nutrients either by leaching, runoff, or in the case of nitrogen fertilizers, nitrous oxide emissions, represent strategies to enhance crop performance under variable climates. Development of plant genetic resources for annual crops to increase their tolerance to stress will be a necessary component of adaptation to climate change. The potential options for crop adaptation to climate change have been described by Redden et al. (2011). There have been many proposed strategies for adaptation to climate change for annual crops; however, there may fewer options for perennial crops. For livestock, adaptation strategies will typically involve some aspect of the housing facilities for animals and may entail a greater cost of implementation than in cropping systems.

Risk Assessment

Exposure to extreme events for both temperature and precipitation can cause reductions in plant production and yield. There is evidence in the observed yield history for crops grown in the Midwest that extremes can have significant impacts on production levels; however, there are impacts on yields from variability in weather during the growing season caused by short-term weather impacts, e.g., less than normal rainfall but not enough deficiency to trigger drought. With the likelihood of an increase in the occurrence of extreme events across the Midwest, we could expect a greater variation in production amounts. It is also interesting to note in these records that not all extreme events impact the entire Midwest. Some events (flooding or drought) are more localized and affect the production within a state or are even isolated to a few counties. Development of a risk assessment for assessment of climate impacts on agriculture will require the application of crop simulation models into which climate scenarios can be incorporated to evaluate potential adaptation strategies. There is an effort to begin to intercompare and improve crop models for the purpose of providing better simulations of crop production around the world this effort know as the Agriculture Model Intercomparison and Improvement project (AgMIP, www.agmip.org). Efforts are underway to provide intercomparisons for corn, soybean, wheat, rice, sugarcane, peanut, and millet using models developed by the international community and evaluated against data sets from different locations around the world. This approach would allow for an assessment of the potential impacts of climate on future production levels but also allow for the evaluation of the efficacy of various adaptation strategies.

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